Estimating the Value of Information in the UK Mortgage Market

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Abstract

This paper measures the value of information mortgage brokers provide to UK households using an application of a structural model of search. Aided by administrative loans data, we document the existence of a substantial degree of unexplained price dispersion, and observe that while mortgages obtained from brokers are cheaper, borrowers who use intermediaries pay more once commissions are factored in. However, our results also show that broker presence exerts negative pressure on lenders' market power. Compared to a world where broker advice is unavailable, brokers reduce average monthly mortgage costs by 21% and eliminate a part of welfare losses arising from costly search. In other words, eliminating brokers from the market would lead to even higher borrowing costs from the group of borrowers who need it most: those with the highest search costs. We also find that regulation in support of market centralization halves lenders' markups and lowers monthly costs of an average mortgage by 4.4%.

Keywords: mortgage markets, consumer search, intermediation, auction estimation

JEL classification: C57, D83, G21, L85

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1 Introduction

For most households, a mortgage is the largest financial commitment they will undertake in their lifetime. A growing body of literature examines the role of search frictions in mortgage selection (Allen, Clark, and Houde 2013, 2017; Woodward and Hall (2012); Agarwal, Grigsby, Hortaçsu, Matvos, Seru, and Yao (2024); Alexandrov and Koulayev (2018); Guiso, Pozzi, Tsoy, Gambacorta, and Mistrulli (2022)). This attention is well justified: searching for a mortgage is both complex and costly. Consumers navigate a cumbersome process involving administrative tasks, product comparisons, and lender applications, while managing the risk that rejected applications may harm their credit scores. Further complicating this process are intricate pricing structures and lenders offering extensive menus of nearly identical products. For instance, Coen, Kashyap, and Rostom (2023) report that the median British household selecting a mortgage faces a choice of 70 different options, with half choosing worse than the average option available. Given these challenges, it is unsurprising that many consumers turn to mortgage brokers for assistance in securing the best deal.

Using a structural model, this paper investigates which consumers benefit from outsourcing their mortgage search by estimating the value of information provided by brokers. We focus on three key questions: (1) What quantifiable savings do brokers provide to consumers? (2) Which types of consumers benefit the most from using brokers? (3) Does the existence of a competitive broker market improve overall welfare compared to a scenario where all mortgage prices are publicly known?

The UK mortgage market presents an ideal setting for this study. Unlike in the US or Canada, an unusually high proportion of UK mortgages originate through brokers. According to the Intermediary Mortgage Lenders Association (IMLA), 67% of borrowers used broker services in the second quarter of 2015, accounting for 71% of the total value of new mortgages during that period (IMLA, 2015). This aligns closely with the patterns observed in our data.

We begin by documenting significant unexplained price dispersion in the mortgage market, a finding consistent with previous studies (e.g. Coen, Kashyap, and Rostom (2023), Bhutta et al. (2020)). This is our motivation in using a structural model of search to analyze the role of brokers. We leverage the model of Myśliwski, Rostom, Sanches, Silva, and Srisuma (2025) to study two counterfactual scenarios on the value of information brokers provide. In their model, heterogeneous consumers decide whether or not to pay a fee and use a broker, and lenders—who privately observe their marginal costs and can sell loans directly to consumers—set a uniform price for both direct and broker-mediated transactions. This pricing structure, referred to as *price coherence* (Frankel, 1998), implies that brokers act as platforms that enable borrowers to access better deals, thereby reducing lender market power.

The estimation approach proposed in Myśliwski et al. (2025) allows us to uncover the unobserved distribution of borrower search costs and lender heterogeneity. While that paper provides an empirical illustration of the estimation approach to recovering cost distributions, here we show how the model estimates can be used for counterfactual analysis, and how comparing equilibrium outcomes with and without intermediaries can be informative of the value of information. The second key difference is that here we follow a completely nonparametric approach to remain agnostic about the shape and modality of the heterogeneity distributions.

The main empirical contribution of this paper is to explore two key counterfactual exercises that, to our knowledge, remain largely unexplored in the literature. First, we assess whether brokers improve consumer welfare by quantifying the value of information they provide. Second, we evaluate an alternative market structure: a centralized platform where all mortgage prices are publicly listed, and consumers are automatically matched with the best offer.

To address the first question, we simulate a scenario in which intermediation does not exist and compare the expected consumer surplus. Our findings indicate that brokers generate net-positive savings. On average, borrowers save £72.31 per month on a median-sized mortgage, with roughly one-third of these savings attributable to brokers securing lower prices and another sixth due to reduced search costs. However, not all consumers benefit equally. Younger, lower-income, and first-time buyers experience the greatest gains, while borrowers opting for longer fixed-rate deals or shorter amortization periods see only marginal price improvements, often offset by broker commissions.

The positive impact of brokers stems from the externality they impose on the direct market (Salz, 2022). By facilitating price discovery, brokers limit lenders' ability to price discriminate between informed and uninformed consumers. In the absence of intermediation, we find that the average Lerner index would approach 24%, with a quarter of all mortgages exhibiting margins above 33.5%.

For the second counterfactual, we examine the implications of a fully centralized mortgage platform. In this scenario, all lenders post their prices, and direct sales are replaced by an automated system that matches consumers with the best available mortgage. We find that such a system would lower average prices by 4.4%, translating to borrower savings of nearly £15 per month. However, lender margins would decrease by almost half. While these online platforms leverage machine learning to replicate the role of traditional brokers, the overall welfare impact is ambiguous. Any modest gains from reduced prices and search costs must be weighed against the sunk costs associated with the decline of physical brokerages and the loss of long-term broker-client relationships, particularly in a market where consumers refinance frequently. Over time, these benefits may dissipate entirely.

■ **Related literature.** We contribute to several strands in the literature. First, there is a growing body of empirical papers using structural models of consumer search to study mortgage markets. Allen, Clark, and Houde (2017) consider a search and bargaining framework with bilateral heterogeneity. They focus on the role of loyalty advantage and exclude brokered loans from their analysis. In contrast, Woodward and Hall (2012) only studies brokered mortgages. They conclude that mortgagors in the US would benefit from shopping at multiple brokers.

Robles-Garcia (2022) studies commission bargaining between lenders and brokers in the mortgage market. She also finds a ban on brokers would lead to higher mark-ups and consumer prices. However, we leverage a model with search frictions, and include a broader definition of costs, which includes mortgage fees.

In another paper, Agarwal, Grigsby, Hortaçsu, Matvos, Seru, and Yao (2024) find that more search does not always result in lower prices. The authors introduce screening and probability of mortgage rejection into a standard search model. Alexandrov and Koulayev (2018) investigate the interplay of search and preference for non-price characteristics (such as branding) to explain sub-optimal shopping of Americans. Thiel (2022) focuses on financial advice more generally, showing that banning financial advisors from receiving commissions leads to a reduction in consumer surplus when advisors exit the market.

There are also a number of empirical papers that examine mortgage price shopping. Coen, Kashyap, and Rostom (2023) use the same data, from an earlier time period, to study how consumers shop for mortgages. They find that young and inexperienced consumers are more likely to face more expensive menus. Bhutta, Fuster, and Hizmo (2020) also document a large degree of price dispersion, with the least financially sophisticated borrowers massively overpaying relative to market rates. They suggest that rising borrowing costs encourages search. Malliaris, Rettl, and Singh (2020) also show that while increased mortgage competition is financially beneficial to both sophisticated and naive borrowers, by encouraging lenders to include attractive offers, it does not remove costly products from the menu. Similarly, Andersen, Campbell, Nielsen, and Ramadorai (2020) find that poorer, older, and less educated households are less likely to refinance, missing out on potential savings as a result. These findings are consistent with earlier work by Lusardi and Mitchell (2014) documenting the strong correlation between personal characteristics and degree of financial literacy. Guiso, Pozzi, Tsoy, Gambacorta, and Mistrulli (2022) study whether in-house bank advisers steer borrowers into taking up more risky and expensive adjustable rate mortgages compared to fixed rate mortgages. They conclude that banning advice altogether would result in an average annual loss of €998. This number is in line with what we also find. Since the advice in our model is akin to being fully impartial, we think our estimate is informative of the upper bound on the change in consumer surplus.

Our work also touches on IO literature, where search models have been used to study welfare effects of intermediation in other industries. For example, Byrne and Martin (2021) argue for consumer protection for different types of households, such as poorer ones who typically do not search. Salz (2022) looks at the role of brokers in contracting trade waste removal in New York City. In particular, the structural model we rely on for our empirical simulations resembles Salz's framework where the same firms participate in both direct and brokered markets and cannot charge different prices. Our empirical findings corroborate Salz's conclusion that intermediation reduces information frictions and reduces market power. However, we show that some estimates can be negligible or even negative for certain types of consumers.

The paper is organized as follows: Section 2 outlines main institutional features of the industry, describes the data and provides some reduced-form evidence on price dispersion and the impact of brokers on transaction prices. Section 3 and 4 discuss the data and the reduced form findings. Section 5 briefly introduces the theoretical model, outlines the estimation method, and summarizes estimation results. Our main counterfactual experiments are presented in Section 6. Section 7 concludes and proposes directions for future research.

2 The UK mortgage market

The UK mortgage market is relatively concentrated– the share of the six biggest banks exceeds 70%. As in the US, mortgage terms in the UK typically amortize over 25 years, although longer durations are also common[1]. However, unlike the US, the most contracts are short-term, and refinancing is common. The most common products are 2-, 3-, and 5-year fixed rate mortgages (FRM), and 2-year adjustable rate mortgages (ARM). Since the Great Financial Crisis (GFC), FRMs make up the vast majority of mortgages, and in our sample period of 2016-17, they account for over 90% of all mortgage contracts (2-year FRMs being the most popular). Upon expiration of the initial contract period, borrowers can negotiate a new contract with the same or a different lender (Belgibayeva et al., 2020).

For each type of product, banks post quoted rates that vary by contract period and loan-to-value ratios, or LTV. Subject to the LTV (and thus the size of the down-payment), borrowers choose the initial interest rate on the mortgage and the fee. In the UK, lender fees are small (usually about £999) and 40% pay no fees at all. As documented by Coen, Kashyap, and Rostom (2023) and Iscenko (2018), lenders offer broad product portfolios with different combinations of fees and rates.

A striking feature of the UK market (since 2014/2015) is that almost 70% of mortgages are accessed via brokers. This number is significantly bigger than the share of brokered mortgages in the US (Alexandrov and Koulayev (2018) report roughly 10%) or Canada (Allen, Clark, and Houde (2017) have 28% of brokered contracts in their data). The *Intermediary Mortgage Lenders Association* (IMLA) report an upward trend in the fraction of borrowers who use intermediaries, noting that the value share of mortgages originating from brokers increased from about 50% before the GFC to 71% in the second quarter of 2015 (IMLA, 2015).

