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The Effects of Interest Rates on Mortgage Prepayments

1. INTRODUCTION

SAVING AND LOAN INSTITUTIONS HAVE EXPERIENCED extremely difficult times in the last four or five years largely because of the term structure of their assets and liabilities. Most of these institutions hold relatively long term fixed yield mortgage assets, while their liabilities are fairly short term savings accounts. Both long and short-term interest rates rose in the 1980–82 period above their level in the preceding period. This depressed the value of the saving and loans' mortgage assets, causing the net worth of many of these institutions to become negative. This fact, however, was somewhat disguised by standard accounting conventions which do not mark assets to their market value. In addition to the negative net worth situation, the institutions faced severe case flow problems caused by the higher interest rates on liabilities and the reduced prepayment experience on mortgages.

The purpose of this study is more limited than an overall assessment of the economic position of the saving and loans. Our purpose is to look at the nature of the mortgage asset itself and ask what determines the probability that the mortgage will be paid off at a particular time or age. For years, the industry has worked with

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"rules of thumb." At one time, the conventional assumption was that mortgages would, on average, be paid off in seven years. The rule currently seems to be twelve years. We want to judge whether these rules are adequate for valuing a mortgage portfolio and, implicitly, what caused the "rule" to change from seven to twelve years.

A mortgage asset is similar to an annuity. The owner receives a fixed stream of dollars for the life of the contract (or, in the case of an annuity, over the life of the owner). The value of both assets is sensitive to interest rate fluctuations. A change in the interest or discount rate from 10 to 11 percent, for example, will change the nominal value of a 30-year annuity or mortgage by 7.85 percent. There are key institutional differences between mortgage assets and annuities, however. First, the mortgage borrower is usually free to buy out of the contract, subject to some modest prepayment penalties, if interest rates fall. It is as if the lending institution had sold a call option to the borrower on its mortgage asset at the time the contract was agreed upon. Presumably this call feature is priced in the interest rate and other terms of the mortgage. Second, most mortgages have traditionally had a due-on-sale (DOS) clause, meaning that the lender can claim the face value of the mortgage if the borrower sells the residence. If interest rates are lower than the contracted rate of the mortgage at the time of the sale, this option of the lender will not be enforced. However, if the prevailing rate is higher than the contracted rate, the homeowner is forced to give up a below-market loan should he sell the house. This sacrifice or "lock-in" presumably affects the likelihood of selling and therefore the effective expected maturity of the mortgage asset and its value. One would not expect people to switch houses as frequently if they had to exchange their low interest rate mortgage for a new one at the higher market rates. The point is that the effective maturity of the mortgage asset is endogenous to the evolution of interest rates and, perhaps, other economic variables.

The main goal of our research has been to estimate the sensitivity of mortgage prepayments to prevailing interest rates. The subject is of immediate importance because of the precarious financial condition of saving and loan and saving bank institutions in the United States. Since due-on-sale, fixed-interest-rate mortgages play a major role in banks' portfolios, assessing their economic net worth position requires valuation of these assets which, in turn, depends on their effective or expected maturity.

One reason why assessing the net worth of the saving and loan financial intermediaries is of current importance is the level of merger activity in the industry. In a fair number of these mergers effective subsidies have been made to the acquiring institution by the FSLIC or FDIC. The subsidy is deemed necessary to entice the purchaser to absorb a weak institution. All parties in such arrangements need to be able to assess the true net worth of the acquired institution. Another demand for mortgage valuation comes from financial markets. Not only is there merger activity in the intermediaries themselves, but there also are financial instruments such as pass-through certificates, mortgage backed bonds, and real estate investment trusts (REITs) which must be priced in markets. The sensitivity of mortgage values to

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interest rate changes is clearly important in this determination. In addition to the standard negative relationship between valuation and interest rates as with fixed term bonds, mortgage assets have the interest effect on maturity which is the subject of our study.

There has been a great deal of activity recently with respect to due-on-sale clauses and their enforceability. In 1978 the case of *Cynthia J. Wellenkamp v. Bank of America, et al.* prohibited the use of due-on-sale clauses for the sole purpose of raising mortgage rates. By denying those owning mortgage assets of their option to collect face value on sale of the residence, a claim of substantial value was transferred from the lending institutions to mortgage holders. Dietrich et al. (1983) estimated that the loss in mortgage value due to the unenforceability of DOS clauses amounted to more than the total net worth for state-chartered California S&Ls in 1981. They figured that the value of the mortgage portfolios of the California institutions was reduced by 9.3 percent by this one action. The following year, the United States Supreme Court found that DOS clauses are enforceable for federally chartered institutions. It is unclear whether the legal aspects are completely settled at this time, but the episode vividly demonstrated the value of the DOS provision to lending organizations.

The previous work on the transfer of value between lenders and homeowners with the invalidation of the DOS provision in mortgages has been theoretical or Monte Carlo simulations (see, e.g., Dietrich et al. 1983; Cassidy 1983). What we provide here are empirical estimates.

The approach we have taken is to collect panel data on individual mortgages and analyze their prepayment experience. A large part of our effort has gone into the collection of the data itself. We have followed the prepayment experience of almost 4,000 mortgages of two California saving and loans for the eight years from 1975 to 1982. What we then estimate is a life table for mortgages. The analogy with mortality tables is rather complete. We compute for each n ($n = 0, 1, \ldots, 29$) the conditional probabilities of a mortgage that has been outstanding n years of being paid off in the $(n + 1)$st year. The sensitivity of this probability series to the lock-in effect of interest rates is estimated. An analogy would be calculating the effect of certain climactic changes on mortality. The estimation techniques used are identical to those used by demographers for life tables.

