MONOPOLY AND INFORMATIONAL ADVANTAGE IN THE RESIDENTIAL MORTGAGE MARKET[*]

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August 2006

Abstract

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I. Introduction

The U.S. residential mortgage market represents close to 30 percent of the nation's total credit market, with important implications for the macroeconomy. The structure of this market has received considerable attention in recent years, with much of the critical focus on Fannie Mae and Freddie Mac. Although the original intent was for them to play a limited role, over the years these two Government Sponsored Enterprises (GSEs) have come to dominate the market. They are now two of the largest corporations in the U.S. as measured by assets, and have 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 (for an excellent review of the relevant issues, see Frame and White (2005)).

Despite the recent critical attention, numerous important aspects of the U.S. residential mortgage loan market remain understudied and not particularly well understood. We focus our attention on two well-known 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 displays surprisingly little variation as a function of mortgage loan credit quality. These phenomena are puzzling given that sophisticated credit evaluation models exist to allow for risk-based loan pricing – a pricing strategy that is commonly thought to maximize lender profits.

To explain these structural characteristics, we present a theoretical model that shows how informational advantage combines with entry deterrence incentives to shape observed underwriting and pricing strategies. To begin to rationalize the model structure, we note that, over the years, Fannie

and Freddie have acquired vast quantities of consumer credit information and have used it to develop sophisticated credit evaluation models. This information and the resulting credit evaluation models create a competitive advantage for these GSEs relative to retail loan originators (i.e., depository institutions and brokers) in the primary market. As a result, loan originators have become increasingly irrelevant: they passively apply the GSE's credit evaluation model to screen loan applicants and charge consumers a price 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 an informationally advantaged monopolist.[1]

In the presence of the threat of competitive entry, informational advantage allows the incumbent lender to manipulate the potential entrant's entry decision. This is done by exploiting the inter-dependence 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 inter-dependence.

Without the threat of entry, the lender's profit-maximizing strategy is to price-differentiate its loans based on 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 the borrower's credit quality, however, since credit quality information contained in the loan rate allows for a more accurate projection of entrant profitability. Risk-based loan pricing thus facilitates entry. Because entry decreases its profitability in the longer run, the incumbent will have incentives to deter entry by

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[1] For additional background on the relation between GSE credit evaluation technology, its role in direct lending, and how it solidifies GSE market power, see a recent article by the Mortgage Bankers Association (2005) entitled "Why the Bright Line Helps Mortgage Markets." Also see Hermalin and Jaffee (1996) for a detailed analysis of the economic structure of the residential mortgage market. They argue that Fannie Mae and Freddie Mac tacitly collude to effectively monopolize the secondary mortgage market.

disguising the true credit quality of particular borrowers. This is done by pool pricing with respect to credit quality.[2]

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 the potential entrant. The incumbent lends to lower credit quality borrowers at a separating (risk-based) price, as entry is naturally deterred in this region. The loan market thus segments into a "prime" market in which lower-risk consumers pay a single uniform rate and a "sub-prime" market in which higher-risk consumers pay a risk-based rate that varies as a function of credit quality.

Although our model predicts a pool-pricing outcome, it does not rule out some variation in the credit spread. In fact, the incumbent lender's information on borrower characteristics can be thought of as falling into two categories: publicly observable and incumbent's private information. Risk-based pricing on publicly observable information (information that is a subset of the incumbent's information set) does not reveal proprietary information to potential competitors, but can improve first-period profits. Therefore, the lender would pool-price based on the unobservable characteristics but price discriminate based on observable characteristics.

Our model can be compared to that of Jaffee and Modigliani (1969). Like us, they are interested in how a loan market segments between higher and lower credit quality applicants. By exogenously imposing uniform pricing, they determine a region in which applicants of higher credit quality obtain a loan at a pooled price. Lower credit quality applicants are rationed out of the market, however. In our model, lower credit quality applicants receive a loan at a risk-based price. The difference follows from the structure of the models. In our model, the uniform rate emerges

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[2] Laffont and Maskin's (1990) perspective directly applies to our setting: "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."

endogenously as an entry-deterrence device by an informationally advantaged incumbent, rather than being exogenously imposed or assumed.

Even though our analysis focuses on the market structure of the residential mortgage market, it 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. Moreover, anecdotal evidence suggests that there is not much variation in rates charged to consumers as a function of their credit risk. While there may be other explanations, such as switching costs or asymmetric information between the cardholder and bank, our paper provides an alternative rationale. To the extent that the incumbent lender acquires private information, either by observing detailed past credit performance or by providing other banking services, there is an incentive to exploit this information to deter entry by charging high loan rates in order to signal low credit quality.[3]

Empirical implications of the model are identified and discussed, and empirical tests are presented that offer direct support for predictions of our model. We present two sets of evidence. The first set is consistent with pool pricing, as opposed to risk-based pricing, in the prime market. We specifically find that mortgage loan rates are significantly less variable in the prime market than in the sub-prime market. Moreover, consistent with both the assumed information structure and an endogenously determined pooling equilibrium, we find that the GSEs do not incorporate all of their private information into the observed mortgage loan rates. The second set of evidence is related to the prime market share across different geographical market areas. Our results show that, consistent with comparative static implications of the model, prime market share is higher in geographical areas with larger banks that have established networks and thus a lower incremental cost of entry.

