Monopoly and Information Advantage in the Residential Mortgage Market

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Information advantage and entry deterrence incentives are investigated as they affect lending outcomes and competitive structure of the U.S. residential mortgage market. In the model, when assessing a loan applicant, the incumbent monopoly lender employs a proprietary screening technology to produce a privately observed estimate of loan credit quality. When faced with potential competitive entry, the incumbent signals poor credit quality by charging high prices to higher-quality borrowers. Market structure and loan pricing strategy are derived endogenously, where the incumbent deters entry first by segmenting consumers into prime and sub-prime loan markets and second by charging prime market borrowers a uniform rate that is higher than the risk-based monopoly rate. Empirical implications of the model are identified, and evidence is presented that is consistent with predictions.

The U.S. residential mortgage market represents close to 30% of the nation's total credit market. The structure of this market has received considerable attention in recent years, with much of the focus on Fannie Mae and Freddie Mac. Over the years these two Government Sponsored Enterprises (GSEs) have come to dominate the market, and are now two of the largest corporations in the United States as measured by assets. They have also become lightning rods for critics concerned about the federal government's implied contingent bailout liability and the associated systemic implications for the broader financial system.[1]

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[1] For a comprehensive review of the relevant issues, see Frame and White (2005).

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Despite the recent critical attention, numerous aspects of the U.S. residential mortgage loan market remain understudied and not particularly well understood. We consider two important aspects of this market. First, it is segmented into a higher-credit quality (prime) market and a lower-credit quality (sub-prime) market. Second, the credit-spread component of the mortgage rate offered in the prime market shows surprisingly little variation as a function of mortgage loan credit quality. These outcomes are puzzling given the sophisticated credit evaluation models that exist to facilitate risk-based loan pricing—a pricing strategy that is commonly thought to maximize lender profits.

To explain these structural characteristics, we develop a theoretical model that shows how information advantage combines with entry deterrence incentives to shape underwriting and pricing strategies in the market. Information advantage derives from the fact that Fannie Mae and Freddie Mac have acquired vast quantities of consumer credit information over time and have used it to develop sophisticated credit evaluation models. This gives them a competitive advantage over retail loan originators (depository institutions and brokers) in the primary market. Loan originators have consequently become less relevant, as they now typically apply the GSE credit evaluation model to screen loan applicants and charge rates based on the GSE-guaranteed price at which the loan is resold in the secondary market. In other words, to a good first approximation, the GSEs effectively lend directly to consumers as informationally advantaged monopolists.[2]

Information advantage allows the incumbent lender to affect competitors' entry decisions. This is done by exploiting the interdependence between the pre-entry loan rate charged to consumers and the potential entrant's expected profits. We show that market segmentation and uniform credit risk pricing for higher-quality borrowers are endogenous equilibrium outcomes that are a result of this interdependence.

Without the threat of entry, the lender's profit-maximizing strategy is to price-differentiate its loans according to assessed credit quality, and to use its market power to mark the mortgage loan rate above marginal cost. Risk-based pricing reveals valuable information about a borrower's credit quality, however. Since credit quality information implicit in the loan rate allows for a more accurate projection of entrant profitability, risk-based loan pricing would facilitate entry. Because entry depresses profitability in the longer run, the incumbent lender will have incentives to deter entry

[2] The Mortgage Bankers Association (2005) explains how GSE credit evaluation technology solidifies its market power. Hermalin and Jaffee (1996) argue that Fannie Mae and Freddie Mac tacitly collude to effectively monopolize the secondary mortgage market.

by disguising the true credit quality of particular borrowers through pool pricing.[3]

Uniform loan pricing is required only with the higher-credit quality borrowers, where the lower bound of the pool pricing region ensures that entry is just unprofitable for a potential entrant. The incumbent lends to lower-credit-quality borrowers at a separating (risk-based) price, as market entry is naturally deterred in this region. The loan market is thus segmented into a "prime" market where lower-risk consumers pay a single uniform rate and a "sub-prime" market where higher-risk consumers pay a risk-based rate that varies as a function of credit quality.

Despite a pool-pricing outcome, some variation in the credit-spread is still possible. The incumbent lender's information on borrower characteristics can be thought of as either publicly observable or private. Risk-based pricing on publicly observable information can improve first-period profits while not releasing any new information into the market. The lender would therefore pool-price on the basis of the unobservable characteristics but price-discriminate using observable characteristics.

Like Jaffee and Modigliani (1969), we are interested in how a loan market segments between higher- and lower-credit-quality applicants. Their model imposes uniform pricing to obtain separate regions, where higher-credit-quality borrowers receive a loan but lower-credit-quality applicants are rationed out of the market. In our model, lower-credit-quality applicants receive a loan at a risk-based price. The primary difference between the models is that, in our case, a uniform rate emerges endogenously as a way to protect information advantage and deter entry, rather than being exogenously imposed or assumed.

Our analysis of the market structure of the residential mortgage market has implications for other consumer credit markets. For example, Ausubel (1991) documents that interest rates on credit card loans are sticky, with little sensitivity to changes in issuers' cost of funds or consumer credit risk. While other explanations may lie in switching costs or asymmetric information between the cardholder and bank, we provide an alternative rationale. A lender that acquires private information, either by observing detailed past credit performance or by providing other banking services, has an incentive to exploit this information to deter entry by charging uniformly high loan rates in order to signal low credit quality.

Empirical implications of the model are identified and supporting evidence is presented. One set of evidence is consistent with pool pricing rather than risk-based pricing in the prime market, where we find that mortgage loan rates are significantly less variable in the prime market than

[3] Laffont and Maskin (1990) note that "a large trader will typically find it advantageous to conceal his private information parameter by ensuring that the equilibrium price is not sensitive to local variation in this parameter, that is, he will induce an equilibrium of a (locally, at least) 'pooling' nature."

in the sub-prime market. Evidence is also consistent with the assumed information structure and endogenously determined pooling equilibrium, as we find that the GSEs do not incorporate all their private information into the observed mortgage loan rates. A second set of evidence is related to the prime market share across different geographic areas. Consistent with comparative static results, we show greater prime market share in geographic areas with larger banks that have established networks and thus a lower incremental cost of entry.

The organization of the paper is as follows. In Section 1, the structure of the U.S. residential mortgage market is described in detail. The model is outlined in Section 2, and preliminary results are presented in Section 3 when entry is not a threat to incumbent lender profitability. Section 4 analyzes the market equilibrium with endogenous learning and entry. Comparative static outcomes and consumer welfare implications of the model are contained in Section 5. Empirical predictions of the model are outlined in Section 6, and Section 7 presents supporting evidence. Further implications of the model for the U.S. residential mortgage market are considered in Section 8. The paper concludes with Section 9.

1. Institutional Background

Despite a large number of retail mortgage lenders, vast segments of the U.S. residential mortgage market have strong monopolistic characteristics. Homebuyers typically obtain financing through retail mortgage lenders like depository institutions or mortgage brokers. Retail mortgage lenders, in turn, decide whether to hold the mortgages or sell them to the secondary market, where the major players are Fannie Mae and Freddie Mac. Frame and White (2005) report that 70% of all "qualified" residential mortgages in recent years have been sold directly to Fannie and Freddie.[4]

GSE secondary mortgage market dominance is derived from several sources, including regulatory barriers that help block entry (Hermalin and Jaffee 1996), government subsidies that possibly result in a lower cost of capital (Van Order 2000), and information advantage in credit evaluation.[5] As a result of their growth and market dominance, Fannie Mae and Freddie Mac have become the second and third largest U.S. companies in terms of assets as of year-end 2003.

[4] Technically, Fannie Mae and Freddie Mac may purchase only conventional-conforming mortgages, which are non-FHA-insured loans below prespecified dollar amounts. A significant proportion of all originated mortgages fall into this category. According to Van Order (2000), the conventional (non-FHA) market is 85–90% of the total market, and the conforming (mortgage-size-limited) market represents 80–85% of the conventional market. Fixed-rate mortgage loans are typically originated for sale into the secondary market, but adjustable-rate loans, although potentially eligible for sale, are typically originated to be held by the retail lender. Fixed-rate loans have historically dominated the market. Therefore, the segment of the residential mortgage market that best fits our setting is the fixed-rate conventional-conforming market.