Applying for a mortgage directly with a bank typically involves interviews with loan officials and lengthy applications, weighed against the backdrop that with each rejected application credit scores could fall. Brokers, on the other hand, help zero-in on the most suitable products and assist borrowers through the application process. The market for intermediation is competitive and geographically dispersed. As noted by IMLA (2015), *"the UK mortgage broking business is dominated by small firms serving local client bases. According to data from the Fi-*

[1]The median first time buyer amortizes over 30 years.

nancial Adviser Confidence Tracking Index in September 2015, 69% of broking firms employed only 1 or 2 mortgage advisers with another 20% employing 3 to 5.”.

While there is no regulation in place that obliges brokers to search through all available mortgage products,[2] broker services offer affordability comparisons across banks– unlike what lenders' in-house advisers offer. Moreover, brokers are bound by a fiduciary duty to their customers, and are expected to find them the most competitive mortgages.[3] In return, intermediaries are compensated in one of three ways. They either receive commissions directly from borrowers, procure a charge from lenders, or get both.[4] The most common payment, however, are lenders paying brokers. Less than half of borrowers, on the other hand, pay fees, and when they do, they are small. Moreover, nearly all the big banks uniformly pay the same fee to brokers which is a fixed percentage of the loan value (typically 0.3-0.4%), which does not vary with other loan characteristics.[5] This double combination of brokers' fiduciary obligations and lenders paying similarly competitive procuration fees strongly suggests that brokers are unlikely to steer borrowers to preferred lenders, and therefore informs one of the key model assumptions that brokers are incentivized to find the best rate for their clients.

3 Data

We use loan-level administrative data from the Product Sales Database (PSD) of all new mortgage originations in the UK. The data contain information from the mortgage application, including borrower characteristics such as age and income; loan details such as the issuing bank, interest rate, and loan size; and property details such as the purchase price and location. The data is patchy until the GFC when collection substantially improved; and in 2016 information on direct sales, brokers, and fees were added.

Our final sample includes over 1.3M mortgage contracts issued in 2016 and 2017. We cannot identify specific brokers, however, as we focus on the biggest lenders, we know their products are available to every potential borrower in the country, and easy to find. Another reason we focus on the big players is because, in our model, we abstract from lenders' budget constraints and capital requirements which are much more important for small lenders (Benetton, 2021). We also exclude ARMs, loans with non-standard FRM lengths, and loans with

[2]The intermediaries that do are known as *whole-of-market* brokers.

[3]For example, in cases where brokers do not advise a customer take the cheapest product, they must explain why. These may be for esoteric reasons, such as slow service or if the loan is provided by a small lender. As we focus on the big banks, these cases are of little relevance to our sample. See the Financial Conduct Authority's *Mortgage advice and selling standards* policy statement for more information.

[4]Woodward and Hall (2012) argue that, in the US, brokers are indifferent about their source of compensation. A different strand of literature studies how different compensation schemes can alter brokers' incentives (see e.g. Inderst and Ottaviani (2012), Robles-Garcia (2022)). We assume that payments from lenders to brokers constitute part of their costs and ultimately passed onto borrowers in the form of higher prices.

[5]In our data, 95% of mortgages referred to by brokers had a lender procuration fee attached to them. The FCA concurs that all big lenders pay a procuration fee. These fees are publicly advertised on comparison sites, e.g. see `www.legalandgeneral.com/adviser/mortgage-club/lenders/producation-fees`. On the other hand, borrowers pay brokers in only 40% of cases in our sample. These fees are typically fixed lump-sums. In our sample, the median fee is £349 paid by a borrower to a broker– £10 a month, on average, over the duration of the initial period.

LTVs greater than 95%. All constitute a very small fraction of the market. Further details on the sample construction and summary statistics can be found in Appendix A.1.

3.1 Mortgage costs

We define a cost metric to compare the mortgage costs faced by borrowers in a consistent and unified way. Constructing this scalar measure of cost means estimates from the structural model of Myśliwski et al. (2025) can be ordered relative to it. Mortgage costs vary along several dimensions: upfront fees, the initial rate, and the length of the initial period.[6] The monthly economic ("sunk") cost is the interest component of the monthly payment plus any upfront fees added onto the loan by the lender:

$$p = iL + \frac{Fee}{N}, \tag{1}$$

where N is the initial period of the mortgage contract (24, 36, or 60 months), L is the size of the loan, and i is the fixed interest rate. In the structural model the loan size is given. So to adequately compare costs of mortgages with different initial loan amounts, we normalize the monthly cost of the loan to correspond to a median loan value in the sample, £150,000. Our approach is similar to Allen, Clark, and Houde (2017) who normalize their price variable to correspond to the monthly payment on a $100,000 loan.

4 Reduced form findings

Using the PSD, we provide descriptive evidence of several features of the UK mortgage market in support of the modelling framework. First, we show a substantial degree of price dispersion in transacted prices. Second, we show that borrowers who used brokers have, on average, lower monthly mortgage costs, but total costs are higher once we factor in broker fees. Finally, we show that observable borrower and product characteristics are poor predictors for whether or not to use a broker. Overall, the type of evidence we present is akin to that in Section 3 of Salz (2022), suggesting that high search costs may be why some households use a broker, and justifying our modelling assumptions.

4.1 Price dispersion

To see whether there are differences in price dispersion by choice of sales channel, we look at the level of unexplained variation after regressing mortgage prices on observed characteristics. We do this for borrowers who got their mortgage directly from lenders from those who used a

[6] A calculation of total mortgage costs could also include the reset rate and mortgage term. However, lenders and brokers focus only on initial period costs as UK borrowers usually refinance (otherwise this would put undue weight on costs in the reset period).

broker. We run the following hedonic regression:

$$p_{ijt} = \mathbf{X}'_{ijt}\boldsymbol{\beta} + \psi_t + \xi_j + u_{ijt} \quad (2)$$

where p_{ijt} is the mortgage price for household i, from bank j, at time t. $\mathbf{X}_{ijt}$ is a vector of household and loan characteristics, e.g. household income, LTV, and the mortgage term.[7] ψ_t and ξ_j are time and bank fixed effects.

We define our dependent variable, p_{ijt}, in two ways. In one calculation we use the interest rate in basis points[8]; and in the other we use normalized interested payments in £, as defined in Section 3.1. Table 1 reports the level of unexplained variation (as captured by $1 - R^2$) and the coefficient of variation, for both measures of the dependent variable, and during the initial period of the loan.

Panel A and B in Table 1 report results for p_{ijt} as measured by interest rates and interest payments respectively. Overall, the level of unexplained variation, $1 - R^2$, is about 30% although its lower for brokers and especially when interest rates are the dependent variable.[9] This proportion is quantitatively similar to the percent of unexplained variation in the Canadian data reported by Allen, Clark, and Houde (2017) who report $1 - R^2$ of 0.39.[10] The table also compares the results with and without lender fixed effects. Fixed effects allows us to control for bank heterogeneity, but leaves within bank variation unexplained. Comparing columns (1) with (3), and (2) with (4), we can see that adding fixed effects substantially reduces the proportion of residual variation from direct sales, but has virtually no effect on the R^2 in the regression using broker data. This finding is consistent with our priors that brokers help borrowers find the most suitable product across lenders. Suppose there exists a lender that, on average, sets higher interest rates than its competitors. Adding lender fixed effects will help explain more of the unobserved variation in prices in the direct segment of the market, especially if consumers do not shop around. However, in the brokered segment, intermediaries compare products against competing offers, making it unlikely for borrowers who use a broker to go with the more expensive lender.

Table 1 about here

4.2 Do brokers offer cheaper prices?

To establish whether brokered mortgages are cheaper, we check whether households who used a broker received a lower rate compared to those who didn't (after controlling for a flexible

[7] More specifically, we control for household income, house price, loan size, LTV (included as a set of dummy variables corresponding to LTV thresholds), first-time buyer (FTB) status, region, mortgage type, length, and other product characteristics, as well as their interactions and allow for potential nonlinearities.

[8] We control for the level of upfront fees on the right-hand side.

[9] The decrease in unexplained variation in Panel A for brokers is likely down to controlling for broker fees in the regressions in Panel A.

[10] See also Allen, Clark, and Houde (2014) for a detailed study of price dispersion in the Canadian market.

function of individual and product characteristics). Table 2 reports regression results on the dependent variable, p_{ijt}, measured using two ways– mortgage interest rates, or the normalized monthly mortgage payments (see Sections 3.1 and 4.1). In both cases, the coefficient is negative and significant, suggesting that those who shopped with a broker received a cheaper product. However, the monetary savings are modest at about 7 basis points or £5 per month for each dependent variable respectively. We also test whether different broker compensation schemes of being paid by the lender versus the borrower affects their incentive to provide unbiased advice. We run the same regression for two sub-samples of the data – one which only includes brokers paid by just lenders, and one which only includes those not receiving any commission from lenders. The sign and the magnitude of the effect measured by the coefficients are little changed across the sub-samples, suggesting that brokers on average offer cheaper loans, regardless of who they are paid by. The results are presented in appendix A.4.

Table 2 about here

The dependent variable used in the regressions presented in Table 2 is constructed in a way to control for lender fees only and our definition of monthly cost does not include broker fees. Once we add them in, the sign of the coefficient switches to positive (see table 3).[11]

Table 3 about here

The findings summarized in Tables 2 and 3 are in line with the descriptive evidence Salz (2022) used to justify the assumption that buyers with higher search cost select themselves into the brokered market. Brokers seem to offer broadly lower prices, but once their commissions are factored in, borrowers end up paying more than they would in the direct market. This finding is crucial to justify that borrowers with higher search costs are more likely to use brokers. Without the sign reversal, standard models of search would have difficulties explaining why brokers are not used by everyone. To provide some intuition, suppose that one always expects to pay less by going to a broker, then borrowers with low search costs would use them as well.

4.3 Predicting broker use

The final fact we document in this section is that a borrower's observable characteristics do not predict broker use. Table A.6 in Appendix A.3 reports results from a linear probability model where we regress an indicator variable for using a broker on individual and mortgage product characteristics, and regional fixed effects. Because of potential identification issues, we do not attempt to extrapolate our interpretation of the effects beyond conditional correlations.

[11] We use broker fees divided by the number of months in the initial period to calculate monthly cost.

Irrespective of the observable characteristics that we do control for, the R^2 is never greater than 0.13, even if we allow for multiple interactions between variables.[12]

All in all, these findings are consistent with our hypothesis that observables have little predictive power in understanding who uses brokers. This opens up scope for an unobserved component, such as search cost, to be a more important driving force behind borrowers' decisions.

