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Anatomy of Prepayments: The Salomon Brothers Prepayment Model

TABLE OF CONTENTS PAGE

FIGURES

Prepayment projections are at the center of all mortgage security valuation and analysis. Since Salomon Brothers pioneered the development of the Street's first prepayment model in the mid-1980s,[1] such models have come to be widely used to obtain prepayment projections and indeed, are critical for valuation techniques such as option-adjusted spread (OAS) analysis.

At the same time, most market participants are well aware that projecting prepayments is not an exact science. While a large body of data now exists on prepayments, it still only partially covers the range of economic and interest rate environments that is possible over the term of a mortgage-backed security (MBS). As with any econometric model, the basic premise is that the conditions and relationships observed in the past will hold going forward. The experience of the refinancing waves of 1991 through 1993, when prepayment models generally were perceived to have failed to predict the high speeds actually observed, has led to a fair degree of investor skepticism about such models. We feel that while many prepayment models indeed proved deficient during the past few years, skepticism about such models is partly due to the fact that they tend to be "black boxes;" thus, human nature being what it is, the models receive little credit, even when they are right.

These considerations suggest that a prepayment model should possess two critical characteristics. First, it needs to be based on fundamental relationships that are likely to persist over time, rather than just on a statistical fit to the data. Second, the model and its projections, and the assumptions that they are based on, should be easily understandable by users. With these caveats in mind, Salomon Brothers has developed a completely new prepayment model. Among its key features are the following:

• The model is modular and transparent, with the different components of the model corresponding to well-known prepayment causes (home sales, refinancings, etc.).

• The model applies to all mortgage types. While different mortgage types may vary in the relative importance of these components and borrower characteristics, the fundamental causes of prepayments apply to all types.

• Each component is well formulated and depends in a logical and rigorous manner on the variables likely to influence mortgagor behavior or response.

• Within each component, relationships can be easily modified, to explore the effects of unanticipated demographic or mortgage market changes on prepayments and hence on MBS value.[2]

This paper presents a general discussion of prepayment behavior and describes how this behavior is captured by the new Salomon Brothers prepayment model. The model has been fit using data from the past 15 years; despite the myriad economic environments and mortgage market changes, the same model accurately predicts prepayments over the whole of this period. We must stress

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[1] See *The Salomon Brothers Prepayment Model: Impact of the Market Rally on Mortgage Prepayments and Yields*, Salomon Brothers Inc, September 4, 1985.

[2] Readers who have access to Salomon Brothers' analytic system, the Yield Book, can use the "Dials" facility to do this.

this critical point, because a widespread perception exists that for, example, the refinancing experiences of 1986-87 and 1991-93 were very different, and hence cannot be accurately described by the same model. **The new Salomon Brothers Prepayment Model demonstrates that an approach that is, first, comprehensive in incorporating the different reasons for prepayments and, second, uses fundamental and hence long-lasting relationships between variables and prepayments rates can be robust and reliable over time.**

Prepayment Causes

What causes prepayments? Most readers are familiar with mortgages and home ownership in general and hence with the various reasons for prepayments. We will use five categories to classify prepayments:

• **Home sales.** The sale of a home generally will lead to the prepayment of a mortgage. Exceptions will arise if the home has a Federal Housing Administration or Veterans Administration (FHA/VA) loan and the new buyer decides to assume the existing loan or if the home happens to be one that does not carry a mortgage.

• **Refinancings.** The second major cause of prepayments refers to mortgagors taking advantage of lower rates by refinancing out of an existing loan into a new one. As we will discuss shortly, this is the most volatile component of speeds, and constitutes the bulk of prepayments when speeds are very high.

• **Defaults.** A prepayment caused by a foreclosure and subsequent liquidation of a mortgage. This is a relatively minor component in most cases, averaging less than 0.5% per year for moderately seasoned loans, and is close to zero for very seasoned loans.

• **Curtailments.** Some mortgagors are in the habit of sending in more than the scheduled payment each month, as a form of forced savings and to build up equity in their homes faster. Such extra payments, referred to as partial prepayments or curtailments, show up as prepayments of principal and, for fixed-rate loans (with a fixed monthly payment), shorten the loan maturity. Data from mortgage servicers (and the observed weighted-average maturity (WAM) shortenings on Federal National Mortgage Association (FNMA) and Federal Home Loan Mortgage Corporation (FHLMC) pools, from which average curtailment rates can be estimated) indicate that, for new and moderately seasoned loans, curtailments typically amount to less than 0.5% per year.

• **Full payoffs.** Evidence exists that many mortgagors pay off their mortgage completely when it is very seasoned and the remaining loan balance is small.[3] Full payoffs also can occur because of the destruction of the home from natural disasters such as hurricanes and earthquakes. In general, full payoffs are negligible until the loans are very seasoned. For 30-year loans, FHA data on loans more than 20 years old suggests that the combination of curtailments and full payoffs averages several percent per year.

The various components, and their relative importance and evolution over time, are illustrated in Figure 1. This figure shows prepayment speeds on 1977 origination Government National Mortgage Association (GNMA) 7.5s, along with the turnover rate on existing homes, which is obtained by dividing the number of existing homes sold in a given month[4] by the estimated number of single-family homes in the United States at that time.[5] The average turnover rate

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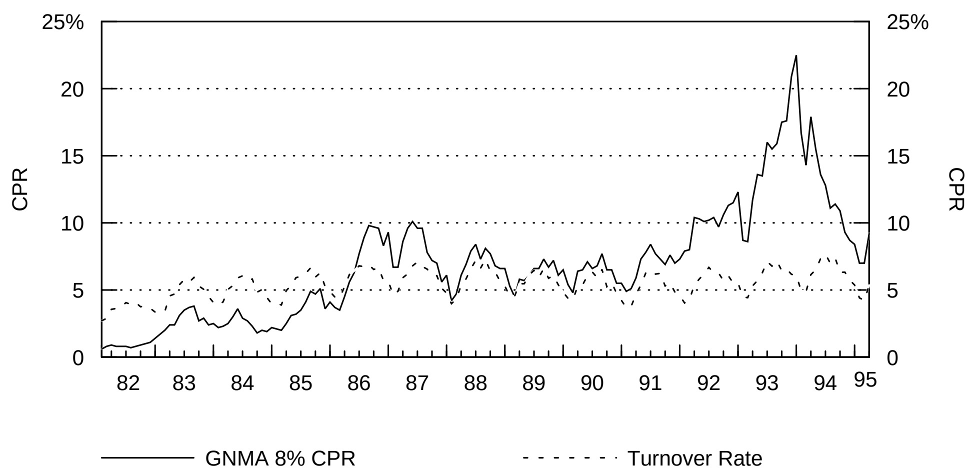
[3] See "Home Owner Mobility and Mortgage Prepayments", Michael S. Carliner and David D'Alessandris, *Housing Economics*, September 1992.

[4] This data is provided by the National Association of Realtors. Note that we are using the actual, rather than the seasonally adjusted number of homes sold.

[5] This is based on U.S. Census Bureau data.

has hovered around 6% per year, and this figure can be considered a baseline prepayment rate for mortgages. This average turnover rate explains the prepayment rate of 6% per year for seasoned loans assumed by the Public Security Association (PSA)'s benchmark 100% PSA rate.

Figure 1. Turnover Rate on Existing Homes and Speeds on 1977 GNMA 7.5s, 1980-Present



Source: Salomon Brothers Inc, National Association of Realtors and U.S. Census Bureau.

During the first half of the 1980s, mortgage rates were high (generally in the teens), leading to a substantial proportion of assumptions on the GNMA 7.5s. This resulted in the prepayment rate on GNMA 7.5s being below the turnover rate for existing homes. In 1986 and early 1987, a period of heavy refinancing activity, speeds on the GNMA 7.5s jumped to well above the turnover rate. However, the weighted-average coupon (WAC) on the GNMA 7.5s is 8%, while mortgage rates in 1986 and 1987 were generally 9% or higher; this discrepancy suggests that the 1977 GNMA 7.5s experienced *cash-out refinancings* in 1986 and 1987, as some homeowners, inspired by the sharp drop in mortgage rates from 1985 to 1986, refinanced into larger loans to make use of the equity in their homes, even if it meant a small increase in the loan rate.

From 1988 through early 1991, speeds on the GNMA 7.5s tracked the turnover rate quite closely, on average being about 1%-2% Constant Prepayment Rate (CPR) higher. This trend indicates that over this period speeds were due mostly to home sales, few assumptions occurred (because the balances on the underlying loans, originated in 1977, were by then small compared with the cost of a new home), and some curtailments occurred. Defaults were quite low (below 0.25% CPR, according to Office of Housing and Urban Development (HUD) data), reflecting the fact that few loans default once they are seasoned more than ten years.

Starting in late 1991, the 1977 GNMA 7.5s begin to experience refinancings, reflecting declining mortgage rates. Note, however, that the 1977 GNMA 7.5s did not experience the sky-high prepayment rate of newer coupons, probably because the small remaining balances on 1977 loans reduced the incentive to refinance the loans.

Structure of Prepayment Model

The Salomon Brothers Prepayment Model is additive in form, consisting of submodels for each of the sources of prepayments discussed above. The first two submodels, for home turnover and refinancings, contribute most of the projected speed. In the next few sections, we describe these two components in more detail, in particular identifying the variables that drive them.

In the absence of refinancings, prepayments will be due mostly to home sales, as Figure 1 illustrates. Hence, the critical component of discount speeds is housing turnover.

While a number of housing industry statistics are published each month, the one that is most relevant for prepayment analysis is *sales of existing homes.* While other statistics, such as housing starts or new home sales, often receive more publicity, they do not have the direct relationship with prepayments that existing home sales do; unless the mortgage is assumed or the home has no mortgage, the sale of an existing home leads to a prepayment.

Figure 2 shows existing home sales from 1978 to the present. Also shown are mortgage rates, total single-family housing stock and the turnover rate on existing homes (the number of homes sold as a percentage of the stock).

Figure 2. Housing Turnover Rates, 1978-Present

Year	Avg. Mtg. Rate	Sales of Exst. Homes [a]	Est. SF Housing Stock [a]	Turnover Rate
1978	9.64%	3.99	51.84	7.70%
1979	11.19	3.83	52.72	7.26
1980	13.77	2.97	53.60	5.55
1981	16.64	2.42	54.27	4.46
1982	16.09	1.99	54.95	3.62
1983	13.23	2.70	55.63	4.85
1984	13.87	2.83	56.31	5.02
1985	12.42	3.31	56.99	5.82
1986	10.18	3.47	57.67	6.02
1987	10.20	3.44	58.35	5.89
1988	10.33	3.51	59.03	5.95
1989	10.32	3.35	59.70	5.60
1990	10.13	3.21	60.38	5.32
1991	9.25	3.22	61.06	5.27
1992	8.40	3.52	61.74	5.70
1993	7.33	3.80	62.42	6.09
1994	8.36	3.95	63.10	6.26

[a] In millions. SF Single family.
Note: Total housing stock is estimated by using U.S. Census Bureau data on detached single-family residences.
Source: FHLMC, National Association of Realtors, US Census Bureau and Salomon Brothers Inc

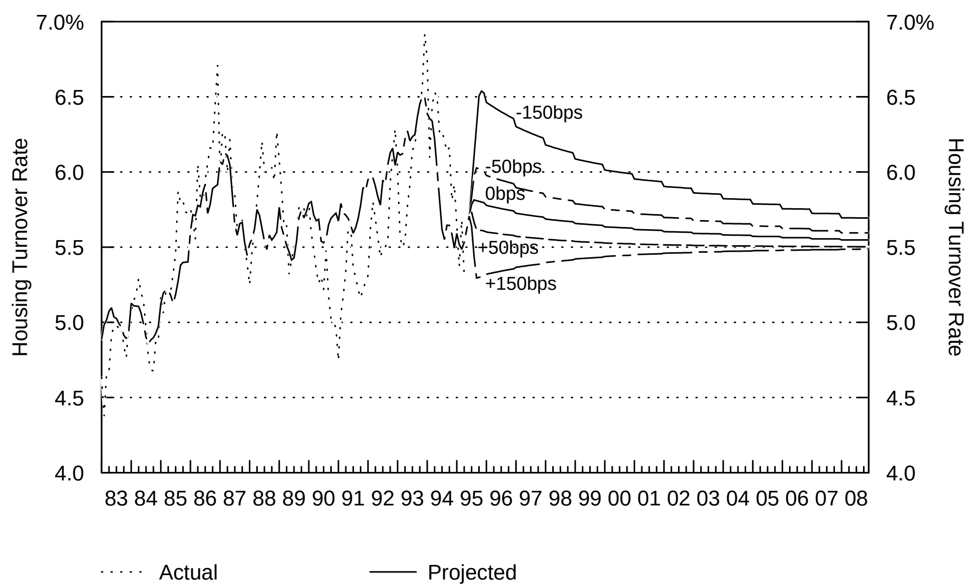
Annual turnover rates on existing homes generally have hovered between 5% and 7%, with somewhat lower rates in the early 1980s, when high mortgage rates and a severe recession severely depressed sales volume. While mortgage rates do affect housing activity through affordability levels, note that economic growth and the business cycle seem to be equally important factors. For example, the turnover rate in 1986 was about the same as that in 1993, despite mortgage rates being several hundred basis points higher in 1986. The turnover rate in 1994, while slightly higher than those in the mid-1980s, was still lower than those in the late 1970s, when mortgage rates were significantly higher.