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[3] There has been empirical evidence that commercial lenders tend to charge higher than risk-based loan rates to long-term borrowers, and that there are not significant differences in loan rates for borrowers with different credit quality (e.g., Petersen and Rajan, 1995). Our paper is also related to a strand of literature on the relation between banking competition and market structure. This literature has focused on the equilibrium number of banks in the market by analyzing an important aspect of competition in which borrowers solicit loan offers from multiple lenders (e.g., Rajan, 1992; Dell'Ariccia et al., 1999). The pricing structure of the loan market is less understood, however.

The organization of the paper is as follows. In Section II, the structure of the U.S. residential mortgage market is described in more detail. We present the theoretical framework and carry out some preliminary analysis in Section III. Section IV analyzes the resulting market equilibrium with endogenous learning and entry. In section V we outline testable empirical implications of the model, and present evidence that supports our theory. Section VI details several further implications of our model for the residential mortgage market, and section VII concludes the paper.

II. Institutional Background of the U.S. Residential Mortgage Market

Despite the existence of a large number of retail mortgage lenders, large segments of the U.S. residential mortgage market have strong monopolistic characteristics. Homebuyers typically obtain financing through retail mortgage lenders, e.g., depository institutions or mortgage brokers, in the primary market. Retail mortgage lenders, in turn, decide whether to hold the mortgages or sell them to the secondary market. The major players in the secondary market are Fannie Mae and Freddie Mac.

In recent years, 70 percent of all "qualified" residential mortgages have been sold directly to Fannie and Freddie.[4] The GSEs' secondary 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 informational advantage in credit evaluation.[5] As a result of their growth and market dominance, Fannie Mae and Freddie Mac have

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[4] See Frame and White (2005). Technically, Fannie Mae and Freddie Mac are eligible to purchase only conventional-conforming mortgages, which are non-FHA insured loans that are below pre-specified 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 percent of the total market, and the conforming (mortgage size limited) market is 80-85 percent of the conventional market. Our focus is on this important segment of market. In addition, fixed-rate mortgage loans are typically originated for sale into the secondary market, whereas adjustable-rate loans, although potentially eligible for sale, are typically originated to be held by the retail lender. Although the relative proportions of fixed- versus variable-rate loans vary as a function of market conditions, fixed-rate loans have historically dominated the market. Thus, 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 the April 5, 2001 *Wall Street Journal* article entitled "Why Big Lenders are So Afraid of Fannie Mae and Freddie Mac".

become the second and third largest U.S. companies, respectively, when ranked by assets as of year-end 2003.

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 systematically correlate this information—as well as information on collateral asset values, macro-market trends, and financial and legal conditions—with historical loan performance in order to learn about loan credit risk (see Straka (2000) and Van Order (2000) for evidence). This information has been used to create sophisticated credit evaluation models that retail loan originators and consumers do not have.

Historically, retail loan originators (depository institutions) could decide whether to sell their mortgages into the secondary market or keep them in portfolio. This created adverse selection concerns for the GSE (see, for example, Passmore and Sparks (1996)). 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]

Information technology has solidified the GSEs' control over the mortgage market. Due to regulatory incentives and production cost disadvantages, and to ensure that their mortgages are marketable, most retail originators passively apply the GSE's credit evaluation models to screen loan applicants with qualified loans automatically sold to the GSE at guaranteed prices. Price guarantees set by the GSE provide the basis for loan rates observed in the retail mortgage marketplace. This structure implies that the GSE, in effect, lends directly to consumers.[7]

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[6] According to Robert 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] According to Robert Van Order (2001), "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,

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Consumers do not have the advantage of scale or repeated play to learn about their own credit risk. A vast majority of consumers have never defaulted on a mortgage loan and probably have little idea about how to begin to evaluate their own credit quality as it interacts with collateral and other 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 their lack of scale and market power work against the development of sophisticated credit evaluation models (see Dixit and Shapiro (1984)).[9]

Not surprisingly, Fannie and Freddie consider their credit evaluation models to be proprietary, and they zealously protect the information underlying their technology.[10] These models decrease screening costs and provide accurate forecasts of future revenues, thus enhancing profits and solidifying their control over the market.[11]

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economically. What matters is that there are different ways of getting money from capital markets as a whole to the mortgage market." A *Wall Street Journal* article entitled "Why Big Lenders are So Afraid of Fannie Mae and Freddie Mac" (4/5/01) states 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." Also see a recent report issued by the Mortgage Bankers Association (2005). This report 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."

[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 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. Our own empirical analysis as related to results presented in Section V.B. also suggests that lower-risk rather than higher-risk loans are sold to the GSEs, as measured by the credit score at the time of loan issuance as well as by actual loan default experience. These findings indicate that the GSEs are not adversely selected against in the secondary market.

[10] According to the Mortgage Bankers Association, "One problem with the GSEs's 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)).