5 Structural model

We rely on a stylized model of mortgage pricing where consumers can search across different lenders directly or use a broker, as proposed in section 5.2 of Myśliwski et al. (2025). For the sake of brevity, we only provide a verbal description of the model here, referring the reader to Myśliwski et al. (2025) for the full mathematical exposition. The key economic intuition relies on the fact that borrowers with different observable and unobservable characteristics decide whether or not to use a broker to search for a mortgage. Banks offer loans with different attributes and compete in a pricing game, where they are allowed to set only one price offered directly or via a broker. Removing brokers in the counterfactual scenario amounts to solving for an equilibrium of a model where everyone needs to search. Conversely, providing full information to all borrowers in the market is equivalent to finding an optimal pricing strategy in a reverse first-price auction in the absence of demand-side information frictions.

Consider an environment with a finite number of J lenders and a continuum of borrowers with unit demands. Borrowers, indexed by i, receive iid draws from a continuous search cost distribution $\kappa_i \sim \mathcal{G}(\cdot|\mathbf{x}^G)$. $\mathbf{x}^G$ is a vector of observables which can shift the distribution of search cost. Lenders are heterogeneous in their marginal cost of providing the loan, $c_{ij} \sim \mathcal{H}(\cdot|\mathbf{x}^H)$, which is their private information. $\mathcal{H}$ is continuously distributed on a compact support $[\underline{c}; \bar{c}]$.[13] In a market with posted prices, $\mathbf{x}^H$ is a vector of covariates which includes key characteristics of the mortgage, but could also include some elements of $\mathbf{x}^G$ if price discrimination or bargaining are an important feature of the market. While direct price negotiation is not typical in the UK, its effects are mimicked by lenders offering wide product menus, and because it is almost costless to introduce a new product with a slightly different fee structure. We further describe the selection of covariates for the model in Appendix B.1.

As in Allen, Clark, and Houde (2017), there exists a time period outside the model where the borrower chooses the property she wishes to purchase, associated loan size, and her mortgage duration and maturity. Therefore, the dimension of search we consider is one where the borrower compares similar products across different banks. The assumptions on intermediation

[12] As the R^2 is not a perfect measure of predictive power, we also plotted propensity score distributions of using a broker for borrowers who actually *did* and *did not* use a broker. We found a large degree of overlap between them (see Figure A.2). Iscenko and Nieboer (2018)) plot a similar chart.

[13] We allow the support to differ for different $\mathbf{x}^H$.

technology closely follow Salz (2022). Brokers are treated as non-strategic players and act in the borrower's best interest by choosing the cheapest offer in the market. Under these assumptions, borrowers use a broker if $\kappa_i > \bar{\kappa}$, and otherwise decide how many lenders to search for directly, based on their expectation of the lowest price they will receive. Therefore, borrowers obtain full information about prices either if they have very low or very high search costs. In the latter case, though, they need to pay a fee to acquire it. Figure 1 below illustrates equilibrium sorting of borrowers according to the number of searches.

Figure 1 about here

On the supply side, a lender with marginal cost c sets a single price for the direct and brokered markets, expecting that Δ^B is the equilibrium proportion of borrowers using brokers. Since banks do not know how many other price quotes the borrower received in the direct market, the profit-maximizing pricing rule turns out to be the best response function in a reverse first-price auction with an unknown number of competitors. Banks' optimal pricing and borrowers' optimal search decisions come together in a Bayesian-Nash equilibrium characterized in Theorem 5 of Myśliwski et al. (2025). In the counterfactuals discussed in Section 6, we show how equilibrium outcomes change if we alter the information structure of the market.

5.1 Nonparametric estimation

The loan-level data allows us to estimate the key primitives of the model which include: (1) the set of conditional search cost distributions $\mathcal{G}(\cdot|\mathbf{x}^G)$ and (2) distribution of cost of providing the loan, $\mathcal{H}(\cdot|\mathbf{x}^H)$. Myśliwski et al. (2025) prove that those objects are nonparametrically identified. Since we also observe broker commissions and which loans are brokered, we can also directly infer the cutoff points in the search cost distributions which make borrowers indifferent between searching and delegating the effort to a broker. One departure from their model is that we allow for banks having private information about borrowers, i.e. the marginal cost to be bank-borrower specific. Further details on the estimation algorithm are provided in Appendix B.2.

We first show non-parametric estimates of borrowers' search costs and lenders' estimated marginal costs and margins. The intention here is to demonstrate the heterogeneity across borrowers and products. Together, they underpin who would ultimately confer the most value from brokers. We present a snapshot of our non-parametric estimates for borrower search costs in Table 4, and lender marginal costs and margins in Table 5. For our price variable, we use real monthly mortgage costs, detrended to remove dispersion from macroeconomic shocks.[14]

Table 4 shows the median monthly cost (£) for first-time buyers obtaining a price quote from an additional bank. For brevity, we only display results for first-time buyers (although we

[14] Real values (deflated to January 2016 prices) are obtained from the residuals of running separate regressions of prices in each $(\mathbf{x}^G, \mathbf{x}^H)$ cell on a full set of monthly dummies.

recover these non-parametric estimates for all combinations of observables: age, income, FTB, and urban location). For older buyers living in rural areas, median costs range from £17.31 for the richer cohort to £72.05 for poorer one. In relative terms, they represent between 5.7 - 21.5% of the median interest-only payment. This disparity can be seen across all different borrowers, depending on their observable characteristics.

Table 4 about here

These numbers are quantitatively similar to estimates from other countries provided in the literature, especially considering the differences in how the mortgage and real-estate markets operate across jurisdictions. Agarwal, Grigsby, Hortaçsu, Matvos, Seru, and Yao (2024) and Allen, Clark, and Houde (2017) estimate mean search costs of \$27 and \$29/month respectively on a representative loan. The numbers are also not identical to those in Table 2 of Myśliwski et al. (2025) because we do not impose the parametric restriction on the distributions.

Median search costs among the borrowers who search across banks are substantially lower, ranging from £6 to about £22. The results point to a high degree of heterogeneity across different demographics. We also find that some distributions are bimodal, with the first peak below £10 for some non FTB's, showing that some consumers who do not use brokers can efficiently search on their own. In summary, the headline finding here is that search costs vary by observable characteristics, with some such as poorer, older borrowers– and especially in rural areas– facing higher search costs.

Our findings support several hypotheses. First, the presence of physical bank branches is lower in rural areas, and would be more commonly used by older borrowers. Younger borrowers prefer digital channels, making mortgage comparisons easier. In urban areas, however, age is not a distinguishing factor between borrowers who prefer brick-and-mortar over online services. This may be because physical bank branches are readily available, older borrowers who live in cities may be more computer-literate, or because young urban dwellers tend to be richer than their rural cousins. We use it as a proxy for experience in using financial services. Second, there will likely be differences in financial literacy, which are typically either directly and indirectly correlated with income (e.g. see Hastings et al. (2013) and Lusardi and Mitchell (2014)). Lastly, as a robustness check, we estimated search costs with more finely discretized grids. We considered 4 different age buckets and 4 income quartiles. This provided us with no additional insight into the effects of age and income on search cost, while keeping the conclusions on the effect of FTB status and location virtually unchanged.

We move on to estimates of lenders' marginal costs and associated markups. As a sense-check, we also examine some of the aggregate statistics of marginal distributions that matter most.[15] For example, we expect riskier mortgages (e.g. higher LTV) to be associated with

[15]We do this instead of showcasing the full set of conditioning variables, $\mathbf{x}^H$.

higher risk premia, which we expect to be captured by these cost estimates. Table 5 summarizes our findings for selected LTV buckets, initial period length, mortgage term and loan size.[16]

Table 5 about here

We find that, on average, estimated costs increase in LTV and length of amortization, and price-cost margins are higher for 5-year FRMs than other durations. LTV is the main indicator of loan riskiness and the main driver of higher costs. FTBs will predominantly hold the longest mortgage durations, e.g. of 25 years or more. We can thus also interpret this finding in terms of the cost of servicing loans, being more idiosyncratic for first-time borrowers who amortize over longer periods of time.

We show in Figure 2 the distribution of markups, which is right-skewed with an average of 10.37% and median of 6.76%. Despite high market concentration, these big banks do not seem to be able to exert substantial market power. As our definition of price includes upfront fees, and we do not model lenders' fixed costs, our estimate is closer to the cost of servicing the loan over the initial period.

Figure 2 about here

Overall, these results are consistent with anecdotal evidence[17] showing the market becoming increasingly competitive, and lenders less able to enjoy high margins. From the perspective of the structural model's mechanics, low markups emerge as an artifact of a high proportion of borrowers using brokers whose presence, by construction, stimulates competition between lenders. We will return to this discussion in the following section.

6 Counterfactual experiments

In the current mortgage market, borrowers have access to different levels of information. Those with low search costs can efficiently compare loan offers from multiple lenders, while those facing higher costs will not be able to search as efficiently. They are limited or uncertain by choices they can find on their own or rely on intermediaries. To explore the implications of these differences, we conduct two counterfactual experiments.

First, we assess the value of information provided by brokers to high-search-cost consumers by simulating a market without intermediaries. On the one hand, eliminating brokers can reduce prices as neither lenders nor consumers have to pay broker commissions and the surplus can be transferred to consumers in the presence of lender competition. On the other hand, since brokers mitigate lenders' monopoly power, their absence would likely lead to higher prices and

[16] We estimate costs for the full set in 5% increments, e.g. 65%, 70%, 75% etc; 2-, 3-, and 5- year FRMs; the full distribution of mortgage terms in 5 year increments, e.g. 10-15 years, 15-20 years, etc; 4 quartiles of loan size; and additional features such as mortgages offering flexibility or cashback.

[17] See, for example, The Guardian article: Low rates, tight margins: the mortgage market looks worryingly familiar.

markups, especially in an oligopolistic market such as in the UK. While borrowers would no longer pay broker commissions, their overall search costs would be affected, altering market dynamics.

The second experiment examines the impact of market centralization. We consider a regulatory intervention where all lenders are required to post their prices on a centralized platform, and borrowers are automatically matched with the best available offer. This setup mirrors a first-price procurement auction with no search frictions. We analyze how such a policy would influence consumer surplus and lenders' pricing strategies.

6.1 Value of information provided by brokers

In the absence of intermediation, the borrower chooses the optimal number of searches given its cost.[18] The new search proportions then feed into the firms' pricing functions to generate a set of counterfactual conditional price distributions which can then be sampled from. The auction model assumes that for all consumers, the valuation of the mortgage, $\bar{v}$, is at least as high as the upper limit of the support of the cost distribution. Therefore, realized consumer surplus, CS, for a borrower paying p is:

$$CS = \bar{v} - p - SE$$

where SE is the search expenditure and is equal to $\kappa(k-1)$ if the borrower with search cost κ accessed the loan directly by contacting $k-1$ additional banks, or ϱ if she used a broker and paid commission equal to ϱ.
Without intermediation,

$$\dot{CS} = \bar{v} - \dot{p} - \dot{SE}$$

where $\dot{p}$ is the new price drawn from the counterfactual distribution, and $\dot{SE}$ is the new realized search expenditure which now does not include the possibility of using a broker. We define the value of information, VoI, as the difference between the expected CS and $\dot{CS}$:[19]

$$\text{VoI} = \mathbb{E}(CS - \dot{CS}) = \mathbb{E}(\dot{p} - p) + \mathbb{E}(\dot{SE} - SE) \tag{3}$$

Tables 6 and 7 report results from our counterfactual experiments. We estimate VOI provided by brokers in this market to be £72.31, on average. Alternatively, this means the existence of brokers helps the average mortgagor save over £72.31 a month (or £868 a year) in *sunk* expenditures (i.e. those not related to paying off the principal). If brokers were not present

[18] Finding a new equilibrium involves solving the fixed-point problem defined in the space of (new) optimal search proportions. Brouwer's theorem guarantees existence of a fixed point. While uniqueness cannot be proved, we experimented with different starting points finding that the algorithm converges to the same solution in the interior of the simplex.