Projecting Housing Turnover

If housing turnover largely drives speeds on discount MBSs, then we need to understand how turnover rates vary over different interest rate cycles. Mortgage rates clearly affect the overall level of home turnover and hence speeds, and most prepayment models use an adhoc adjustment to vary discount speeds as interest rates change. To establish a sounder basis for estimating prepayment speeds resulting from home sales, Salomon Brothers has developed an innovative model for projecting housing turnover rates.

We discuss the main features of the model in Appendix A. The model is fitted to historical data over the past 15 years. Its projections include the influence of current interest rates as well as the lingering influence of the recent interest rate history on the present level of home sales.

Figure 3. Actual and Projected Housing Turnover Rates



Source: National Association of Realtors, U.S. Census Bureau and Salomon Brothers Inc.

Figure 3 depicts the turnover model's fit to actual data, as well as its turnover predictions for various interest rate changes. The model realistically captures mortgagors' real-life response to interest-rate changes. For example, if rates rise by 1.5% and hold steady, it projects that turnover rates will fall initially but subsequently revert toward historical means as consumers adjust to the new economic situation. Conversely, a drop in rates leads to an initial surge in turnover, followed by a gradual drop, as satiation of demand causes a reversion toward historical means.

Seasonal Variation in Home Sales

Home sales volume exhibits a pronounced but consistent seasonal pattern, which obviously passes through to prepayment speeds. The extent and consistency of the seasonal cycle is indicated in Figure 1 on page XX; it is also shown in Figure 4, which demonstrates the monthly seasonal adjustments calculated by the National Association of Realtors (NAR) for existing home sales from 1980 to the present.[6]

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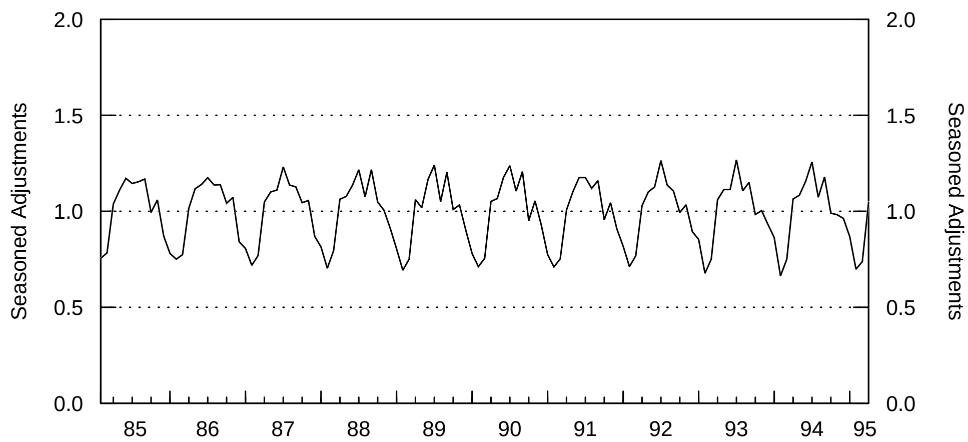
[6] The NAR uses the U.S. Census Bureau's X-11 statistical program to estimate seasonal adjustments.

Figure 4. Seasonal Adjustments for Existing Home Sales, 1986-Present



CPR Constant Prepayment Rate.
Source: National Association of Realtors, Salomon Brothers Inc.

As one might expect, the seasonal highs occur in the summer and the lows in the winter, with the school year calendar and the weather the driving forces behind the seasonal cycle. MBS investors need to be aware of the magnitude of the seasonal variation. There is almost a two-to-one ratio between summer highs and winter lows and some significant month-to-month changes. Figure 5 shows a weighted-average seasonal factor for each month, based on the past 27 years of NAR adjustments, along with the change from the previous month.

Figure 5. Estimated Seasonal Adjustments for Sales of Existing Homes

Month	Seasonal Adjustment	Pct. Change from Previous Month
Jan	0.70	-15%
Feb	0.77	+9
Mar	1.05	+37
Apr	1.09	+4
May	1.14	+5
Jun	1.23	+8
Jul	1.11	-10
Aug	1.16	+5
Sep	0.99	-15
Oct	1.02	+3
Nov	0.91	-10
Dec	0.83	-10

Sources: National Association of Realtors and Salomon Brothers Inc.

The largest one-month change is from February to March, when home sales typically increase by about 37%. In the fall and winter months, a series of double-digit percentage declines occurs until the seasonal cycle reaches its low in January.

While these adjustments can form the basis for incorporating seasonal factors in prepayment projections, readers should be aware of one or two complications. First, in reporting sales volume to the NAR, local realtors do not consistently define a sale. The majority defines a sale as a closing, which implies an immediate mortgage prepayment, but some fraction (the NAR is not sure as to the number) defines it as a sales contract, which implies a mortgage prepayment a couple of months later. Second, depending on the servicer and servicing agreement, for some closings that take place near the end of the month, the prepayment may not actually show up in pool factors until the following month.

The Salomon Brothers Prepayment Model starts with the NAR adjustments and uses historical correlations between home sales changes and discount speed changes to derive monthly seasonal factors for each agency.

Given an overall level of housing turnover, how do specific loan or borrower characteristics affect resulting prepayment speeds? Among the most important characteristics are loan seasoning (which in addition to age depends on other features such as whether the loan was originated as a purchase or a refinancing, the points paid, etc.), the loan coupon relative to prevailing mortgage rates, relative loan balance, and last but not least, loan type.

The Seasoning Process

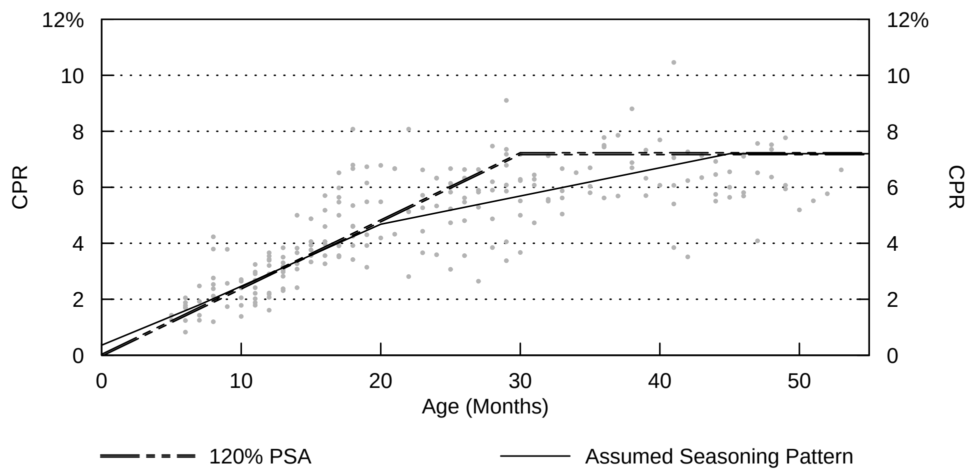
A large fraction of currently outstanding MBSs are new discounts, many of which were originated in the refinancing waves of 1992 and 1993. A critical question for MBS investors concerns the rate at which the underlying loans will season.

The current industry standard, the PSA aging ramp, assumes that loans season linearly over the first 30 months. In fact, as is by now fairly well established, loan seasoning is a complex process that depends on a number of factors and will differ depending on whether the mortgagor is contemplating moving versus refinancing. We will discuss the seasoning process for refinancings in the next section; here we discuss the seasoning process as it pertains to home turnover.

• **The base seasoning ramp.** This factor refers to the core age-dependent part of the seasoning process. The transaction costs incurred in a home purchase are substantial, amounting to several percent of the purchase price. Most home purchases therefore are followed by a quiescent settling-in period, when the family avoids relocation unless compelled by circumstances. Hence prepayments associated with newly originated purchase loans are initially quite small, and increase to the "natural" level implied by the housing turnover rate gradually over a **seasoning period.**

Self-selection by borrowers implies that the length of this period depends on the type of loan, but we illustrate the basic form in Figure 6, which shows speeds on discount conventional 30-year MBSs as a function of age. Also shown is an appropriate multiple of the industry-standard PSA curve. The base seasoning ramp typically starts above the PSA curve in the initial months of the mortgage, but then drops below it, leading to the so-called PSA **elbow**, which is most pronounced around the age of 30 months. This type of seasoning ramp leads to high initial PSAs, which then decrease but eventually increase until the collateral is fully seasoned.

Figure 6. Seasoning Patterns for Conventional Discounts



Note: Data points represent seasonally adjusted speeds for FNMA 30-Year discounts centered around -150 basis points relative coupon.
Source: Salomon Brothers Inc.

A number of other effects that vary with age are superimposed on the basic seasoning ramp. The most important of these effects are as follows:

• **The percentage of refinanced loans in the pool.** The presence of a substantial number of refinanced loans in a mortgage pool can indicate higher prepayments during the seasoning period. It could be argued that refinanced loans should season faster than purchase loans, because many of the elements that determine seasoning (a growing family, expanding income, etc.) are already developed to some extent in a refinanced loan. The very act of purchase sends a much stronger message than a refinancing that the mortgage holder plans to put down some "roots." Moreover, the circumstances that tend to make the purchasers of a home unwilling/unable to move immediately, such as a high loan-to-value ratio (LTV), the fresh memory of the "joys" of moving and the typically higher transaction costs of relocation continue to distinguish purchase loans from refinanced loans.

However, the view that refinanced loans season faster is not universally held. Homeowners who plan to move in the near future can now refinance into a balloon or adjustable-rate mortgage (ARM). Therefore some speculation has occurred as to whether mortgage holders refinancing into 30-year loans nowadays might actually be sending the opposite message, namely that they plan to stay awhile.

