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Borrower Mobility, Self-Selection, and the Relative Prices of Fixed- and Adjustable-Rate Mortgages*

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This paper analyzes the effect of borrower self-selection between fixed- and adjustable-rate mortgages (FRMs and ARMs) on the pricing of FRMs. Self-selection occurs according to borrower mobility, with the most mobile borrowers favoring ARMs and less mobile borrowers choosing FRMs. The FRM interest rate depends on the average mobility of the FRM borrower pool, which determines the average duration of FRM loans. Comparative-static analysis of the equilibrium shows that any exogenous change that increases the relative attractiveness of FRMs enlarges the FRM borrower pool, which lowers its average mobility, shortens the duration of FRM loans, and thus reduces their price. Thus, an increase in the demand for FRMs actually reduces the FRM interest rate. *Journal of Economic Literature* Classification Numbers: G21, R20.

1. INTRODUCTION

A large body of recent research in the economics of real estate is directed toward the analysis of mortgage markets. Two lines of inquiry stand out distinctly in this literature. The first focuses on the borrower's choice between fixed- and adjustable-rate mortgages (FRMs and ARMs). Alm and Follain (1987) and Brueckner (1986) analyze the FRM–ARM choice theoretically, and Brueckner and Follain (1988) and Dhillon *et al.* (1987) offer empirical evidence on the factors affecting the borrower's decision.[1] A second important line of research focuses on the pricing of

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[1] See also Baesel and Biger (1980), Phillips and VanderHoff (1991), and Sa-Aadu and Sirmans (1990).

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FRMs, taking into account the endogeneity of prepayment behavior. This literature, which makes use of option-pricing methods, includes studies by Follain *et al.* (1992), Hall (1985), and Kau *et al.* (1992).[2]

Despite substantial interest in mortgage choice, on the one hand, and the pricing of FRMs, on the other, there has been little study of the *connection* between FRM–ARM choices and the pricing of fixed-rate mortgages. Two facts account for the existence of such a connection. First, borrowers self-select across mortgage types according to expected mobility. Highly mobile borrowers favor ARMs because their low initial rate guarantees lower mortgage payments over a short loan life. This preference, which is confirmed in the empirical literature, means that the mobility of FRM borrowers is comparatively low. Second, the FRM interest rate depends on the duration of fixed-rated loans, which in turn reflects the average mobility of FRM borrowers. Their low mobility implies a long loan duration and thus a correspondingly high FRM interest rate, assuming an upward-sloping yield curve. The exact level of the rate depends, however, on the proportion of borrowers selecting FRMs, which determines average mobility in the FRM borrower pool.

The resulting connection between self-selection and FRM pricing can be appreciated by considering the effect of a market shock that increases the attractiveness of FRMs relative to ARMs. Such a shock enlarges the FRM borrower pool by shifting the dividing line in mobility space between the ARM and FRM pools. Since growth of the FRM pool is achieved via the addition of relatively mobile borrowers, loan duration falls and the FRM interest rate declines. Thus, an exogenous shock that increases the demand for FRMs actually *reduces* their price.[3]

The purpose of the present paper is to formally illustrate these points by developing an equilibrium model of FRM pricing in which borrowers self-select across mortgage types according to expected mobility.[4] Comparative-static analysis of the model illustrates the unusual demand effect identified above. In the model, borrowers differ in their probabilities of moving at the end of the first period within a two-period setting, an event that leads to mortgage prepayment. A particular division of borrowers between FRMs and ARMs constitutes a market equilibrium when the average mobility of the resulting FRM pool leads to an FRM interest rate

[2] A complete list of references is given in the survey article by Hendershott and Van Order (1987).

[3] In the credit-rationing model of Stiglitz and Weiss (1981), the loan interest rate is also related to the makeup of the borrower pool. In particular, as the interest rate rises, borrowers with less risky projects drop out of the pool, making its average riskiness (and thus the average default probability) higher.

[4] For a related self-selection model focusing on the choice of mortgage points, see Chari and Jagannathan (1989).

that makes borrowers satisfied with their assumed choices. This equilibrium condition is developed Section 2, and the comparative-static analysis is carried out in Section 3. Among other things, the comparative statics show the effect on the mortgage market equilibrium of an increase in interest-rate risk and of an economywide increase in borrower mobility.

An important feature of the basic model is that mortgage prepayment occurs *exogenously* in response to a move by the borrower. Prepayment in response to a decline in interest rates (i.e., refinancing) thus does not arise in the main part of the analysis.[5] The advantage of assuming away financially motivated prepayment is that the FRM interest rate can then be expressed as a simple function of the average mobility of the FRM borrower pool. Section 4 shows, however, that a simple type of refinancing behavior can be introduced into the model, generating another source of prepayment, without affecting the main conclusions of the analysis.

Some of the lessons of the analysis are contained in an earlier paper by Rosenthal and Zorn (1993). While these authors state some of the points made below, their arguments are based on a model that is not completely specified. The present paper complements their work by carrying out a full analysis of self-selection and mortgage pricing.[6]

2. MODEL AND EQUILIBRIUM CONDITIONS

a. *The Model*

The model divides time into discrete periods and assumes that the term of all mortgages is two periods. The FRM lender engages in long-term (two-period) lending by borrowing short-term funds. The short-term interest rates in the two periods, 0 and 1, are denoted r_0 and r_1. The initial rate r_0 is observed by the lender in period 0, while the future rate r_1 is random but follows a known probability distribution. In particular,

$$r_1 = r_0 + \varepsilon, \tag{1}$$

where ε is a random variable with density function $f(\cdot)$ and expected value $\mu > 0$. The future short rate thus equals the initial short rate plus a drift factor with positive expected value. The reason for this expectation assumption, which implies that the interest-rate yield curve is upward sloping, becomes clear below.

[5] For empirical studies of refinancing, see Green and Shoven (1986) and Quigley and Van Order (1990).

[6] The present research was initiated before the author became aware of Rosenthal and Zorn's work.