[5] For further details on GSE informational advantage, see an April 5, 2001, *Wall Street Journal* article entitled "Why Big Lenders Are So Afraid of Fannie Mae and Freddie Mac."

Market dominance, large transaction volumes, and standardized contracting allow Fannie and Freddie to acquire vast quantities of consumer credit information at relatively low cost and to correlate this information—plus information on collateral asset values, macroeconomic market trends, and financial and legal conditions—with historical loan performance to gain insight into loan credit risk (see Straka 2000 and Van Order 2000). As a result of their information access and scale, Fannie Mae and Freddie Mac have created sophisticated credit evaluation models that retail loan originators and consumers do not have.

Retail loan originators (depository institutions) have had the option of selling their mortgages in the secondary market or retaining them in their portfolios. Passmore and Sparks (1996) note that this created adverse selection concerns for the GSE. Today, sophisticated credit evaluation models, combined with mechanisms that identify and punish deviant mortgage sellers (e.g., licensing agreements), have greatly mitigated the adverse selection problems in the secondary market, allowing the GSE "more direct control and less delegation."[6]

Advances in information technology have only strengthened GSE control over the mortgage market. To ensure that their mortgages are marketable, most retail originators simply apply the GSE's credit evaluation model to screen loan applicants and automatically sell qualified loans at guaranteed prices. Price guarantees set by the GSE provide the basis for the loan rates we see in the retail mortgage marketplace. As a result, the GSE in effect lends directly to consumers.[7]

Because consumers do not have the advantage of scale or repeated play to learn about their own credit risk, most have little idea about how to evaluate their own credit quality as it relates to collateral and other

[6] According to Van Order (2000), former chief economist at Freddie Mac, "recent developments in information technology . . . have changed the way that principal-agent problems are managed by allowing more direct control and less delegation [by the GSE]. In particular, credit scoring models are allowing the secondary market to use almost all information available to the primary market. . . . While the secondary market may find it too expensive to monitor individual loans, it receives [and aggregates] free information about the default history of loans sold to it across lenders."

[7] Van Order (2001) states that "the relevant industry for F[annie] and F[reddie] is not the secondary market but the mortgage market as a whole. The distinction between the primary and secondary markets is largely irrelevant, economically. What matters is that there are different ways of getting money from capital markets as a whole to the mortgage market." In "Why Big Lenders Are So Afraid of Fannie Mae and Freddie Mac" (*Wall Street Journal,* 4/5/01) it is stated that "The [large financial] institutions fear that new technology created by Fannie and Freddie threatens to drive many of them out of home lending . . . Lenders attribute the recent proliferation of mortgage brokers in part to the introduction in the mid-1990s of Fannie's and Freddie's automated underwriting systems . . . Banks face a predicament similar to that of travel agents, stock brokers and other traditional middlemen who have watched millions of customers defect to inexpensive online services. In the mortgage market, it threatens to reduce big lenders to a 'shrinking and increasingly irrelevant' part of the industry." A Mortgage Bankers Association (2005) article states, "Because lenders rely on Freddie Mac and Fannie Mae to buy loans, the GSEs have leverage in the market for technology products. Private underwriting vendors have fallen by the wayside as Freddie Mac and Fannie Mae have taken over the market. Today, the GSEs have the ability together to dictate terms to the marketplace."

external conditions.[8] Moreover, it would be quite costly to invest the time and effort to acquire this information, even if they knew it existed. Even potential competitors do not have the information technology that Fannie and Freddie have, as a lack of scale and market power work against the development of new sophisticated credit evaluation models (see Dixit and Shapiro 1984).[9]

The GSE credit evaluation models decrease screening costs and provide accurate forecasts of future revenues, thereby enhancing profits and solidifying their control over the market. Not surprisingly, Fannie and Freddie consider their credit evaluation models to be proprietary, and they zealously protect the information underlying their technology. According to the Mortgage Bankers Association, "One problem with the GSEs' technology is that the GSEs keep under tight wraps the technology's inner workings. Both GSEs used to clearly delineate the criteria by which they decide what loans they would or would not buy. But with the advent of technology, the GSEs were able to make secret their purchase criteria. The GSEs do not divulge how their technology decides who can get a mortgage loan approved" (Mortgage Bankers Association 2005).

Finally, a distinctive characteristic of the U.S. residential mortgage market is that it is segmented into prime and sub-prime markets. Credit spreads in prime market mortgage loan rates are largely uniform, exhibiting surprisingly little variation as a function of mortgage loan credit quality. This outcome is puzzling given the existence of sophisticated GSE credit evaluation technologies that allow for precise estimates of loan credit quality.

With a focus on GSE market dominance, technology-enhanced information advantage, and entry deterrence incentives, we develop a model to explain market segmentation and the pooling of credit spreads seen in the residential mortgage market.

2. Model Description

We assume a residential mortgage market structure in which: (1) consumers are price takers; (2) there is initially a monopolistic secondary market supplier of mortgage funds (the GSE); and (3) retailer lenders are passive financing conduits that impose GSE-determined loan rates on qualified

[8] In their empirical study of adverse selection in the market for life insurance, Cawley and Philipson (1999) find that "consumer beliefs on mortality explain little actual mortality beyond life insurance premia. Premia themselves are not highly correlated with actual one-year mortality risk." Further analysis leads them to conclude that "Producers in this market may know their costs of production better than consumers."

[9] Ambrose et al. (2005) document lower realized default rates experienced by Fannie and Freddie relative to retail lenders, and are otherwise unable to find evidence of adverse selection in the secondary market, suggesting that borrowers and their originating lenders are no better informed (and likely worse informed) than the GSEs.

applicants. Market entry may be possible in the future, where the potential entrant can be characterized as either a secondary market supplier of mortgage funds or a single retail lender that competes directly with the secondary market and operates independently of the current retail market structure.

Atomistic consumers are capital constrained and wish to borrow to finance the purchase of a home. The loan amount, or demand schedule, $D(r)$, for each individual is determined by the loan interest rate, r. Individual loan demand is assumed to exhibit constant price elasticity.

Standardized loan contracts mature in one period, with principal and interest due at that time. All consumers are identical except for credit quality. Consumer credit quality can vary across a number of dimensions, but can be uniquely summarized by a single measure, θ, where θ varies continuously in the interval (0,1).[10] The probability of default is $1 - \theta$. If default actually occurs, the lender's payoff is assumed for simplicity to be zero. Credit quality, θ, has a probability density function of $f(\theta)$, which is common knowledge. Without any loss of generality, the size of the consumer population is normalized to 1 (i.e., $\int_0^1 f(\theta)d\theta = 1$).

Assume in the entry game there are two risk-neutral suppliers in the market for mortgage loans: the incumbent and a potential entrant. There are three periods and therefore three rounds of lending to consumers whose credit quality, θ, stays constant over time. Qualified consumers receive a one-period loan in the first round. All consumers subsequently reappear in later rounds to demand a new one-period loan. The incumbent is a monopolist in period one. For any given consumer, the incumbent knows precisely the credit quality and needs to decide the interest rate, r_1, to charge in the first period.

At the beginning of period two, consumers reapply for a new loan. To the potential entrant, each borrower is a random draw from the density function, $f(\theta)$. Although the potential entrant does not observe θ, the borrower's first-period loan rate, r_1, can be observed at no cost.[11] On the basis of that loan rate, the potential entrant must determine whether to enter.