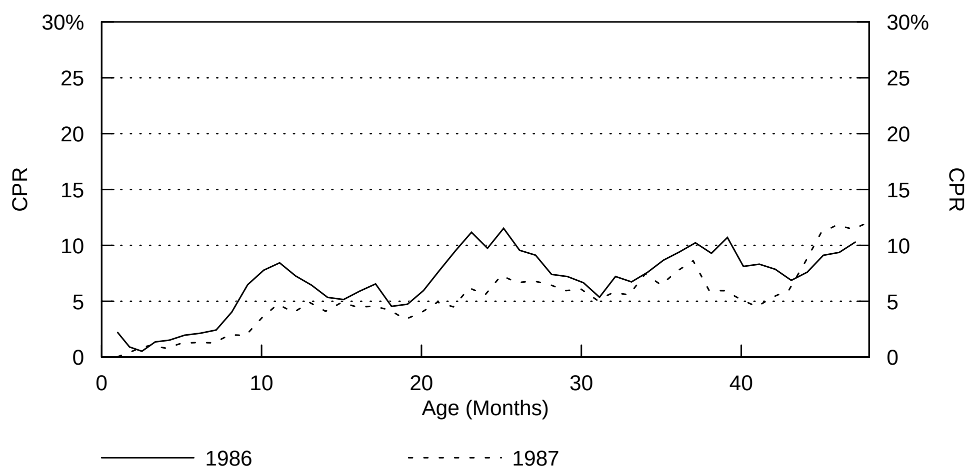
On balance, we believe that a high percentage of refinancings is still likely to lead to a somewhat faster seasoning process. The fixed-rate 30-year mortgage has retained its popularity as the refinancing vehicle of choice for mortgagors with an existing 30-year loan. For example, in 1993 the percentage of 30-year conventional mortgage holders refinancing into another 30-year fixed-rate loan was 52%, compared with 57% in 1986. This comparison suggests that the characteristics of borrowers refinancing into a 30-year loan were not substantially different in 1993 than in 1986.

However, the data to prove this theory is limited. The loans refinanced in 1991 and 1992 were themselves subject to refinancings in 1992-93. Data from the

1986-87 refinancing episodes do suggest faster seasoning for refinanced loans, but care has to be taken in separating the effects of seasoning from other factors such as a strong housing market and the amount of points paid. In Figure 7, we compare the seasoning ramp of the FNMA 30-year 9.5% pass-throughs backed by mortgages originated respectively in the fourth quarters of 1986 and 1987. Other characteristics, such as points paid, are comparable, yet the 1986 cohort, with a higher percentage of refinancings at origination, prepaid faster.

Refinanced loans may season faster.

Figure 7. Seasoning Ramp of FNMA 30-Year 9.5 Backed by Mortgages Originated in 4Q 86 Versus 4Q 87



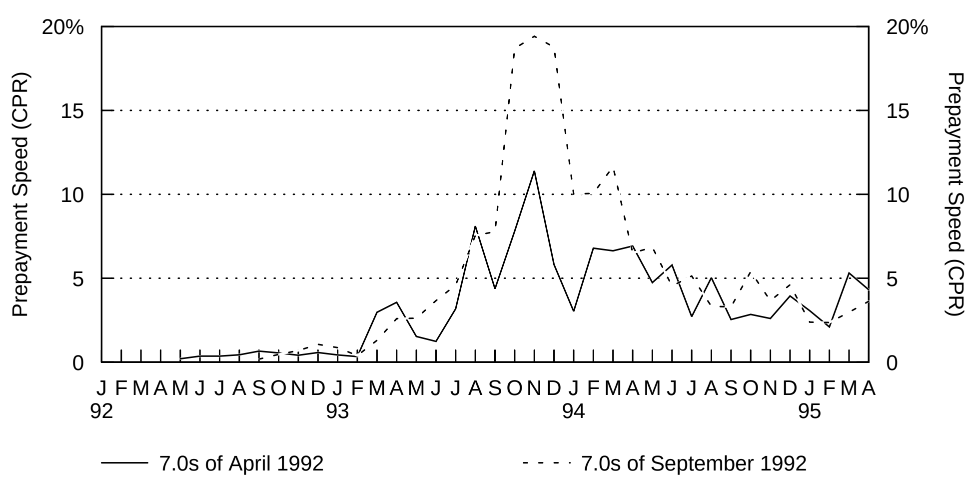
Source: Salomon Brothers Inc.

The data available for discount collateral originated after 1992 seems inconclusive on the distinction between the seasoning rates of refinanced versus purchased loans. Future speeds on these loans should help to resolve the issue. In the meantime, our model conservatively projects a slightly higher trajectory of prepayments during the seasoning period based on the percentage of refinancings at origination.

• **The "points" effect.** Another distinguishing feature useful in predicting seasoning characteristics is the estimated points paid at origination. It has become common for lenders to offer loans with differing amounts of points. At one extreme are "low-point" or "no-point" loans, with which the borrower accepts a higher coupon rate in exchange for a lower down payment. As discussed later in the section on refinancings, such borrowers tend to be "fast" refinancers. At the other extreme, borrowers can pay extra points to obtain a lower coupon rate. Both theory and empirical evidence indicate that borrowers who choose to put down points to lower their rates are signaling an intent to stay for some period of time. Although the number of points paid is not part of the available data for agency mortgage pools, we can estimate it from the difference between the prevailing mortgage rate at the time of origination and the WAC of the pool.

Figure 8 compares FNMA 7s (with WACs of around 7.60% to 7.70%) originated in April and September 1992. Mortgage rates in early 1992 were around 8.50% to 8.80%, suggesting that borrowers paid substantial points to obtain mortgages with rates below 8%. By the late summer, mortgage rates were close to 8%, indicating that the September 1992 FNMA 7s contain mostly "normal point" loans. The April 1992 FNMA 7s have prepaid much more slowly in PSA terms than the September 1992 FNMA 7s. Even on a CPR basis, the April 1992 FNMA 7s have been slower, despite their extra six months of seasoning.

Figure 8. The Effect of Points Paid on Discount Speeds



The Salomon Brothers Prepayment Model uses the difference between the rates prevailing at the origination date of the loans and their WAC to deduce the points paid and their effect on turnover and seasoning behavior.

The Lock-In Effect: Disincentive and Assumability

Lock-in refers to the disincentive to move due to the existing loan being a discount, so that a new home would also entail a higher mortgage rate; for FHA/VA loans, which are assumable, the effect is stronger because even if the current homeowner decides to move, the new buyer may well decide to assume the existing loan. While the lock-in effect is often considered part of the seasoning process, it is worth a separate discussion, because of its importance and because it depends on factors other than age.

It is possible that low speeds on newer discounts, which appear to reflect a lock-in effect, could well be caused by other factors such as the points effect discussed above. Given that this is not the case for a particular cohort of discount loans and that the lower speeds are in fact due to a lock-in effect, how do we model the effect? Common sense suggests that over time, as inflation makes the price of a new home larger relative to the existing loan balance, both the disincentive to move and (in the case of FHA/VA loans) the likelihood of a new buyer assuming the existing loan will diminish over time. In fact, a straightforward economic argument shows that the disincentive to move (and the incentive to refinance) is a function of two quantities:

(1) The present value cost per dollar of changing from an existing loan rate of C to a new loan rate M, which we estimate as

$$1-\frac{\mathrm{C}}{\mathrm{M}}*\frac{1-(1+\mathrm{M}\_-^{(\mathrm{TERM}-\mathrm{AGE})}}{1-(1+\mathrm{C})-^{\mathrm{TERM}}} \qquad (1)$$

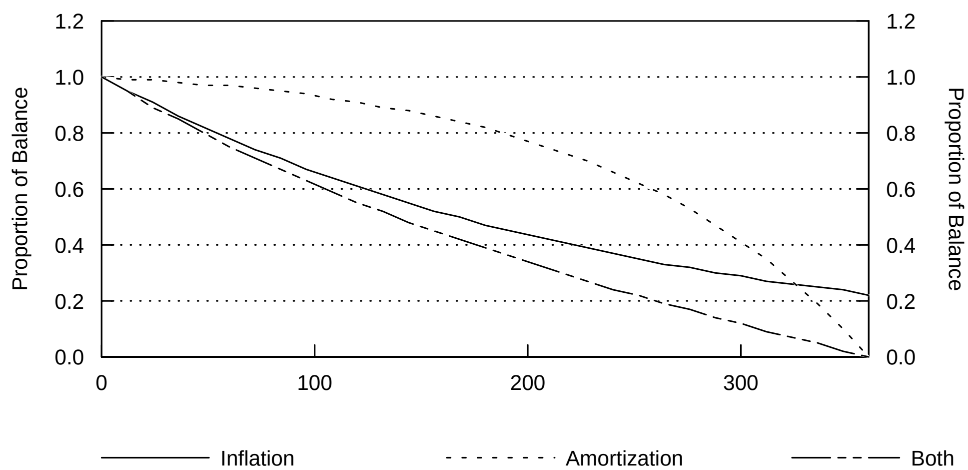
where C and M are expressed as monthly decimals, TERM is the original loan term, and AGE is the number of months since loan origination; and

(2) The amortized loan balance as a proportion of the likely amount of a new loan (that is, the amortized inflation-adjusted balance of the existing loan). We estimate this as

$$\frac{(1+C)^{TERM} - (1+C)^{AGE}}{INF * [(1+C)^{TERM} - 1]}, \tag{2}$$

where INF is a deflator based on the cumulative housing inflation rate from the mortgage origination date to the present. Figure 9 shows a plot of the amortized loan balance, the inflation deflater (1/INF), and the combined value (Eq. (2)), assuming a 360-month original term and an inflation rate of 5% per year.

Figure 9. Amortized Inflation-Adjusted Loan Balance Over Time



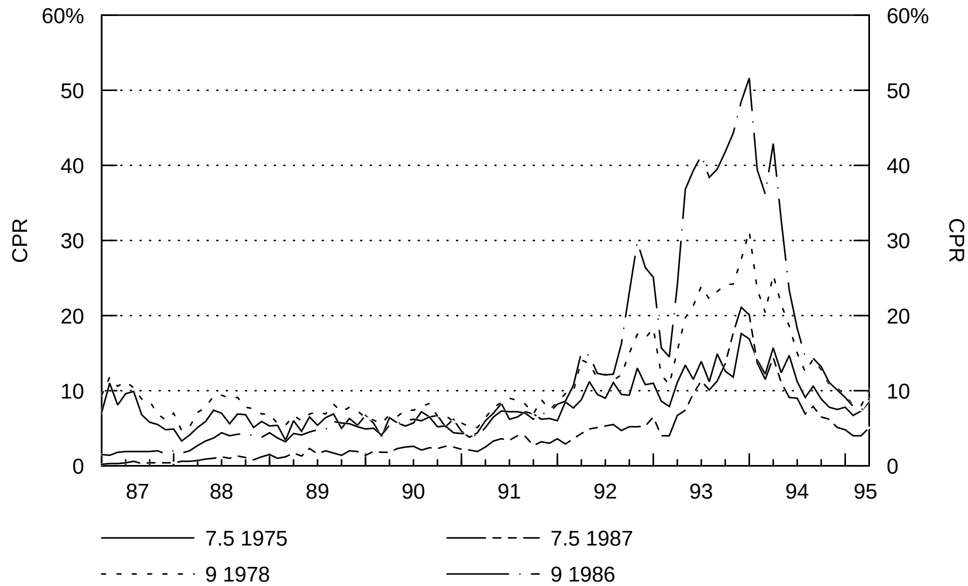
Source: Salomon Brother Inc.

In essence, we are assuming that the lock-in effect is a function of the relative coupon differential between the loan rate and current rates and that it diminishes over time because of housing inflation (and to a lesser extent, amortization).

Figure 10 illustrates the effects of inflation, amortization and assumability using GNMA 7.5s and 9s issued in the 1970s and 1980s. The 1987 7.5 GNMAs, newer discounts that were attractive to assume throughout the late 1980s, had the slowest seasoning ramp, whereas the 1986 9s, which were less attractive to assume, seasoned within the first three years of origination. In contrast, the 1970s coupons experienced brisk prepayments throughout the late 1980s, with even the 1975 7.5s reflecting diminished lock-in and assumability because of several years of above-average housing inflation along with regular amortization.

GNMA speeds show interaction of inflation, amortization and assumability.

Figure 10. GNMA 7.5s and 9s, 1970s versus 1980s Originations



Source: Salomon Brothers Inc.

The Salomon Brothers Prepayment Model calculates the LTV throughout the life of the mortgage, using it to compute the negative impact of lock-in and assumability on prepayments.