[11] The same MBA article states, "GSEs do not permit outside competition in technology for underwriting loans…Competing technology vendors could, for example, create technology that enables lenders to easily and routinely shop prices and terms from non-GSE investors before selling loans into the secondary market. Freddie Mac and Fannie Mae have a strong incentive to prevent lenders from shopping around for the best place to sell their loans."

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

We take this institutional market structure characterized by GSE market dominance and technology-enhanced informational advantage, and combine it with entry deterrence incentives, to develop a model to explain observed lending practices that result in market segmentation and the pooling of loan rates.

III. Model Set-Up

III.A. Description of the Model

We consider a residential mortgage market structure in which: i) consumers are price takers; ii) there is initially a monopolistic secondary market supplier of mortgage funds (the GSE); and iii) retailer lenders act as passive financing conduits that impose GSE-determined loan rates on qualified applicants.[12] The possibility of entry exists 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 existing conduit retail market structure.

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[12] Although the GSE sets a price guarantee for the secondary market sale of mortgages, it does not technically set rates in the primary market – the retail lender sets the rate. Fannie and Freddie either buy individual mortgages or pools of mortgages that satisfy stated criteria at a preset (forward) rate of interest. Retail lenders almost always behave passively, however, in the sense that they simply apply GSE screening software that produces an accept/deny decision. Accepted loans are delivered, often as a pool, at the guaranteed weighted average coupon rate plus a mark-up to account for the constant (credit risk related) guarantee fee.

There are an atomistically large number of consumers that are capital constrained and who wish to borrow to finance the purchase of a home. The loan amount for each individual, which we will also refer to as the demand schedule, $D(r)$, is determined by the loan interest rate, r.[13] This 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 that they may differ in 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 on the interval $(0,1)$. The probability of default is $1-\theta$. If default actually occurs, the lender's payoff is zero.[14] 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., $\int_0^1 f(\theta)d\theta = 1$).

We now define 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 thus 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 perfectly the credit quality, θ, 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. Prior to entry, to the potential entrant each borrower is a random draw from the density function, $f(\theta)$. Although the

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[13] 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 home buyers tend to have very limited alternative sources of financing and are thus 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.

[14] The assumption of zero recovery is made to streamline the analysis. One can simply adjust the default probabilities to account for the effects of expected recovery resulting from the borrower's default.

potential entrant does not precisely observe θ, the borrower's first-period loan rate, r_1, is observed at no cost.[15] Based on the observed first-period loan rate, the potential entrant must determine whether or not to enter. If entry occurs, a one-time cost of κ^E is incurred to lend to this particular borrower. The entry fee is related to start-up costs of loan production, and is known to the incumbent. Based on this structure, the potential entrant must formulate an entry policy for each and every loan applicant. For loan applicants for whom the entrant decides not to enter, credit is denied at no cost.

As is typically assumed, once entry occurs the consumer's credit quality, θ, is fully revealed (see Milgrom and Roberts (1982) for a similar approach and related discussions). Conditional on entry, suppliers split equally the monopoly profits in the final two rounds of lending. It is worth noting that the assumptions of full information revelation and equal profit sharing upon entry are made for simplicity. They do not drive the results: it is not difficult to generalize the main results to settings where information is revealed only through first-period loan rates and where profit sharing is asymmetric.[16] If entry does not occur at the beginning of round two, it never occurs and the incumbent monopolizes the loan market in the remaining two 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".

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[15] The model is easily adapted to the case where the first period loan rate is observed with only a probability.

[16] 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 sufficiently large discount factor. Thus our assumption of equal sharing of profits can be viewed as an equilibrium outcome of an infinitely repeated game with asymmetric profit sharing and an appropriately specified discount rate. Given our assumption 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 of our results are robust to profit splitting outcomes.

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 exist off-equilibrium beliefs that support the equilibrium strategies.

III.B. 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. Consider 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, 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. 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 that there exists 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:

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

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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-Klein loan mark-up relation (see Monti (1972), Klein (1971)). The expected profit from a loan with credit quality θ is

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

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

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

I.V.   Equilibrium with Endogenous Learning and Entry

IV.A.   The Equilibrium

As a preview to the limit-pricing equilibrium, we first provide intuition on the type of pre-entry pricing behavior we should expect to observe. To fix ideas, consider a given borrower with credit quality, θ. As noted earlier, upon entry, θ is fully revealed and the two lenders split the monopoly

profits. Without loss of generality, we assume an intertemporal discount rate of zero and identical

capital costs of κ^C for both the incumbent and the entrant.[17] The entrant's total expected (two-period)

post-entry profit is:

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

where $\pi^{RB}(\theta)$ and $r^{RB}(\theta)$ are the risk-based monopoly profit and loan rate as defined in equations (3)

and (2), respectively. The fixed cost of entry, κ^E, is constant for all θ.[18]

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

will require that:

$$\int_0^1 \pi^E(\theta) f(\theta) d\theta \leq 0 \qquad (6)$$

Otherwise, if the unconditional expectation of π^E is positive, i.e., $\int_0^1 \pi^E(\theta) f(\theta) d\theta > 0$, the entrant

does not have to be informed of the borrower's credit quality in order to enter the market and expect to

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[17] The potential entrant is likely to be a financial institution that has capital costs and regulations that are similar to the GSE. It is easy to verify that 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 contain other priced risks such as institutional-level default risk. Discounting only affects the incumbent's decision to deter entry or not. In the region 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 have qualitative effects on the results.