The next section of the paper presents the methodology and estimation procedure we utilize. Then, the third section describes our data set in some detail. The fourth section presents the estimation results and our interpretation of them. We conclude with some observations on the usefulness of the information we have learned.

2. METHODOLOGY

We want to estimate the effect of changes in interest rates on the turnover rates of mortgages. It is most important to recognize that the primary determinants of the decision to sell a house are not related to interest rate fluctuations. They are largely concerned with the personal circumstances of the owner: job changes, births of

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children, changes in family income or wealth, changes in taste for the type of housing, divorce, marriage, etc. We have no way of knowing why any given mortgage did or did not turn over in a given year. The only evidence of individual characteristics that we do have is the length of tenure in the house.

There are, thus, two relevant variables in our study: length of tenure in the house, and an imputed "recapitalized" or "market" value of the mortgages. We want to estimate the probability of turnover at each tenure as a function of the relationship between this market value of the mortgage and its remaining principal balance.

Estimating the effect of the interest rate lock-in on mortgage prepayments presents the problem of a time-varying covariate. In addition, the fact that much of the sample remained alive in 1982 (the last year of observation) gives us the commonly encountered econometric problem of a censored sample. Below we discuss these problems in detail and describe our econometric method.

The Problem of Parameterization and Sample Size

The most flexible specification would allow for a different hazard function for each value of the exogenous variables affecting turnover. However, estimating separate life tables for each risk-exposure category would require vastly more data than we have available. Let us suppose that we divided the interest rate differentials or lock-in magnitudes into five or ten groups. The sample size within each group would be less than 1,000. For some ages, particularly those beyond ten years from date of issue, the number of mortgages at risk would be too low to permit an accurate assessment of their turnover rate. Separating the sample in this way, even if it were possible, would implicitly assume that there is no relationship at all between the turnover rates at the same age for various interest rate differentials. But economic theory and common sense tell us that the extent of the lock-in effect should be increasing in the interest rate differential. An accurate estimation procedure should take these restrictions into account.

Moreover, even though we have quite a large sample, the number of parameters that would have to be estimated by the separate group method would be beyond what the data could reliably provide. More structure, that is to say, a more parsimonious parameterization is needed. We employ the proportional hazards model, which is widely used in demography and medical research, as well as in economics.[1] Under the proportional hazards hypothesis, the probability of a turnover can be divided into two multiplicative factors as follows:

$$\begin{array}{l}\text{probability of turnover} \\ \text{of mortgage age } (a) \text{ if} \\ \text{exogenous factors are} \\ x_1, \ldots, x_n \text{ at time } t\end{array} = \lambda(a) \cdot \pi(x_1, \ldots, x_n) . \quad (1)$$

Here $\lambda(a)$ is the "base line hazard"—that proportion of the population that would turn over even under completely stationary, homogeneous conditions. The second

[1]See Heckman and Singer (1982a, 1982b).

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factor, $\pi(x_1, \ldots, x_n)$ is greater or less than one according to whether the exogenous factors $x_1, \ldots, x_n$ make turnover more or less likely. The essential assumption is that of *proportionality*. If $x_1, \ldots, x_n$ make turnover more likely at one age, they have an equiproportional impact at all ages. Finally, it is implicit in the above formula that the effect of $x_1, \ldots, x_n$ on turnover is time-separable. Past attributes of the environment and anticipated future values are assumed not to have any effect on turnover in the present.

We defer a discussion of the functional form of $\pi(x_1, \ldots, x_n)$ and the choice of exogenous variables to the section on estimation, below. While we continue to develop the methodology for the general n variable case, in the empirical section we will deal only with the "interest rate lock-in" variable, that is, $n = 1$.

Nonconstancy of Factors Affecting Turnover

The standard proportional hazards model is based on the presumption that factors affecting turnover are specific to the individual but do not vary during the period over which the individual is followed in the sample. For instance, in a medical context, a history of previous illness may be known and may be thought relevant to the life expectancy of the patient. The selected method of treatment in a randomized clinical trial would also be such a time-invariant variable.

In our model it is essential to recognize that the differential between an imputed "market" value of the loan and the contractual value is fluctuating over time. The holder of a mortgage has an option to prepay, and the value of that option depends on his expectations about the course of future interest rates. We assume that borrowers consider the current value of their mortgage in deciding whether or not to prepay. They do not attempt to buy options or futures contracts whose value would fluctuate so as to insulate them from the risks inherent in the mortgage contract. They make their decisions myopically, year by year. For the vast majority of homeowners, this is undoubtedly correct.

This time-separability assumption allows us to estimate the hazard function $\pi(x_1, \ldots, x_n)$ even in the time-varying case, by using a maximum likelihood technique that treats each year for each mortgage as a separate observation whose value is the binary decision: prepay or do not prepay. The details are given in the estimation section.

Estimation

The proportional hazards model described above is implemented by parameterizing the function π as follows:

$$\pi(x_1, \ldots, x_n) = e^{\sum_{i=1}^{n} \beta_i x_i}. \tag{2}$$

We first discuss the estimation of the coefficients $\beta_1, \ldots, \beta_n$ when the exogenous variables $x_1, \ldots, x_n$ are fixed for each mortgage. Of course, as interest rates do vary, that is not the case. A more general estimation procedure is necessary for the time-varying case. We discuss this subsequently.