Housing Inflation and Geographical Factors

Apart from the lock-in effect, housing inflation also can affect the ability of a homeowner to move. Rapid price appreciation leads to a quick increase in the amount of equity in the home, which can spur "trade-up" moves, as well as reflect a generally vigorous housing market. In contrast, price depreciation will dampen the ability to move and overall housing activity.[7]

To a large extent, observed differences in speeds between geographical areas often reflect differences in the current state of the housing markets in the respective areas. Such differences are often transient. For example, the Pacific Northwest has had one of the most active housing markets over the past few years; ten years ago, because of recessions in the lumber and aircraft industries, it had one of the slowest.[8] This observation indicates that care should be taken in applying geographical adjustments to projections on a long-term basis, unless long-term underlying factors are behind geographic differences. An example of the latter would be California speeds, which because of the demographics of California's population, might be expected to be typically faster than the average.

Recognizing the highly specific and transitory nature of inflation and regional economic conditions on prepayments, we have based the Salomon Brothers prepayment model on an expected rate of national housing inflation derived from the demographic outlook and historical trends. Specific adjustments to this basic projection may be made where warranted after careful analysis of the data underlying certain pools or deals on a case-by-case basis.

Loan Type

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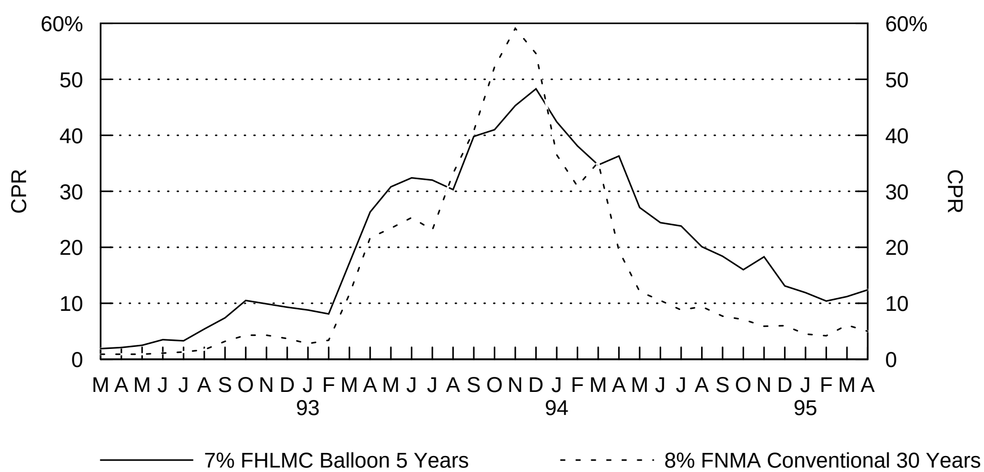
[7]This observation also applies, of course, to the ability to refinance a loan.

[8] See *Regional Differences in Mortgage Prepayments*, Salomon Brothers Inc, August 1984.

Observed speeds on discounts tend to vary by loan type; for example, balloon discounts typically prepay faster than conventional discounts, which in turn usually prepay faster than GNMA discounts. A large proportion of these differences result from differences in the loan characteristics described above. However, even after controlling for the latter, a residual difference often remains resulting from self-selection or demographics. For example, observed speeds and anecdotal evidence from originators indicate that borrowers who select balloon loans often expect to move again soon, leading to a higher base-line mobility rate (as well as faster seasoning) than the average.

An example of such loan-specific differences may be found by comparing FNMA 30-year 8% mortgages from 1992 with FHLMC 5-year 7% balloons from the same origination year, as shown in Figure 11. While the overall pattern of prepayments is the same for the two classes, the shorter seasoning ramp and, the higher overall level of turnover rates (a balloon mortgage is often chosen by borrowers who intend to move in a relatively short period of time) are indications of the fundamental differences engendered because of the characteristics of the loan type.

Figure 11. The Effect of Loan Type: Speeds on FNMA 30-Year 8s and 5-Year FHLMC Balloon 7s



Source: Salomon Brothers Inc.

The Salomon Brothers model was developed first to take full advantage of universal mortgage characteristics to explain as much of the variation in prepayments as possible. However, the model also reflects the specific characteristics of each loan type, provided they satisfy the following carefully observed conditions:

• Systematic differences in prepayments between the loan type and other loan types persist after variations due to the universal variables common to all types have been removed.

• The differences may be explained logically by differences in the nature of the loan terms, regulations, borrower characteristics, geography, etc.; and

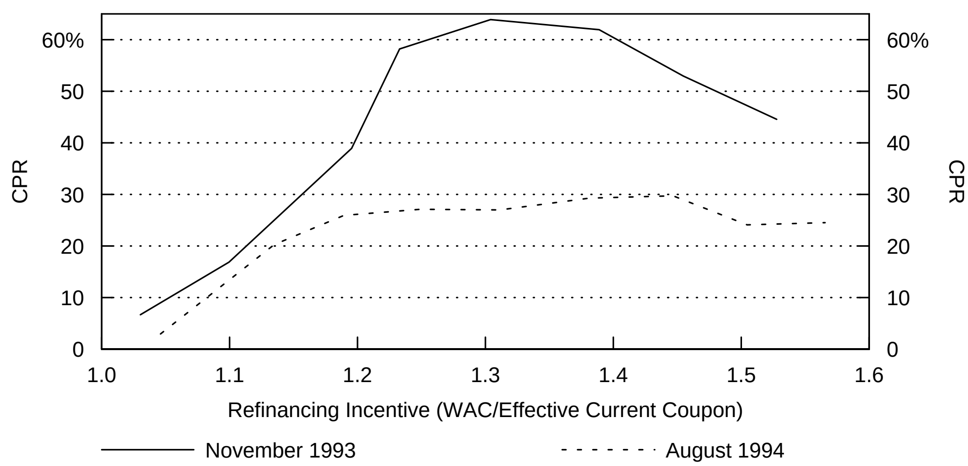
- The differences are consistent over the period for which data is available for the loan type, and the model as amended provides a superior fit (by statistical and other measures) to the data.

A consistent application of these principles has led to a family of models that are identical in their fundamental structure for the full universe of mortgage instruments, including GNMA, FNMA and non-agency mortgages, with 30-year and 15-year maturities as well as 5-/7-year Balloon and ARM products. Yet, each is custom-fit to predict the idiosyncrasies of the prepayments of the individual instrument it represents with the precision expected of an independently developed model.

Very high prepayment speeds are primarily due to refinancings. Housing turnover by itself will rarely lead to prepayment rates above 10%-12% CPR. Hence, an accurate modeling of prepayments during market rallies such as those from 1991-93, when speeds sometimes exceeded 60% CPR, requires a sound understanding of refinancing behavior.

A refinancing is an economic prepayment and can be thought of as an exercise of a call option on the existing loan by the mortgagor. However, traditional option theory is of limited use in analyzing refinancings, because mortgagor behavior seems to represent an inefficient exercise of the option. This observation is illustrated in Figure 12, which shows prepayment rates versus refinancing incentive at two different points in time.[9]

Figure 12. Prepayment Rates on FNMAs versus Refinancing Incentive, Nov 93 and Aug 94



Source: Salomon Brothers Inc.

Both sets of speeds display the familiar "S-curve" known to all mortgage analysts. This curve is an approximation to the "0-1" step-function that represents an efficient option exercise by the mortgagor; that is, do not refinance if the savings from a refinancing is less than some hypothetical transaction cost and refinance otherwise. A striking feature of Figure 12 from an option-theoretic point of view, albeit one very familiar to anyone who has looked at prepayment speeds, is the difference between the speeds in November 1993 and August 1994; for the same refinancing incentive, speeds in August 1994 were one third to one half of what they were nine months earlier. This phenomenon, whereby refinancing rates decline over time even if no change occurs in the refinancing incentive, is known as "**burnout.**" This term, often misunderstood and sometimes controversial, is typically understood to mean that a pool of mortgages that experienced previous exposure to refinancing opportunities will have lower refinancing rates than a pool with no such prior exposure. It also explains why the speeds in Figure 12 actually begin to decline for higher

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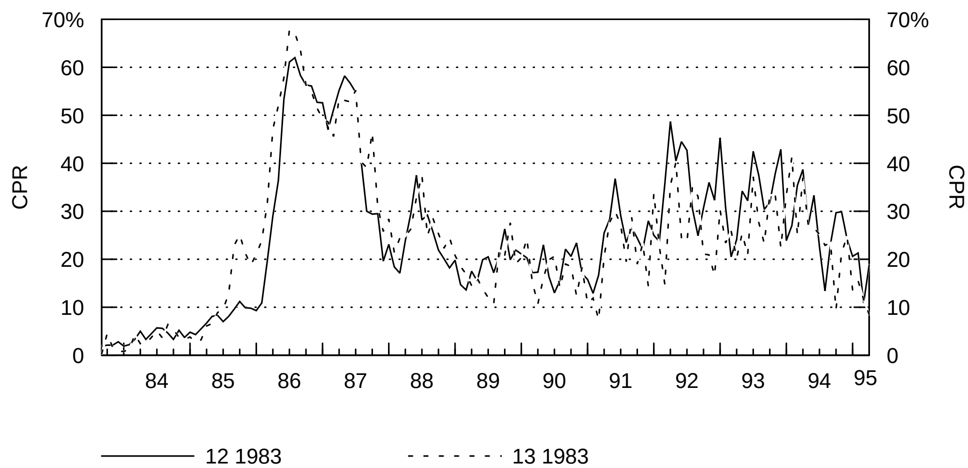
9 As discussed in the box on page XX, we use the ratio of the coupon on the refinanced loan to the refinancing rate to measure refinancing incentive.

refinancing incentives; these coupons have had greater past exposure to refinancing opportunities.

The market's belief in burnout was severely shaken in the refinancing waves of 1991-93, when speeds on many coupons remained at stubbornly high levels, or even increased, during successive waves. Furthermore, the speeds of many high-premium coupons from the early 1980s, which were considered completely burnt out, more than doubled in this period. We show this pattern in Figure 13, for 1983 origination FNMA 12s and 13s.

Figure 13. Prepayment Speeds on FNMA 12s and FNMA 13s



Source: Salomon Brothers Inc.

The FNMA 12s and 13s experienced a heavy round of refinancings in 1986 and 1987, and then, from 1988 to early 1991, gradually stabilized at an average speed of around 18% CPR. Two additional factors seemed to confirm the heavy hand of burnout. First, for much of the 1988-90 period mortgage rates averaged about 10%, around the same level prevailing at the time of the first spike in 1986; however, speeds on the FNMA 12s and 13s were roughly one third of the peak values in 1986. Second, speeds on the FNMA 12s averaged about the same as those on the FNMA 13s, despite the roughly 100-basis-point higher coupon on the 13s. Hence, the jumps in speeds for the FNMA 12s and 13s in 1991 and 1992 are difficult to understand in the context of burnout and amount of refinancing incentive.

We feel that burnout, and refinancing patterns in general, are best modeled within a behavioral or statistical framework.

How Do We Measure Refinancing Incentive?

The traditional measure of refinancing incentive has been the difference, or spread, between the WAC and prevailing mortgage rates. This measure is simple and easily understood. However, the experience in the 1991-93 refinancing waves suggested that refinancing from a 9% loan to a 7% one was not quite the same as refinancing from a 12% loan to a 10% one. The fact that 9% to 7% represents a significantly bigger percentage savings than 12% to 10% was cited as a reason that some spread-based prepayment models underpredicted refinancing levels for this period.