[18] Similar to many full-information models, entry cost is needed to deter entry in our model. 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.

make a profit. Thus entry would always occur and there would be nothing the incumbent could do to deter entry.[19]

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

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

Because $\pi^E(\theta)$ is continuous and monotonically increasing in borrower credit quality, θ, if π^E is negative when $\theta = 1$ (κ^E is high), it would never profitable for entry to occur, which makes limit pricing unnecessary. The above two conditions, combined with the continuity of θ and the monotonicity of $\pi^E(\theta)$, ensure that there exists a unique credit quality cutoff value, θ^0, such that $\pi^E(\theta^0) = 0$.

Now suppose the incumbent sets a loan rate that is monotonically decreasing in θ. Having observed r_1, the potential entrant can exactly infer θ since the inverse of $s(\theta)$ exists. As the potential entrant's expected post-entry profits are increasing in the perceived credit quality, θ, the pre-entry loan rate, r_1, signals profits that the entrant would earn upon entry. 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, $\theta \in (0,1)$. To see this, 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

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[19] As entry could not be deterred, the incumbent would end up charging risk-based loan rates in that region in period one, which fails to explain observed pricing patterns in the residential mortgage market.

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

where π^{RB} is the monopoly profit as defined in equation (3). Terms in the first bracket are first period expected profits plus expected monopoly profits from periods 2 and 3 given that entry has been deterred. Terms in the second bracket 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

$$w(\theta) = \pi_1(\theta) > 0. \qquad (9)$$

As entry deterrence is preferred by the incumbent for all possible θ's, a separating strategy for sufficiently high credit quality cannot be part of the equilibrium. Specifically, a separating equilibrium does not exist 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:

$$f(\theta \mid r_1 = r^{LP}) = \begin{cases} \dfrac{f(\theta)}{1-F(\hat{\theta})}, & if\ \theta \in (\hat{\theta},1) \\ 0, & otherwise \end{cases} \qquad (10)$$

Based on this posterior belief, the potential entrant calculates his 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 exists 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 $\int_{0}^{1} \pi^E(\theta) f(\theta) d\theta \leq 0$ as in equation (6) and the

fact that $\pi^E(\theta)$ is strictly increasing in θ.

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

Proposition 1: _A Perfect Bayesian Equilibrium_ (s^*, t^*) _exists, where_

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

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

The set of off-equilibrium beliefs that supports the entrant's strategy when he 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 that is less than $\underline{\theta}^{LP}$ can also serve as the lower bound of the pooling region. Thus, a continuum of equilibria exists where each one is defined by a different lower bound, $\hat{\theta}$, $\hat{\theta} \leq \underline{\theta}^{LP}$. 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 presented in the above 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. Therefore, in what follows, we focus on the Pareto optimal equilibrium as presented in Proposition 1. Figure 1 illustrates the Pareto-optimal equilibrium. A risk-based loan rate is applied to consumers with $\theta < \underline{\theta}^{LP}$ and a uniform loan rate is applied to consumers with $\theta \geq \underline{\theta}^{LP}$. The uniform loan rate is the risk-based monopoly rate for borrowers with $\theta = \underline{\theta}^{LP}$.

Figure 1 About Here

Although our model derives uniform pricing as an entry deterrence device, it does not rule out some variation in the observed credit spread. For example, retail lenders might be observed to set loan specific prices that get to an aggregate average price, which is the price at which the GSE purchases a pool of mortgage loans. Such behavior is not inconsistent with our model. The GSE's information about borrower characteristics can be divided into two categories: publicly observable to all and private information unobservable to the public. Risk-based pricing based on publicly observable

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information does not reveal proprietary information to potential competitors, but can improve first-period profits. Retail lenders, which do not have the private information on the unobserved characteristics, can only charge differentiating prices based on 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.

IV.B. Comparative Statics and Consumer Welfare

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

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

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

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

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

Distribution of Credit Risk: *If the new distribution G(θ) dominates F(θ) in the sense of hazard-rate order, then $\underline{\theta}^{LP}|_{G(\theta)} < \underline{\theta}^{LP}|_{F(\theta)}$ and $r^{LP}|_{G(\theta)} > r^{LP}|_{F(\theta)}$.*[20]
$$\tag{15}$$

Proof: See Appendix.

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

An increase 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 relatively *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 informational advantage. A relatively smaller prime market increases the credit quality of the marginal borrower, which leads to a lower (uniform) loan rate.