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The data in the time-invariant case give, for each observation, the issue date of the mortgage, its termination date if it was prepaid, the original interest rate, and the original principal amount. From this we compute the magnitudes actually used as the exogenous x variables in the hazard function. If the mortgage was still active at the time our data collection stopped, the observation is referred to as "censored"; if it has been prepaid, we refer to its age at prepayment as the "failure age."

A typical mortgage will be denoted by the subscript l, and the total number of mortgages is k, thus we let $l = 1, \ldots, k$. The data relevant to each mortgage is a vector of n numbers which may vary over the lifetime of the mortgage. At calendar time t, the characteristics of mortgage l are described by

$$x_{lt} = (x_{1lt}, \ldots, x_{nlt}) .$$

For each mortgage, t runs from its issue date to the termination date. If it is observed to be prepaid, the last t is the prepayment date; if it is not prepaid, the last t is the date of our study, that is 1982.

Because the maximum possible age of a mortgage is 30 years, we let $i = 1, \ldots, 30$ describe the age of the mortgage at termination, whether this is a prepayment ("failure") or a nonprepayment as of 1982 ("censored"). For each i, let D_i be the set of mortgages that failed at age i, and let d_i be the number of mortgages in D_i. Let R_i be the set of mortgages at risk of failure at age i; that is, the mortgages that did not fail at any age less than i. Since, at age i, some mortgages fail and some do not, D_i is a subset of R_i.

We now describe the log-likelihood of a given sample. It is a function of the vector of parameters ($\beta = \beta_1, \ldots, \beta_n$) that correspond to the influence of each of the n characteristics of mortgage l at time t, $x_{lt} = (x_{1lt}, \ldots, x_{nlt})$. In vector notation, the proportional hazards model (2) is written

$$\pi(x) = e^{\beta x} .$$

The log likelihood is factored into a part due to age alone and the part above due to the variables x. The parameters β are found by maximizing the second of these parts.

Kalbfleisch and Prentice (1980) present an approximation to this expression, known as the partial likelihood. Let

$$s_i = \sum_{l \varepsilon D_i} x_{lt_{l}} ,$$

where t_l is the calendar time at which mortgage l failed (i.e., it was age i). The log partial likelihood is

$$\sum_{i=1}^{30} s_i\beta - d_i\left\{\log \sum_{l \varepsilon R(i)} e^{x_{lt_l}\beta}\right\} , \tag{3}$$

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where t_{li} is the calendar time at which mortgage l is age i. (Kalbfleisch and Prentice discuss this partial likelihood method in their chap. 4, sec. 4.2.2.)

Given an estimate of β, we can estimate the hazard for a mortgage age i whose characteristics are $x_{lt_{li}}$, which is

$$\lambda_i e^{x_{lt_{li}} \cdot \beta} \tag{4}$$

by a second maximum likelihood method. Defining $\alpha_i = 1 - \lambda_i$ as the baseline survival probability at each age i, the overall likelihood of the sample is

$$\prod_{i=1}^{30} \left[\prod_{l \varepsilon D(i)} (1 - \alpha_i e^{x_{lt_{li}} \cdot \beta}) \prod_{l \varepsilon R(i) - D(i)} \alpha_i e^{x_{lt_{li}} \cdot \beta} \right] \tag{5}$$

(Kalbfleisch and Prentice present an iterative method for the maximization of (5) with respect to $(\alpha_1, \ldots, \alpha_{30})$ in chap. 4, sec. 4.3.)

The likelihood functions, equations (3) and (5), are maximized by an iterative Gaussian or Newton-type technique. The approach is to make a first guess or estimate of α or β, calculate the first derivatives of the log likelihood function and the matrix of second partials and solve the linearized system of equations for a zero of the first derivatives. This will give a "next guess" value for α or β which meets the first-order conditions for a maximum, except that the assumed linearity of the first derivatives is inaccurate. The procedure is repeated until convergence is achieved. It should be noted that only local maxima are calculated from this type of procedure and that multiple equilibriums are a real possibility. We have not experienced this problem as far as we can tell, but it cannot be ruled out a priori. A principal advantage of the proportional hazard specification is that the maximum likelihood estimate of β is separable from the estimation of the baseline hazard function $\lambda(a)$. Therefore, β is computed first and $\lambda(a)$ is computed by a separate maximum likelihood routine holding β fixed.

The key covariate (x) for our analysis is a measure of the lock-in caused by an interest rate differential between that prevailing in the mortgage market and the contracted rate of the mortgage. We considered a number of specifications of this phenomenon. The most straightforward, of course, would simply be the dollar value difference between the two valuations. We felt that this was not the correct specification since a \$15,000 lock-in presumably affects the owner of a \$60,000 dwelling more than someone who owns a \$300,000 home. It was our feeling that the prepayment probability was probably affected by the percentage of the lock-in relative to the value of the house. The lock-in effect can be thought of as a transaction cost of moving similar to the brokers fees (which traditionally are 5 or 6 percent). The sacrifice of a mortgage with a below-market interest rate can easily be more important as a fraction of the value of the house than the explicit agent's fee. Unfortunately, one piece of information not in our data set is the market value of the dwelling. What we have done is create a lock-in variable defined as the difference

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between the face and market values of the mortgage (where the market value is calculated using current mortgage rates for the full remaining life of the mortgage) divided by the initial principal amount updated by the ratio of the price index for urban California housing units to its level at the time of issuance. This gives us a proxy for the percentage lock-in relative to the "real" initial mortgage amount. If households financed similar proportions of their purchase, then it would be proportional to our preferred lock-in measure. As it stands, this measure imperfectly captures what we would expect to be most closely related to prepayment behavior, but it seems the most satisfactory available option given the data.[2]

3. DATA SET

The data set contains 3,938 mortgages held by two large California Savings and Loan Associations. A sample of mortgages active in a base year was selected and followed through 1982. The base year in each case was chosen on the basis of data availability; for the first association data were available beginning in 1975, and for the second association data were available in 1976. The mortgages were all issued for California homes and all areas of the state were represented. Officials at both S&Ls believe their portfolios are typical of those of California savings and loans. (The data set we assembled with identifiers removed can be obtained by writing the authors.)