A straightforward argument shows that, in present value terms, the savings per dollar from refinancing a loan with rate C to a new loan at a rate M is

$$\frac{C}{M} * \frac{1-(1+M)^{-(TERM-AGE)}}{1-(1+C)^{-TERM}} - 1, \qquad (3)$$

where C and M are expressed as monthly decimals, TERM is the original term of the existing loan in months and AGE is the number of months since origination. If the mortgage loan is still in the first half of its term, Eq. (3) can be approximated by

$$\frac{C}{M} - 1$$

which argues for using a ratio rather than a difference to measure refinancing incentive. Some data from FHLMC seems to offer further evidence for using the ratio.[10] For refinancings from 1986 to 1994, FHLMC examined the rates on the refinanced loan and on the new loan. Its analysis showed that while the average difference, C-M, between the new and old loan rates has been narrower in the past few years than in 1986-87, the average ratio, C/M, was pretty constant (at around 1.30). Of course, it is possible that this evidence just reflects a more efficient mortgage market, with borrowers now willing to refinance for a lower coupon differential

In reality, different mortgagors will look at the potential savings from a refinancing in different ways. Furthermore, the possibility of being able to refinance from, say a 30-year loan into a 15-year loan, means that the mortgagor can consider a complex mix of rates and monthly payments. We have chosen to base our refinancing function on the ratio rather than difference (with the refinancing rate M reflecting both 30-year rates and shorter-maturity refinancing alternatives), for two reasons. First, from Eq. (3), basic economic arguments imply using the ratio. Second, and perhaps more important, it allows us to fit speeds well in both the 1986-87 and 1991-93 refinancing waves, something difficult to do if we use the spread difference to measure refinancing incentive

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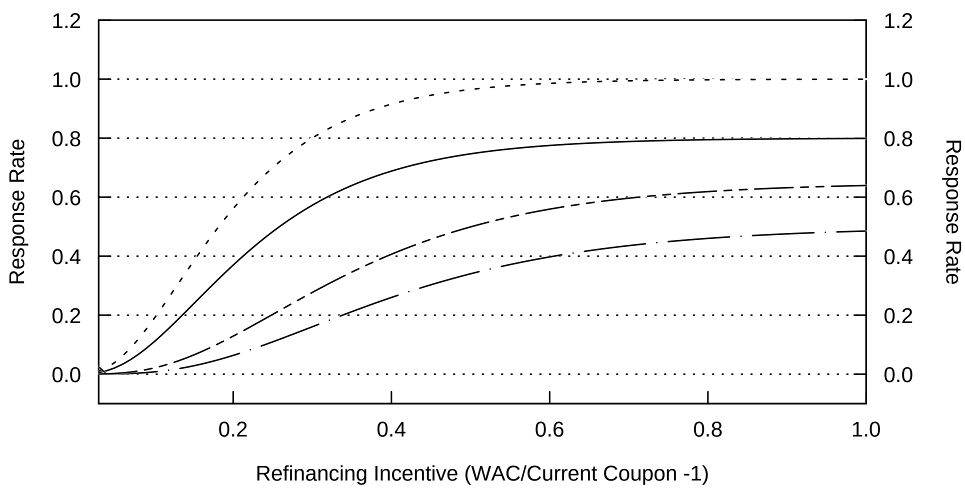
[10] See *Secondary Mortgage Markets*, Mortgage Market Review, FHLMC, 1994.

Explaining Refinancing Patterns Using a Statistical Approach

In previous publications, one of the authors has outlined a statistical approach to describing refinancing patterns.[11] The Appendix gives a mathematical description of this approach. Its basic elements are as follows:

• **Diverse pool of mortgagors.** The mortgagors in a given pool are assumed to differ in their intrinsic propensity to refinance. The simplest case is to assume that each person is either a "slow" or a "fast" refinancer. At the other extreme, we could assume that there is a continuous spectrum of borrower types. Different borrower types have different response rates (likelihoods of refinancing) for a given level of refinancing incentive, as illustrated in Figure 14.

Figure 14. Refinancing Curves for Different Borrower Types



WAC Weighted-Average Coupon
Source: Salomon Brothers Inc.

All of the refinancing curves in Figure 14 have the familiar empirically observed S-shaped curve that speeds tend to follow and that is displayed in Figure 12. The refinancing rate is low for a low incentive, accelerates as the incentive increases (the "cuspy" part of the refinancing curve) and levels off, as further incentive increases seem to have little incremental impact. However, the rate at which the refinancing response rate rises with incentive, and the cuspiness or steepness of the curve, varies according to borrower type.

The observed refinancing rate for the pool will be the average of the refinancing rates for the different categories of borrowers, weighted by the proportion of the pool in that category in that particular month. For example, if in month one half the mortgagors are "slow" refinancers with a refinancing rate (for a given level of refinancing incentive) of 2% per month, and the other half are "fast" refinancers with a rate of 18% per month, then the expected refinancing rate for the pool in month one will be 10%.[12]

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[11] See, for example, "A Simple Statistical Framework for Modeling Burnout and Refinancing Behavior," Lakhbir Hayre, *Journal of Fixed Income*, December 1994.

[12] In general, the pool refinancing rate is the expected value across the probability distribution of borrower types and is given by Equation (A1) in the Appendix.

• **Evolution of the pool over time.** As the pool undergoes refinancings, faster refinancers will leave the pool at a faster rate. For example, in the simple "slow"/"fast" case discussed above, 18% of the fast refinancers, but only 2% of the slow refinancers, will leave the pool each month. Hence the slow refinancers will form an increasingly larger proportion of the remaining population, and other things being equal, the refinancing rate of the pool will gradually slow down toward the 2% rate of the slow group.[13] This gradual slowdown in the pool refinancing rate, caused solely by the change in the pool's composition as faster refinancers leave at a faster rate, is what we term burnout.

• **The media effect and the migration of borrowers.** We have assumed that the intrinsic refinancing propensity of a borrower does not change over time. The experience of the past few years has made it fairly obvious that this is not the case. Borrower propensities can change for a variety of reasons:

(1) A blitz of media publicity about refinancing opportunities after a big market rally (especially pronounced when rates hit generational lows in 1992 and 1993);

(2) More proactive mortgage lenders when refinancing rates are at attractive levels; or

(3) Dormant accumulated changes in the personal circumstances of borrowers who did not refinance in the past (improved credit, more equity in the home, etc.).

The first two reasons will lead to a higher overall level of refinancings, while the combination of all three will lead to a pickup in the speeds of even very seasoned, burnt-out coupons, as illustrated by the FNMA 12s and 13s in Figure 5.

This phenomenon has been labeled the *media effect*. In terms of our statistical framework, it can be modeled as a shift in the distribution of borrowers toward a higher average refinancing propensity, which can temporarily overwhelm the downward trend in average refinancing propensity resulting from burnout.

Modeling the Media Effect

How do we actually capture the media effect? Clearly, it will be high when a widespread impression prevails that mortgage rates are low relative to "historical levels." At the same time, the recent rather than the distant past will tend to weigh more in people's minds. The Salomon Brothers Prepayment Model uses a comparison of current mortgage rates to a weighted average of past rates to estimate the media effect. Figure 15 shows 30-year mortgage rates, a weighted average of past mortgage rates and the ratio of the two.

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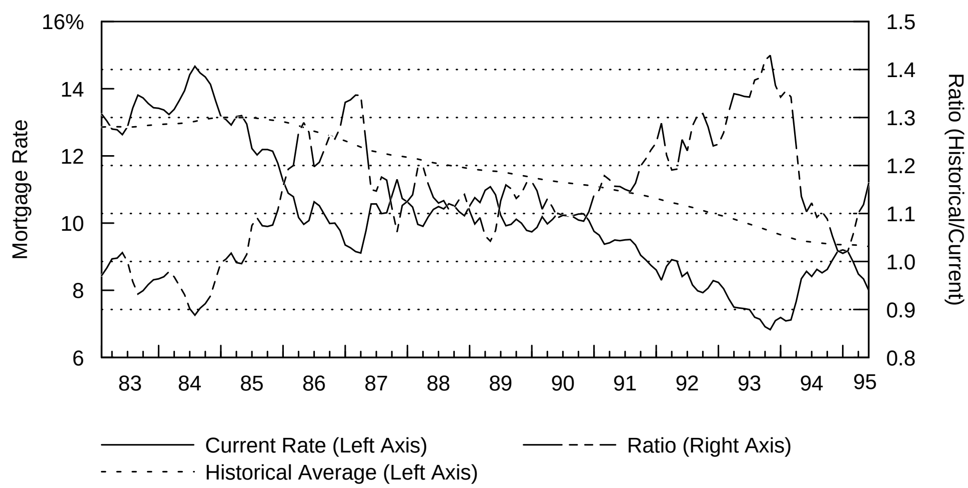
[13] Equation (A2) in Appendix B gives a mathematical model of the evolution of the population mix. A detailed examination of the "slow"/"fast" case is given in the Salomon Brothers publication "A Simple Statistical Framework for Modeling Burnout and Refinancing Behavior," Lakhbir Hayre, *Journal of Fixed Income*, December 1994.

Figure 15. Modeling the Media Effect: A Comparison of Current and Historical Mortgage Rates, 1983-94



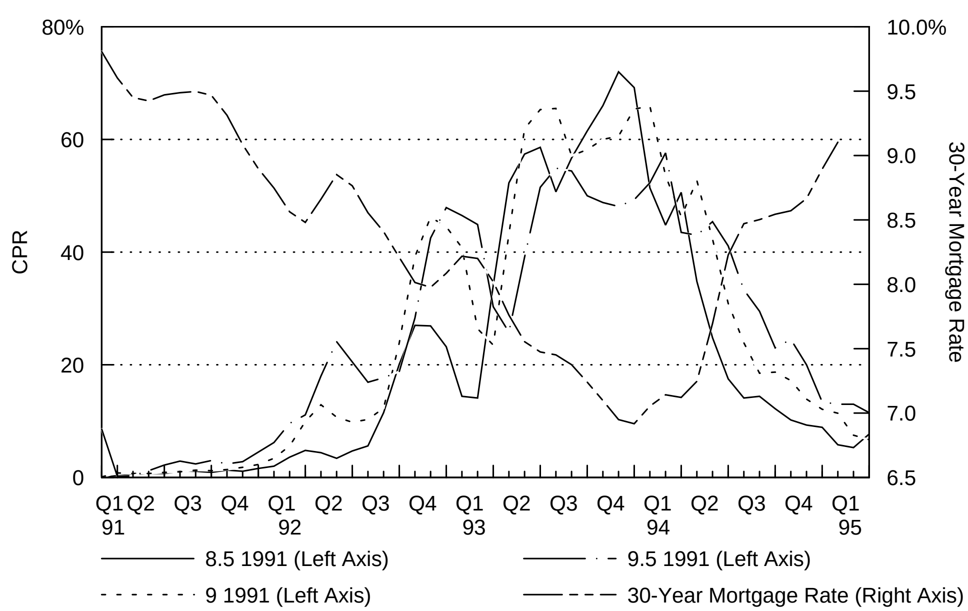
Source: Salomon Brothers Inc.

The ratio of the historical average rate to the current rate has been an excellent indicator of the level of refinancing activity. The ratio first peaked in the spring of 1986, had a slightly higher peak in early 1987, then remained relatively low until early 1991, before reaching a series of ever higher peaks through the end of 1993, faithfully following the refinancing waves that occurred in this period.

Capturing a Complex Combination of Effects

The interaction of refinancing incentive, burnout and the media effect can be seen in Figure 16, which shows historical speeds on 1991 FNMA 8.5s, 9s and 9.5s.

Figure 16. Speeds on 1991 Origination 8.5s, 9s and 9.5s, and 30-Year Mortgage Rates

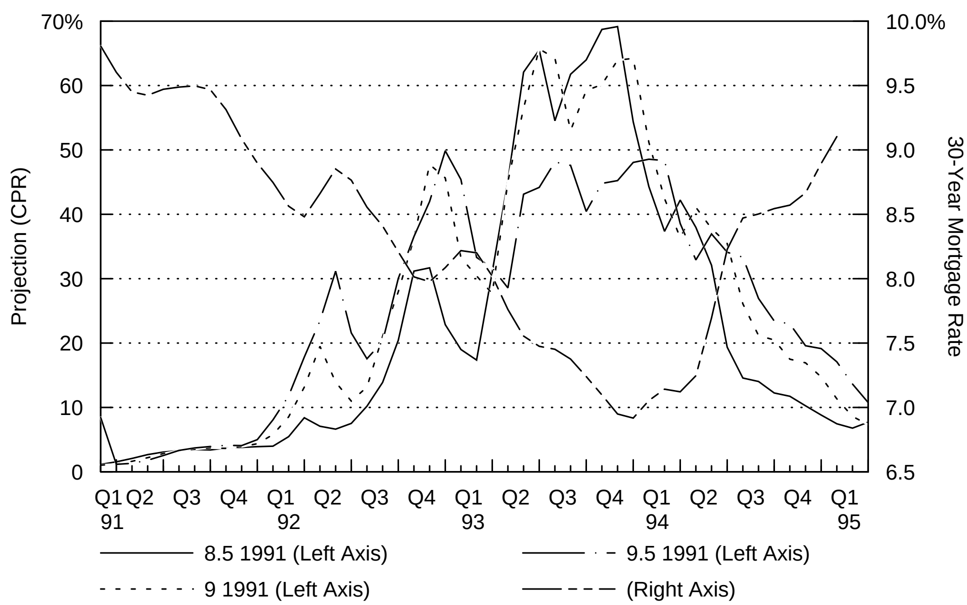


Source: Salomon Brothers Inc.