The interest rate on a fixed-rate mortgage written in period 0 is denoted i. The level of i is determined by the requirement that the lender earn a "normal" profit on fixed-rate lending. To formalize this condition, the lender is assumed to be risk neutral and to discount period 1 profit by a factor $\theta < 1$. In addition, the lender recognizes that some fraction of his borrowers will move at the end of period 0, prepaying their mortgages. Letting $\alpha < 1$ denote this expected prepayment rate, the expected discounted value of profit for FRMs written in period 0, expressed per dollar of loan, can be written

$$(1 - \alpha)\left[(i - r_0) + \theta \int_{-\infty}^{\infty} (i - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon\right] + \alpha(i - r_0). \tag{2}$$

Observe that profit per dollar of loan for borrowers who prepay at the end of period 0 is $(i - r_0)$, and that profit from nonmovers has a random component (realized in period 1) that depends on the difference between i and r_1. Note also that (2) reflects the absence of financially motivated prepayment in that the integral runs over the entire range of ε. Otherwise, the integral would be written $\int_k^{\infty} (i - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon$, indicating that refinancing occurs (and period 1 profit is zero) when ε falls below some critical value k. Note finally that the FRM characterized by (2) is nonamortizing, paying interest only.

Setting (2) equal to zero and solving for i yields the FRM rate consistent with zero lender profit,

$$i = r_0 + \frac{(1 - \alpha)\theta}{1 + (1 - \alpha)\theta}\,\mu \equiv r_0 + b(\alpha)\mu, \tag{3}$$

where $\mu = \int_{-\infty}^{\infty} \varepsilon f(\varepsilon)d\varepsilon$ and $b(\alpha) \equiv (1 - \alpha)\theta/[1 + (1 - \alpha)\theta] < 1$. The FRM rate is thus equal to the initial short rate plus a fraction $b(\alpha)$ of the expected drift μ (recall that $\mu > 0$). An important fact to note in (3) is that $b(\cdot)$ is a decreasing function of the prepayment rate α. This implies that

$$\frac{\partial i}{\partial \alpha} = b'(\alpha)\mu < 0, \tag{4}$$

indicating that the FRM interest rate falls as the prepayment rate rises. To see the reason, note from (3) that $r_0 < i < r_0 + \mu$, so that the FRM rate exceeds r_0 and is less than the expected value of r_1 (recall $b(\alpha) < 1$). The return to fixed-rate lending is therefore positive in period 0 and negative (in expected value) in period 1. As a result, when α falls and the amount of actual period 1 lending rises, the FRM rate i must rise to maintain zero expected profit.

Another point to be noted in (3) is that if μ were negative instead of positive, indicating a downward drift in interest rates, then $i < r_0$ would hold, indicating that the FRM rate is less than the period 0 short rate. This unrealistic outcome is possible because financially motivated prepayment has been omitted as a determinant of FRM prices.

To introduce the mortgage choice problem, suppose that each borrower has access to a stylized ARM contract that, unlike actual contracts, has no interest-rate caps to constrain the movement of the loan rate (ARMs typically have both adjustment-period and life-of-loan caps). The absence of caps means that each period's ARM rate is simply equal to the short-term interest rate, an equality that guarantees zero ARM profit per period. Aside from the FRM and this stylized ARM, no other contracts are available to the borrower. This restriction is realistic in that no other class of contract generates significant lending volume in today's mortgage market.[7]

Borrowers are assumed to be identical in all respects other than mobility. Let ρ denote the borrower's probability of moving at the end of period 0, and assume that ρ differs across individuals. Let y denote the common level of borrower income, which is constant across periods. Normalizing the size of the mortgage to unity, income net of the mortgage payment is thus equal to $y - i$ in both periods with an FRM and equal to $y - r_0$ and $y - r_1$ in periods 0 and 1 with an ARM. Finally, let $V(\cdot)$ denote the borrowers' common Von Neumann–Morgenstern utility function, which is concave, and let δ equal the common discount factor. The expected utility associated with an FRM loan is then equal to

$$(1 - \rho)[V(y - i) + \delta V(y - i)] + \rho V(y - i). \tag{5}$$

In a similar fashion, the expected utility associated with an ARM loan can be written

$$(1 - \rho)\left[V(y - r_0) + \delta \int_{-\infty}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon\right] + \rho V(y - r_0). \tag{6}$$

[7] From an analytical point of view, the restriction is limiting because, given the model's maintained assumptions, other types of mortgage contracts would dominate both the FRM and the ARM. Because the lender is risk neutral and borrowers are assumed to be risk averse (see below), an efficient mortgage contract requires complete risk absorption by the lender (see Arvan and Brueckner, 1986). The efficient contract thus has fixed payments that are graduated over time to balance the time preferences of lender and borrower.

The FRM–ARM utility differential, denoted Ω, is found by subtracting (6) from (5), which yields

$$\Omega = V(y - i) - V(y - r_0) + (1 - \rho)\delta\left[V(y - i) - \int_{-\infty}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon\right]. \quad (7)$$

The first part of (7) equals the difference in period 0 utilities between an FRM and an ARM. The second term is the analogous difference in period 1 expected utilities, weighted by the discount factor times the probability that period 1 payments are actually made.

To simplify Ω, observe that period-one expected utility with an ARM, $\int_{-\infty}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon$, can be expressed as a certainty-equivalent utility, where the certainty equivalent is equal to the expected value of net income, $y - (r_0 + \mu)$, a minus a risk premium $R \geq 0$. In other words,

$$\int_{-\infty}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon = V(y - [r_0 + \mu] - R). \quad (8)$$

Substituting in (7), Ω becomes

$$\Omega(\rho, i) = V(y - i) - V(y - r_0) + (1 - \rho)\delta[V(y - i) - V(y - [r_0 + \mu] - R)], \quad (9)$$

where the dependence of Ω on ρ and i has been made explicit. Note that the period 0 component of the FRM–ARM utility differential, which equals the difference between the first two terms in (9), is negative given that the FRM rate $i = r_0 + b(\alpha)\mu$ exceeds the period 0 ARM rate. Conversely, because $y - i = y - (r_0 + b(\alpha)\mu) > y - (r_0 + \mu) - R$, the period 1 utility differential (the difference between the last two terms) is positive (recall $b(\alpha) < 1$).