Approximately 52 percent of the sample came from the first association. Extensive information was available regarding the active mortgages, including original mortgage amount, interest rate, principal and interest payments, current principal balance, payment history, loan-to-value ratio, term, and due date. Information on paid-off mortgages was much more limited; usually interest rate, principal and interest payment, balance at payoff, and date of payoff were available. The sample consists primarily of conventional mortgages, although some Veteran's Administration (VA) and Federal Home Administration (FHA) mortgages are included. All of the mortgages have fixed interest rates.

The remaining 48 percent of the sample came from the second association. Eighty-four percent are conventional mortgages, 10 percent are VA mortgages, and 6 percent are FHA mortgages. Information available on the active mortgages included principal amount, interest rate, monthly principal and interest payment, issue date, mortgage type, and impounds. For paid-off mortgages, data include interest rate, principal and interest payment, mortgage type, and payoff date.

While we know the aggregate proportions for conventional, FHA, and VA mortgages, we do not know which individual mortgages are of which type. This is

[2]We examined an alternative measure for x, where the difference between the face and market value of the mortgage is divided by the amount of money that would be needed in a second mortgage to bring the total financing up to the original fraction of the house value. This measure is implicitly suggested in Hendershott, Hu, and Villani (1983). It should be particularly appropriate when mortgages are assumable. It is the ratio of the advantage of assumption to the required second mortgage. However, it resulted in less plausible and less precise estimates than our preferred dependent variable, particularly in the Wellenkamp period when it would seem most appropriate.

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unfortunate, since VA and FHA loans are contractually assumable and should, therefore, be treated separately. Obtaining this information for our data set is difficult or impossible at this point, but this problem should be recognized in designing similar studies in the future. The effect of this mixture of mortgages on our estimates will be discussed below.

Our data set is described in Tables 1 and 2. The first of these shows the age and payoff distribution for the entire set. Of the 3,938 mortgages, 2,037 were paid off in the 1975–82 period, while 1,901 were still active at the end of 1982. Most of our mortgages were issued between 1962 and 1975, and thus were ages 0 through 20 in the 1975–82 interval. Table 2 gives descriptive data for the sample by mortgage issue year. The rising pattern of interest rates is shown, as is the concentration of the sample (in terms of total principal amount) in mortgages issued between 1970 and 1975.

There are a number of problems with the data set. Among the relatively minor, technical difficulties, issue dates for paid-off mortgages had to be estimated by loan number. At both associations, numbers are assigned to loans chronologically within

TABLE 1

PAYOFF EXPERIENCE BY ISSUE YEAR 1975–82

Issue Year	Payoff Years 1975	1976	1977	1978	1979	1980	1981	1982	Active	Total Each Row
1947	0	0	1	0	0	0	0	0	0	1
1951	0	0	0	0	0	1	0	0	0	1
1952	0	0	0	0	0	1	0	0	0	1
1953	0	0	0	0	0	1	0	0	0	1
1954	0	1	0	0	1	1	0	0	4	7
1955	0	0	1	0	2	0	0	0	4	7
1956	1	1	1	1	1	0	0	0	2	7
1957	0	1	3	4	2	0	0	0	5	15
1958	0	3	2	2	3	1	1	0	3	15
1959	1	4	9	6	10	1	0	0	3	34
1960	2	1	13	8	1	0	1	0	9	35
1961	6	5	14	11	6	5	3	3	25	78
1962	9	4	18	10	8	12	4	2	50	117
1963	8	9	33	13	19	6	5	2	104	199
1964	9	11	30	24	11	6	5	2	113	211
1965	6	11	35	20	20	5	3	5	116	221
1966	0	3	13	7	5	3	0	3	62	96
1967	4	5	26	13	13	2	4	2	84	153
1968	5	5	17	9	13	2	0	3	75	129
1969	8	5	19	6	6	8	3	1	70	126
1970	11	18	41	15	19	4	1	0	80	189
1971	21	31	46	22	33	8	4	1	140	306
1972	45	46	81	59	40	14	3	11	292	591
1973	23	40	107	58	37	11	5	7	309	597
1974	17	43	96	43	46	15	3	5	187	455
1975	0	21	67	29	28	8	4	4	132	293
1976		0	10	1	7	2	0	1	32	53
Totals: Paid off = 2,037									1,901	3,938