In 1992 and 1993, mortgage rates followed a consistent pattern of hitting a multiyear low, briefly stabilizing or slightly backing up, before declining again to hit another multiyear low, and in October 1993 culminating in the lowest rates seen for almost 30 years. This led to a corresponding pattern in prepayment speeds. Speeds would spike as rates declined, then start declining as rates stabilized or backed up -- even though ample refinancing incentive still remained -- as burnout begin to play a role. However, a new multiyear low, and the media publicity it generated, led to a new and higher spike. Burnout was still present, as exemplified by the 8.5s' prepaying at higher rates than the 9.5s in 1993, but its effect was fairly weak in the refinancing frenzy that occurred during this time.

Figure 17 shows projected speeds for the three coupons in Figure 16. A comparison of Figures 16 and 17 shows a close match between the actual and projected speeds, indicating that the Salomon Brothers Prepayment Model faithfully captures this complex combination of effects driving speeds in this period.

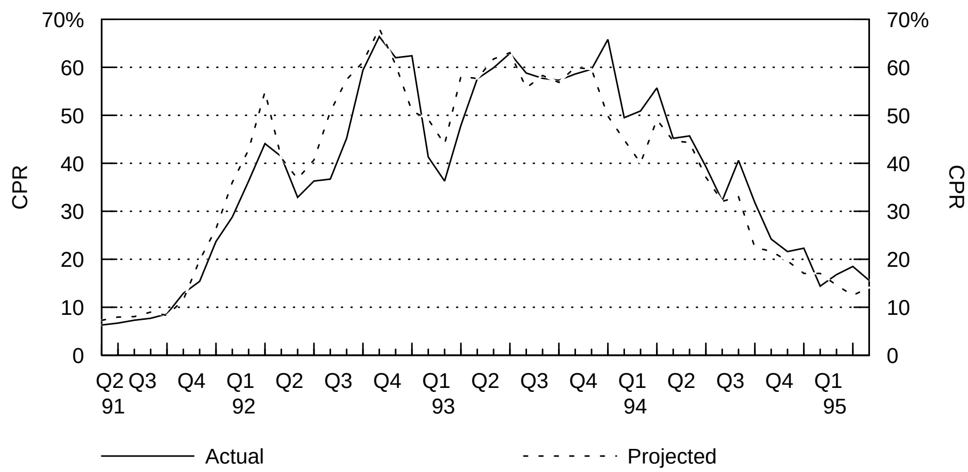
Figure 17. Projected Speeds on 1991 FNMA 8.5s, 9s and 9.5s



Source: Salomon Brothers Inc.

Two more graphs illustrate the changing effect over time of refinancing incentive, burnout and the media effect. Figure 18 shows actual and projected speeds on 1990 origination FNMA 7-year balloons. Speeds on this coupon started accelerating in early 1992 and stayed well over 50% CPR for most of the period from the fall of 1992 to early 1994, suggesting a close balancing of increases in refinancing incentive, burnout and the media effect.

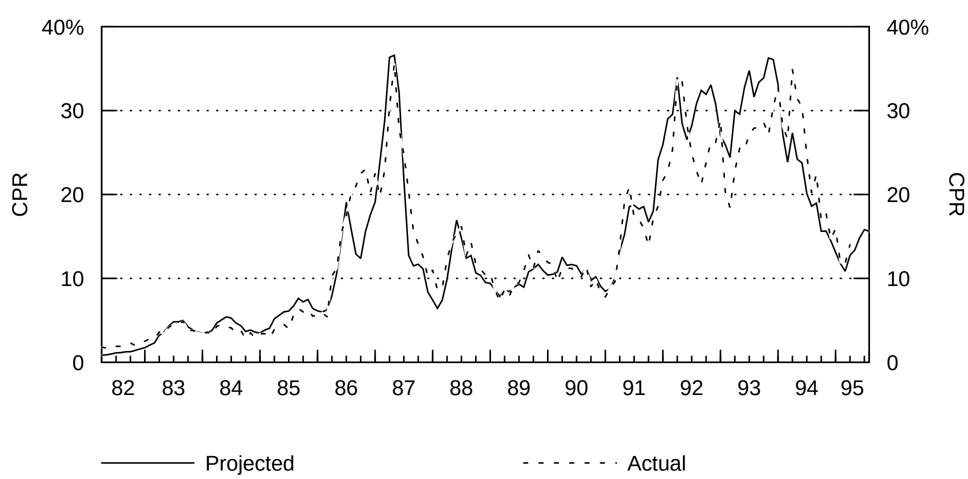
Figure 18. Actual and Projected Speeds on 1990 FNMA 7-Year Balloons



Source: Salomon Brothers Inc.

Finally, Figure 19 shows actual and projected speeds on 1980 GNMA 11s, a seasoned coupon that has seen its share of interest rate and economic cycles, not to mention several refinancing waves. This coupon went through its first refinancing wave in 1986 and early 1987, then settled into a typical burnt-out state for several years before beginning a series of spikes in 1991, and finally entered a sustained decline in speeds in early 1994. The projected speeds closely track the actual ones for most of the 14-year period shown in Figure 19, suggesting that, despite the widespread perception of fundamental changes in the mortgage markets, a well-formulated model can withstand the test of ages.

Figure 19. Actual and Projected Speeds on 1980 Origination GNMA 11s

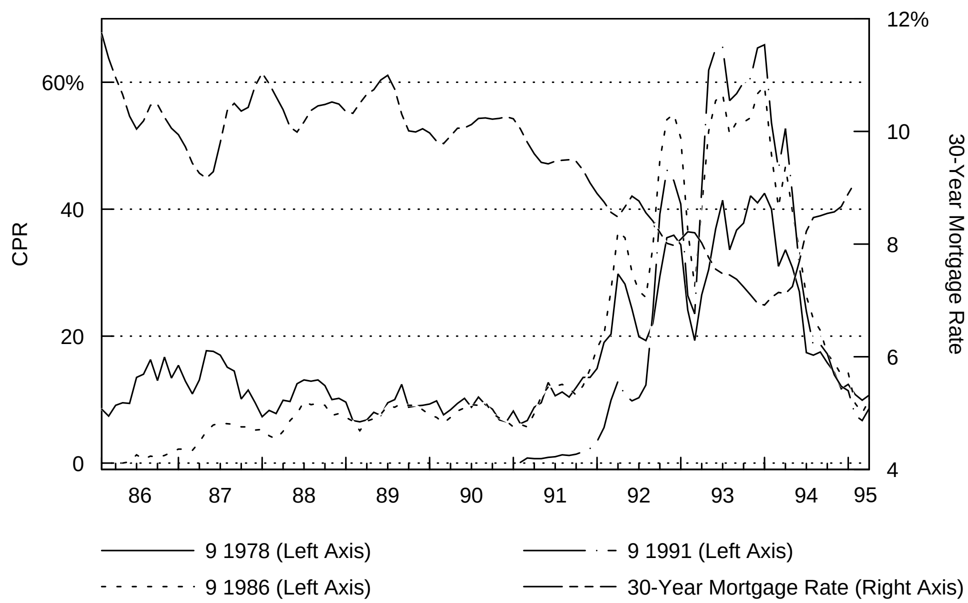


Source: Salomon Brothers Inc.

The Effect of Relative Loan Size

The combination of refinancing incentive, burnout and the media effect explain a large proportion of the refinancing patterns seen during the past few years. One feature not captured is the slower response of very seasoned loans, which is illustrated in Figure 20.

Figure 20. Speeds on 1978, 1986 and 1991 FNMA 9s



Source: Salomon Brothers Inc.

Although the 1978 FNMA 9s had a mild degree of refinancing exposure in 1986-87, essentially all three coupons had no burnout prior to 1992. Despite this, the 1978 9s experienced significantly lower prepayment rates during 1992 and 1993 than the 1986 9s, which in turn were a little slower than the 1991 9s. This pattern is repeated for other coupons and sectors and is particularly pronounced for GNMAs; in the refinancing waves of 1992 and 1993, 1986-87 origination GNMA 8s through 9.5s prepaid at between 70%-80% of newer (90 and onwards originations) coupons, while 1970s origination 8s through 9s prepaid at only 50% of the newer coupons.

An explanation for the dampened refinancing rates of older coupons is not difficult to find. If a loan was taken out some time ago, housing inflation has made its balance small relative to current levels. If the loan is fairly seasoned, amortization has accentuated this process; for a loan halfway through its term (which means mid-1980s originations in the case of 15-year MBSs) the amortized loan balance will be about 80% of the original balance (not counting any curtailments). Given that a refinancing involves some fixed costs, as well as some general hassle and paperwork, obviously a smaller incentive exists to refinance a low-balance loan.

The Salomon Brothers prepayment model uses Equation (2) (see page XX), which gives the amortized, inflation-adjusted value of a $1 mortgage taken out a specified time ago[14] as the basis for dampening the refinancing responses of seasoned loan.[15] Figure 21 shows projections for the coupons in Figure 20; the adjustment based on equation (2) captures the differentials quite well.

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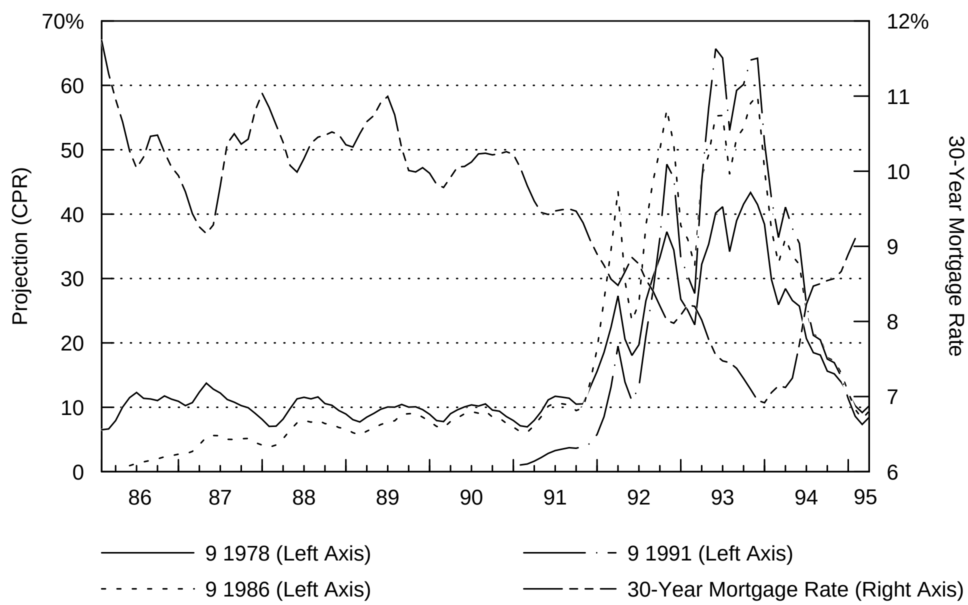
[14] This quantity can also be thought of as an estimated current LTV as a fraction of the original LTV. Figure 9 on page YY provides a graph of this fraction as a function of loan age.