[19] The definition we adopt is slightly different from e.g. Baye, Morgan, and Scholten's (2006) discussion of the Varian (1980) model who define value of information as the difference between the expected price of consumers who access the clearinghouse and those who do not.

in the market, borrowers would be paying 21.16% more, on average, in monthly installments and forgoing an additional 70.66% in search cost. These calculations suggest the role brokers themselves play in limiting lenders' monopoly power, which arises when consumers do not search enough. Importantly, intermediation generates a positive externality for borrowers who search directly because competition disciplines the lenders.[20]

So far, these results are for the average borrower. But we also show that borrower heterogeneity matters for whether they are winners or losers. Tables 6 and 7 disaggregate cost savings by borrower characteristics and mortgage type, respectively.

Table 6 about here

One can see from Table 6 that young, low-income, first-time buyers benefit most from having brokers in the market. The counterfactual price they would pay increases markedly in a world with no intermediaries, reaching up to almost 32%. These are also paired off by significant changes in their total cost of search.

Table 7 about here

More interestingly, in Table 7, we find that not everyone benefits equally from intermediation. Borrowers with 3- and especially 5-year initial periods, and those with with short mortgage terms of under 20 years gain little benefit. These results are driven by modest changes in equilibrium prices which come with massive reductions in total search expenditure. They imply that the level of consumer search for those products is low, and consequently– even with brokers present– commissions, market power, and prices are high.[21]

However, the presence of intermediaries substantially affects pricing of mortgages with longer amortization periods. A world without brokers doubles prices when mortgage terms are 30 years or more. Similarly, brokers help buyers with less popular mortgage products, e.g. flexible repayment schemes, or cashback. They do so by exerting negative pressures on lenders' prices, and by reducing overall search expenditures.

Overall, as the model does not deliver general equilibrium effects, our results should be interpreted with three caveats. First, we treat broker fees as exogenous. And while our results make it tempting to conclude that increasing them by a substantial amount would make borrowers better off than in a scenario without intermediation, doing that would reduce the demand for broker services and force many brokers to exit the market. Our analysis remains agnostic about what happens then. Second, we do not allow switching to different mortgage types in our counterfactual. Some consumers could switch mortgages if they knew brokers almost exclusively provide value when shopping for 2-year fixed rate deals, for example. Third, we do

[20]This is a natural consequence of the price coherence assumption and is somewhat different from the same finding in Salz (2022) who allowed separate price setting in the two market segments.

[21]Relatively higher mean markup estimates in Table 5 confirms this hypothesis.

not run a full welfare analysis.[22] With all that in mind, our result provide estimates under the current market structure.

6.2 Market centralization

In the second experiment, we consider a hypothetical market centralization. Recently, startups such as Habito [23] have facilitated mortgage search by creating a free online platform propelled by machine learning algorithms, matching borrowers' needs with best prices on offer. Unlike traditional price comparison websites like Moneyfacts, which only list prices, Habito mimics broker services, even helping borrowers through the mortgage application process.

We simulate the effects of extending such a technology to the entire market. We stop lenders from offering products directly, but only through the public platform. In a centralized market, lenders price according to the standard first-price procurement bid formula:

$$\beta(c|\mathbf{x}^G, \mathbf{x}^H) = \beta(c|\mathbf{x}^H) = c + \frac{\int_{s=c}^{\bar{c}} (1 - \mathcal{H}(s|\mathbf{x}^H))^{J-1} ds}{(1 - \mathcal{H}(c|\mathbf{x}^H))^{J-1}} \tag{4}$$

Canonical results from auction theory Milgrom and Weber (1982) assure that the symmetric equilibrium of the bidding game is unique. Therefore, solving for the counterfactual is straightforward, only involving finding the best responses defined by 4 without having to determine optimal consumer search behaviour.

We look at projected benefits from such market regulation, assuming platform access is costless and the environment completely frictionless. The results are summarized in Table 8.

Table 8 about here

In a market without search frictions, consumers would pay £14.75 less per month on average (or 4.39% less than currently). The benefits are further compounded by search expenditure savings of roughly £7.47 per loan. The sum of these two numbers corresponds to increase in consumer surplus quantitatively very close to the \$27.92 Allen et al. (2017) find when eliminating search frictions and limiting banks' market power in the Canadian market. The average reduction of price is double the welfare gains from eliminating search frictions,[24] suggesting that centralization would have a greater impact on competition between lenders than reducing information asymmetries between borrowers.

[22] The model does not provide an estimate for total broker payoffs. Woodward and Hall (2012) argue that brokers are indifferent between the main source of compensation (i.e. contributions from the lender versus borrower), caring only about total compensation. In our model, procuration fees– provided they are passed onto the borrowers– can be seen as part of estimated lenders' costs. In section A.4 we provide a robustness check where we adjust the estimated cost distributions by potential savings faced by the lenders assuming full pass-through of procuration fees. Overall, the average VOI drops from £72 to £62, and all the results are quantitatively similar to the ones presented here.

[23] For the of description of Habito's business model see e.g. The Financial Times

[24] In fact, it might appear that ΔSE is small compared to our estimates of median search costs from section 5.1. It should be however noted that in our framework, the first offer is free, and a substantial fraction of borrowers does not engage in search at all.

As in the first counterfactual, the magnitude of the change varies across borrower and product types. Richer and older borrowers would benefit more from market centralization than younger and low income borrowers, which is expected given that this exercise is the flipside of the first one where we found that currently mostly the latter group benefits from brokerage. Increased competition between lenders would render 3- and 5-year mortgages significantly cheaper (by 7.5% and 10%, respectively). Finally, high LTV borrowers and those with higher loan value and longer term would not see a major difference if the entire market was centralized.

Establishing a market-wide platform would certainly stimulate competition between lenders and make borrowers better off. However, in our framework, mortgagors are the only market participants who benefit from this regulation. Banks' markups do get affected, and in the following section we examine what market centralization means for them. However, to comprehensively assess the cost of the regulation, we would need to take a stance on the profits of brokers and the potential sunk costs they would be facing if they had to exit the market.

6.3 Summary of findings

The current market structure is perhaps more closely aligned with a centralized market given that 70% of all mortgages are currently brokered. Figure 3 displays the distributions of markups and prices in the data, and the two counterfactual scenarios.

Figure 3 about here

Without brokers, lenders would enjoy much more market power. The average Lerner index would increase to 24.03% and dispersion would also be larger, with 25% of borrowers facing margins of 33.5% or more. In a centralized market, the median PCM is only 3.95%, nearly half of the baseline estimate of 6.4%.

We conclude that the market is currently much more competitive than it would be if brokers were not present. While complete centralization would reduce mortgage prices and lenders' margins, the overall change would be modest and may not sufficiently compensate for the (potentially high) costs of establishing such a platform. Overtime, the emergence (and success) of online brokerages may be all we need at present to ensure a fully competitive market. Our policy conclusion is therefore one where the regulator should focus on facilitating broker competition, easing barriers to entry, but without necessarily banning lenders from forming direct sales.

7 Conclusion

This paper estimates the value of information provided by brokers using a structural model of borrower search. Using administrative data on all mortgage originations in 2016 and 2017, we document the existence of price dispersion and the modest pecuniary benefits of shopping with a broker. We find that a significant portion of the decision to use a broker cannot be explained by observable borrower characteristics, suggesting that unobserved heterogeneity in search costs plays a key role. Our main identifying assumption is that borrowers with high search costs rely on brokers to secure the best deals.

We use the structural model of Myśliwski et al. (2025) to identify the distribution of borrower search costs and lenders' costs of providing loans. In this paper, we simulate the effects of removing intermediaries from the market, and the resulting difference in consumer surplus quantifies the value of information. On average, we find that broker advice is worth approximately £72.31 per month, though not all borrowers benefit equally. Without brokers, lenders would wield significantly greater monopoly power, and consumers would face higher search costs. In a second counterfactual, we simulate the effects of market centralization, finding that it leads to only a modest reduction in prices and lenders' market power.

This paper makes two main contributions. First, our empirical findings contribute to the policy debate on the regulation of banks, brokers, and the mortgage market, showing how prevalent the degree of price dispersion is. Second, we run counterfactual experiments to help assess the value of information brokers provide in a heterogeneous market where some have high search costs. There are policy implications from our findings. First, central planners should facilitate the presence of intermediaries to alleviate groups of consumers with high search costs. Second, they should ensure readily available platforms where consumers can easily and cheaply access this information to find the best deals.