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

Consumer welfare in the limit pricing equilibrium can be compared with the alternative regime where there is no threat of entry and the incumbent charges risk-based prices. Since 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, it equals or exceeds the risk-based monopoly price for every borrower in that region. Thus, aggregate consumer welfare in our limit pricing equilibrium is even lower than in the no-entry risk-based monopoly pricing regime. Note that this result is in contrast to Milgrom and Roberts (1982), who show that limit pricing is not harmful to consumer welfare.

V. Empirical Implications of the Model and Supporting Evidence

In our model, the lender is initially endowed with informational advantage that allows it to secure a competitive edge in the market for mortgage loans. Empirical implications of the model derive from incentives of the incumbent to protect its competitive position over time. In particular, the incumbent uses its informational advantage to create barriers to entry through its loan pricing policy. Informational advantage is thus the cause and effect of limit pricing, since entry would otherwise dissipate monopoly rents accruing to the incumbent due to its lost control over loan-level credit quality information.

Empirical implications derive from endogenously determined outcomes of the model, which prominently include market segmentation, pooled loan pricing, and comparative statics regarding prime market size and mortgage loan rates. In this section we highlight these predictions and present evidence that supports the model's predictions. We note that a common difficulty in testing any limit pricing model is that the main consequence of limit pricing—entry that could but does not occur—is by definition, "a dog that doesn't bark." However, by establishing the GSE's information advantage (which is both 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 comparatic statics of our model, we believe that a strong case can be made for limit pricing as a driving force of the observed market structure. Indeed, it is hard to think of an alternative story that can simultaneously account for *all* these empirical facts.

V.A.   Empirical Implications

1. Predictions about Pooled Versus Risk-Based Credit Pricing in the Prime Market

One of the main predictions of our model is that in equilibrium the lender will divide consumers into two segmented sub-markets based on credit quality. Those with higher credit quality

pay a pooling rate, and those with lower credit quality pay risk-based rates. 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 following formal prediction:

Prediction 1a: The cross-sectional variability of credit spreads in the prime market is smaller than that in the sub-prime market.

A slightly different approach is to examine variation in credit spreads that can be explained by borrower characteristics. Recall that these characteristics fall into two categories: those that are publicly observable and those that are privately observed only by the incumbent lender. We predict that the incumbent will pool-price based on private information but price discriminate based on public information. When the lender charges a pooling rate, variation in credit spread should be mainly driven by publicly observed borrower characteristics. That is, publicly observed information should explain a larger proportion of variation in credit spreads in the prime market. This leads to the following testable prediction:

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

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: (i) the cost of entry decreases; (ii) the cost of financial capital decreases;

and (iii) the distribution of the borrowers' credit quality improves.[21]

All three of these factors will vary over time. Specifically, the cost of an automated underwriting system for credit evaluation, an important part of entry cost, has declined over time. Furthermore, the cost of financial capital and the distribution of borrower quality vary over business cycles. During a tightening of monetary policy, banks are more likely to face a higher cost of funds. And, during a market downturn, the distribution of borrower credit quality is likely to deteriorate. Thus the effects of these latter two factors can be tested by analyzing how credit spreads and the relative size of the prime market vary over business cycles.

Another identification strategy is to take advantage of the fact that credit spreads in the sub-prime market (given in Equation (2)) move inversely with those in the prime market as the cost of financial capital and the distribution of borrower credit quality change. Therefore, the impact of these two factors can be tested by examining the change of differences in credit spreads between prime and sub-prime markets as a function of different market conditions. Such a "difference-in-differences" approach is particularly useful, since it can reduce the impact of noise in measuring the credit spread.

In sum, we have the following testable predictions:

Prediction 2a: _Prime market share increases over time in response to lower-cost automated underwriting, but decreases during periods of tight monetary policy and economic downturn (relative to periods of economic expansion)._

Prediction 2b: _The credit spread of the prime market increases in response to lower-cost automated underwriting. During periods of tight monetary policy and economic downturn, the credit spread in the prime market declines whereas the differences in (average) credit spread between the sub-prime and the prime market increase.[22]_

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[21] 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. It is straightforward to show that, 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 changes.

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

In addition to tests at the aggregate level, one may exploit variation in entry cost and the distribution of borrower credit quality across different market areas. For example, consolidation in the retail lending market and the resulting larger banking networks may lower the incremental entry costs into the GSE's market (Marquez 2002). Moreover, variables such as unemployment rate and the actual historical default rate can be useful indictors of the distribution of borrowers' credit quality. Thus we have the following hypotheses:

Prediction 2c: *The relative size of the prime market is higher in geographical areas with a more concentrated banking market and better borrower credit quality.*

Prediction 2d: *In geographical areas with a more concentrated banking market and better borrower credit quality, the credit spread of the prime market is higher.*

V.B   Supporting Evidence

1. Data

We rely on four sources of data to test implications of our theory. The first two data sources are used to examine variability in loan rates. They 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). Our 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 contain 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 prime-market size, we take advantage of Home Mortgage Disclosure Act (HMDA) data, which provides information on MSA-level prime market share. We supplement this 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 information from data compiled by Pennington-Cross (2002) for use in his study of sub-prime mortgage lending.