To understand the reason for these sign differences, recall that because the expected path of the short-term interest rate is upward, the FRM lender charges more than the short rate in period 0 and less than the expected short rate in period 1. Because the short and ARM rates are the same, the difference between FRM and ARM payments is thus positive in period 0 and has a negative expected value in period 1. The FRM's period 1 advantage is further increased by the fact that the future ARM payment involves risk. This assures that the signs of the period 0 and period 1 utility differentials are negative and positive, respectively. While this relationship may appear to depend critically on upward drift of the short rate ($\mu > 0$), the analysis of a model with refinancing in Section 4 shows that this assumption is not required in general.

Since the period 0 and period 1 utility differentials in (9) are of opposite signs, the sign of Ω and thus the direction of the FRM–ARM choice are indeterminate for an arbitrarily chosen borrower. Several facts, however, follow from inspection of (9). The first is that for a borrower who is certain to move, Ω is negative and an ARM is preferred. This follows from evaluating (9) for $\rho = 1$, which yields $\Omega(1, i) = V(y - i) - V(y - r_0) < 0$. The certain mover can thus exploit the tilt of the expected ARM payment path to guarantee himself lower mortgage costs. Second, since the period 1 utility differential in (9) is positive, it follows that

$$\frac{\partial \Omega}{\partial \rho} < 0. \tag{10}$$

Thus, the FRM–ARM utility differential decreases as the expected mobility of the borrower rises. Given these results, we might expect the utility differential to be positive for small values of ρ, so that less-mobile borrowers prefer FRMs. To investigate this issue, suppose that the borrower is risk neutral, that his discount factor equals the lender's ($\delta = \theta$), and that his move probability equals α, the expected prepayment rate. In this case, the borrower's evaluation of the mortgages mirrors that of the lender, and he is indifferent between them. However, if $\rho < \alpha$, then more weight is placed on the positive period 1 portion of Ω, and the entire utility differential becomes positive, indicating that an FRM is preferred (the reverse conclusion applies when $\rho > \alpha$). In the Appendix, it is shown that a similar result holds with risk aversion: when $\delta = \theta$, Ω is guaranteed to be positive for all ρ's between zero and $\alpha + \nu < 1$, for some $\nu > 0$. Thus, with risk aversion, the FRM is preferred by borrowers with ρ values in an interval that extends above α. A parallel result applies when $\delta > \theta$.

Finally, by raising the cost of FRMs, an increase in i lowers the FRM–ARM utility differential. Differentiating (9),

$$\frac{\partial \Omega}{\partial i} = -(1 + [1 - \rho]\delta))V'(y - i) < 0. \tag{11}$$

b. *Equilibrium Conditions*

To begin the equilibrium analysis, assume that $\delta = \theta$ holds (all the results remain true in the more general case where $\delta \geq \theta$). Furthermore, suppose that the population consists of a continuum of borrowers with different values of ρ, and assume that all ρ values in the interval [0, 1] are represented in the continuum. This means that for arbitrary $\alpha > 0$, there will always exist borrowers who prefer FRMs (recall from above that any borrower with $\rho < \alpha$ belongs to this group). Then, let the "critical borrower" denote the individual with the highest ρ among FRM borrowers, and let ρ^* denote his ρ value. Given this definition and the fact that $\partial\Omega/\partial\rho < 0$, it follows that the FRM borrower pool consists of individuals with ρ values lying in the interval $[0, \rho^*]$.

The first requirement for a mortgage market equilibrium is that the critical borrower be indifferent between an FRM and an ARM. If this condition did not hold, other borrowers with ρ values above ρ^* would join the FRM pool. The indifference condition is written

$$\Omega(\rho^*, i) = 0. \tag{12}$$

The key additional observation needed to characterize equilibrium is that the lender's expected prepayment rate α, which has so far been taken as given, *is equal to the average move probability among FRM borrowers*, which in turn depends on the location of ρ^*. To formalize the relation between α and ρ^*, let the distribution of ρ values in the population be described by the continuous density function $g(\cdot)$. Then the average move probability among FRM borrowers equals the expected value of ρ conditional on ρ being below ρ^*, which is given by

$$\frac{\int_0^{\rho^*} \rho g(\rho) d\rho}{\int_0^{\rho^*} g(\rho) d\rho} \equiv h(\rho^*). \tag{13}$$

Note that $h(\rho^*) < \rho^*$ holds when $\rho^* > 0$, and that $h'(\rho^*) > 0$, indicating that the average move probability rises with ρ^*. Equality of α, the lender's expected prepayment rate, and the average FRM move probability then reduces to the requirement $\alpha = h(\rho^*)$.

This relationship can be substituted in (3), the equation giving the FRM rate as a function of α. The resulting equation,

$$i = r_0 + b(h(\rho^*))\mu \equiv \Phi(\rho^*), \tag{14}$$

shows the relation between the FRM rate and ρ^* consistent with zero lender profit. Note that since $b'(\alpha) < 0$ and $h'(\rho^*) > 0$, it follows that

$$\frac{\partial\Phi}{\partial\rho^*} = b'h'(\rho^*)\mu < 0. \tag{15}$$

Growth of the FRM borrower pool thus lowers i by raising the pool's average mobility.

The mortgage market equilibrium is characterized by Eqs. (12) and (14), which jointly determine the values of ρ^* and i. These conditions may be collapsed into a single condition by substituting (14) into (12) to yield

$$\Omega(\rho^*, \Phi(\rho^*)) = 0. \tag{16}$$

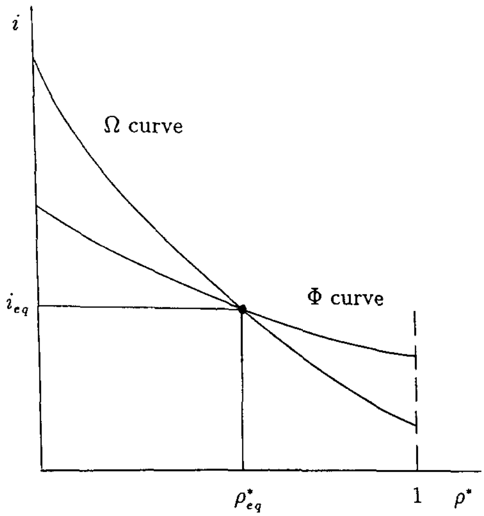

FIGURE 1

The following result establishes that a solution to (16) exists under the maintained assumptions:

PROPOSITION 1. *When borrowers are risk averse and all ρ values in the interval* $[0, 1]$ *are represented in the population, there exists at least one equilibrium ρ^* satisfying* $0 < \rho^* < 1$.