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TABLE 2

AVERAGE MORTGAGE SIZE AND INTEREST RATE BY YEAR OF ISSUE

Issue Year	Number of Mortgages	Total Principal Value (dollars)	Average Principal Value (dollars)	Average Interest Rate
1947	1	$ 15,267.34	$15,267.34	6.50
1951	1	18,650.00	18,650.00	5.00
1952	1	18,650.00	18,650.00	5.00
1953	1	18,650.00	18,650.00	5.00
1954	7	72,586.68	10,369.53	5.07
1955	7	84,294.80	12,042.12	4.75
1956	7	93,511.38	13,358.77	5.78
1957	15	219,853.42	14,656.89	5.21
1958	15	238,614.14	15,907.61	6.14
1959	34	844,513.25	24,838.63	6.46
1960	35	569,492.31	16,271.21	6.60
1961	78	1,540,570.25	19,750.90	6.40
1962	117	2,512,234.50	21,472.09	6.45
1963	199	5,157,870.50	25,918.95	6.37
1964	211	4,909,534.00	23,267.93	6.43
1965	221	5,159,343.50	23,345.45	6.40
1966	96	2,141,375.25	22,305.99	6.51
1967	153	3,688,972.25	24,110.93	6.56
1968	129	3,958,028.25	30,682.39	7.06
1969	126	3,605,869.25	28,618.01	7.84
1970	189	7,119,306.00	37,668.29	8.27
1971	306	10,087,308.00	32,965.06	7.49
1972	591	20,907,446.00	35,376.39	7.35
1973	597	21,036,692.00	35,237.34	7.75
1974	455	16,026,642.00	35,223.39	8.91
1975	293	11,762,383.00	40,144.65	9.49
1976	53	3,755,278.75	72,216.90	8.56

large groups of numbers, so paid-off mortgages were assigned the issue dates of active mortgages with similar loan numbers. This method of dating is not precise, and some mistakes were surely made, but it is unlikely that any assigned issue year is off by more than one year in either direction. Original mortgage amounts were not always available for paid-off mortgages, so these values were calculated assuming each mortgage had a 30-year term; almost all active mortgages had 30-year terms, so this is not a bad assumption.

Another problem involves the sample of "old" (20 year or longer) mortgages. A random sample of 2,000 mortgages active in 1975 will yield few old mortgages because associations currently issue a much larger number of mortgages each year than they did in the 1950s, and most of the mortgages that were issued in the early 1950s were paid off before the base year of 1975. While mortgages exist for each age, for the longest lives there may be only two or three mortgages available. The sample would have to be either increased drastically or drawn on a stratified basis to correct this problem.

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The most severe problem, however, is that the two institutions, while now federally chartered, were state chartered until 1981. Both of them changed the nature of their charter largely because of the Wellenkamp decision regarding the enforceability of due-on-sale clauses. Both institutions included due-on-sale clauses in their mortgages and enforced its provisions for single-family home mortgage contracts before the court decision, but were prohibited from doing so thereafter unless they could show that allowing assumption by the purchaser of the house would impair the security of the mortgage due to an increased risk of default. For practical purposes, this meant that the DOS clauses were not enforceable. This situation has been reversed with the DeLaCuesta decision and the Garn–St. Germain Act in 1982, but their impact was not effective until after the completion of our data sample.

The approach we have taken is to divide the sample into two periods, 1975–78 and 1979–82, and separately estimate for each of these intervals the sensitivity of prepayment experience to interest rate fluctuations. Clearly this reduces the power of our estimation procedures, since it leaves us with a smaller number of observations in each of the two periods, but our estimates are still reasonably precise. It also permits us to judge the effect of the Wellenkamp decision on prepayment experience and hence the valuation of mortgage portfolios.

4. RESULTS

In our empirical work, we have used the proportional hazards model with one variable. The lock-in variable is defined as

$$\text{lock-in}_t^i = \frac{\text{face value}^i - \text{market value}^i}{\text{initial principal amount}^i \; x \dfrac{P_t}{P_0}},$$

where P_t is a price index for urban California residential housing at time t and P_0 is that index at the time the mortgage was issued.[3]

This lock-in measure is calculated for each mortgage still alive in each year during the 1975–82 interval. Since the mortgages in our sample were issued between 1947 and 1976, mortgages of all ages are observed. Tables 3 and 4 show the number of mortgages which reached each age in the 1975–78 and the 1979–82 interval, respectively. Again, the data are separated in this way because of the Wellenkamp decision. Any mortgage that reached a particular age in the interval of observation is termed "at risk." The number of mortgages that were at risk for each age is shown in the first column of Tables 3 and 4. The number that prepaid (or "died") is shown in the second columns. The third and fourth columns report the average lock-in for all at risk mortgages and for only those which prepaid, respectively. Interestingly, the average lock-in is lower for those mortgages which paid off for almost every age in both the pre-Wellenkamp period and in the 1979–82 interval. This gives some

[3]The price index was compiled by the California Department of Industrial Relations and is published in the *California Statistical Abstract*.

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TABLE 3

LOCK-IN BY MORTGAGE AGE FOR THOSE PAID OFF AND FOR ALL AT RISK, 1975–78

Mortgage Age	Number at Risk	Number Paid Off	Average Lock-in for Those at Risk (%)	Average Lock-in for Those Paid Off (%)
1	800	47	0.12	0.69
2	1350	134	4.23	2.44
3	1765	210	6.98	4.80
4	1685	217	8.52	7.23
5	1401	181	9.07	9.07
6	977	131	8.68	9.04
7	615	73	7.41	6.23
8	509	43	7.62	6.20
9	458	28	8.35	7.29
10	563	44	8.92	8.37
11	637	46	8.57	7.97
12	685	61	7.96	7.30
13	668	68	7.45	7.05
14	529	67	6.87	6.00
15	360	38	6.41	5.64
16	220	26	5.75	5.09
17	133	28	5.16	4.73
18	78	20	4.75	3.74
19	54	10	4.56	4.13
20	37	6	4.24	3.94
21	30	5	3.83	3.35
22	19	3	3.11	2.44
23	14	0	2.66	0.00
24	9	0	2.08	0.00
25	4	0	1.47	0.00
26	4	0	1.02	0.00
27	3	0	0.63	0.00
28	3	0	0.31	0.00
29	2	0	0.10	0.00
30	1	0	0.00	0.00

preliminary indication that interest rate lock-in may be an important determinant of prepayment probabilities.