If entry occurs, a one-time cost of κ^E is incurred by the entrant to lend to this particular borrower. The entry fee, which is related to the start-up costs of loan production, is known to the incumbent. Given this structure, the potential entrant must formulate an entry policy for every individual

[10] In our model, consumers do not manipulate their loan demands to affect their credit quality. This is defensible from two perspectives. First, for most households, buying a house is a major investment in relation to their savings. Unlike commercial enterprises, private homebuyers tend to have very limited alternative sources of financing and are therefore credit constrained. Second, consumers are relatively uninformed about their own credit risk and the credit valuation model that predicts that risk. Therefore, they have a limited ability to manipulate the lender's credit evaluation outcome.

[11] The model is easily adapted to observation of the first-period loan rate with only a probability.

loan applicant. Credit is denied at no cost when the entrant decides not to enter.

Once entry occurs, the consumer's credit quality, θ, is fully revealed (see Milgrom and Roberts 1982 for a similar approach and discussion). Conditional on entry, suppliers split the monopoly profits equally in the final two rounds of lending. The assumptions of full information revelation and equal profit sharing upon entry are made for simplicity—they do not drive the results. For example, the main results can be generalized to settings where information is revealed only through first-period loan rates and where profit sharing is asymmetric.[12] If entry does not occur at the beginning of round two, it never occurs and the incumbent monopolizes the loan market in the two remaining periods.

The incumbent's pricing strategy in the first round is a mapping from the privately observed credit quality measure, θ, to an observed loan rate, r_1. Denote this function as $s(\theta)$, where s:(0,1)$\rightarrow R_+$. The potential entrant will observe the first-period loan rate and then make an entry decision for that borrower at the beginning of the second period. This strategy, denoted as $t(r_1)$, is a mapping from the set of possible values of r_1 to a decision on entry; $t : R_+ \rightarrow \{1, 0\}$, where we interpret 1 as "Entry" and 0 as "No Entry."

A pair of strategies (s^*, t^*) is considered a Perfect Bayesian Equilibrium (PBE) of the game if: (i) $s^*(\theta)$ maximizes the expected discounted profits of the incumbent, given the strategy of the potential entrant; (ii) $t^*(r_1)$ calls for entry if and only if the entrant's expected post-entry profits are positive for all values of r_1 that can be observed in equilibrium; and (iii) there are off-equilibrium beliefs that support the equilibrium strategies.

3. Profit-Maximizing Loan Pricing for a Monopolistic Lender

As a preliminary analysis, we examine the monopoly lender's profit-maximizing strategy without any entry threat; that is, we analyze a risk-based loan pricing regime. Assume a monopolistic lender that, after the initial loan screening, is perfectly informed as to each consumer's credit quality, θ. The lender's objective is to maximize expected profits in each period through a determination of the optimal loan rate for each borrower,

[12] According to the well-known Folk Theorem, in an infinitely repeated game, any feasible payoff above the lowest payoff in a single play of the simultaneous-move component game (which is zero with Bertrand competition) can be sustained for a sufficiently large discount factor. Thus our assumption of equal sharing of profits can be viewed as an equilibrium outcome of an infinitely repeated game and an appropriately specified discount rate. Given the other model assumptions (i.e., that credit quality is fully revealed upon entry and that the two lenders are equally placed in the market), we simply treat the symmetric profit-maximizing equilibrium as "focal." In fact, as long as total post-entry profit increases with credit quality, all our results are robust to profit-splitting outcomes.

as follows:

$$\underset{r}{Max}\ \pi(\theta) = \underset{r}{Max}\ (\theta r - \kappa^C)D(r). \tag{1}$$

The first term to the right of the maximand, θr, is the loan's expected return, and the second term κ^C, is the per unit cost of financial capital, $\kappa^C > 1$. Both terms are adjusted by the loan size, $D(r)$, and therefore map into total expected revenue and loan production cost.

It is straightforward to show there is an optimal loan rate, $r^{RB}(\theta)$, that is offered to a consumer with the credit quality measure, θ. Define the price elasticity of the consumer loan demand as $\eta = -(dD/dr)\ (r/D) > 1$. The optimal mortgage loan rate is:

$$r^{RB}(\theta) = \frac{\kappa^C}{\theta}\left(\frac{\eta}{\eta - 1}\right). \tag{2}$$

The expected return, $\theta r^{RB}(\theta)$, exceeds marginal cost by an adjustment for the price elasticity of the demand. This is the well-known Monti (1972)–Klein (1971) loan mark-up relation. The expected profit from a loan with credit quality θ is

$$\pi^{RB}(\theta) = \frac{\kappa^C D(r^{RB}(\theta))}{\eta - 1}. \tag{3}$$

Given that loan demand is decreasing in the risk-adjusted loan rate, and the loan rate in turn is inversely related to credit quality, lending to higher-credit-quality borrowers is more profitable than lending to lower-credit-quality borrowers. We thus have the lemma:

Lemma 1. $\dfrac{\partial \pi^{RB}(\theta)}{\partial \theta} > 0.$

The lender's aggregate expected profit in a given period under a risk-based pricing scheme is:

$$\Pi^{RB} = \int_0^1 \frac{\kappa^c D(r^{RB}(\theta))}{\eta - 1} f(\theta) d\theta. \tag{4}$$

4. Equilibrium with Endogenous Learning and Entry

With the potential for entry, we should expect the incumbent lender to modify its pricing behavior in an effort to deter an entry outcome.

To see this, suppose a given borrower has credit quality θ. If entry occurs, θ is fully revealed and the two lenders split the monopoly profits. Without loss of generality, we will assume an intertemporal discount rate of 0 and identical capital costs of κ^C for both incumbent and entrant.[13] As a result, the entrant's total expected (two-period) post-entry profit is

$$\pi^E(\theta) = \pi^{RB}(\theta) - \kappa^E = \frac{\kappa^C}{\eta - 1} D(r^{RB}(\theta)) - \kappa^E \tag{5}$$

where $\pi^{RB}(\theta)$ and $r^{RB}(\theta)$ are the risk-based monopoly profit and loan rate as defined in Equations (3) and (2). The fixed cost of entry, κ^E, is constant for all θ.[14]

For the limit-pricing analysis to be interesting, we impose two restrictions on $\pi^E(\theta)$. First, we will require that

$$\int_0^1 \pi^E(\theta) f(\theta) d\theta \leq 0. \tag{6}$$

Otherwise, if the unconditional expectation of π^E is positive, that is, $\int_0^1 \pi^E(\theta) f(\theta) d\theta > 0$, the entrant does not have to be informed of the borrower's credit quality in order to enter the market and expect to make a profit. Thus entry would always occur, and there would be nothing the incumbent could do to discourage it.[15]

A second restriction on $\pi^E(\theta)$ is

$$\pi^E(1) > 0. \tag{7}$$

If π^E is negative when $\theta = 1$ (κ^E is high), it would never be profitable for entry to occur, which makes limit pricing unnecessary. These two restrictions, combined with the continuity of θ and the monotonicity of $\pi^E(\theta)$, ensure that there is a unique credit quality cutoff value, θ^0, such that $\pi^E(\theta^0) = 0$.

Now suppose the incumbent sets a loan rate that declines monotonically with θ. Having observed r_1, the potential entrant can exactly deduce θ because it knows the inverse of $s(\theta)$. As the potential entrant's expected post-entry profits increase with perceived credit quality, θ, the pre-entry loan rate, r_1, signals profits that the entrant would earn upon entry.

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13 The potential entrant is likely to be a financial institution subject to capital costs and regulations similar to those for the GSE. Differential costs of capital would not change the nature of the equilibrium in our model. In addition, there is no inconsistency between the assumptions of no discounting and κ^C possibly greater than 1. Capital costs possibly include other priced risks such as institutional-level default risk. Discounting affects only the incumbent's decision to deter entry or not. Where entry deterrence is preferred, discount rates have no impact on the equilibrium strategies. Thus our assumptions on the magnitudes of the discount rate and the cost of financial capital do not affect our basic results.

14 As in many full information models, entry cost is needed to deter entry. Information asymmetry lowers the threshold of entry cost above which entry does not occur, however. With only minimal complication, the model could accommodate differential entry costs that depend on the amount of information revealed in the first-period loan rate.