Proof. Since $\Omega(1, i) < 0$ for any $i > r_0$ (see above), it follows that $\Omega(1, \Phi(1)) < 0$. The FRM–ARM utility differential for a perfectly mobile borrower is therefore negative when all borrowers choose FRMs ($\rho^* = 1$). In addition, when borrowers are risk averse, results in the Appendix yield $\Omega(0, \Phi(0)) > 0$. The utility differential for a sedentary borrower is therefore positive when all borrowers choose ARMs ($\rho^* = 0$). Since $\Omega(\rho^*, \Phi(\rho^*))$ is thus positive for $\rho^* = 0$ and negative for $\rho^* = 1$, continuity implies that there exists at least one ρ^* between zero and one where (16) holds. This means that FRMs and ARMs coexist in equilibrium. ■

The equilibrium is illustrated graphically in Fig. 1. The downward-sloping curve corresponding to $i = \Phi(\rho^*)$ is shown in (ρ^*, i) space, as is the curve along which $\Omega(\rho^*, i) = 0$ holds. This "Ω curve" is also downward sloping, as shown, with slope equal to $-(\partial\Omega/\partial\rho)/(\partial\Omega/\partial i) < 0$ (see (10) and (11)). Intuitively, the negative slope arises because, as the critical borrower's ρ value rises, increasing the relative attractiveness of ARMs, a lower FRM rate is required to make him indifferent in the FRM–ARM choice. Previous results imply that the Ω curve intersects the vertical axis above the Φ curve and that it cuts the vertical line at $\rho^* = 1$ below the Φ

curve, as shown.[8] The intersection point of the curves gives the equilibrium value of ρ^* and the equilibrium FRM rate.

c. *Stability*

The equilibrium shown in Fig. 1 is stable because the Ω curve cuts the Φ curve from above.[9] Unstable equilibria may also arise, but this outcome requires the existence of multiple equilibria. If the curves in Fig. 1 intersect three times, for example, then there are two stable and one unstable equilibrium.[10] For stability, the condition

$$\frac{\partial\Omega/\partial\rho}{\partial\Omega/\partial i} > -b'h'(\rho^*)\mu \tag{17}$$

must hold, indicating that, in absolute value, the slope of the Ω curve exceeds the slope of the Φ curve at their intersection point.

Stability of an equilibrium depends in part on the local properties of the distribution of ρ values, as reflected in the expression $h'(\rho^*)$ on the right-hand side of (17). Inspection of (17) suggests that an equilibrium will be stable when $h'(\rho^*)$ is sufficiently small. This statement is made more precise, as follows:

PROPOSITION 2. *The stability condition* (17) *is satisfied if* $h'(\rho^*) \le 1$ *holds at the equilibrium.*

Proof. See the Appendix. ∎

If this condition is satisfied for all values of ρ^* in the interval [0, 1], then an equilibrium is unique and globally stable. Otherwise, there may be multiple equilibria, some of which are not stable.

The condition $h'(\rho^*) \le 1$, which states that the average move probability of the FRM borrower pool increases less rapidly than ρ^*, can be stated

[8] Note first that since $\partial\Omega/\partial i < 0$, the regions below (above) the Ω curve correspond to $\Omega > 0$ (<0). Then, since $\Omega(1, \Phi(1)) < 0$ means that $\Omega < 0$ holds on the Φ curve at $\rho^* = 1$, it follows that the Ω curve lies below the Φ curve. Similarly, $\Omega(0, \Phi(0)) > 0$ means $\Omega > 0$ holds on the Φ curve at $\rho^* = 0$, so that the Ω curve lies above the Φ curve.

[9] This can be seen in Fig. 1 as follows. Starting from a point on the Φ curve to the left of the intersection, $\Omega > 0$ holds, indicating that the critical borrower prefers an FRM. This means that the FRM borrower pool will grow via an increase in ρ^*. Holding i fixed, ρ^* rises (leading to a rightward horizontal movement in the diagram) until the Ω curve is reached. With i now above the Φ curve, profits are positive, and i must fall to reduce profit to zero. The resulting downward movement again raises Ω, and the process continues. Because this series of adjustments moves the (ρ^*, i) point toward the intersection of the curves, the equilibrium is stable.

[10] If there are multiple equilibria, the one with the lowest value of i (the highest ρ^*) yields the highest welfare. Any increase in i lowers the expected utility of FRM borrowers while leaving ARM borrowers unaffected.

in terms of the underlying density $g(\cdot)$. From (13), $h'(\rho^*) \leq 1$ is equivalent to

$$\rho^* g(\rho^*) - \int_0^{\rho^*} g(\rho) d\rho < g(\rho^*) h(\rho^*). \tag{18}$$

To interpret (18), observe that the first term on the left is the area of a box with its northeast corner on the density function at ρ^* while the second term is the area under the density up to ρ^*. Equation (18) requires that the difference in these areas be "small," a condition that is satisfied when the density is sufficiently flat. For example, if $g(\cdot)$ is uniform on [0, 1], then the left-hand side of (18) is identically zero and the inequality is satisfied. A flat density, in turn, means that move probabilities are widely dispersed in the population, exhibiting little central tendency. This condition appears realistic in that the population would appear to contain large numbers of both highly mobile and very sedentary households.