The maximum likelihood estimates confirm this preliminary finding and also allow us to measure the impact of the Wellenkamp decision. The estimate for β in the pre-Wellenkamp period is -4.37 with a standard error of 0.55, while the figure for the 1979–82 period is -13.07 with a standard error of 1.37. To aid in interpreting these numbers, note that they indicate that a modest 10 percent lock-in would have reduced prepayment probabilities by 33 percent in the due-on-sale period 1975–78 and by 63 percent in 1979–82. The results indicate that even in a due-on-sale regime, the likelihood of prepayment depends on the relationship between the contractual rate on the mortgage and the market rate. In the period when the due-on-sale clause was unenforceable, the prepayment experience was even more sensitive to interest rates. In that period, prepayment would seldom occur unless the

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TABLE 4

LOCK-IN BY MORTGAGE AGE FOR THOSE PAID OFF AND FOR ALL AT RISK, 1979–82

Mortgage Age	Number at Risk	Number Paid Off	Average Lock-in for Those at Risk (%)	Average Lock-in for Those Paid Off (%)
1	0	0		
2	0	0		
3	42	7	15.019	14.785
4	211	30	10.424	13.050
5	437	54	13.186	12.465
6	752	57	16.108	14.998
7	1023	58	17.077	15.497
8	1019	57	17.896	14.729
9	879	37	17.812	13.881
10	621	25	16.459	15.874
11	397	23	14.013	11.014
12	339	18	12.357	10.952
13	314	8	11.883	10.257
14	385	30	10.836	9.540
15	393	18	10.152	8.590
16	321	31	9.990	8.110
17	248	24	9.516	8.170
18	114	25	8.486	7.480
19	209	12	7.677	7.221
20	107	15	6.678	5.458
21	50	8	5.709	4.969
22	24	3	4.570	3.767
23	15	2	3.768	3.307
24	16	2	2.906	2.350
25	17	2	2.118	1.452
26	12	1	1.580	1.426
27	10	1	1.049	0.893
28	6	1	0.532	0.464
29	1	1	0.164	0.164

buyer could for some reason not assume the loan. Also, for older mortgages the lock-in is smaller (relative to the current cost of the house) and therefore the loan may be prepaid at the time of sale.

Recall that a small fraction of our mortgages were FHA and VA loans which are contractually assumable. This would bias the estimate in the 1975–78 interval upwards in absolute value. Therefore, the large effect we attribute to the Wellenkamp decision may be underestimated.[4] However, Hendershott and Hu (1983) implicitly suggest a different hypothesis for the decrease in prepayments in 1979–82.

[4]The method which resulted in the $\beta = -4.37$ estimate looked only at the mortgages that were at risk in the 1975–78 window. An alternative consistent estimator under the maintained hypothesis of the proportional hazards model would include the experience of these mortgages in the pre-1975 period as well, notwithstanding the fact that the sample is selected so as to include only those which survive to 1975. Reestimating with this alternative, we find $\beta = -2.52$ with a standard error of 0.46. The discussion will stick with the original estimate, but this alternative procedure confirms the significant effect of the Wellenkamp decision on mortgage prepayment.

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They argue that the real user cost of housing was falling in the 1962–78 period, causing people to move and "trade up"—but that there was a sharp increase in user cost in 1979–82, stopping or at least slowing this phenomenon. Separately testing this hypothesis against our interest rate lock-in effect will have to await further research. Further, Proposition 13 created a lock-in effect of its own by capping property taxes on homes as long as they are not sold. This lock-in is probably relatively minor relative to the mortgage one, but its existence may affect our results slightly.

The estimated base line hazard as a function of mortgage age is shown in Table 5. The hazards for the first 18 years or so are estimated with reasonable precision, while for mortgages older than that the relative scarcity of data means that the hazard cannot be precisely determined. Throughout, it should be recalled that our data (and therefore results) refer only to California mortgages. It is possible that the $\lambda(a)$ baseline hazard probability is higher for California than for the rest of the country. This would not necessarily change our estimates of the sensitivity of prepayments to interest rate fluctuations.