15 Without a deterrent to entry, the incumbent would end up charging risk-based loan rates to all consumers in period one, which fails to explain the pricing patterns we see in the residential mortgage market.

Therefore, in order to deter entry, when the credit quality is sufficiently high, the incumbent may charge a rate higher than $r^{RB}(\theta)$ in order to act as if θ is low to signal low post-entry profits.

The incumbent will prefer to construct a pricing strategy that deters entry for any θ, $\theta \in (0, 1)$. Define $w(\theta)$ as the incremental total expected profit to the incumbent from an entry-deterrence pricing policy relative to an entry-inducing pricing policy. Denote $\pi_1(\theta)$ as the resulting first-period profit of the incumbent when entry is deterred. With zero discounting, the incremental profit is

$$w(\theta) = [\pi_1(\theta) + 2\pi^{RB}] - \left[\pi^{RB} + 2\left(\frac{1}{2}\pi^{RB}\right)\right] \tag{8}$$

where π^{RB} is the monopoly profit as defined in Equation (3). Terms in the first set of brackets are first-period expected profits plus expected monopoly profits from periods two and three given that entry has been deterred. Terms in the second set of brackets are the opportunity costs of failing to maximize first-period profits. Maximizing profits in the first period requires setting a risk-based price, which fully reveals credit quality and hence accommodates entry in the second and third periods.

Equation (8) simplifies to

$$w(\theta) = \pi_1(\theta) > 0. \tag{9}$$

As entry deterrence is preferred by the incumbent for all possible θ, a separating strategy for sufficiently high credit quality cannot be part of the equilibrium; that is, there is no separating equilibrium for $\theta > \theta^0$.

The potential for entry causes the incumbent to pool-price with higher credit quality loans. Suppose, in equilibrium, that the incumbent charges one rate, denoted as r^{LP}, to all borrowers in the pool-pricing region $(\hat{\theta}, 1)$. In this case, the entrant cannot exactly infer θ, but does learn that $\theta \in (\hat{\theta}, 1)$. Using Bayes' rule, the entrant's posterior density function is

$$f(\theta|r_1 = r^{LP}) = \begin{cases} \frac{f(\theta)}{1-F(\hat{\theta})}, & \textit{if } \theta \in (\hat{\theta}, 1) \\ 0, & \textit{otherwise}. \end{cases} \tag{10}$$

According to this posterior belief, the potential entrant calculates its expected post-entry profits as

$$E[\pi^E] = \int_{\hat{\theta}}^{1} \pi^E(\theta)\frac{f(\theta)}{1 - F(\hat{\theta})}d\theta. \tag{11}$$

Note that this type of learning rules out θ^0 as a lower bound of a pool-pricing region, since $\int_{\theta^0}^{1} \pi^E(\theta)\frac{f(\theta)}{1-F(\theta^0)}d\theta > 0$. Indeed, learning through the credit quality cutoff forces the incumbent to lower the cutoff below θ^0 in order to deter entry.

The following lemma states the maximum pool-pricing region cutoff value, $\underline{\theta}^{LP}$, that will successfully deter entry by the potential entrant:

Lemma 2. *There is a unique* $\underline{\theta}^{LP}, \underline{\theta}^{LP} \in (0, 1)$*, such that* $\int_{\underline{\theta}^{LP}}^{1} \pi^E(\theta) \frac{f(\theta)}{1-F(\underline{\theta}^{LP})} d\theta = 0$.

The proof of this lemma follows immediately from $\int_0^1 \pi^E(\theta) f(\theta) d\theta \leqslant 0$ as in Equation (6) and the fact that $\pi^E(\theta)$ is strictly increasing with θ.

Perfect Bayesian Equilibrium can now be described in the following proposition:

Proposition 1. *A Perfect Bayesian Equilibrium* (s^*, t^*) *exists, where*

$$s^*(\theta) = \begin{cases} r^{RB}(\theta), & \textit{if } \theta \leqslant \underline{\theta}^{LP} \\ r^{LP} = r^{RB}(\underline{\theta}^{LP}), & \textit{if } \underline{\theta}^{LP} < \theta \leqslant 1 \end{cases}$$

$$t^*(r_1) = \begin{cases} 0, & \textit{if } r_1 \geqslant r^{RB}(\underline{\theta}^{LP}) \\ 1, & \textit{if } r_1 < r^{RB}(\underline{\theta}^{LP}). \end{cases}$$

The set of off-equilibrium beliefs that supports the entrant's strategy when it sees a deviation, $r_1 < r^{LP}$*, is that* r_1 *is charged to a borrower with* $\theta > \underline{\theta}^{LP} + \varepsilon$*, where* $\varepsilon > 0$.

Proof. See Appendix. ■

It is well known that there are multiple equilibria in most signaling models. In our model, any θ below $\underline{\theta}^{LP}$ can also serve as the lower bound of the pooling region. Thus, there is a continuum of equilibria, each defined by a different lower bound, $\hat{\theta}, \hat{\theta} \leqslant \underline{\theta}^{LP}$. Clearly, the equilibria with the cutoff $\hat{\theta} < \underline{\theta}^{LP}$ are Pareto-dominated by the equilibrium with $\hat{\theta} = \underline{\theta}^{LP}$, which is the equilibrium described in the proposition.

If we consider the restriction on the entrant's conjectures that signaling by the incumbent will not be unnecessarily wasteful, we obtain a unique equilibrium in this class of PBE that is Pareto-optimal. This outcome is illustrated in Figure 1. A risk-based loan rate is applied to consumers with $\theta < \underline{\theta}^{LP}$ and a uniform loan rate to consumers with $\theta \geqslant \underline{\theta}^{LP}$. The uniform loan rate is the risk-based monopoly rate for borrowers with $\theta = \underline{\theta}^{LP}$.

Although uniform pricing achieves entry deterrence, this does not rule out some variation in the observed credit spread. To see why, note that GSE's information about borrower characteristics falls into two categories: public information observable by all, and private information observable only by the GSE. Risk-based pricing based on publicly

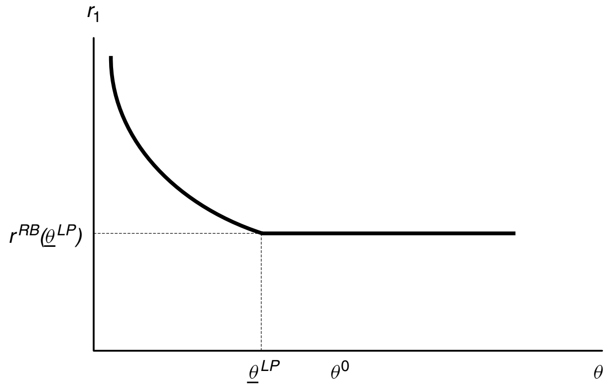

Figure 1
Observed first-period loan rate, r_1, as a function of borrower credit quality, θ. This figure displays the equilibrium loan rate, r_1, offered by the incumbent in the first period as a function of consumer credit quality, θ. A risk-based rate is offered to consumers with lower credit quality, since entry is naturally deterred in this region. A uniform rate is offered to consumers with higher credit quality to conceal the incumbent's credit quality information in order to deter entry.

observable information does not reveal proprietary information to potential competitors, but can improve first-period profits. Retail lenders, without any private information on the unobserved characteristics, can charge differentiating prices only on the basis of observable borrower characteristics around the uniform price set by the GSE. To the extent that such characteristics are idiosyncratic with zero mean, we expect the aggregated prices to approach the uniform price set by the GSE.

5. Comparative Statics and Consumer Welfare

An analysis of the condition for $\underline{\theta}^{LP}$ in Lemma 2 produces comparative static results. Because $\underline{\theta}^{LP}$ and $r^{LP}(= r^{RB}(\underline{\theta}^{LP}))$ always move in the opposite directions with the underlying parameters, comparative static results for r^{LP} follow directly from the $\underline{\theta}^{LP}$ results.