2. Analysis

2.1 Pooled Mortgage Loan Pricing in the Prime Market

We first examine the variability of mortgage loan rates (Prediction 1a). We use two measures of variability: one is dispersion as measured by the distance between the 90th and 10th percentile; the other is standard deviation. We compare the dispersion of credit spreads in the prime and sub-prime markets in Panel A of Table 1, based on the survey data at 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 those in the sub-prime market. The 18-month average of the dispersion in the prime market is 1.0 percent, whereas in the sub-prime market it is 2.6 percent.

Table 1 about Here

In Panel B of Table 1, we report the standard deviation of loan rates from a sample of loans originated in 2002 by Wells Fargo Home Mortgages. The standard deviation of loans rates in the prime market is 0.91 percent (with a mean of 6.62 percent). It is 3.94 percent (with a mean of 7.69 ercent) for sub-prime loans, which is over four times higher than prime market variability. An F-test indicates that the difference is statistically significant at the 1% level.

To further pin down pool pricing in the prime market, we now examine the information content of mortgage loan rates revealed in lenders' loan retention decisions. While retail lenders routinely sell

loans to the secondary market as we discussed earlier, they sometimes retain certain loans in their own portfolio. To the extent that the retention decision is related to borrower credit quality, we can infer information content in 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. In contrast, our theory predicts that the lender will not price its private information in fear of revealing higher quality borrowers to potential entrants. Thus, there will be additional information about credit risk contained in actual default data *over and above* the observed credit spread.

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

$$\mathrm{Re}tained_{it} = aSPD_{it} + bD\mathrm{Pr}ob_{it} + cX_{it} + dZ_{t} + \varepsilon \qquad (17)$$

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} contains 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 non-linearity of the effect of predicted loan termination probability with respect to credit spread. Z_{t} contains market-wide variables as commonly used in the literature, including the yield spread between Moody's "AAA" and "Baa" bond indices, the spread between the 10-year and one-year Treasury bond rates, and the volatility in the risk-

free rate as measured by the standard deviation of one-year Treasury bond rate over the 24 months prior to loan origination.

Thus, *X* and *Z* summarize observable risk characteristics, and *DProb* proxies for the effects of unobserved risk characteristics. 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 primarily interested in the coefficient, *b*, associated with *DProb*. It should be statistically insignificantly different from zero if all information about credit quality—publicly observed as well as private—is already reflected in the loan spread. Our theory implies that *b* is positive, however, since we predict that the lender *chooses not to* price all its private information by charging a pooling rate.

As reported in Table 2, the predicted default probability is, as expected, significantly positively related to loan retention at the one percent 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 earlier discussions that adverse selection is not a significant factor in the residential mortgage market.

Table 2 about Here

2.2 Entry Cost and the Relative Size of the Prime Market

We now examine the relative size of the prime market in response to changes in entry cost. We first note that there is evidence at the aggregate level of a general trend towards 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, occurring shortly after

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the introduction of GSE AU systems in 1995. Gates, Perry, and Zorn (2002) further document that

borrowers that were previously excluded from the prime market have more recently been able to

borrow from that market, an outcome they attribute to lower-cost automated underwriting. These

outcomes are consistent with Prediction 2a, which asserts that 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, since

there are many other events happening during the same period. Therefore, in this section 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). In particular, geographical

areas with larger banks are such that they are likely to have lower-cost access to borrower credit

information (Marquez 2002). This implies a lower incremental cost of entry in that area, where, as a

result, we predict a larger prime market size.

To assess this prediction, we estimate the following model:

$$\text{Pr}ime\ Market\ Share_{jt} = a\ +\ b\ Concentration_{jt}\ +\ c\ X_{jt} + \varepsilon_{jt} \qquad (16)$$

where j indexes MSAs and t indexes time. *Prime Market Share* is the number of prime-market loans as

a percent of the total number of mortgage loans in the MSA. *Concentration* is banking market

concentration. We supply two measures of concentration. One is the log of the number of banks, which

is an inverse measure of concentration. Both theoretical and empirical banking research has suggested

a direct link between the number of banks and their competitive behavior (e.g., Besanko and Thakor,

(1993) and Gan (2004)). This measure does not directly reflect the size distribution of banks, however.

Since we are particularly interested in the concentration of large banks, we also proxy entry cost with a

four-firm concentration ratio, defined as the proportion of deposits or assets held by the largest four

banks in the MSA.[23] 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 contained in X. 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 10 years. The second set of MSA characteristics are local economic conditions, including personal income growth from 1979-89 and unemployment rate in the previous year. Lastly, similar to the specification employed by Pennington-Cross (2002), we control for MSA demographic variables, including the percentage of minority mortgage applicants and a racial segregation index.[24] Gan (2004) suggests that the number of banks in an MSA area is strongly related to population density; therefore, we control for population density. In the estimations we also include a time dummy for year 1995.