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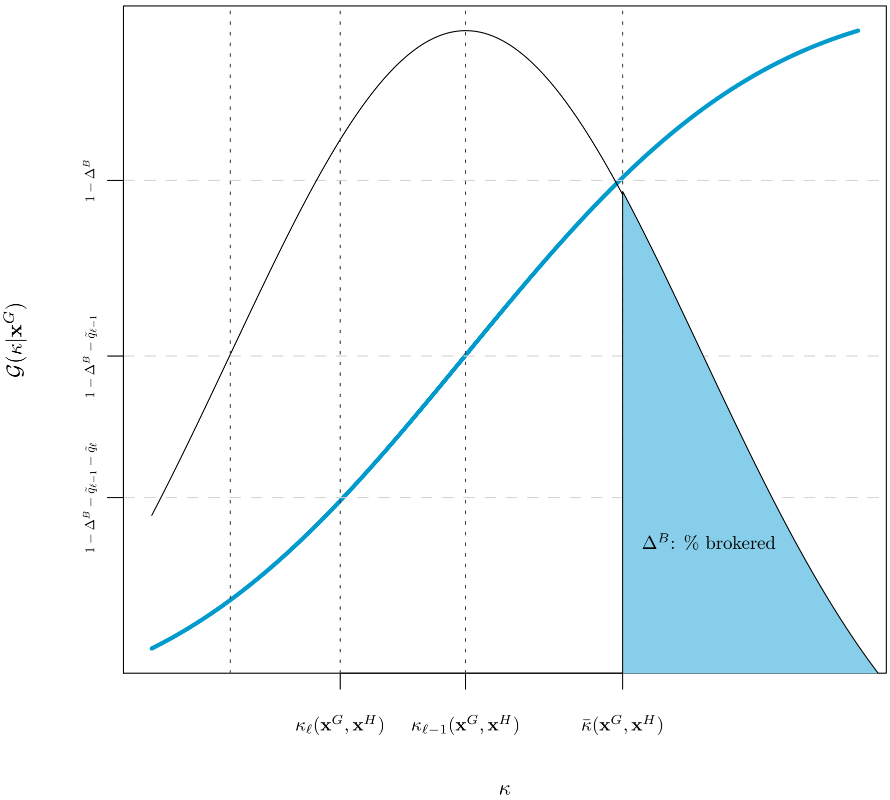
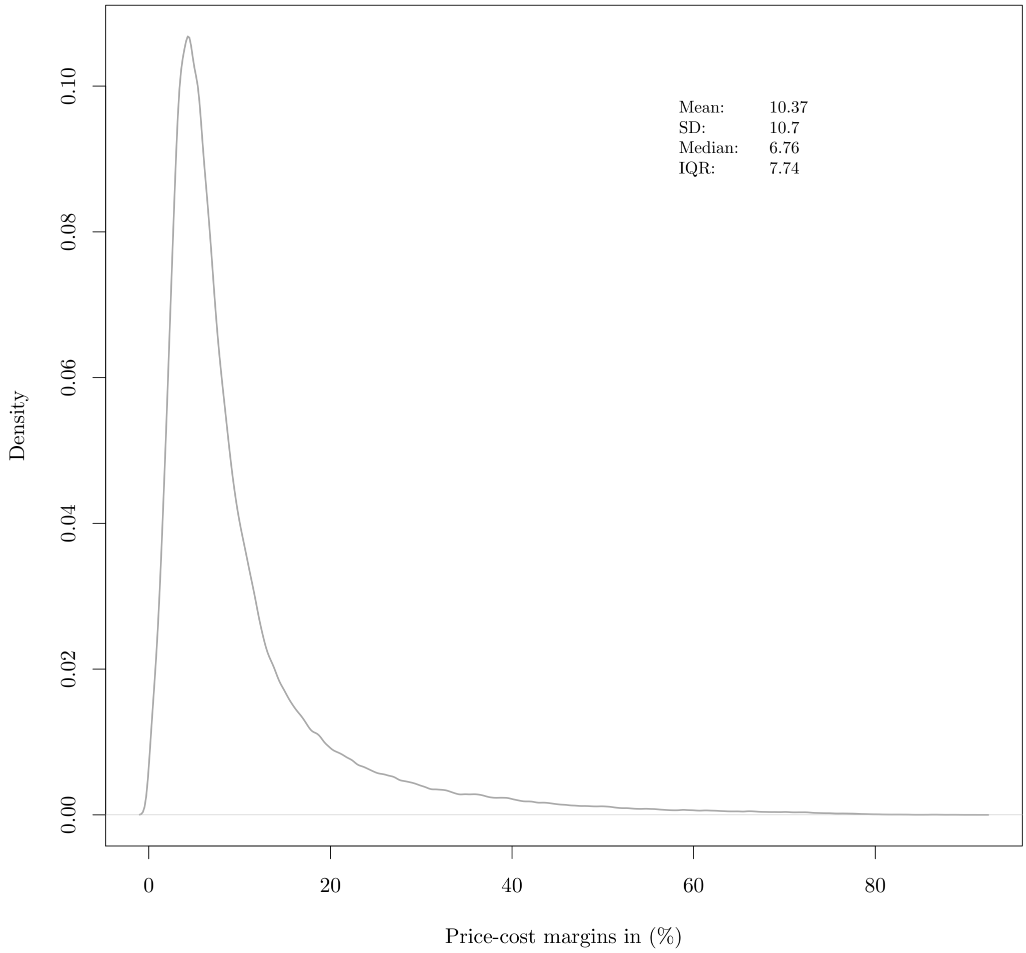
Figures

Figure 1: Equilibrium sorting.



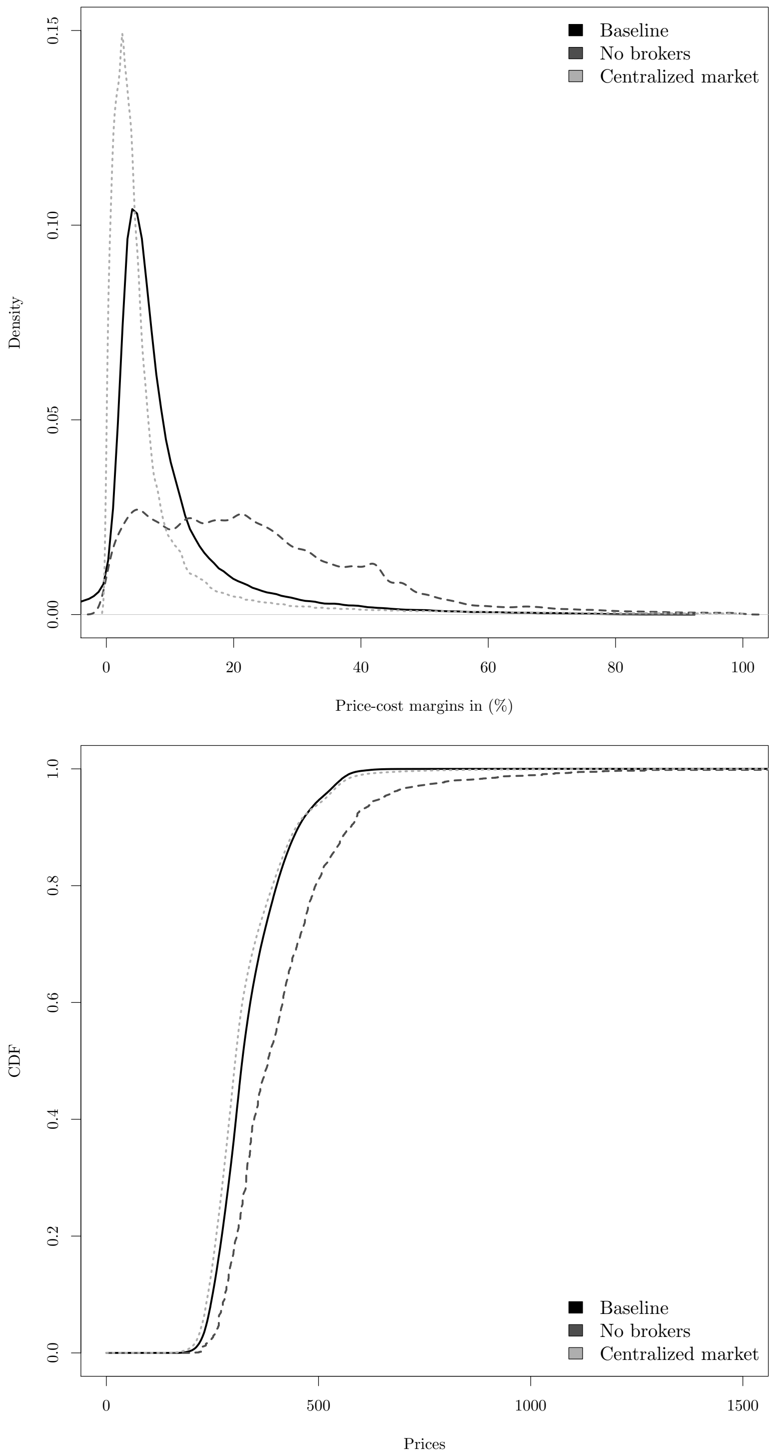
Note: Figure shows equilibrium sorting of buyers into types defined by the number of searches and use of brokers. The proportion of borrowers who use brokers is the blue shaded area under the search cost density. The areas between the cutoffs on the x-axis determine the proportions of buyers who search different number of firms. PDF not drawn up to scale.

Figure 2: Distribution of price-cost margins.



Note: Kernel estimate of the density of price-cost margins defined as $PCM_{ij} = 100 \cdot \frac{p_{ij} - c_{ij}}{p_{ij}}$.

Figure 3: Distributions of prices and price-cost margins in the counterfactual scenarios.



Note: Kernel estimates of the density of price-cost margins defined as $PCM_{ij} = \frac{p_{ij}-c_{ij}}{p_{ij}}$(top panel) and estimated CDFs of prices (bottom panel).

Tables

Table 1: Price dispersion by sales channel.

	Panel A: Interest rate			
	No FE		With FE	
	Direct	Broker	Direct	Broker
	(1)	(2)	(3)	(4)
$1 - R^2$	0.316	0.181	0.232	0.172
Coefficient of variation	0.307	0.316	0.307	0.316

	Panel B: Interest payments			
	No FE		With FE	
	Direct	Broker	Direct	Broker
$1 - R^2$	0.369	0.364	0.283	0.355
Coefficient of variation	0.294	0.305	0.294	0.305

Note: Table presents 1-R^2 from the regression defined by 2, separately by direct and broker sales channels and for two different definitions of price. The second row in each panel is the coefficient of variation defined the ratio of the standard deviation to the mean.

Table 2: Price benefits of using a broker.

	(1)	(2)	(3)	(4)	(5)
Dependent variable:	Interest	Interest	Interest	Monthly Payment	Monthly Payment
Used a broker	-7.761***	-6.710***	-7.428***	-5.103***	-3.562***
	(0.0824)	(0.0822)	(0.0816)	(0.119)	(0.122)
Lender Fees	Linear	Linear	Non-linear	-	-
Controls	Yes	Yes	Yes	Yes	Yes
Regional FE	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	1,309,067	1,309,067	1,309,067	1,309,067	1,309,067
R^2	0.768	0.772	0.778	0.627	0.632

Note: *** denotes significant at 1% level. Robust standard errors in parentheses. Interest is measured in basis points. Monthly interest is the component of the initial monthly payment that goes towards payment of the interest, including lender fees, and normalized by the size of the loan. Controls are income, house price, loan size, LTV, first time buyer and mortgage term. Time fixed effects are at the monthly level. Regional fixed effects are at the Government Office Region level and include a flag for an urban region. Non-linearities in lender fees are controlled for using a fifth-order spline.

Table 3: Impact of using a broker on price plus broker fees.

Dependent variable:	(1)	(2)	(3)	(4)
	Monthly payment + broker fee			
Used a broker	1.729***	2.985***	7.049***	11.40***
	(0.122)	(0.126)	(0.140)	(0.152)
Controls	Yes	Yes	Yes	Yes
Regional FE	No	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	1,309,067	1,309,067	792,023	792,023
R^2	0.607	0.610	0.626	0.632

Note: *** denotes significant at 1% level. Robust standard errors in parentheses. Monthly interest is the component of the initial monthly payment that goes towards payment of the interest, including lender and broker fees, and normalized by the size of the loan. Columns (1) and (2) show estimates obtained using the entire sample whereas columns (3) and (4) restricts the sample to only brokers who charge borrowers directly (i.e. the fees are non-zero).