Proposition 2. *Comparative statics in the limit pricing model are as follows:*

$$\textit{Elasticity of Loan Demand:} \quad \frac{d\underline{\theta}^{LP}}{d\eta} > 0, \quad \frac{dr^{LP}}{d\eta} < 0. \tag{12}$$

$$\textit{Cost of Financial Capital:} \quad \frac{d\underline{\theta}^{LP}}{d\kappa^C} > 0, \quad \frac{dr^{LP}}{d\kappa^C} < 0. \tag{13}$$

$$\textit{Cost of Entry:} \quad \frac{d\underline{\theta}^{LP}}{d\kappa^E} > 0, \quad \frac{dr^{LP}}{d\kappa^E} < 0. \tag{14}$$

Distribution of Credit Risk: *If the new distribution $G(\theta)$ dominates $F(\theta)$ in the sense of hazard-rate order, then $\underline{\theta}^{LP}|_{G(\theta)} < \underline{\theta}^{LP}|_{F(\theta)}$ and*

$$r^{LP}|_{G(\theta)} > r^{LP}|_{F(\theta)}.\text{[16]} \tag{15}$$

Proof. See Appendix. ■

Increases in the elasticity of loan demand, η, the cost of financial capital, κ^C, and the cost of entry, κ^E, all result in a *smaller* prime mortgage market and a *lower* pooled loan rate. This occurs because an increase in these variables reduces post-entry profits, which in turn reduces the need to pool-price to protect information advantage. A smaller prime market means the marginal borrower is of higher credit quality, which results in a lower (uniform) loan rate.

If the general distribution of credit risk shifts to lower average quality (in the sense of hazard-rate-order stochastic dominance), the size of the prime market *contracts* and the credit-spread *decreases*. This happens because a deterioration in the distribution of credit quality makes entry less attractive and therefore reduces the need to pool-price. Note that this explanation is different from conventional rationales of why market size contracts in response to deteriorating credit conditions. Other explanations generally rely on adverse selection, regulatory tightening, or some sort of *ex post* settling up arguments; we are instead focused on the incumbent's incentives to deter market entry. Our result generates the additional interesting prediction that credit spreads actually decrease in the higher-quality segment of the market as credit conditions worsen in general.

Aggregate consumer welfare in our limit pricing equilibrium is even lower than in the no entry risk-based monopoly pricing regime. This result follows because the pooling rate in our limit pricing equilibrium is simply the risk-based monopoly loan rate for a borrower at the lower bound of the pooling region, which equals or exceeds the risk-based monopoly price for every borrower in that region.

6. Empirical Implications

In our model, the lender has an initial information advantage that allows it to secure a competitive edge in the market for mortgage loans. In general terms, empirical implications of the model derive from the incumbent's incentives to protect its competitive position through limit

[16] A random variable with distribution $G(\theta)$ dominates another random variable with distribution $F(\theta)$ in the sense of hazard rate order if and only if $g(\theta)/(1 - G(\theta)) < f(\theta)/(1 - F(\theta))$ for all θ (see Shaked and Shanthikumar 1994).

pricing. Information advantage is thus both the cause and the effect of limit pricing, since entry would dissipate monopoly rents accruing to the incumbent owing to its lost control over loan-level credit quality information.

Specific empirical implications derive from endogenously determined market segmentation, loan pricing, and comparative statics. The following subsections outline some of the model's predictions.

6.1 Predictions about pooled versus risk-based credit pricing in the prime market

One of the primary predictions of our model is that the lender will divide consumers into two submarkets segmented by credit quality. Those with better-quality credit pay a pooling rate, and those with poorer-quality credit pay a risk-based rate. This division between higher- and lower-quality borrowers corresponds well with the observed market segmentation between the prime and sub-prime mortgage market.

Since pooled versus risk-based pricing can be distinguished by examining cross-sectional variation in the credit-spread, we have the formal prediction:

Prediction 1a. *There is less cross-sectional variability of credit spreads in the prime market than in the sub-prime market.*

A slightly different approach is to examine variation in credit spreads that can be explained by borrower characteristics. These characteristics are either publicly observable or privately observed only by the incumbent lender. We predict that the incumbent will pool-price using its private information but price-discriminate using public information. Thus, when the lender charges a pooling rate, variation in credit spread should be driven mainly by publicly observed borrower characteristics. Publicly observed information therefore should explain a larger proportion of variation in credit spreads in the prime market. This leads to the testable prediction:

Prediction 1b. *A higher proportion of credit-spread variation is explained by publicly observed borrower characteristics (i.e., the R-square in a standard credit-spread regression) in the prime market than in the sub-prime market.*

6.2 Predictions about credit spread and prime market share

Comparative static results in Proposition 2 suggest that the prime market credit spread and market share are higher as: (1) the cost of entry is reduced; (2) the cost of financial capital is reduced; and (3) the distribution of the borrowers' credit quality improves.[17]

All three of these factors will vary over time. Automated underwriting systems for credit evaluation, an important part of entry cost, have become less expensive to develop. The cost of financial capital and the distribution of borrower quality will vary over business cycles. When monetary policy tightens, banks are more likely to face a higher cost of funds. And during a market downturn, borrower credit quality is likely to deteriorate. These latter two effects can be tested by analyzing how credit spreads and prime market size vary over business cycles.

Another identification strategy relies on the fact that credit spreads in the sub-prime market (given in Equation (2)) move inversely with credit spreads in the prime market as the cost of financial capital and the distribution of borrower credit quality change. These two factors can be tested by examining the change of differences in credit spreads as a function of different market conditions. Such a "difference-in-differences" approach is useful because it can reduce the impact of noise in measuring the credit spread.

Summarizing, the testable predictions are:

Prediction 2a. *Prime market share increases over time in response to lower-cost automated underwriting, but declines during periods of tight monetary policy and economic downturn.*

Prediction 2b. *Credit spreads in the prime market widen in response to lower-cost automated underwriting. During periods of tight monetary policy and economic downturn, credit spreads narrow in the prime market, while differences widen between (average) credit spread in the sub-prime and the prime market.*[18]

Entry cost and the distribution of borrower credit quality across different markets can be examined. Marquez (2002), for example, notes that consolidation in the retail lending market and the resulting larger banking networks may lower the incremental entry costs. Variables such as unemployment rate and actual historical default rates can also be useful indicators of the distribution of borrowers' credit quality. This results in two additional predictions:

[17] A change in the cost of financial capital can be driven by either the risk-free rate or a risk premium reflecting the lender's business risk. In both cases, the loan rate and the credit spread (loan rate less the risk-free rate) move in the same direction as the cost of financial capital.

[18] These are joint tests of the segmented conventional-conforming mortgage loan market (the relevant market to Fannie Mae and Freddie Mac). It would not be appropriate, for example, to examine credit spreads for adjustable-rate mortgages (ARMs) to make inferences about our model, as ARMs are typically held by originating lenders and are not typically part of the secondary market.

Prediction 2c. *The prime market is larger in geographic areas with a more concentrated banking market and better borrower credit quality.*

Prediction 2d. *Credit spreads are higher in the prime market in geographic areas with a more concentrated banking market and better borrower credit quality.*

7. Evidence

A common difficulty in testing any limit pricing model is that the primary result of limit pricing—entry that could but does not occur—is by definition unobservable (it is "a dog that doesn't bark"). We believe, however, that by establishing the operation of GSE's information advantage (which is both the cause and effect of limit pricing over time) and pool pricing (which is costly relative to risk-based monopoly pricing, but implemented nonetheless), as well as empirical observation that is consistent with the comparative statics of our model, a strong case can be made that limit pricing drives the observed market structure. Indeed, it is hard to think of alternative explanations that can simultaneously account for all the empirical facts.

7.1 Data

We rely on several data sources to test implications of our theory. The first two data sources, used to examine variability in loan rates, are a telephone survey conducted by the Gallup Organization for Freddie Mac and the 2002 loan origination records of Wells Fargo Home Mortgage (WFHM) obtained by LaCour-Little (2004). A third source is a sample of 26,179 conventional fixed-rate mortgage loans made between January 1995 and December 1997 by a national lender, its correspondent lenders, and mortgage brokers. These data include detailed information on individual borrower characteristics and loan sale versus retention outcomes, which allows us to study the information content of the credit spread.