The results are presented in Table 3. Consistent with our model's prediction, the coefficient on banking market concentration, inversely measured as the log of the number of banks, is significantly negative at the 1 percent level (column (1) of Table 3). 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 applicants is associated with smaller prime market size (significant at the 1 percent level), which is not surprising to the extent that this variable proxies for lower credit quality on average. Interestingly, underserved locations as defined by the HUD tend to have larger prime market share, which suggests that lenders may have adjusted

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[23] Another common measure of market concentration is the Herfindahl index, which incorporates both the number of firms and their size distribution. A Herfindahl index, however, contains information on the size distribution of both large and the small banks, 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.

[24] This is often called a Gini coefficient, which measures the spatial distribution of the black ethnical group across the local regions. It has a value of 0 to 100, with 100 indicating maximum segregation.

their behavior to meet the Community Reinvestment Act (CRA) requirements. In column (2) of Table 3, concentration is measured as the four-firm concentration ratio. Its coefficient is, as predicted, positive and marginally significant at the 15 percent level. Since we are really testing a one-sided hypothesis, this result supports our model's prediction.

Table 3 about Here

To summarize, this section provides two sets of evidence in support of our model. The first set addresses whether pooled, as opposed to risk-based, pricing occurs in the prime market. We document lower variation in prime market credit spreads as well as provide evidence that the lender chooses not to price all of the private information it has about credit risk. The second set addresses the relation between entry cost and prime market size. We find larger prime-market shares in more concentrated local banking markets, where large banks with established networks presumably enjoy a lower incremental cost of entry.

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

VI.A. The Sub-Prime Mortgage Market

In the market for mortgage loans, we observe limited GSE participation in the sub-prime market. Where there is participation, it is in the higher-quality portion of the market 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 lowest 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.

VI.B. Racial Discrimination in Mortgage Lending

A controversial literature has developed in recent years on racial discrimination in residential mortgage lending. In this literature, if the borrower's race explains mortgage loan denial probabilities or the mortgage loan rate independently of legitimate credit risk variables, racial discrimination is often asserted.

Our paper suggests two potential biases in such an approach. First, pooled loan pricing reduces the power of a test of racial discrimination. Consider a situation in which minority borrowers qualify for a loan in the prime mortgage market, but are of lower average credit quality than the average prime market borrower. Thus, credit quality and racial status are 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 what did occur was loan rate subsidization going from higher to lower credit-quality borrowers—*rationally imposed by the lender*.

Second, GSEs' private information about borrower characteristics can lead to assertion of racial discrimination even if it does not exist. As emphasized in our analysis, the GSEs have credit-quality information that others—including independent research specialists—do not have. If omitted variables are correlated with race, a spurious relationship between race and mortgage loan denial rates / prices may lead to an incorrect inference of racial discrimination.

VI.C. Competing Risks

This study has 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.[25] In addition to its detailed knowledge of consumer credit risk, 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: i) additional observable characteristics that can be priced, and/or ii) an additional source of noise that inhibits outside identification of credit risk. The implication in the context of 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. As discussed above, minority borrowers may have below-average credit quality, which combined with other factors may result in fewer 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).

VII.   Conclusion

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

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[25] Credit risk has historically been the most important source of risk in GSE portfolios. However, in recent years the GSEs have (somewhat controversially) retained increasing amounts of prepayment risk: see Jaffee (2002) and Downing, Jaffee and Wallace (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.

Entry deterrence is accomplished by, first, segmenting consumers into a prime and sub-prime market based on measured credit quality, and second, 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 contained 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 the determination of incumbent's loan underwriting-pricing policy.

Empirical implications of our model are identified and discussed. Empirical tests support two important predictions of our model. The first is pooled as opposed to risk-based pricing in the prime market. We find that mortgage rates are less variable in the prime market than the sub-prime market, and that the GSEs do not price all of their information into (pooled) prime market mortgage loan rates. Second, consistent with the comparative statics of the model, prime market share is higher in geographical markets with more concentrated banking and thus lower incremental cost of entry.

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Appendix

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 $\theta = \dfrac{\kappa^C}{r_1}\left(\dfrac{\eta}{\eta-1}\right)$. Thus, given that $r_1 > r^{LP}$, $\theta < \underline{\theta}^{LP}$. Notice that, since $\pi^E(\theta)$ is strictly increasing in θ, and $\underline{\theta}^{LP}$ satisfies $\int_{\underline{\theta}^{LP}}^{1} \pi^E(\theta)\dfrac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta = 0$, it must be the case that $\pi^E(\underline{\theta}^{LP}) < 0$. 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. She only learns that $\theta \in (\underline{\theta}^{LP}, 1)$. Using Bayes' rule, the entrant's updated belief about θ has a posterior density function as follows:

$$f(\theta \,|\, r_1 = r^{LP}) \;=\; \begin{cases} \dfrac{f(\theta)}{1-F(\underline{\theta}^{LP})}, & if \ \ \theta \in (\underline{\theta}^{LP}, 1) \\[2mm] 0, & otherwise \end{cases} . \tag{A1}$$

The entrant's expected post-entry profit based on this posterior density function is $\int_{\underline{\theta}^{LP}}^{1} \pi^E(\theta)\dfrac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta$, 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 $\underline{\theta}^{LP}$, i.e., borrower quality is $\theta > \underline{\theta}^{LP} + \varepsilon$. Based on this belief, the minimum expected post-entry profit, $\int_{\underline{\theta}^{LP}+\varepsilon}^{1} \pi^E(\theta)\dfrac{f(\theta)}{1-F(\underline{\theta}^{LP})}d\theta$, is strictly positive by Lemma 2. Therefore the entrant's optimal strategy is "Entry", which is her equilibrium strategy.