Table 4: Nonparametric estimates of search cost distributions for first-time buyers

#	$\mathbf{x}^G$ bin				Median	Median	% median
	Age	Inc	FTB	Urb		searchers	price
1	L	L	Y	R	27.40 (6.08)	12.23 (1.42)	7.89%
2	H	L	Y	R	72.05 (18.62)	21.03 (4.44)	21.52%
3	L	H	Y	R	22.08 (27.47)	22.08 (7.07)	6.91%
4	H	H	Y	R	17.31 (4.68)	7.16 (3.03)	5.68%
9	L	L	Y	U	36.31 (7.58)	11.16 (0.94)	10.13%
10	H	L	Y	U	27.56 (16.41)	8.65 (0.62)	7.94%
11	L	H	Y	U	49.44 (11.82)	13.72 (4.19)	14.89%
12	H	H	Y	U	32.81 (13.73)	6.17 (0.69)	10.37%

Note: Table presents selected features of nonparametrically estimated search cost distributions for 16 different borrower types (referred to as $\mathbf{x}^G$ bins). Age: L (below 30)/H (over 30). Inc(ome): L (below median)/H (above median). FTB (first time buyer status): Yes/No. Urb(an): U (urban area)/R (rural area). Column 6 contains the median search cost in £/month in the initial period. Column 7 reports the median search cost among borrowers who do not use brokers. These expressed in relative terms (divided by median monthly payment) are in column 8. Bootstrap standard errors in parentheses based on 500 replications.

Table 5: Summary statistics for selected estimates marginal costs and margins..

$\mathbf{x}^H$ category	Marginal cost			Price-cost margin		
	Mean	Median	IQR	Mean	Median	IQR
LTV						
80	294.7	286.2	69.8	8.59	6.11	6.72
85	322.9	311.9	72.6	6.06	5.06	6.37
90	410.9	407.6	67.7	6.17	5.13	5.71
Initial period						
2 years	311.7	283.3	119.8	7.10	5.80	6.88
5 years	310.1	302.6	62.3	12.64	7.66	9.84
Term						
(25;30] years	326.9	307.0	116.1	7.49	5.68	6.14
(30;35] years	366.9	344.1	153.6	2.69	3.82	5.47
Loan size						
1st quartile	316.8	300.4	95.2	10.81	8.26	9.31
4th quartile	291.0	272.7	94.2	7.32	5.52	6.26

Note: Means, medians and interquartile ranges of estimated marginal cost and price-cost margins defined as $PCM_{ij} = \frac{p_{ij} - c_{ij}}{p_{ij}}$. Costs expressed in £, PCMs in %.

Table 6: Value of information: breakdown by borrower types.

	VOI	$\%\Delta p$	$\%\Delta SE$
Overall	**72.31**	**+21.16%**	**+70.66%**
Age			
<30	114.08	+30.39%	+163.44%
30+	63.19	+19.14%	+50.39%
Income			
Low	119.81	+31.64%	+120.18%
High	54.89	+17.31%	+52.50%
FTB			
FTB	88.66	+25.56%	+119.16%
Non-FTB	56.75	+16.96%	+119.67%
Location			
Urban	69.14	+19.94%	+79.44%
Rural	84.24	+25.74%	+37.59%

Note: Second column of the table reports the estimated average value of information as defined in equation (3) in GBP per month. The third and fourth columns report the (weighted) average percentage change in prices and search expenditures, respectively. Calculations made by simulating new prices and search behavior from the new equilibrium, assuming that lenders had the same marginal costs as in the baseline scenario.

Table 7: Value of information: breakdown by loan characteristics.

	VOI	$\%\Delta p$	$\%\Delta SE$
Overall	**72.31**	**+21.16%**	**+70.66%**
LTV			
≤70	56.90	+19.33%	-10.36%
71-75	94.21	+28.36%	+192.95%
76-80	56.72	+17.43%	+57.27%
81-85	97.23	+26.71%	+220.56%
86-90	107.33	+22.84%	+177.51%
91-95	38.80	+8.02%	-58.06%
Deal			
2 years	101.64	+29.27%	+133.04%
3 years	42.18	+14.66%	-35.63%
5 years	4.48	+2.25%	-70.26%
Term			
≤10 years	50.04	+19.11%	-70.55%
(10;15]	26.39	+11.29%	-77.65%
(15;20]	26.82	+9.92%	-76.19%
(20;25]	52.51	+15.98%	-0.98%
(25;30]	87.97	+25.16%	+95.67%
(30;35]	156.39	+40.15%	+409.79%
Value			
Q1	87.01	+26.36%	-30.94%
Q2	63.12	+18.15%	+14.86%
Q3	72.63	+20.59%	+70.43%
Q4	66.15	+19.36%	+218.25%
Flexible			
Flexible	25.67	+11.52%	-68.58%
Regular	79.72	+22.68%	+92.78%
Cashback			
No cashback	76.07	+21.88%	+89.83%
Cashback	47.45	+16.39%	-56.51%

Note: Second column of the table reports the estimated average value of information as defined in equation (3) in GBP per month. The third and fourth columns report the (weighted) average percentage change in prices and search expenditures, respectively. Calculations made by simulating new prices and search behaviour from the new equilibrium, assuming that lenders had the same marginal costs as in the baseline scenario.

Table 8: Price changes in a centralized market.

	Δp	$\%\Delta p$	ΔSE		Δp	$\%\Delta p$	ΔSE
Overall	**-14.75**	**-4.39%**	**-7.47**	**LTV**			
Age				≤70	-22.45	-7.16%	-8.87
<30	-6.92	-1.51%	-6.79	71-75	-2.64	-0.49%	-5.08
30+	-16.46	-5.01%	-7.62	76-80	-13.46	-3.92%	-5.88
Income				81-85	-5.22	-1.11%	-5.83
Low	-8.97	-1.98%	-6.78	86-90	-8.31	-2.61%	-6.61
High	-16.87	-5.27%	-7.23	91-95	-8.14	-1.44%	-6.13
FTB				**Deal**			
FTB	-15.83	-4.31%	-9.54	2 years	-5.65	-1.95%	-8.30
Non-FTB	-13.73	-4.45%	-5.51	3 years	-25.39	-7.58%	-11.36
Location				5 years	-35.69	-9.96%	-5.17
Urban	-14.05	-4.15%	-7.60	**Value**			
Rural	-17.38	-5.27%	-6.99	Q1	-21.55	-5.99%	-13.72
Term				Q2	-16.63	-4.73%	-7.01
≤10 years	-30.74	-9.63%	-15.48	Q3	-12.79	-3.99%	-5.17
(10;15]	-33.53	-10.55%	-10.72	Q4	-5.22	-1.11%	-5.83
(15;20]	-28.82	-9.01%	-8.11	**Flexible**			
(20;25]	-18.98	-5.54%	-6.66	Flexible	-7.72	-2.49%	-8.23
(25;30]	-9.98	-2.61%	-6.07	Regular	-15.87	-4.68%	-7.35
(30;35]	-14.21	-4.51%	-5.27	**Cashback**			
				No cashback	-13.75	-4.09%	-7.35
				Cashback	-21.37	-6.33%	-8.28

Note: The second column of each panel shows the average absolute difference between prices charged by lenders in a centralized market and prices observed in the data. The third column is the same difference but in relative terms. The fourth column shows the average search expenditure savings a fully frictionless market would generate (per loan in GBP/month).

A Appendix: data and reduced form results

A.1 Data and summary statistics

Table A.1 summarizes our main variables of interest by broker usage for different types of mortgage products– the two-, three-, and five-year FRMs. There is variation in loan size, fees, and offered interest rate across product type, but between borrowers who go direct or use brokers. The last row in the table shows monthly interest payments normalized by the size of the loan, which is our preferred measure of calculating mortgage cost. Section 3.1 outlines the calculation in detail.

Table A.1: Summary statistics

	2 yr FRM		**3 yr FRM**		**5 yr FRM**	
	Direct	**Broker**	**Direct**	**Broker**	**Direct**	**Broker**
Interest (bps)	232	213	245	235	259	247
Loan (£)	161,070	185,578	166,804	176,525	145,680	167,747
Loan Fees (£)	373.97	575.18	434.58	578.43	495.12	620.56
Monthly payment (£)	788.47	781.00	831.52	796.33	782.82	791.66
Monthly interest (£)	317.85	358.93	345.73	363.63	316.03	355.56
Normalized payment (£)	305.84	298.95	314.16	312.54	331.70	320.59

Note: Interest is the interest rate in basis points. Loan is the size of the mortgage issued by the bank. Monthly payment is the payment of capital and interest during the initial contract period of the loan, excluding lender fees. Monthly interest is the component of the monthly payment that goes towards payment of the interest, and includes the fees. Normalized interest payment is the monthly interest payment normalized to take into account the size of the loan.

Mortgage contracts in the UK are short-term, with an initial duration of 2-, 3-, or 5-years. Following the expiration of the initial period, and if the household does not refinance, the mortgage contract reverts to the bank's posted rate, or Standard Variable Rate (SVR). There are two types of contracts in the UK: fixed and variable. Fixed rate mortgages (FRM) have a fixed interest rate during the initial period, while adjustable rate mortgages (ARM) have a fluctuating rate that is a discount off of the SVR. Mortgage rates are arranged according to the length of the initial period and by LTV band. The longer the period and the higher the LTV, the more expensive the product. Table A.2 shows that, on average in our sample, households pay 230 basis points on their mortgage product, but that there is a spread of 280 basis points between the 2-year FRM at 70% LTV (cheapest) and the 5-year FRM at 95% LTV. Given that yield curves were roughly flat during this period, spreads across products have remained more or less constant.

Just over one-third of our sample are FTB, with the remainder either moving home or remortgaging their current home. But there is variation in the distribution of mortgagors at different LTV bands. Table A.3 shows that 80% of mortgagors on 95% LTV products are FTB, whereas 80% of mortgagors who took out an LTV of 70% or less are non-FTB.

Different banks also specialize in different products, with the share of longer term products more likely to be offered by some banks over others. This can be seen in table A.4.