3. COMPARATIVE-STATIC ANALYSIS

This section conducts a comparative-static analysis of the mortgage market equilibrium characterized in Section 2. The goal is to deduce how changes in the market environment affect the equilibrium division of borrowers between ARMs and FRMs. The analysis relies on Fig. 1 and focuses on a stable equilibrium. From the figure, any parametric change that shifts the Ω curve upward *increases* the equilibrium ρ^* and *decreases* the equilibrium i. Conversely, any parametric change that shifts the Φ curve upward *decreases* the equilibrium ρ^* and *increases* the equilibrium i (downward shifts in the curves have the reverse effects).[11]

The effect of a parameter change on the position of the Φ curve can be seen directly from differentiation of (14). The effect on the height of the Ω curve is found by differentiating (12), which yields $\partial i/\partial\lambda = -(\partial\Omega/\partial\lambda)/(\partial\Omega/\partial i)$, where λ represents a parameter. Since $\partial\Omega/\partial i < 0$, the Ω curve shifts up (down) when $\partial\Omega/\partial\lambda$ is positive (negative). Intuitively, any change that increases the relative attractiveness of FRMs (raising Ω) requires an increase in i to restore the critical borrower's indifference between the mortgage types.

[11] It should be noted that when there are multiple equilibria, the comparative-static results may give a misleading picture of the effect of discrete changes in the parameters. With multiple intersections of the Ω and Φ curves, a large shift in either curve could eliminate one of the equilibria, causing ρ^* and i to jump to neighboring equilibrium values. Thus, unless the equilibrium is unique, the comparative-static results apply only to the case where parameter changes are infinitesimal.

Consider first the effect of an increase in interest-rate risk, as manifested by an increase in the risk premium R. Higher risk could be a consequence of a mean-preserving spread of the distribution of r_1 (an increase in the variance with μ held constant). Other distributional changes could also raise the risk premium. A higher R affects borrowers by increasing the risk associated with the ARM choice, making it less attractive. The FRM–ARM utility differential therefore rises, as seen by differentiating (9):

$$\frac{\partial \Omega}{\partial R} = (1 - \rho^*)\delta V'(y - [r_0 + \mu] - R) > 0. \qquad (19)$$

Given the earlier discussion, (19) implies that the Ω curve in Fig. 1 shifts up as R rises. Because the Φ curve is unaffected (see (14)), it follows that $\partial\rho^*/\partial R > 0$ and $\partial i/\partial R < 0$. This establishes

PROPOSITION 3. *An increase in risk (a higher R) leads to an increase in ρ^*, enlarging the FRM borrower pool. The FRM interest rate i declines.*

An increase in risk thus alters the division of borrowers between FRMs and ARMs, with marginal ARM borrowers entering the FRM pool. Because this shift raises the average mobility of the FRM pool, reducing the duration of fixed-rate loans, it leads to a decline in the FRM rate.[12] The self-selection phenomenon that underlies the equilibrium thus leads to an unusual relation between the demand for FRMs and their price. Because borrowers who switch to the FRM pool have a higher tendency to prepay than current borrowers, which makes them less costly to serve, higher demand *drives down* the price of FRMs rather than raising it. Proposition 3 illustrates this phenomenon in the case where the increase in FRM demand comes from greater interest-rate risk. Empirically, the proposition suggests that during periods of great interest-rate volatility, when risk is high, we should expect a high market share for FRMs and low FRM interest rates.

Suppose next that there is an exogenous increase in mobility in the economy, which is reflected in a change in the move-probability density function $g(\cdot)$. In particular, let g depend on a parameter γ, which then becomes a parameter of h (the function is now written $h(\rho^*, \gamma)$). Suppose

[12] If lenders were risk averse instead of risk neutral, then maintaining constant expected utility (analogous to zero profit in the risk-neutral case) as R rises would require an increase in i, holding ρ^* constant. At the same time, any increase in ρ^* would put downward pressure on i. The net effect of these two forces would appear to be ambiguous, indicating that the effect of an increase in R may be indeterminate with lender risk aversion. A complete analysis of this alternate case could be the subject of further research.

that an increase in γ raises the value of h at the current equilibrium ρ^*, indicating that the average move probability in the current FRM borrower pool increases exogenously ($\partial h(\rho^*, \gamma)/\partial\gamma > 0$). It can be shown that under the conditions of Proposition 2, a rightward shift in the density $g(\cdot)$ leads to such an increase in h.[13] Adding γ as an argument of h in (14) and differentiating yields

$$\frac{\partial\Phi}{\partial\gamma} = b' \frac{\partial h}{\partial\gamma} \mu < 0, \tag{20}$$

indicating that the Φ curve shifts down as γ rises. Since γ has no effect on the Ω curve (see (9)), it follows from Fig. 1 that $\partial\rho^*/\partial\gamma > 0$ and $\partial i/\partial\gamma < 0$, establishing

PROPOSITION 4. *An exogenous increase in mobility (a higher γ) leads to an increase in ρ^*. The FRM interest rate declines.*

Observe that, by shifting the Φ curve, the exogenous increase in mobility lowers the i value corresponding to the original equilibrium ρ^*. This makes Ω positive, which draws marginal ARM borrowers into the FRM pool, raising its average mobility (and lowering the FRM rate) yet further.

Note that an increase in mobility may either raise or lower the FRM market share. The former outcome, where the mortgage instrument favored by mobile borrowers (the ARM) loses market share as the population becomes more mobile, is counterintuitive. The share impact is ambiguous because the increase in ρ^* is accompanied by a shift in the density $g(\cdot)$, which causes the increase in h. The ARM share will *fall*, for example, if the area under g below the original ρ^* rises or stays constant despite the fact that h grows. When this happens, the fact that ρ^* itself rises (from Proposition 4) implies an *increase* in the FRM market share. Empirically, the proposition thus suggests that when mobility in the economy rises for some reason, the price of FRMs should fall while their market share may move upward *or* downward (an example of such an event is the recent upsurge in internal migration in the United States in response to the decline of the "rust belt" states).