[15] Note that this approach assumes that all the loans of a particular type originated at a given time had the same loan balances. If we know that a particular cohort has an average original loan balance different from the average for that origination period, this information can of course be combined with Equation (2) in adjusting the refinancing response.

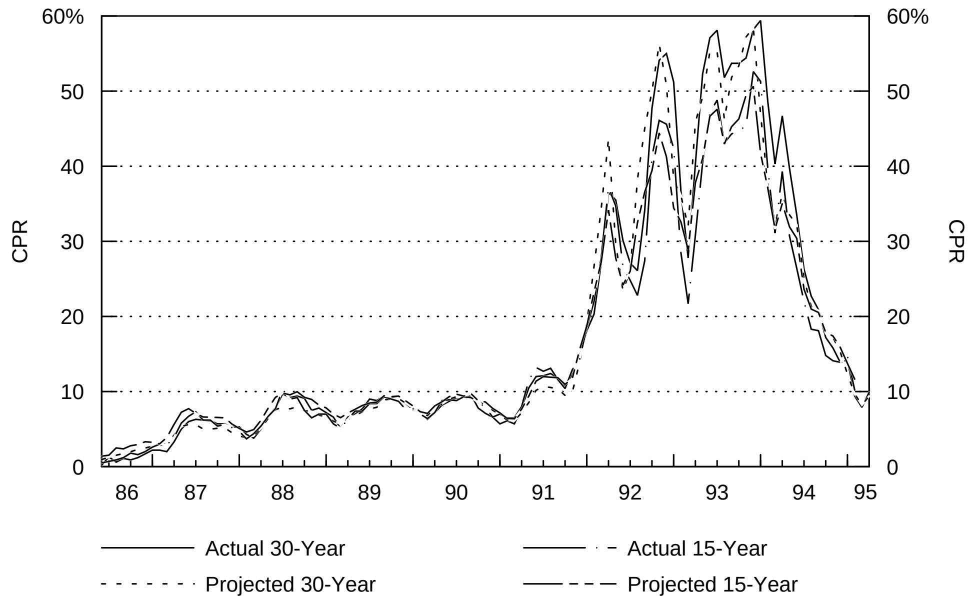
Figure 21. Capturing Differences in Loan Balances: Projected Speeds on 1978, 1986 and 1991 FNMA 9s



Source: Salomon Brothers Inc.

Amortization differences also explain why speeds on mid-1980s 15-year MBSs were slower during the recent refinancing waves than similar vintage 30-year MBSs. The slower 15-year speeds have sometimes been attributed to their smaller original loan balances vis-a-vis 30-year loans. However, speeds on post-1990 origination 15-year MBSs were just as fast as their 30-year peers. A more likely explanation is the faster amortization of 15-year loans; whereas the mid-1980s 30-year loans had very little principal amortization by 1992, the 15-year loan balances were down to about 80% of the original. This differential is captured by the amortization component in Equation (2), as illustrated in Figure 22, which shows actual and projected speeds for 1986 origination 15-year and 30-year FNMA 9s.

Figure 22. Capturing Amortization Differences: Actual and Projected Speeds on 1986 15-Year and 30-Year FNMA 9s



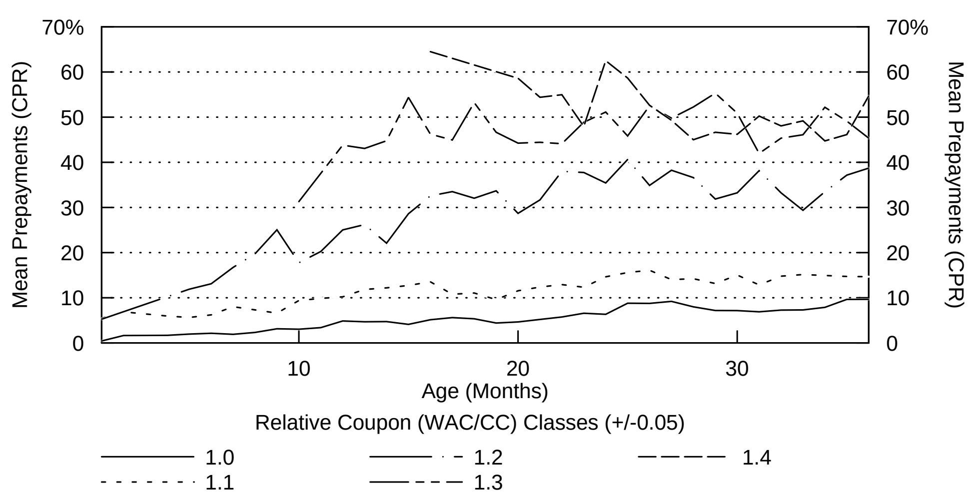
Source: Salomon Brothers Inc.

Seasoning Patterns for Newer Loans

In the previous section, we have discussed the dampened refinancing responses of older loans. What about newer loans ? The fact that a loan was taken out fairly recently will tend to dampen refinancing rates. However, as became apparent in 1992 and 1993, if sufficient refinancing incentive exists, speeds can accelerate sharply even for relatively new loans.

Figure 23 shows speeds of premiums by age and degree of refinancing incentive and makes clear the accelerated seasoning curve for well in-the-money mortgages.

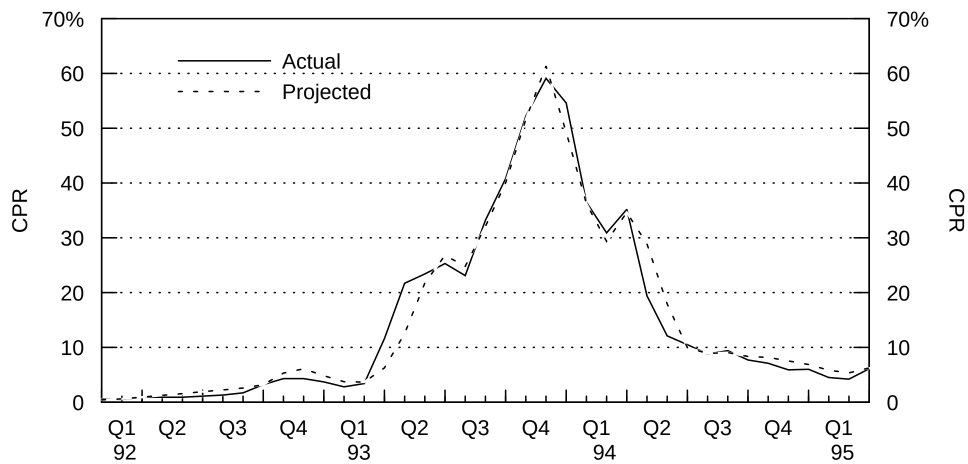
Figure 23. Speeds of FNMAs by Age and Refinancing Incentive



Source: Salomon Brothers Inc.

We use a refinancing seasoning curve that starts out above zero (to reflect the fast PSAs of very new premiums) and shortens as the refinancing incentive increases. Figure 24 shows actual and projected speeds for 1992 origination FNMA 8s. Actual speeds on these coupons reached 60% CPR in the fall of 1993, although they were barely more than a year old. The "elastic" seasoning ramp in the model allows projections to match these high actual speeds.

Figure 24. Actual and Projected Speeds for 1992 FNMA 8s



Source: Salomon Brothers Inc.

• **The "points" effect.** Another reason for the high speeds on newer premiums in 1992 and 1993 is that many were originated as "low-point" or "no-point" loans, with the borrower paying a higher coupon rate to reduce or eliminate refinancing costs. This practice not only leads to a very sharp seasoning ramp, but also means that the mortgagor only needs a minor drop in rates to refinance again into another "no point" loan. If a particular collateral is identified as consisting of such loans, then a very sharp seasoning ramp and an accelerated base refinancing curve is needed.

However, care has to be taken in identifying no-point loans. An above-market loan rate could either mean a no-point loan, or it could indicate credit or other difficulties; the latter may imply lower rather than faster prepayment levels for that segment of borrowers. Indeed, small amounts of premium pass-throughs have been originated at above-market rates since the late 1980s, but they did not prepay abnormally faster in the refinancing waves of 1992-93 -- if anything, they showed slightly **slower** refinancing rates than other comparable premiums.

The evidence therefore suggests that prepayments of mortgages originated above market rates would reflect the combined behavior of two very different types of borrower: (1) opportunistic refinancers who jump at the first refinancing opportunity, causing elevated prepayments in the initial years of the life of the pool; and (2) borrowers who could not get loans at or below market rate and who might depress prepayments over the longer term to some degree.

At the other extreme are the borrowers who pay high points to secure a below-market loan rate. As discussed in the previous section, the evidence indicates that such borrowers have a slow seasoning period as far as housing turnover is concerned. Is there evidence that such borrowers have a slow refinancing seasoning period as well?

Our analysis of the data clearly shows that they do. Indeed, as Figure 8 in the previous section illustrates with 1992 origination FNMA 7s, "high-point" coupons did prepay more slowly in the refinancing waves of 1992-93. As with other origination-related effects, the "curing" and seasoning process will, over time, eliminate these effects, so that their impact on the prepayments of say, a ten-year old mortgage pool, should be small to negligible.

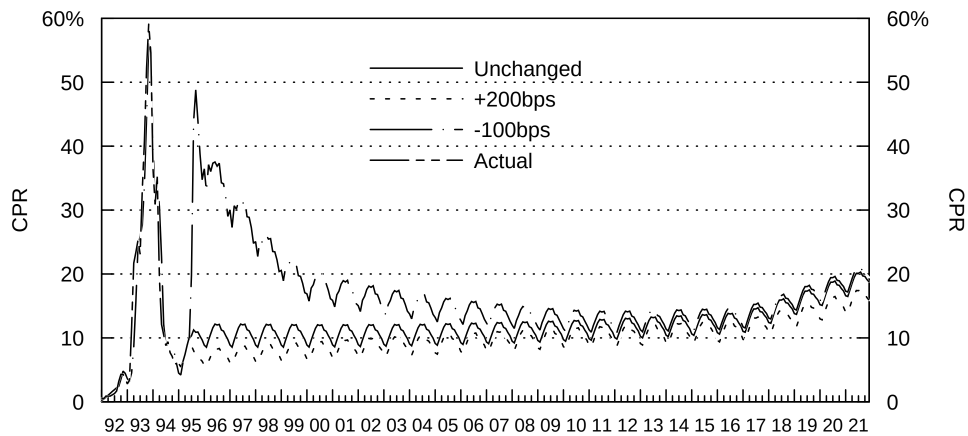
As mentioned earlier, our estimate of the points paid is based on the difference between the gross coupon and the prevailing mortgage rate at the time of origination. The Salomon refinancing submodel then takes account of "high-points" and "no-points" effects by appropriately adjusting the mortgage pool's refinancing response and rate of seasoning. Our application of the effect is careful and conservative, because substantial variation in mortgage rates across regions and originators reduces the accuracy of our estimate of points paid, diluting its predictive power.

While MBS investors often display a degree of skepticism about the long-term predictive power of prepayment models, they have little choice but to use them -- key valuation measures, such as OASs and effective durations, cannot be calculated without a prepayment model. Given this imperative, what do users need to be aware of concerning the uses, misuses and limitations of prepayment models?

Some Basic Properties of Model Projections

Figure 25 shows projections for a FNMA 8% pass-through under three assumed interest rates scenarios: rates unchanged; rates up by 200 basis points; and rates down 100 basis points.[16] The numbers shown are the vectors of monthly projections from the model.

Figure 25. Prepayment Projections for a FNMA 8%



Source: Salomon Brothers Inc.