To test predictions about size of the prime market, we use Home Mortgage Disclosure Act (HMDA) data, which provide information on prime market share at the Metropolitan Statistical Area (MSA) level. We supplement these data with banking market concentration information calculated from the Federal Reserve Bank's Summary of Deposits tables, information on local economic conditions and demographics from the Census Bureau, and data compiled by Pennington-Cross (2002) in a study of sub-prime mortgage lending.

7.2 Pooled mortgage loan pricing in the prime market

We initially examine the variability of mortgage loan rates (Prediction 1a). Two measures of variability are considered. The first is dispersion as measured by the distance between the 90th and 10th percentile. The second is standard deviation.

The dispersion of rates in the prime and sub-prime markets is presented in Panel A of Table 1 for survey data from Freddie Mac. For every semi-annual observation between 1996 and 1997, the dispersion of loan rates in the prime market is less than one-half of that in the sub-prime market. The 18-month average of the dispersion in the prime market is 1.0% compared to 2.6% in the sub-prime market.

Panel B of Table 1 reports the standard deviation of loan rates based on a sample of loans originated in 2002 by Wells Fargo Home Mortgage. The standard deviation of loan rates in the prime market is 0.91% (with a mean of 6.62%) compared to 3.94% (with a mean of 7.69%) for sub-prime loans. An F-test indicates that the difference is statistically significant at the 1% level.

For further perspective on pool pricing in the prime market, we examine the information content of mortgage loan rates revealed in lenders' loan retention decisions. Given that the decision to retain a loan rather than sell it in the secondary market is related to borrower credit quality, we can infer information from the loan rate. Specifically, risk-based pricing implies that all available information about credit risk is reflected in the credit spread, which *on average* is consistent with *ex post* default experience. Our theory, however, predicts that the lender will not price its private information with higher-quality borrowers, for fear of revealing that information to potential entrants. Thus, we predict there is additional information about

Table 1
Variability of loan rates in the prime and sub-prime mortgage markets

	Prime Market			Sub-Prime Market		
Panel A. Dispersion of Loan Rates						
Year:Month	10th Percentile	90th Percentile	Difference	10th Percentile	90th Percentile	Difference
1996:01	6.59	7.73	1.15	7.86	10.22	2.36
1996:06	7.48	8.54	1.06	8.54	11.01	2.47
1996:12	7.12	8.16	1.04	8.88	11.27	2.38
1997:06	7.49	8.43	0.94	9.35	12.95	3.60
18-Month Average	7.20	8.22	1.02	8.69	11.30	2.61
Panel B. Standard Deviation of Loan Rates						
Year	Mean	Standard Deviation		Mean	Standard Deviation	
2002	6.62	0.91		7.69	3.94***	

This table presents evidence of pooled mortgage loan rate pricing in the prime mortgage market. In Panel A, the variability of loan rates is measured as the dispersion between the 90th and 10th percentile of loan rates. The data are from Figure 24 in Lax et al. (2004) using SmartdrawPro.graph software. In Panel B, the variability of loan rates is measured as the standard deviation of loan rates. The data are from LaCour-Little (2004). F-tests of differences in variances are performed, with significance levels based on two-tailed tests. Significance at the 1% level is indicated by ***.

credit risk embedded in actual default data *over and above* the observed credit spread.

Estimation of a logistic regression of loan retention (versus sale into the secondary market) on both the credit spread and realized default rate can distinguish between our theory and the conventional wisdom. We thus estimate the model

$$Retained_{it} = aSPD_{it} + bDProb_{it} + cX_{it} + dZ_t + \varepsilon_{it} \qquad (16)$$

where i indexes the borrowers/loans, and t indexes the years.

Retained is a binary variable indicating whether the loan is retained in the retail lender's portfolio as a sub-prime mortgage. *SPD* is the credit spread at the time of loan origination. *DProb* is the predicted default probability estimated using actual default data as described in Ambrose et al. (2005, Table 3). X_{it} expresses other loan/borrower characteristics, including a dummy variable indicating whether the loan exceeds the conforming limit, the predicted prepayment probability, an interaction between the predicted default/prepayment probability, and a low-/high-credit-spread measure to capture the nonlinearity of the effect of predicted loan termination probability with respect to credit spread. Z_t represents marketwide variables that are typical in the literature, including the yield spread between Moody's AAA and Baa bond indices, the spread between ten-year and one-year Treasury bond rates, and volatility in the risk-free rate as measured by the standard deviation of the one-year Treasury bond rate over the 24 months prior to loan origination.

The coefficient on credit spread, a, indicates the lender's motive in loan retention. We expect a to be non-negative; that is, all else equal, retail lenders do not retain the higher-quality loans. We are particularly interested in the coefficient, b, associated with *DProb*. It should be statistically insignificantly different from 0 if all information about credit quality—publicly observed as well as private—is already reflected in the loan spread. Our theory suggests that b will be positive, however, since we predict that the lender chooses not to price all its private information by charging a pooling rate.

Table 2 reports that the predicted default probability is, as expected, significantly positively related to loan retention at the 1% level, suggesting that the lender *chooses not to* price all its private information into the loan rates it charges to borrowers. Interestingly, the coefficient on credit spread is significantly positive (at the 1% level), implying that retail lenders sell higher-, rather than lower-, quality loans into the secondary market. This is consistent with our model structure that posits that adverse selection is not a significant factor in the residential mortgage market.

Table 2
Effects of unobserved information in the secondary mortgage market

Independent variables	Coefficient	Standard error
Individual Loan Characterisits		
Credit spread	3.055***	(0.315)
Predicted default	87.532***	(18.437)
Predicted default × low spread	−30.986	(22.720)
Predicted default × high spread	−12.248	(26.727)
Jumbo	−0.018	(0.180)
Predicted prepayment	−24.495***	(5.022)
Predicted prepayment × low spread	20.855***	(3.558)
Predicted prepayment × high spread	2.314	(3.754)
Variables Related to Interest Rate Environment		
Credit spread (AAA−Baa)	−7.148*	(4.399)
Yield curve (10 year − 1 year Bond Rate)	2.046***	(0.661)
24-Month standard deviation of 1-year treasury rates	7.278***	(2.586)
Number of Observations	6325	
Likelihood ratio	286.6***	

This table presents estimates from a logit model of the probability of loan retention. The data source is Ambrose, LaCour-Little, and Sanders (2005). Credit spread is the effective mortgage yield less the 10-year Treasury rate. Jumbo is a dummy variable indicating whether the loan is above the conforming loan limit. Predicted default probabilities are estimated using actual (*ex post*) default data. Low (High) Spread is a dummy variable indicating whether the residual from a loan spread regression is negative or positive. Credit Spread (AAA-Baa) is the yield difference between Moody's AAA and Baa bond indices. Yield Curve is the difference between the 10-year and one-year Treasury bond rates. Significance at the 1%, 5%, and 10% levels is indicated by ***, **, and *, respectively.

7.3 Entry cost and prime market size

At the aggregate level, there is evidence of a general trend toward a softening of GSE underwriting standards (see, e.g., Temkin et al. 2002, LaCour-Little 2004, and Ambrose and Thibodeau 2004). This softening is indicative of a larger prime market share that occurred shortly after the introduction of GSE automated underwriting systems in 1995. Gates et al. (2002) further document that borrowers once excluded from the prime market have more recently been able to borrow in that market, an outcome they attribute to lower-cost automated underwriting. These outcomes are consistent with Prediction 2a, which asserts that a lower entry cost causes an increase in prime market share.

It is hard to attribute a larger prime market share solely to lower entry costs, however, as there were many other events happening during the same period. Consequently, we take a more structured approach and exploit variation at the MSA level to show that the size of the prime market is related to local banking market concentration (Prediction 2c). Specifically, geographic areas with larger banks are likely to provide lower-cost access to borrower credit information (Marquez 2002). This implies a lower incremental cost of entry in such areas, with a larger prime market as the predicted result.