TABLE 5

CONDITIONAL PAYOFF PROBABILITIES AS A FUNCTION OF MORTGAGE AGE

Age	Estimated Hazard Function $\lambda(a)$ (%)	Standard Deviation (%)
1	5.59	0.79
2	11.18	0.91
3	15.34	0.97
4	17.99	1.10
5	18.38	1.23
6	18.67	1.46
7	15.85	1.70
8	11.52	1.65
9	8.66	1.56
10	11.29	1.60
11	10.31	1.44
12	12.36	1.48
13	13.80	1.55
14	16.73	1.86
15	13.73	2.06
16	14.93	2.69
17	25.65	4.17
18	30.70	5.71
19	22.15	6.17
20	19.19	7.04
21	19.41	7.79
22	17.91	9.37
23	20.92	13.09
24	17.79	11.36
25	7.70	7.39
26	10.15	9.61
27	11.39	10.70
28	17.77	16.11

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Tables 6 and 7 show the sensitivity to market interest rates of the cash flow (interest plus principal plus prepayments) from $1,000,000 of 10 percent 30-year mortgages. The first of these tables is calculated for the 1975–78 period and hence with $\beta = -4.37$. If interest rates climb to 15 percent, the pattern of the cash flow from the 10 percent mortgages is changed significantly. For instance, the cash flow from the mortgages at age 2 is reduced from $203,455 to $138,401. This is due entirely to the reduced prepayment experience. The cash flow is higher at 15 percent than at 10 percent for older mortgages because more of the mortgages survive to these ages. For instance, at 20 years, the cash flow at 10 percent is $8,914, whereas at 15 percent, it is $23,475.

During the 1979–82 Wellenkamp period, this sensitivity of cash flows to interest rates was greatly increased as is evidenced by Table 7. In this period, $1,000,000 of 10 percent mortgages could be expected to generate $203,455 at age 2 with interest rates at 10 percent, but only $108,881 at 15 percent interest. At age 20, the numbers are $8,914 at 10 percent versus $80,704 at 15 percent. This nine to one

TABLE 6

Cash Flows from $1,000,000 in 10 Percent Mortgages as a Function of Age and Market Interest Rates (for 1975–78; $\beta = -4.37$)

Age	10%	11%	12%	13%	14%	15%
1	160,876	145,890	136,169	129,587	124,964	121,615
2	203,455	180,731	164,629	153,095	144,676	138,401
3	214,042	196,028	180,574	168,187	158,470	150,865
4	198,497	191,944	182,585	173,158	164,731	157,560
5	164,049	168,788	167,885	164,162	159,425	154,613
6	134,341	145,630	151,147	152,613	151,694	149,576
7	98,271	111,622	121,011	126,813	129,918	131,218
8	69,058	81,155	91,144	98,744	104,187	107,920
9	53,156	63,741	73,202	81,091	87,354	92,173
10	54,448	65,712	75,977	84,689	91,696	97,124
11	45,850	56,001	65,654	74,254	81,540	87,497
12	44,468	54,678	64,606	73,667	81,531	88,105
13	40,790	50,533	60,253	69,388	77,569	84,627
14	38,527	48,039	57,739	67,092	75,702	83,341
15	28,405	35,700	43,349	50,979	58,279	65,036
16	25,170	31,764	38,778	45,897	52,844	59,412
17	28,772	36,402	44,588	52,982	61,269	69,202
18	23,440	29,799	36,738	44,005	51,361	58,601
19	12,811	16,357	20,286	24,482	28,830	33,226
20	8,914	11,401	14,174	17,158	20,281	23,475
21	7,001	8,963	11,158	13,530	16,026	18,594
22	5,209	6,673	8,315	10,095	11,975	13,918
23	4,413	5,656	7,051	8,566	10,170	11,832
24	3,069	3,935	4,907	5,966	7,088	8,253
25	1,837	2,355	2,938	3,573	4,247	4,948
26	1,734	2,224	2,775	3,375	4,012	4,674
27	1,513	1,940	2,421	2,944	3,500	4,079
28	1,367	1,753	2,187	2,660	3,162	3,685
29	859	1,102	1,375	1,672	1,988	2,317
30	859	1,102	1,375	1,672	1,988	2,317

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TABLE 7

CASH FLOWS FROM $1,000,000 IN 10 PERCENT MORTGAGES AS A FUNCTION OF AGE AND MARKET INTEREST RATES (for 1979–82; $\beta = -13.07$)

Age	10%	11%	12%	13%	14%	15%
1	160,876	127,068	115,000	110,152	108,000	106,960
2	203,455	148,650	125,723	115,816	111,200	108,881
3	214,042	163,271	134,821	121,187	114,474	110,969
4	198,497	169,164	141,258	125,695	117,494	113,026
5	165,049	162,232	141,970	127,507	119,136	114,337
6	134,341	125,692	141,562	129,070	120,822	115,777
7	98,271	128,786	130,650	124,216	118,552	114,679
8	69,058	101,673	113,879	114,732	113,041	111,319
9	53,156	84,284	101,664	107,359	108,613	108,568
10	54,448	88,255	107,826	113,554	113,884	112,832
11	45,850	77,854	100,260	109,313	111,706	111,767
12	44,468	77,503	102,623	113,405	116,146	115,911
13	40,790	73,303	100,933	114,527	118,739	118,980
14	38,527	71,137	101,709	118,612	124,546	125,211
15	28,405	54,312	82,348	101,816	111,760	115,849
16	25,170	49,023	76,801	98,227	110,564	116,437
17	28,772	56,680	90,587	118,052	134,181	141,390
18	23,440	47,218	78,940	108,779	130,011	142,283
19	12,811	26,341	46,084	67,773	86,859	101,295
20	8,914	18,482	32,978	50,044	66,607	80,704
21	7,001	14,582	26,308	40,664	55,418	68,889
22	5,209	10,884	19,795	31,025	43,086	54,739
23	4,413	9,238	16,877	26,663	37,445	48,215
24	3,069	6,435	11,802	18,779	26,647	34,759
25	1,837	3,854	7,086	11,326	16,180	21,291
26	1,734	3,640	6,696	10,712	15,322	20,193
27	1,513	3,176	5,845	9,357	13,400	17,688
28	1,367	2,869	5,281	8,459	12,122	16,016
29	859	1,804	3,321	5,321	7,629	10,087
30	859	1,804	3,321	5,321	7,629	10,087

ratio reflects the vastly greater interest payments from the much greater number of old mortgages in the 15 percent case.