Following the discussion in final paragraph of Section 2, we examine the distribution of procuration fees as a percentage of the loan value. Our data corroborates the anecdotal evidence cited in footnote 10– namely that the distribution is stable over the sample period, with an interquartile range of 0.05% in

Table A.2: Interest Rates by LTV and Rate Duration

	2 yr FRM	3 yr FRM	5 yr FRM	Average
≤ 70	1.8	2.2	2.3	2.0
71 - 75	1.8	2.2	2.5	2.0
76 - 80	1.9	2.4	2.6	2.1
81 - 85	2.1	2.5	2.8	2.2
86 - 90	2.8	3.0	3.3	2.9
91 - 95	3.0	4.0	4.6	4.0
Total	2.2	2.4	2.5	2.3

Table A.3: Share by Household type and LTV

	Non-FTB	FTB	Total
≤ 70	82	18	100
71 - 75	60	40	100
76 - 80	68	32	100
81 - 85	56	44	100
86 - 90	36	64	100
91 - 95	19	81	100
Total	64	36	100

Table A.4: Share by Bank and Product Type

	2 yr FRM	3 yr FRM	5 yr FRM	Total
Bank 1	76.61	0.89	22.50	100
Bank 2	67.48	2.26	30.26	100
Bank 3	58.80	9.75	31.45	100
Bank 4	66.22	4.71	29.07	100
Bank 5	44.19	10.74	45.07	100
Bank 6	72.30	1.42	26.28	100
Total	66.27	4.33	29.40	100

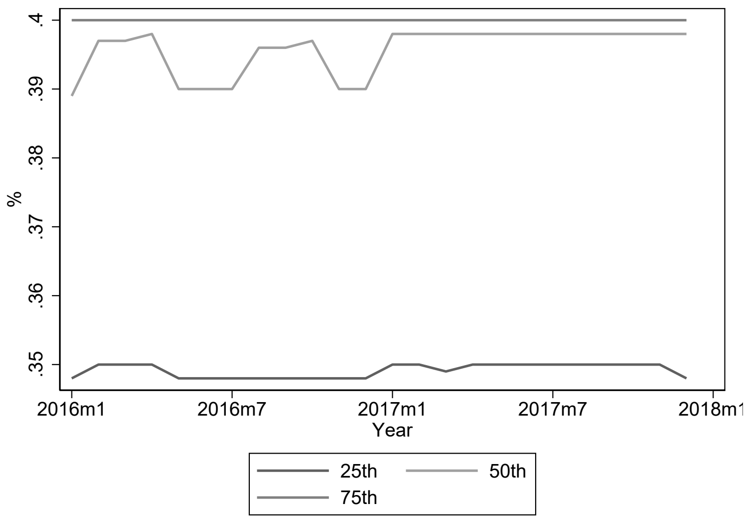
most months (between 0.35% and 0.4%) and the median ranging from 0.39% to 0.398%). This suggests that conditional on loan value, most big banks offer almost exactly the same commission to the broker, while the lack of time variation points to limited scope for dynamic competition between lenders in the size of broker remuneration.

A.2 Estimation sample

We restrict our sample to standard[25] fixed rate mortgage products with two-, three-, and five-year durations; and to loan sizes less than £1M. This leaves us with about 82% of the sample (1.7M loans) for

[25] These are products that include repayment of the capital.

Figure A.1: Distribution of procuration fees as % of loan value over time.



Note: The graph shows the evolution of the first, second and third quartile of the distribution of procuration fees for brokered loans expressed as a % of the loan value.

analysis. We further restrict our sample to the six largest mortgage providers which made up about 75% (or 1.3M loans) in 2016 and 2017. The differences between the raw and final sample are tabulated in table A.5.

Table A.5: Raw and Final Sample

	Big Six	%	Raw Sample	%
Total	1,539,009	100.00	2,138,754	100.00
Interest-only mortgages	43,276	2.81	81,482	3.81
Non-FRM	114,099	7.41	152,856	7.15
Not 2, 3, 5yrs	61,765	4.01	141,054	6.60
£1M+ loan	4,186	0.27	5,886	0.28
Outliers	6,606	0.43	13,892	0.65
Final Sample	**1,309,077**	85.06	1,743,584	81.52

A.3 Probability of using a broker

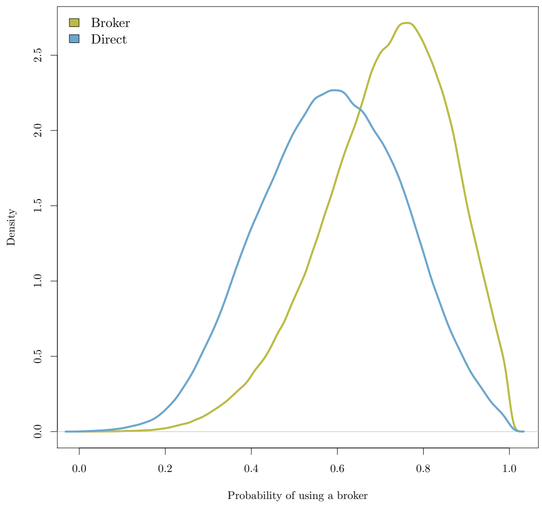
Table A.6 reports the estimates from a linear probability model where we regressed the indicator whether the contract was brokered on a number of personal and product characteristics. The first observation is that the signs are in line with intuition. For example, lower income, first time buyers, the employed, and older mortgagors are more likely to use a broker. Moving to column 2, adding product characteristics shows that mortgagors who took longer term contracts were less likely to visit brokers (the causality may also be in the other direction, so we interpret the results in terms of conditional correlations, rather than causal relationships). In fact, a recent FCA investigation (Iscenko and Nieboer, 2018) hypothesises that brokers might be more likely to suggest 2-year contracts knowing that this makes borrowers use their services more frequently in the future. A longer mortgage term is also associated with increased probability of using brokers. However, column 2 also shows that when product characteristics are added, the sign on LTV indicators is reversed from positive (column 1) to negative. In fact, the higher the LTV the less likely a household uses a broker. This may be for a number of reasons, for example, households on low LTV products typically have smaller absolute loans, therefore the costs of visiting a broker and paying a lump-sum is relatively higher. Finally, column 3 shows that even after controlling for regional fixed effects, the coefficients remain unchanged and the R^2 remains low, so the observables are rather poor predictors for broker use.

Table A.6: Probability of using a broker

	(1)	(2)	(3)
Dependent var: Used a broker	Personal Characteristics	Product Characteristics	Regional Characteristics
Income	-0.002***	-0.016***	-0.037***
First Time Buyer	0.048***	0.016***	0.009***
Aged 25 - 29	0.024***	0.028***	0.024***
Aged 30-34	0.042***	0.068***	0.063***
Aged 35- 39	0.049***	0.121***	0.115***
Aged 40 - 45	0.036***	0.179***	0.172***
Aged 45+	-0.022***	0.251***	0.241***
71 - 75 LTV	0.131***	0.063***	0.078***
76 - 80 LTV	0.042***	-0.029***	-0.012***
81 - 85 LTV	0.075***	-0.019***	-0.000
86 - 90 LTV	0.035***	-0.066***	-0.041***
91 - 95 LTV	0.028***	-0.111***	-0.084***
Employed	-0.054***	-0.046***	-0.045***
Mortgage Term		0.021***	0.020***
3 Year FRM		-0.229***	-0.228***
5 Year FRM		-0.187***	-0.184***
Flexible Mortgage		0.086***	0.083***
Urban area			-0.011***
Regional FE	No	No	Yes
Observations	1,309,067	1,309,067	1,307,538
R^2	0.020	0.124	0.130

Note: *** denotes 1% significance level. Robust standard errors used.

Figure A.2: Distributions of predicted probabilities of using a broker.



Note: Density estimates of the distributions of $\widehat{\Pr}(\mathrm{d_i} = \mathrm{broker}|\mathbf{X})$ based on the LPM in the third column of table A.6 for the brokered and direct subsamples.

A.4 Robustness checks

This section presents robustness checks, which examine potential effects of procuration fees paid by the lenders to the brokers. The first two tables display the results of the regression of prices on brokered dummy (table 2 in the main text) for two subsamples of the data – A.7 only uses data on brokers who are not paid by the borrowers directly and are only compensated by the lenders, while A.8 only uses data on brokers who are not paid by the lenders and are only paid directly by the borrowers. The signs on the variables of interest are negative for all specifications and subsamples. This suggests that there is no evidence that different sources of compensation can alter brokers incentives to provide advice about cheaper products.

Table A.7: Price benefits of using a broker: brokers who do not charge the borrowers.

Dependent variable:	(1) Interest	(2) Interest	(3) Interest	(4) Monthly Payment	(5) Monthly Payment
Used a broker	-6.509***	-6.370***	-7.720***	-2.091***	-2.210***
	(0.0902)	(0.0917)	(0.0927)	(0.143)	(0.153)
Lender Fees	Linear	Linear	Non-linear	-	-
Controls	Yes	Yes	Yes	Yes	Yes
Regional FE	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	940,921	940,921	940,921	940,921	940,921
R^2	0.741	0.747	0.754	0.600	0.605

Note: *** denotes significant at 1% level. Robust standard errors in parentheses. Interest is measured in basis points. Monthly interest is the component of the initial monthly payment that goes towards payment of the interest, including lender fees, and normalized by the size of the loan. Controls are income, house price, loan size, LTV, first time buyer and mortgage term. Time fixed effects are at the monthly level. Regional fixed effects are at the Government Office Region level and include a flag for an urban region. Non-linearities in lender fees are controlled for using a fifth-order spline.

Table A.8: Price benefits of using a broker: brokers who are not paid by lenders.

Dependent variable:	(1) Interest	(2) Interest	(3) Interest	(4) Monthly Payment	(5) Monthly Payment
Used a broker	-6.181***	-2.443***	-4.390***	-6.151***	-1.046***
	(0.180)	(0.177)	(0.182)	(0.244)	(0.245)
Lender Fees	Linear	Linear	Non-linear	-	-
Controls	Yes	Yes	Yes	Yes	Yes
Regional FE	No	Yes	Yes	No	Yes
Time FE	Yes	Yes	Yes	Yes	Yes
Observations	464,012	464,012	464,012	464,012	464,012
R^2	0.689	0.698	0.704	0.628	0.636

Note: *** denotes significant at 1% level. Robust standard errors in parentheses. Interest is measured in basis points. Monthly interest is the component of the initial monthly payment that goes towards payment of the interest, including lender fees, and normalized by the size of the loan. Controls are income, house price, loan size, LTV, first time buyer and mortgage term. Time fixed effects are at the monthly level. Regional fixed effects are at the Government Office Region level and include a flag for an urban region. Non-linearities in lender fees are controlled for using a fifth-order spline.

Tables A.9 and A.10 display alternative calculations of the value of information under the assumption that removing brokers would reduce lenders' costs by the expected amount of procuration fees. To implement this, we adjust each estimated $\mathcal{H}(\cdot|\mathbf{x}^H)$ by $\overline{\Delta^B} \cdot \overline{\phi}(\mathbf{x}^H)$, where the first term is the average proportion of brokered loans with characteristics $\mathbf{x}^H$ and the second term is the average observed procuration fee for a mortgage characterized by $\mathbf{x}^H$ taken from the data. The results of this exercise are valid under the assumption that the mortgage sold through a broker and directly is indeed the same product so any additional cost, such as the procuration fee if it is sold through a broker, is also indirectly passed onto consumers who obtain it directly from the lender.

The numbers in the tables below should be compared to tables 6 and 7 in the main text. Overall, adjusting for procuration fees reduces the value of information by about $£10$ through a smaller increase in prices (18% vs. 21%) coupled with a 18pp increase in search cost.