Consider next the effects of changes in borrower preferences. If the discount factor δ falls, borrowers care less about future consumption, and the period 1 portion of the FRM–ARM utility differential receives less weight. Since the period 1 differential is positive from above, the reduc-

[13] For a rightward shift to be possible, the support of g must be a subset of the unit interval, requiring a modification of the maintained assumption that the borrower continuum extends over the entire interval. Given these circumstances, it can be shown that a rightward shift in $g(\cdot)$ increases (reduces) $h(\rho^*)$ when $h'(\rho^*) < (>) 1$. As an example, let g be uniform on the interval $[\gamma, \gamma + a]$. Then $h(\rho^*) = (\rho^* + \gamma)/2$, an increasing function of γ.

tion in δ reduces the attractiveness of FRMs. $\partial\Omega/\partial\delta$ is therefore positive, and the Ω curve shifts down in response to the decline in δ. Since the Φ curve is unaffected, ρ^* falls and i rises ($\partial\rho^*/\partial\delta > 0$ and $\partial i/\partial\delta < 0$). This establishes

PROPOSITION 5. *A decline in the discount factor of borrowers (a lower δ) reduces ρ^*, shrinking the FRM borrower pool. The FRM interest rate rises.*

Empirically, Proposition 5 suggests that any change that reduces the future orientation of borrowers (a decline in child rearing, for example) should shrink the market share of FRMs and increase their prices.

Now suppose that borrower risk aversion rises. To parameterize such an effect, assume that preferences exhibit constant absolute risk aversion, which implies that the utility function is of the form $V(x) = -e^{-\sigma x}$, where $\sigma = -V''/V'$ is the absolute risk aversion measure. In this case, the FRM–ARM utility differential (using (7) instead of (9)) is proportional to

$$1 - [1 + (1 - \rho^*)\delta]e^{\sigma(i-r_0)} + (1 - \rho^*)\delta \int_{-\infty}^{\infty} e^{\sigma\varepsilon}f(\varepsilon)d\varepsilon \qquad (21)$$

(the proportionality factor is $e^{-\sigma(y-r_0)}$). Differentiating (21), $\partial\Omega/\partial\sigma$ has the same sign as

$$-\frac{1 + (1 - \rho^*)\delta}{(1 - \rho^*)\delta}(i - r_0)e^{\sigma(i-r_0)} + \int_{-\infty}^{\infty} \varepsilon e^{\sigma\varepsilon}f(\varepsilon)d\varepsilon. \qquad (22)$$

Since $xe^{\sigma x}$ is a convex function, Jensen's inequality implies that $-\mu e^{\sigma\mu} + \int_{-\infty}^{\infty} \varepsilon e^{\sigma\varepsilon}f(\varepsilon)d\varepsilon > 0$. Thus, if the expression before the integral in (22) (without the minus sign) is less than or equal to $\mu e^{\sigma\mu}$, (22) will be positive, implying $\partial\Omega/\partial\sigma > 0$. The FRM–ARM utility differential is then an increasing function of borrower risk aversion, as intuition would suggest. The Appendix shows that the assumed relationship between $\mu e^{\sigma\mu}$ and the expression in (22) is likely to hold, and that the outcome is guaranteed when $\rho^* \leq 1/2$. In this case, the Ω curve shifts up as σ increases, implying $\partial\rho^*/\partial\sigma > 0$ and $\partial i/\partial\sigma < 0$ (the Φ curve is unaffected). This establishes

PROPOSITION 6. *An increase in borrower risk aversion (a higher σ) leads to an increase in ρ^* if the initial value satisfies $\rho^* \leq 1/2$. In this case, the higher σ also lowers i.*

Thus, an increase in risk aversion drives marginal ARM borrowers into the FRM pool, raising its average mobility and reducing the FRM rate. The sufficiency condition of Proposition 6 ($\rho^* \leq 1/2$) in effect requires that the ARM market share be "large," a requirement that is not unrealistic given recent experience in the United States.

Turning to other parameters of interest, it can be shown that increases in μ, the expected drift of the short-term interest rate, and r_0, the initial short-term rate, both have ambiguous effects on the mortgage market equilibrium (in these cases, both the Ω and the Φ curves shift up). One final conclusion is not, strictly speaking, a comparative-static result because it deals with a large-scale shock to the mortgage market resulting from a change in government regulation. The shock is the regulatory event in the early 1980s that facilitated the actual introduction of the ARM. In effect, this event allowed ρ^* to change from a disequilibrium value of unity (indicating that all mortgages were FRMs) to some intermediate value described by the equilibrium conditions of the model. The model predicts that the introduction of the ARM should have led to a dramatic decline in the average mobility of FRM borrowers as the most mobile individuals in the population switched to the new mortgage instrument. By now-familiar reasoning, this large drop in mobility should have generated a large, once-and-for-all increase in FRM rates. Summarizing yields[14]

PROPOSITION 7. *The FRM interest rate rises when ARM contracts are introduced into a mortgage market where they were previously unavailable.*

Proposition 7 suggests that an empirical test of the model could focus on the behavior of FRM rates over the early 1980s, when ARMs first became popular. However, disentangling the effect of ARM introduction from other secular trends in the financial markets of this volatile period might prove difficult.

4. A MODEL WITH FINANCIALLY MOTIVATED PREPAYMENT

Up to this point, the analysis has ruled out financially motivated prepayment (refinancing) in exploring the effect of borrower self-selection on the equilibrium of the mortgage market. A natural question is whether the lessons of the analysis would be altered in a model that includes this type of prepayment. The purpose of this section is to show that when a simple type of refinancing behavior occurs along with mobility-induced prepayment, the main conclusions reached above are unaffected.

Intuitively, refinancing occurs when the interest rate on a new mortgage falls sufficiently far below the rate on the borrower's current loan to

[14] Rosenthal and Zorn (1993) also make this point.

justify the cost of the transaction. Use of a simple present-value approach to compute the required spread is, however, inappropriate because it fails to capture the potential gain from postponement of refinancing (i.e., enjoyment of even more favorable rates tomorrow). Indeed, because refinancing is properly viewed as the exercise of an option, use of option-pricing methods is required to characterize optimal behavior (see Follain *et al.*, 1992; Kau *et al.*, 1992). While this approach is too complex for present purposes, the problem becomes manageable if the borrower has *just one opportunity* to refinance. Postponement of refinancing is then not feasible, and the resulting problem can be solved directly.