These cash flows can be put into perspective by calculating their present value at the time of issue. This is done in Table 8. The small discrepancy from $1,000,000 of the value of the portfolio at 10 percent interest is due to the difference between monthly compounding (the practice with mortgages) and the continuous compounding technique we used to calculate present values. The table shows that as market interest rates rise from 10 percent to 15 percent, the decline in the value of the mortgages depends on what happens to expected prepayment experience. If prepayments were presumed to be unaffected ($\beta = 0$), the fall in value would be analogous to what happens to fixed maturity instruments such as bonds. In this case, the mortgage portfolio would fall in value by 17.71 percent due to the five-point rise in interest rates. However, as lines 2 and 3 of Table 8 show, the decline in value is much greater than this when the endogenous nature of prepayments is taken into

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TABLE 8

PRESENT VALUE OF 10 PERCENT MORTGAGE CASH FLOWS AS A FUNCTION OF MORTGAGE INTEREST RATES

	10%	11%	12%	13%	14%	15%
$\beta = 0$; no interest effect on prepayment probabilities	995,483	954,918	917,288	882,296	849,680	819,212
(loss as a % of original PV)		4.07	7.86	11.37	14.65	17.71
$\beta = -4.37$; estimated coefficient for the period when DOS was enforceable, 1975–78	995,483	951,491	905,240	858,571	812,863	769,083
(loss as a % of original PV)		4.42	9.07	13.75	18.34	22.74
$\beta = -13.07$; estimated coefficient for the Wellenkamp period, 1979–82	995,483	944,723	883,887	822,810	766,357	715,740
(loss as a % of original PV)		5.10	11.21	17.35	23.01	28.10
Difference in loss as a % of original PV between $\beta = -4.37$ and $\beta = 0$		0.35	1.21	2.38	3.69	5.03
Difference in loss as a % of original PV between $\beta = -13.07$ and $\beta = 0$		1.03	3.35	5.98	8.36	10.39
Difference in loss as a % of original PV between enforceable DOS period and Wellenkamp period		0.68	2.14	3.60	4.67	5.36

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account. Our estimate for the 1975–78 pre-Wellenkamp period ($\beta = -4.37$) indicates that the portfolio value would fall by 22.74 percent if interest rates jumped from 10 to 15 percent. In the Wellenkamp period, the fall in value would be 28.10 percent. The difference between the numbers in the first three rows of Table 8 shows the inappropriateness of assuming unchanged prepayment experience and also highlights the cost of the Wellenkamp decision to mortgage values when interest rates climb. The loss in the value of the mortgages caused by a hypothetical 10 to 15 percent jump in interest rates is 5.36 percent more with Wellenkamp than in a DOS environment. This 5.36 percent difference could easily eliminate the net equity position of a savings and loan. Thus, the table indicates both that the value of mortgages is highly sensitive to interest rates and that this value depends significantly on the rules regarding due-on-sale.

The sensitivity of the average time to repayment to interest rates is shown in Table 9 for 10 percent mortgages. If β were zero, of course, the average time to payoff would not be affected by market interest rates. However, if prepayments are according to our point estimates, the figures in Table 9 indicate that a 10 percent mortgage will, on average, prepay in 7.331 years if market rates have gone up to 12 percent and due-on-sale clauses are enforced. If mortgages are assumable, the average time to repayment is 10.337 years. The numbers indicate that interest rate changes alone are sufficient to account for the changing rule of thumb regarding standard lifetime assumptions, but they also indicate how inappropriate any fixed rule of thumb really is.

TABLE 9

Average Time to Payoff for 10 Percent Mortgages as a Function of Market Interest Rates

	10%	11%	12%	13%	14%	15%
$\beta = 0.0$	5.831	5.831	5.831	5.831	5.831	5.831
$\beta = -4.37$	5.831	6.610	7.331	7.982	8.563	9.076
$\beta = -13.07$	5.831	8.255	10.337	11.855	12.886	13.560

4. CONCLUSION

We began this research with the feeling that the determinants of prepayment experience had received too little attention. The importance of the matter seemed far too great to rely uncritically on rules of thumb to assess prepayment likelihoods. The first thing we learned in this study was that the data to examine prepayment experience are not readily available. While longitudinal panel surveys do exist for households, similar information regarding mortgages does not seem to be publicly available. We have corrected this situation to an extent by collecting information on 3,938 individual California mortgages which were active in 1975 and 1976 and by following them through 1982. Certainly research in the area of mortgage evaluation would be aided by better data. We found the institutions quite willing to provide the data and were limited only by the usual time and money constraints.

Our results indicate that market interest rates are a significant determinant of prepayment probabilities. When due-on-sale clauses were applicable, our informa-

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tion indicates that a 10 percent lock-in reduces prepayment probabilities 35 percent. If the clause cannot be enforced, the reduction in probability becomes 63 percent. Both of these effects would be eliminated if mortgages had floating interest rates. Our analysis indicates that the rules regarding due-on-sale clauses significantly affect the value of mortgage portfolios, possibly enough in some circumstances to wipe out the net worth of savings and loan institutions. We also find that the average age to prepayment is highly dependent on interest rates.

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