To assess this prediction, we estimate the model

$$Prime\ Market\ Share_{jt} = a + b\ \ Concentration_{jt} + cX_{jt} + \varepsilon_{jt} \qquad (17)$$

where j indexes the MSA and t indexes time.

Prime Market Share is the number of prime market loans as a percentage of the total number of mortgage loans in the MSA. *Concentration* is banking market concentration. We use two measures of concentration. The first is the log of the number of banks, which is an inverse measure of concentration. Both theoretical and empirical banking research suggest a direct link between the number of banks and competitive behavior (e.g., Besanko and Thakor 1993 and Gan 2004). This measure does not, however, directly reflect the size distribution of banks. As we are particularly interested in the concentration of large banks, our second measure to proxy for entry cost is a four-firm concentration ratio, defined as the proportion of deposits or assets held by the largest four banks in the MSA.[19] The coefficient of interest, b, is expected to be negative when banking concentration is measured by the number of banks and positive when concentration is measured by the four-bank concentration ratio.

MSA level control variables are included in X_{jt}. To ensure that banking market concentration is not simply picking up other MSA characteristics that might influence prime market size, we control for three sets of MSA effects. The first is housing market characteristics, including lagged percentage housing price growth and the standard deviation of housing price growth in the past ten years. The second is local economic conditions, including personal income growth over 1979–1989 and unemployment rate in the previous year. Finally, similar to the specification in Pennington-Cross (2002), we control for MSA demographic variables, including the percentage of minority mortgage applicants and a racial segregation index.[20] Gan (2004) suggests that the number of banks in an MSA area is strongly related to population density, so we also control for population density. In the estimations a time dummy for year 1995 is included.

The results are presented in Table 3. Consistent with model predictions, the coefficient on banking market concentration, inversely measured as the log of the number of banks, is significantly negative at the 1% level. Both housing price growth and population density are significantly related to a larger prime market, probably indicating a more attractive urban area and thus better borrower quality on average. The percentage of minority

[19] Another common measure of market concentration is the Herfindahl index, which incorporates both the number of firms and their size distribution. A Herfindahl index includes information on the size distribution of both large and small banks, however, while our focus is more on the large banks. Indeed, when we compute a Herfindahl index, although the sign of the coefficient is consistent with model predictions, the estimation is noisier, rendering the coefficient estimate statistically insignificant.

[20] This is often called a Gini coefficient, which measures the spatial distribution of the black ethnic group across local regions. It ranges from 0 to 100, where 100 indicates maximum segregation.

Table 3
Relative size of prime market as explained by banking market structure

Independent Variables	Log (number of banks) as the concentration measure (1) Coefficient	Standard error	Four-bank concentration ratio as the concentration measure (2) Coefficient	Standard error
Banking market concentration	-0.042^{***}	(0.009)	0.059^{c}	(0.040)
Housing market characteristics				
Housing price growth in the previous year	0.149^{*}	(0.089)	0.121	(0.090)
10-year standard deviation of housing price growth	0.001	(0.004)	0.000	(0.005)
Local economic condition				
10-Year growth in personal income (1979-89)	−0.037	(0.053)	−0.059	(0.052)
Unemployment rate in the previous year	−0.002	(0.005)	−0.002	(0.005)
Demographics				
Population density	0.000^{**}	(0.000)	0.000	(0.000)
% Minority applicants	-0.437^{***}	(0.062)	-0.436^{***}	(0.060)
Racial segregation index	−0.001	(0.000)	-0.001^{**}	(0.000)
HUD defined underserved locations	0.309^{***}	(0.071)	0.302^{***}	(0.073)
Observations	424		424	
R-squared	0.45		0.43	

This table presents the effect of MSA banking market structure on the relative size of the prime market. The analysis is based on HMDA data. In column (1), banking market concentration is (inversely) measured as the log of number of banks; in column (2), banking market structure is measured as the four-firm concentration ratio, defined to be the proportion of deposits or assets held by the largest four banks. Robust standard errors are presented in parentheses. Significance at the 1%, 5%, 10%, and 15% levels is indicated by ***, **, *, and ^{c}, respectively.

applicants is associated with smaller prime market size (significant at the 1% level), which is not surprising to the extent that this variable proxies for poorer credit quality on average. Interestingly, underserved locations as defined by the Department of Housing and Urban Development tend to have a larger prime market share, which suggests that lenders may have adjusted their behavior to meet the Community Reinvestment Act (CRA) requirements.

Column (2) of Table 3 measures concentration in terms of the four-firm concentration ratio. Its coefficient is, as predicted, positive and marginally significant at the 15% level. Since we are really testing a one-sided hypothesis, this result supports our model's prediction.

8. Further Implications for the U.S. Residential Mortgage Market

8.1 The sub-prime mortgage market

We observe limited GSE participation in the sub-prime market for mortgage loans. Where there is participation, it is in the higher-quality portion of that market and at credit spreads that approximate risk-based prices. In the lower-quality portion of the sub-prime market, consumers are either denied credit altogether or are offered high loan rates by more specialized "sub-prime" lenders.

We believe that exogenously imposed lending restrictions are at least partially responsible for this market outcome. If restrictions such as an upper limit of loan rates were to be imposed, the lower end of the sub-prime market would be unprofitable for the GSE and the poorest credit quality consumers would, in the short run, be denied credit altogether. The pool-pricing cutoff point identified in our model remains as before, however.

8.2 Racial discrimination in mortgage lending

Research conducted in recent years has led some to assert racial discrimination in residential mortgage lending. In these cases, racial discrimination is charged if the borrower's race explains mortgage loan denial probabilities or the mortgage loan rate independently of legitimate credit risk variables.

We suggest there are two potential biases in such an approach. First, pooled loan pricing reduces the power of a test of racial discrimination. Suppose minority borrowers qualify for a loan in the prime mortgage market, but are of poorer average credit quality than the average prime market borrower. As a result, credit quality and racial status will be correlated in the data. If an *ex post* measure of mortgage investment performance is applied to detect racial discrimination, the data will show that loans made to minorities performed worse on average than loans made to non-minorities. Thus racial discrimination goes undetected, or even reverse discrimination is found. While these inferences are plainly incorrect, our model suggests instead loan rate subsidization going from higher- to lower-credit-quality borrowers—*rationally imposed by the lender*.

Second, GSE private information about borrower characteristics can result in a charge of racial discrimination even if there is none. We have noted that the GSEs have credit quality information that others—including independent research specialists—do not have. If omitted (unknown) variables are correlated with race, a spurious relation between race and mortgage loan denial rates or prices may lead to an incorrect inference of racial discrimination.

8.3 Competing risks

Although we have focused on incentives to disguise credit quality information from outsiders, in reality there are two sources of competing risks with residential mortgage lending: credit risk and prepayment risk.[21]

[21] Credit risk has historically been the most important source of retained risk in GSE portfolios. However, in recent years the GSEs have (somewhat controversially) retained increasing amounts of prepayment risk (see Jaffee 2002 and Downing et al. 2003) for further analysis). Going forward, we expect more regulatory vigilance on the external distribution of interest rate risk, and that credit risk will remain the primary retained risk at the GSEs.

The GSEs know quite a bit about prepayment risk and how it interacts with credit risk to affect mortgage prices. Prepayment risk therefore potentially introduces: (1) additional observable characteristics that can be priced, or (2) an additional source of noise that inhibits outside identification of credit risk. The implication for our model is that competing risks may allow the GSE to apply (quasi-) risk-based pricing more broadly than it might otherwise.

Competing risks also have implications for tests of racial discrimination. Minority borrowers may have below-average credit quality, which combined with other factors may result in fewer loan prepayments as compared to non-minority borrowers. Consequently, even though minority borrowers may have higher *ex post* default rates than non-minority borrowers, fewer prepayments may result in higher *ex post* returns to the GSE (see Deng and Gabriel 2002 and Van Order and Zorn 2002 for empirical evidence on lower prepayment rates among minority borrowers).