To achieve this simplification, suppose (somewhat unrealistically) that the borrower's lifespan is the same as the term of mortgages, that is, two periods. Then consider the refinancing decision that an FRM borrower who does not move faces in period 1. Such an individual has only one period remaining, and thus one mortgage payment to make, before the end of his life. As a result, if he were to prepay, he would refinance with an ARM rather than an FRM (this follows because the ARM will be cheaper over the single period). Therefore, the refinancing decision reduces to a simple comparison: if the period 1 ARM rate, which equals r_1, is far enough below the borrower's current FRM rate to cover the transaction costs of refinancing, then prepayment occurs. For simplicity, let transaction costs be represented by an increment to the initial ARM rate. Thus, the effective interest rate paid for a new ARM in period 1 is $r_1 + s$, where s is the transaction-cost component. Since the borrower contemplating refinancing compares a single FRM payment at rate i to a single ARM payment at rate $r_1 + s$, refinancing occurs when $r_1 + s < i$, or when $\varepsilon < i - r_0 - s$.

This decision rule helps determine the FRM interest rate. The expected discounted profit of the FRM lender, who knows the prepayment behavior of borrowers, now equals

$$(1 - \alpha)\left[(i - r_0) + \theta \int_{i-r_0-s}^{\infty} (i - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon\right] + \alpha(i - r_0). \quad (23)$$

The difference between (23) and (2) is that the integral runs only over the range of ε where refinancing by nonmovers does not occur (period 1 profit from nonmovers is zero otherwise). Equating (23) to zero and solving for i yields

$$i = r_0 + \frac{(1 - \alpha)\theta \int_{i-r_0-s}^{\infty} \varepsilon f(\varepsilon)d\varepsilon}{1 + (1 - \alpha)\theta \int_{i-r_0-s}^{\infty} f(\varepsilon)d\varepsilon} \equiv r_0 + c(i, \alpha)\eta(i), \quad (24)$$

where $\eta(i) \equiv (\int_{i-r_0-s}^{\infty} \varepsilon f(\varepsilon)d\varepsilon)/[1 - F(i - r_0 - s)]$ is the expected value of ε given $\varepsilon > i - r_0 - s$, F is the cumulative distribution function of f, and

$$c(i, \alpha) \equiv \frac{(1 - \alpha)\theta[1 - F(i - r_0 - s)]}{1 + (1 - \alpha)\theta[1 - F(i - r_0 - s)]} < 1. \quad (25)$$

While (25) does not yield a closed-form solution for i (which appears on both sides of the equation), differentiation shows that $\partial i/\partial\alpha < 0$ holds, just as in the earlier analysis. Therefore, even with refinancing, the FRM interest rate is a decreasing function of α, the average move probability of FRM borrowers. Note also that $i > r_0$ requires only that $\eta(i) > 0$, an inequality that can be satisfied even when μ itself is negative. Therefore, as noted above, the FRM rate can exceed the ARM rate even with downward drift of interest rates when refinancing occurs.

It can be shown that the modified FRM–ARM utility differential reduces to[15]

$$\begin{aligned}\Omega(\rho, i) \equiv\ & V(y - i) - V(y - r_0) \\ & + (1 - \rho)\delta(1 - F)[V(y - i) - V(y - [r_0 + \eta(i)] - Q)]. \quad (26)\end{aligned}$$

In (26), the previous risk premium R is replaced by Q, which is computed conditional on the nonoccurence of refinancing, and the period 1 utility differential is multiplied by $(1 - F)$, the probability of no refinancing (F is evaluated at $i - r_0 - s$). As in (9), the period 0 and period 1 differentials in (26) are respectively negative and positive. The latter fact means that the FRM–ARM utility differential is a decreasing function of ρ, which implies (as before) that mobile borrowers tend to favor ARMs. As noted earlier, the positive and negative signs of the single-period utility differentials, which are critical properties of the model, emerge in the refinancing case without the assumption of upward drift in the short-term rate.

As before, using (26), the requirement $\Omega(\rho^*, i) = 0$ defines a downward-sloping Ω curve in (ρ^*, i) space. Similarly, a downward-sloping Φ curve is generated after substituting $\alpha = h(\rho^*)$ in (24). Since the impacts on these curves of changes in the risk premium Q, the mobility parameter γ, and the discount factor δ are all the same as before, analogs to Propositions 3, 4, and 5 follow immediately. Establishing a result similar to Proposition 6, however, would require more analysis. Finally, Proposition 7 continues

[15] The expected utility associated with the ARM choice is given by (6) (note that nonmoving ARM borrowers have no reason to prepay). Expected utility for FRM borrowers is $(1 - \rho)(V(y - i) + \delta[\int_{i-r_0-s}^{\infty} V(y - i)f(\varepsilon)d\varepsilon + \int_{-\infty}^{i-r_0-s} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon]) + \rho V(y - i)$ (note that the integrals are expected period 1 utilities for a nonmover without and with refinancing, respectively). Subtracting (6) from the above expression and simplifying, the FRM–ARM utility differential becomes $V(y - i) - V(y - r_0) + (1 - \rho)\delta[\int_{i-r_0-s}^{\infty} V(y - i)f(\varepsilon)d\varepsilon - \int_{i-r_0-s}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon]$. As before, the last integral can be expressed as a certainty-equivalent utility. Letting Q denote the risk premium, $\int_{i-r_0-s}^{\infty} V(y - [r_0 + \varepsilon])f(\varepsilon)d\varepsilon/(1 - F)$ can be written $V(y - [r_0 + \eta(i)] - Q)$, where F is evaluated at $i - r_0 - s$. The utility differential can then be written as (26).

to hold, so that the FRM rate rises in response to the introduction of the ARM in a more realistic setting where refinancing may occur.

5. CONCLUSION

This paper has shown how self-selection according to borrower mobility helps determine equilibrium in the market for fixed- and adjustable-rate mortgages. The analysis demonstrates that the cost of a fixed-rate loan depends on the division of borrowers between FRMs and ARMs, a division that is itself endogenous and responsive to market conditions. Because mobile borrowers favor ARMs, any enlargement of the FRM borrower pool (caused by the entry of marginal ARM borrowers) raises its average mobility. Since this increase in mobility shortens the duration of fixed-rate loans and lowers the FRM interest rate, it follows that an increase in demand for FRMs leads to a reduction in their price. Identification and exploration of this unusual effect, which has been largely overlooked in the literature, are the main contributions of the paper.