The second step in our 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 $\theta \leq \underline{\theta}^{LP}$, a monopolist's (one-period) profit maximizing loan rate is $r^{RB}(\theta)$. Since $r^{RB}(\theta) \geq r^{LP}$, 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 her equilibrium strategy.

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

QED

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 the above equation is $E[\theta^{\eta} \mid \theta > \underline{\theta}^{LP}]$. Thus, we have,

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

where $\eta > 1$. The LHS of equation (A3) depends only on η, the distribution of θ, and $\underline{\theta}^{LP}$. It is straightforward that the RHS of equation (A3) increases with κ^{E} and κ^{C} while the LHS remains unchanged. Thus, $\frac{d\underline{\theta}^{LP}}{d\kappa^{E}} > 0$ and $\frac{d\underline{\theta}^{LP}}{d\kappa^{C}} > 0$. Now it remains for us to show the effect of η. Denote the RHS 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 LHS of equation (A3) is decreasing in 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 LHS of equation (A3) increases. Hence $\underline{\theta}^{LP}$ decreases.

QED

Figure 1

Observed First Period Loan Rate, r_1, as a Function of Borrower Credit Quality, θ
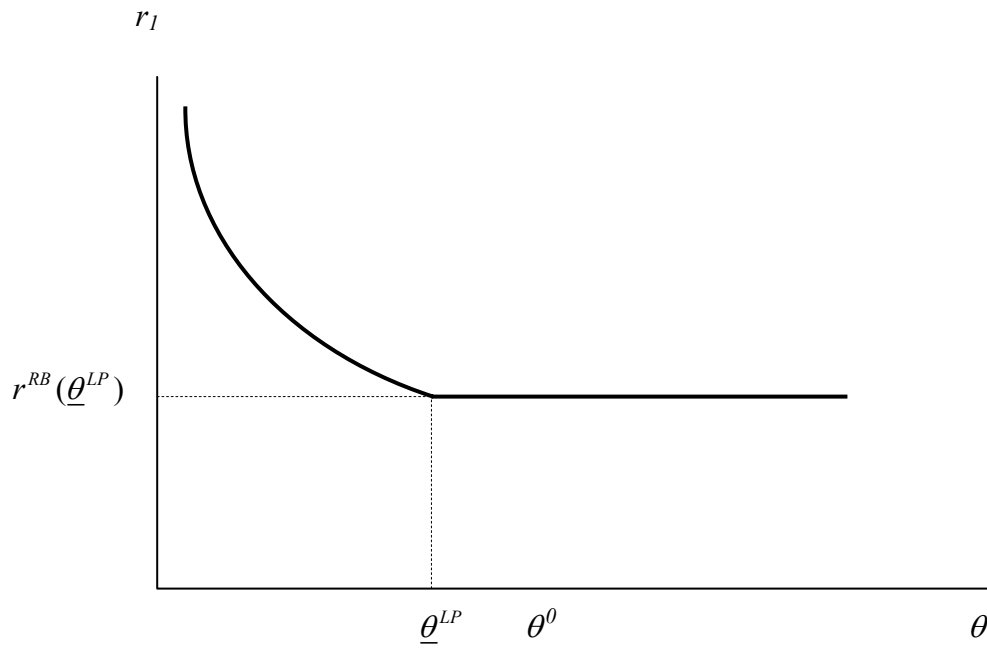
Table 1. Variability of Loan Rates in the Prime and Sub-Prime Mortgage Markets

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 is extracted from Figure 24 in Lax et al. (2004) using Smartdraw Pro.graph software. In Panel B, the variability of loan rates is measured as the standard deviation of loan rates. The data is from LaCour-Little (2004). F-tests of differences in variances are performed and significance levels are based on two-tailed tests; significance at the 1% level is indicated by ***.

	Prime Market			Sub-Prime Market		

Panel A. Dispersion of Loan Rates

Year:Month	10th Percentile	90th Percentile	90th-10th Percentile	10th Percentile	90th Percentile	90th-10th Percentile
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***	

Table 2. Effects of Unobserved Information in the Secondary Mortgage Market

This table presents estimates from a logit model of the probability of loan retention. The data source is Ambrose, LaCourLittle, 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 Moddy'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.

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***	

Table 3. Relative Size of the Prime Market as Explained by Banking Market Structure

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%, 15% levels is indicated by ***, **, *, and [c] respectively.

Independent Variables	Log (Number of Banks) as the Concentration Measure (1)		Four-Bank Concentration Ratio as the Concentration Measure (2)	
	Coefficient	Standard Error	Coefficient	Standard Error
Banking Market Concentration	-0.042***	(0.009)	0.059[c]	(0.040)
Housing Market Characterstics				
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 segragation 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	