9. Conclusion

We construct a model to explain the underwriting and loan pricing outcomes observed in a supplier-dominated residential mortgage market. The incumbent lender (the GSE) simultaneously exerts market power and embeds proprietary credit quality information into its screening technology. When this information is a source of market power, the incumbent has strong incentives to protect its information advantage from potential entrants.

Entry is deterred first by segmenting consumers into prime and sub-prime markets on the basis of measured credit quality, and second by applying a uniform rate to the more profitable prime market consumers. Market segmentation and the pooled credit spread are determined endogenously. Pooled loan pricing blocks information that is otherwise included in risk-based credit spreads, which impedes learning and therefore entry by potential competitors. The cost of entry deterrence for the incumbent lender is lower profits in the short run. Thus, monopoly rents are traded off with information rents in determination of the incumbent's loan underwriting and pricing policies.

Empirical implications of our model are identified, and evidence supports two important predictions. The first is pooled as opposed to risk-based pricing in the prime market. Mortgage rates are less variable in the prime market than the sub-prime market, and the GSEs do not price all their information into (pooled) prime market mortgage loan rates. Second, consistent with the comparative statistics of the model, prime market share is greater in geographic markets with more concentrated banking and therefore lower incremental costs of entry.

Appendix A:

Proof of Proposition 1.

The proof involves two steps. In the first step, we show that, given the incumbent's equilibrium strategy, $s^*(\theta)$, and the entrant's system of belief, $t^*(r_1)$ is an optimal strategy. There are three cases to consider.

(1.a) *The entrant observes a loan rate,* $r_1 > r^{LP}$. Given the incumbent's equilibrium strategy, $s^*\ (\theta)$, the entrant knows that a risk-based loan rate is charged. Moreover, according to Equation (2), the inverse of $s^*\ (\theta)$ exists for $r_1 > r^{LP}$. The entrant can therefore infer the true credit quality as $\theta = \frac{\kappa^C}{r_1}\left(\frac{\eta}{\eta-1}\right)$. Thus, given that $r_1 > r^{LP}$, it follows that $\theta < \underline{\theta}^{LP}$. Notice that, since $\pi^E(\theta)$ is strictly increasing with θ, and $\underline{\theta}^{LP}$ satisfies $\int_{\underline{\theta}^{LP}}^1 \pi^E(\theta)\frac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta = 0$, it must be the case that $\pi^E(\theta^{LP}) < 0$. Therefore, $\pi^E(\theta) < 0$ as $\theta < \underline{\theta}^{LP}$. That is, for borrowers with $\theta < \underline{\theta}^{LP}$ and thus the observed loan rate $r_1 > r^{LP}$, the entrant's post-entry profit is strictly negative. It follows that equilibrium strategy of "No Entry" is the optimal strategy.

(1.b) *The entrant observes a loan rate,* $r_1 = r^{LP}$. Given $s^*\ (\theta)$, the entrant cannot exactly infer the true credit quality, θ. It learns only that $\theta \in (\underline{\theta}^{LP}, 1)$. Using Bayes' rule, the entrant's updated belief about θ has a posterior density function as follows:

$$f(\theta|r_1 = r^{LP}) = \begin{cases} \frac{f(\theta)}{1-F(\underline{\theta}^{LP})}, & \mathit{if}\ \theta \in (\underline{\theta}^{LP}, 1) \\ 0, & \mathit{otherwise} \end{cases}. \tag{A1}$$

The entrant's expected post-entry profit based on this posterior density function is $\int_{\underline{\theta}^{LP}}^1 \pi^E(\theta)\frac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta$, which is zero by Lemma 2. Given our assumption that the entrant enters only if its expected post-entry profit is strictly positive, "No Entry" is the optimal strategy.

(1.c) *The entrant observes a loan rate,* $r_1 < r^{LP}$. Given the incumbent's equilibrium strategy, this is an off-equilibrium path. The incumbent's off-equilibrium belief is that r_1 is charged to a borrower whose credit quality is strictly above $\underline{\theta}^{LP}$ that is, borrower quality is $\theta > \underline{\theta}^{LP} + \varepsilon$. According to this belief, the minimum expected post-entry profit, $\int_{\underline{\theta}^{LP}+\varepsilon}^1 \pi^E(\theta)\frac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta$, is strictly positive by Lemma 2. Therefore the entrant's optimal strategy is "Entry," which is the equilibrium strategy.

The second step in the proof is to establish the optimality of the incumbent's strategy, $s^*(\theta)$, given the entrant's equilibrium strategy, $t^*(r_1)$. We consider separate cases with θ below and above the cutoff value, $\underline{\theta}^{LP}$.

(2.a) *For* $\theta \leqslant \underline{\theta}^{LP}$, a monopolist's (one-period) profit-maximizing loan rate is $r^{RB}\ (\theta)$. Since $r^{RB}(\theta) \geqslant r^{LP}$, there is no entry (which is what the incumbent always prefers) even if $r^{RB}(\theta)$ is charged. Therefore, the incumbent's optimal strategy is to simply charge the profit-maximizing loan rate $r^{RB}(\theta)$, which is the equilibrium strategy.

(2.b) *For* $\theta > \underline{\theta}^{LP}$, a monopolist's (one-period) profit-maximizing rate is $r^{RB}(\theta) < r^{LP}$. If this rate is charged, according to $t^*(r_1)$, there will be entry. Given that the incumbent always prefers "No Entry," its optimal strategy is to charge r^{LP} so that entry does not occur. ■

Proof of Proposition 2. As $\underline{\theta}^{LP}$ and r^{LP} move in opposite directions with the underlying parameters, it suffices to prove the comparative statics results for $\underline{\theta}^{LP}$. Note that when demand has constant elasticity, $D(r)=qr^{-\eta}$, where q is a constant. It is helpful to rewrite the condition for $\underline{\theta}^{LP}$ in Lemma 2 as

$$\frac{\int_{\underline{\theta}^{LP}}^1 \theta^\eta f(\theta)d\theta}{1-F(\underline{\theta}^{LP})} - \frac{\kappa^E(\eta-1)^{1-\eta}}{q(\kappa^C)^{1-\eta}\eta^{-\eta}} = 0. \tag{A2}$$

The first term in Equation (A2) is $E[\theta^{\eta}|\theta > \underline{\theta}^{LP}]$. Thus, we have

$$E[\theta^{\eta}|\theta > \underline{\theta}^{LP}] = \frac{\kappa^{E}(\eta-1)^{1-\eta}}{q(\kappa^{C})^{1-\eta}\eta^{-\eta}} \tag{A3}$$

where $\eta > 1$. The left-hand side of Equation (A3) depends only on η, the distribution of θ, and $\underline{\theta}^{LP}$. It is straightforward that the right-hand side of Equation (A3) increases with κ^{E} and κ^{C} while the left-hand side remains unchanged. Thus, $\frac{d\underline{\theta}^{LP}}{d\kappa^{E}} > 0$ and $\frac{d\underline{\theta}^{LP}}{d\kappa^{C}} > 0$.

It remains for us to show the effect of η. Denote the right-hand side of Equation (A3) as A, that is, $A = \frac{\kappa^{E}(\eta-1)^{1-\eta}}{q(\kappa^{C})^{1-\eta}\eta^{-\eta}}$. It follows that $\frac{dLnA}{d\eta} = Ln\left[\frac{\kappa^{C}\eta}{\eta-1}\right]$, which is always positive. Meanwhile, the left-hand side of Equation (A3) declines with η. Therefore, we have $\frac{d\underline{\theta}^{LP}}{d\eta} > 0$.

Lastly, for a new distribution, $G(\theta)$, that stochastically dominates $F(\theta)$ in the hazard-rate sense, the left-hand side of Equation (A3) increases. Hence $\underline{\theta}^{LP}$ declines.

■

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