The analysis generates a number of comparative-static predictions. Several of these are difficult to test empirically, while others are easily tested. Measuring changes in the future orientation or risk aversion of borrowers, for example, to test Propositions 5 and 6 would not be practical. By contrast, testing for a relationship between interest-rate risk and the level of FRM rates (the subject of Proposition 3) would be feasible, with intertemporal variation in risk measured by changes in the variance of short-term interest rates. Also, as noted above, a test for structural change in the determination of FRM rates between the pre-ARM and post-ARM periods could be used to evaluate Proposition 7. ARM introduction, however, was collinear with other events in the 1980s, such as the recession at the beginning of the decade and the fall in inflation, which might obscure any post-ARM rise in FRM rates. Perhaps the most natural test of the model focuses on Proposition 4 and the impact of exogenous changes in borrower mobility. This test, however, has already been carried out by Rosenthal and Zorn (1993). Working from an analytical model similar to the current one, these authors present a cross-section regression showing that FRM rates are relatively low in regions of the United States characterized by high mobility, a result consistent with Proposition 4. Further refinement of this type of test could be a profitable path for empirical research.

APPENDIX

a. *The Sign of* (9) *under Risk Aversion*

To investigate the sign of (9) when the borrower is risk averse and $\rho < 1$, observe that strict concavity of V implies $V(z) - V(x) < V'(x)(z - x)$ for any z and x. Using this fact and eliminating i using (3), the first two terms of (9) exceed

$$-b(\alpha)\mu V'(y - [r_0 + b(\alpha)\mu]) \tag{a1}$$

while the last two terms exceed

$$[(1 - \rho)\delta([1 - b(\alpha)]\mu + R)]V'(y - [r_0 + b(\alpha)\mu]). \tag{a2}$$

Gathering terms, Ω is then greater than

$$\frac{(1 - \rho)\delta(\mu + R)}{1 + (1 - \rho)\delta} - b(\alpha)\mu \tag{a3}$$

times $[1 + (1 - \rho)\delta]V'(y - [r_0 + b(\alpha)\mu])$. Recalling that $R > 0$ holds with risk aversion, and using the definition of $b(\alpha)$, (a3) is positive (implying $\Omega > 0$) when $(1 - \rho)\delta \geq (1 - \alpha)\theta$. In the case where the borrower and lender discount the future identically ($\delta = \theta$), this condition reduces to $\rho \leq \alpha$. Since $\Omega > 0$ then holds for $\rho = \alpha$, it follows (given (10)) that Ω is also positive over a range of ρ values above α. More generally, as long as $\delta \geq \theta$, Ω is guaranteed to be positive for $\rho \leq 1 - (1 - \alpha)\theta/\delta$, a value greater than α (as before, Ω remains positive over a range of ρ's above this value). Finally, the conclusion $\Omega(0, \Phi(0)) > 0$ follows from the above results. In this case, $\rho = 0$ and $\alpha = h(0) = 0$, where the last equality is established by applying l'Hopital's rule to (13).

b. *Proof of Proposition* 2

First, recalling that $\partial\Omega/\partial i < 0$, (17) is rewritten as

$$\frac{\partial\Omega}{\partial\rho} + \frac{\partial\Omega}{\partial i} b'h'(\rho^*)\mu < 0. \tag{a4}$$

Then observe that, after eliminating i using (3), (9) yields

$$\begin{aligned}\frac{\partial\Omega}{\partial\rho} &= -\delta[V(y - [r_0 + b(\alpha)\mu]) - V(y - [r_0 + \mu] - R)] \\ &\leq -\delta V'(y - [r_0 + b(\alpha)\mu])([1 - b(\alpha)]\mu + R),\end{aligned} \tag{a5}$$

where the inequality follows from concavity of V. Using (11) and (a5), it follows that (a4) is less than or equal to

$$\begin{aligned}-V'(y - [r_0 + b(\alpha)\mu])[\delta([1 - b(\alpha)]\mu + R) \\ + b'(\alpha)h'(\rho^*)\mu[1 + (1 - \rho^*)\delta]],\end{aligned} \tag{a6}$$

where $\alpha = h(\rho^*)$. Equation (a6) has a sign opposite to that of the expression in brackets. Computing $b'(\alpha) = -\theta/[1 + (1 - \alpha)\theta]^2$ from (3) and substituting in (a6), the bracketed expression reduces to δR plus an expression with the sign of $\delta\mu[1 + (1 - h(\rho^*))\theta] - \theta\mu h'(\rho^*)[1 + (1 - \rho^*)\delta]$. The latter expression is positive, making (a6) (and thus (a4) and (17)) negative when

$$h'(\rho^*) < \frac{\delta + [1 - h(\rho^*)]\delta\theta}{\theta + (1 - \rho^*)\delta\theta}. \tag{a7}$$

With $\delta = \theta$ by assumption and $h(\rho^*) < \rho^*$ for $\rho^* > 0$, the right-hand side of (a7) exceeds unity, and the inequality holds if $h'(\rho^*) \leq 1$.

c. *Derivation of the Sign of* (22)

The goal is to show that $\mu e^{\sigma\mu}$ exceeds or equals the first term in (22). Substituting for $i - r_0$ from (3), setting $\alpha = h(\rho^*)$, and gathering exponential terms, this condition reduces to

$$\frac{1 + (1 - \rho^*)\delta}{(1 - \rho^*)\delta} \, \frac{[1 - h(\rho^*)]\theta}{1 + [1 - h(\rho^*)]\theta} \leq e^{\sigma\mu/(1+[1-h(\rho^*)]\theta)}. \tag{a8}$$

Using the fact that $e^{\sigma\mu x} > 1 + x$ for any x, (a8) will be satisfied if the left-hand side is less than or equal to $1 + [1 + (1 - h(\rho^*))\theta]^{-1}$. Rearranging, this inequality reduces to $[1 - h(\rho^*)]\theta \leq 2(1 - \rho^*)\delta$. With $\delta = \theta$, the inequality reduces further to $2\rho^* - h(\rho^*) \leq 1$. While this last inequality is likely to hold, satisfaction is guaranteed when $\rho^* \leq 1/2$. When $g(\cdot)$ is uniform on [0, 1], $h(\rho^*) = \rho^*/2$ and the above inequality reduces to the weaker statement $\rho^* \leq 2/3$.

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