Table A.9: Value of information with adjusted costs: breakdown by borrower types.

	VOI	$\%\Delta p$	$\%\Delta SE$
Overall	**61.72**	**+17.51%**	**+88.59%**
Age			
<30	100.31	+26.27%	+181.86%
30+	53.29	+15.59%	+68.23%
Income			
Low	105.95	+27.75%	+128.79%
High	45.49	+13.75%	+73.85%
FTB			
FTB	78.52	+22.04%	+49.52%
Non-FTB	45.72	+13.19%	+125.80%
Location			
Urban	58.00	+16.10%	+99.68%
Rural	75.68	+22.80%	+46.89%

Note: Second column of the table reports the estimated average value of information as defined in equation (3) in GBP per month. The third and fourth columns report the average percentage change in prices and search expenditures, respectively. Calculations made by simulating new prices and search behaviour from the new equilibrium, assuming that lenders drew had the same cost draws as in the baseline scenario. Marginal cost distributions are adjusted to account for the fact that in a world without brokers, lenders do not pay procuration fees.

Table A.10: Value of information with adjusted costs: breakdown by loan characteristics.

	VOI	$\%\Delta p$	$\%\Delta SE$
Overall	**61.72**	**+17.51%**	**+88.59%**
LTV			
≤70	47.30	+15.44%	-19.16%
71-75	83.79	+24.70%	+206.88%
76-80	42.61	+12.65%	+69.13%
81-85	85.23	+23.18%	+216.12%
86-90	96.52	+20.24%	+181.55%
91-95	27.06	+5.71%	-47.65%
Deal			
2 years	87.09	+24.48%	+136.02%
3 years	48.46	+17.07%	-51.79%
5 years	2.00	+0.83%	-13.72%
Term			
≤10 years	52.45	+19.64%	-71.94%
(10;15]	17.17	+7.56%	-44.89%
(15;20]	16.90	+6.05%	-46.12%
(20;25]	43.77	+12.91%	+12.02%
(25;30]	76.72	+21.34%	+122.05%
(30;35]	137.86	+34.62%	+412.65%
Value			
Q1	79.72	+23.94%	-17.81%
Q2	54.72	+14.99%	+51.08%
Q3	61.52	+16.81%	+102.69%
Q4	50.87	+14.21%	+211.50%
Flexible			
Flexible	14.64	+6.93%	-33.92%
Regular	69.20	+19.19%	+108.06%
Cashback			
No cashback	65.32	+18.19%	+105.75%
Cashback	37.85	+12.99%	-25.22%

Note: Second column of the table reports the estimated average value of information as defined in equation (3) in GBP per month. The third and fourth columns report the average percentage change in prices and search expenditures, respectively. Calculations made by simulating new prices and search behaviour from the new equilibrium, assuming that lenders drew had the same cost draws as in the baseline scenario. Marginal cost distributions are adjusted to account for the fact that in a world without brokers, lenders do not pay procuration fees.

B Appendix: Structural model

B.1 Covariate selection for the structural model

Borrower and loan characteristics used in our structural model are displayed in Table B.1. Since the model needs to be solved for each combination of $(\mathbf{x}^G, \mathbf{x}^H)$, we rely on discretizing continuous variables. A related issue is that for kernel methods to provide a reliable estimate of the pdf of observed prices we need possibly many data points in each of the bins. Therefore, out of the initial 27,648 bins we used only those with 50 or more observations. This leaves us with 3,697 combinations (86.68% of the total number of mortgages in our main sample) representing the most popular products and borrower types. While by doing this we are no longer working with the entire universe of mortgages, the scope of loans we look at is still much broader than in previous literature using search models to study mortgage markets.[26]

Table B.1: Borrower and loan characteristics.

Variable	Discretization	# bins
	$\mathbf{x}^G$ (16 combinations)	
Age	<30, 30+	2
Income	Below median, Above median	2
FTB status	FTB, Non-FTB	2
Location	Urban, Rural	2
	$\mathbf{x}^H$ (1,728 combinations)	
LTV	≤70, 71-75, 76-80, 81-85, 86-90, 91-95	6
Deal length	2-, 3-, 5-year	3
Duration	<10, (10;15], (15;20], (20;25], (25;30], (30;35]	6
Loan value	4 quantiles	4
Flexible	Yes, No	2
Cashback	Yes, No	2
	Total: 27,648 bins	

Note: Table presents the selection of conditioning variables and associated bins used in the estimation of the structural model. The total number of bins is the cardinality of the Cartesian product of the elements of $\mathbf{x}^G$ and $\mathbf{x}^H$.

B.2 Estimation algorithm

To ease the notation, let s index distinct discrete combinations of $(\mathbf{x}^G, \mathbf{x}^H)$ and, for the sake of brevity, let $\mathcal{F}_s(p) \equiv \mathcal{F}(p|s)$, $f_s(p) \equiv f(p|s)$, and $\Delta_s^B \equiv \Delta^B(s)$. The estimation algorithm used in this paper differs only slightly compared to the full description in Section 7.2 of Myśliwski et al. (2025). The key point of departure is that we use nonparametric estimators for price and marginal cost distributions, whereas in the empirical illustration in the mentioned paper, the authors assumed they follow Beta distributions with mean and dispersion parameters being flexible functions of loan and borrower characteristics. Therefore, to avoid introducing cumbersome notation, below we only summarize the key steps needed to estimate the model.

1. Nonparametrically estimate $\mathcal{F}_s(p)$ and $f_s(p)$ separately for all $s \in \{\mathbf{x}^G \times \mathbf{x}^H\}$, where the cardinality of the set of covariates depends on how the variables are discretized (can potentially be

[26] For example, Allen, Clark, and Houde (2013) look exclusively at FTBs taking out loans with 25 year amortization and 5-year initial deal period.

very large). The CDF is estimated simply as:

$$\hat{\mathcal{F}}_s(p) = \frac{1}{n_s}\sum_{i=1}^{n_s} \mathbf{1}\{p_i \leq p\}.$$

To estimate the density, we need to to address the problem of bias near the lower boundary and the possibility that the density near the upper boundary may be unbounded. To tackle this, we use an asymmetric Beta kernel suggested by Chen (1999) that performs well on densities defined over compact supports[27].

2. Obtain an estimate of $\tilde{\mathbf{q}}_\mathbf{s}$, which is the vector of proportions of consumers searching a given time of banks. To do that, we regress market shares on a vector of explanatory variables constructed by evaluating the estimated CDFs from step 1 at the average rate charged by bank j conditional on s. The intuition behind this step is that, conditional on price, the observed difference in market shares can only be explained by some consumers having different number of offers to compare than others. Therefore the variation in market shares conditional on price identifies the search proportions.
   This step also accommodates the restriction that $\tilde{q}_{J_s}(s) \geq \Delta_s^B$, i.e. the proportion of consumers obtaining quotes from all banks needs to be greater or equal than the fraction of brokered loans. To do so, we use constrained quadratic programming to solve the least squares problem, where the RHS of the constraint, Δ_s^B is directly observed in the data.

3. Estimate the vectors of cutoff types $\boldsymbol{\kappa}_s \equiv \boldsymbol{\kappa}(s)$ for each s, where for $\ell \in \{1, \ldots, J_s - 1\}$:

$$\kappa_\ell(s) = \mathbb{E}_{\mathcal{F}_s}\left[p_{(1:\ell)}\right] - \mathbb{E}_{\mathcal{F}_s}\left[p_{(1:\ell+1)}\right]$$

   and the marginal type who is indifferent between using a broker and searching directly is estimated as:

$$\bar{\kappa}(s) = \frac{\varrho(s) - \left(\mathbb{E}_{\mathcal{F}_s}\left[p_{(1:k^*)}\right] - \mathbb{E}_{\mathcal{F}_s}\left[p_{(1:J)}\right]\right)}{k^* - 1}.$$

   $\varrho(s)$ is the average (observed) broker commission and k^* is the equilibrium number of searches of the marginal type. To determine k^*, we find the lowest ℓ, such that $\kappa_\ell(s) < \bar{\kappa}(s)$.[28] To estimate the expectations of the order statistics, we draw repeatedly from the price distributions and calculate the sample averages of the minimum prices.
   Finally, $\hat{\tilde{\mathbf{q}}}(s)$ estimated in the previous step can be used to recover $\mathcal{G}$ evaluated at the cutoff points as follows: $\mathcal{G}(\bar{\kappa}(s)|\mathbf{x}^G) = 1 - \Delta_s^B$; $\mathcal{G}(\kappa_{k^*}(s)|\mathbf{x}^G) = 1 - \Delta_s^B - \hat{\tilde{q}}_{k^*}(s), \ldots, \mathcal{G}(\kappa_{J_s-1}(s)|\mathbf{x}^G) = 1 - \Delta_s^B - \hat{\tilde{q}}_{k^*}(s) - \cdots - \hat{\tilde{q}}_{J_s-1}(s)$.

4. After steps 2 and 3, we have nonparametrically estimated values of the search cost distributions $\mathcal{G}$ for a finite number of points. To be precise, for each $\mathbf{x}^G$, we have the number of cutoffs times

[27] The implementation comes from the `npuniden.boundary` function from the `np` package in `R` (Hayfield and Racine, 2008).

[28] Clearly, $\bar{\kappa}(s)$ is not identified if $k^* = 1$, so if a borrower is now indifferent between using a broker or not, she would not search beyond the first offer she receives for free if intermediation was not available. In this case, we replace $\bar{\kappa}(s) = \kappa_1(s) + \epsilon$ where $\epsilon \sim \text{Unif}[0, \kappa_1(s)]$.

the cardinality of $\mathbf{x}^H$. We now pool those estimates to estimate a collection of smooth search cost CDFs $\mathcal{G}(\cdot|\mathbf{x}^G)$ using Bernstein polynomials which can accommodate shape restrictions (non-decreasingness of the CDF). The method and its theoretical properties are described in Section 4 of (Sanches et al., 2016).

5. In the final step, we recover the distributions of lenders' marginal costs. This step is reminiscent of recovering the distribution of valuations from observed bids in a first-price auction (Guerre et al., 2000). First, for each observed price, we construct pseudo-marginal costs using the inverse of the bidding function:

$$\hat{c}_{ij}(s) = p_{ij} - \frac{\sum_{\ell=1}^{J_s} \hat{\tilde{q}}_\ell \ell \left(1 - \hat{\mathcal{F}}_s\left(p_{ij}\right)\right)^{\ell-1}}{\hat{f}_s\left(p_{ij}\right) \sum_{\ell=1}^{J_s} \hat{\tilde{q}}_\ell \ell \left(\ell - 1\right) \left(1 - \hat{\mathcal{F}}_s\left(p_{ij}\right)\right)^{\ell-2}}, \tag{B.1}$$

Then we proceed to estimate $\mathcal{H}(\cdot|\mathbf{x}^H)$ and $h(\cdot|\mathbf{x}^H)$ using the same methods as in Step 1.