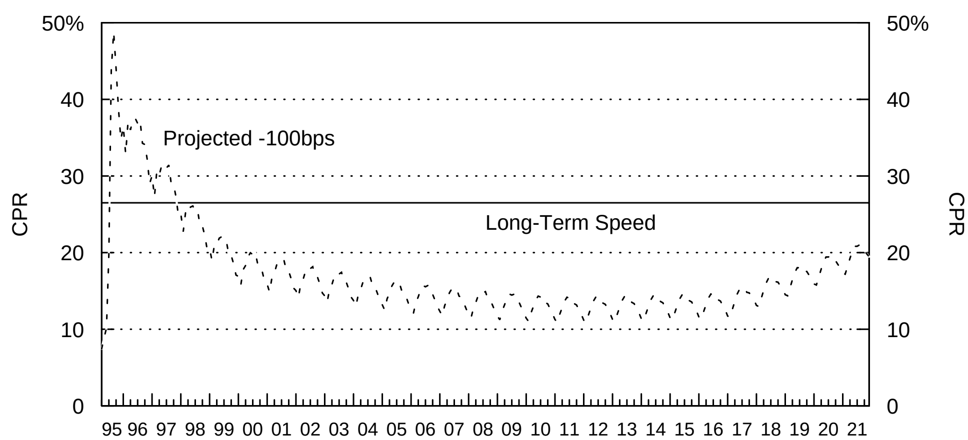
There are several points to note from Figure 25:

• **The conditional nature of projections.** Projections from a prepayment model are for a *for a specified path of interest rates*. In other words, projections are conditional upon the realization of the prescribed path of interest rates -- a path which in reality is never going to be *exactly* realized. While this observation will not be news to most investors, two implications are worth noting. First, prepayment projections should always be obtained for a variety of bullish and bearish interest rate scenarios. Second, in evaluating the accuracy of a model, it is necessary to determine what its projections were for interest rate scenarios approximating those which actually occurred. While many models did fail to accurately predict the high speeds that occurred in 1991-94, investors should remember that mortgage rates fell by approximately 300 basis points between 1990 and 1993; hence, the relevant predictions from 1990 would be those for a 300-basis-point drop in rates.

[16] We are assuming parallel shifts in interest rates.

• **Use long-term projections with care.** Even if interest rates were to stay unchanged forever, prepayments (actual and projected) would still differ over time, for a variety of reasons. Premium speeds tend to decline over time because of burnout; newer discount speeds tend to increase as a result of seasoning. On a month-to-month basis, seasonal factors can lead to double-digit percentage changes. Changes in speeds over time will be even greater in changing interest rate scenarios. For convenience and practicality, a long-term average of the projected speeds is typically reported as the model's projection.[17] The somewhat obvious point here is that a single long-term projected speed is inadequate for most investors. Figure 26 shows the vector and the long-term average speed for the FNMA 8s in the "down-100" scenario.

Figure 26. Monthly Projections and the Long-Term Average for FNMA 8s



The long-term average projection is below model projections for the first few years and above in later years. For an investor analyzing, for example, a short-term Collateralized Mortgage Obligation (CMO) bond, the long-term projection can be quite misleading. Yet a surprising proportion of investors still seem to evaluate MBSs using a single speed.

• **Noise: The random component of speeds.** Model projections represent a statistical estimate of the *expected* prepayment rates along a specified path of interest rates. Hence, random variation ("noise") means that actual month-to-month speeds will differ from projections even if the model is perfectly accurate (in this context, "perfectly accurate" just means that the average deviation will be zero). This is a particularly important point for CMO or Interest Only/Principal Only (IO/PO) deals; even for relatively large deals, the random errors can be significant.[18]

Our analysis shows that the effect of purely random variation in speeds has almost no impact on OASs of pass-throughs and a minimal impact for IOs and

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17 The long-term projection is a weighted average of the vector of month-by-month projections. The method used in the Salomon Brothers model is to find the single speed that gives the same average life as the vector; another common method is to find the single speed that gives the same yield as the vector.

18 For a discussion of random variation in speeds, see "Fact and Fantasy About Collateral Speeds," Michael Bykhovsky and Lakhbir Hayre, *Journal of Portfolio Management*, Summer 1992.

POs. In other words, if the model is accurate on average, then the averaging over many interest rate paths involved in OAS calculations minimizes the effect of noise.

Of course, no model is ever likely to be perfectly accurate for any length of time; projections incorporate a number of assumptions (explicitly or implicitly) about various factors (such as housing sales rates and housing inflation) which are unlikely to hold forever. In the next section, we discuss ways of quantifying the impact of systematic errors.

Prepayment Risk: Partial Prepayment Durations

We use the term prepayment risk to signify the risk that the market price will reflect prepayment assumptions that differ from model projections. This risk measure is distinct from the risk associated with interest rate movements causing changes in prepayments. We note that prepayment risk may arise either because actual prepayments are substantially different from projected levels (for example, because of structural changes in the mortgage finance industry and housing market) or because market expectations about prepayment prospects differ from model projections.

A useful measure of prepayment risk is the concept of **prepayment duration**. This was defined in an earlier Salomon Brothers publication[19] as the percentage change in price, holding OAS constant, for a given percentage deviation in speeds from some defined base level projections. The base level could be the straight model projections, or some market-implied multiple of the projections- for example, the multiple of the projections that would equalize OASs on the IO and PO of a chosen benchmark strip issue.

An extension of this concept is to calculate partial prepayment durations; that is, price sensitivity with respect to deviations from the projections for a specific component of speeds. One can define partial prepayment durations for any of the important variables discussed in the previous few sections. In general, the most important ones are the following:

• **Housing turnover rate.** The impact of higher- or lower-than- projected home sales.

• **Refinancing rate**. The impact of refinancing rates being higher or lower than projected refinancing rates.

We have computed overall prepayment durations as well as partial durations associated with these two components using the new Salomon Brothers prepayment model projections as the base. Figure 27 shows prepayment durations and partial prepayment component durations for these two components for a range of representative FNMA 30-year pass-throughs.[20]

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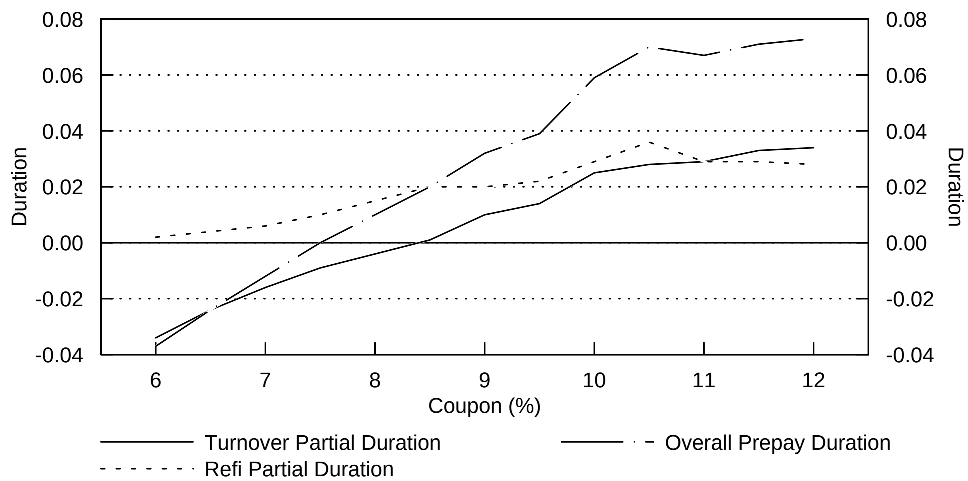
[19] *Beyond Duration: Dimensions of Mortgage Risk*, Michael Waldman, Salomon Brothers Inc, July 1992.

[20] The durations are calculated by the following formula:

$$D_c \frac{P_{-10} - P_{+10}}{20P_0} * 100 \text{ , where}$$

D_c = Prepayment partial duration w.r.t. component C, and
P_d = Price when projections for component C are changed by d% in Salomon Brothers prepayment model, holding OAS constant.

Figure 27. Prepayment Component Partial Durations



Source: Salomon Bothers Inc.

The durations represent the estimated change in price for a 1% change in prepayments associated with the total prepayment or prepayment component. From the formula in footnote 20, if slower than expected speeds lead to an increase in price the prepayment duration will be positive. Note that the current coupon for the calculations in Figure 27 is approximately 7.5%. We may draw a number of interesting observations from these durations.

The overall prepayment durations and partial durations for the turnover component are negative for discounts and current coupons, while they are positive for the premiums. This is because slower-than-projected speeds hurt mortgage pass-throughs in discount scenarios but help them when they are premiums. However, the partial durations for the refinancing component are always positive, because the refinancing component is zero except in premium scenarios, in which lower prepayments lead to higher prices. Newer premiums that have had less exposure to refinancing opportunity have the highest durations, because refinancing represents the largest component of prepayments for such coupons. Note that the overall prepayment duration is approximately, although not exactly, the sum of the partial durations for the turnover and refinancing components.

The durations are most significant for deep discounts (about -0.03 for the turnover component) and substantial premiums (about +0.03 each for the turnover and the refinancing components). These levels imply a price change of roughly one tick per 1% change in prepay component projections.

For seasoned premiums, the partial durations for the turnover and refinancing components are more or less of equal importance. While this pattern should not be surprising, given that long-term projections for each of those components is roughly the same (around 6%-10% CPR), it may come as a revelation to investors accustomed to thinking of refinancing rates as posing the major prepayment risk for premiums. At the same time, the partial durations associated with deep discounts for the turnover component are quite high, suggesting that there is substantial prepayment risk associated with that sector. The risk is accentuated by substantial recent divergence in predictions about the strength of the housing market and the seasoning rates of discounts among Street firms.[21]

If desired, these prepay components may be dissected further, and partial durations computed for other more specific factors:[22]

• **Turnover seasoning length**. The length of time after origination required for seasoning of the turnover component.

• **The refinancing elbow**. The degree of refinancing incentive at which refinancing rates begin to accelerate.

• **Steepness (or "cuspiness") of the refinancing curve**. The slope of the refinancing response curve.

• **Refinancing amplitude**. Peak speeds when premium coupons are first exposed to significant refinancing opportunities.

• **Degree of burnout**. The rate at which speeds slow down after a refinancing peak.

These more elaborate measures can be very useful in certain contexts, such as risk management or in evaluating complex mortgage derivatives.

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[21] The actual price risk could be thought of as the **product** of the partial duration with some measure of dispersion or volatility for the projected prepayment component. Disagreement and uncertainty among market players would tend to increase the volatility of the component's projected levels.

[22] Readers who have access to Salomon Brothers' *Yield Book* will recognize these as some of the "Dials" available for customizing the prepayment model.

The projection of prepayments is a maturing field that has benefited from the varied and rapidly changing market environment over the past 15 years and the intensive attention paid to it by researchers and investors. The best prepayment models of the future will be those that have absorbed and incorporated the lessons learned during this process, benefiting from past information while fully recognizing its limitations when predicting the future. In other words, a good model should fit past prepayment data well, but at the same time it should account for the recent secular shifts in mortgage marketplace and mortgage-holders' behavior.

We have presented a model that remains consistent with past observed behavior, while incorporating the best available understanding of the processes that underlie the behavior of today's mortgage holder. Our model is modular (projections are additive, incorporating the different well-known causes of prepayments), **universal** (designed to handle virtually all mortgage types) and **transparent** (relationships among the different components of the projections are visible to and alterable by the user). The design should help dispel investor skepticism about the intelligence behind the model's predictions.

Prepayments due to **home sales**, **refinancings**, **curtailments**, **full payoffs**, and **defaults** are individually modeled using economically and behaviorally sound relationships with underlying independent variables such as age, mortgage rates and home prices. The subtler individual differences within a mortgage type related to **seasonality**, **refinancing percentage at origination**, **points paid at origination**, **lock-in**, and **assumability**, among others, are superimposed on a fundamental projection of housing turnover rates to produce a realistic projection of the home-sales component of prepayments. A statistical approach to modeling the refinancing decision of the mortgage-holder leads to an economically sound methodology to project the refinancing component. Such a projection naturally incorporates the observed characteristics of refinancing behavior such as **seasoning**, **burnout** and the **"media effect**."

The combination of these carefully sculpted submodels produces projections that are universal in consistency across mortgage types and yet are highly specific to the salient characteristics of the individual mortgage security. The model provides a powerful tool to value and compare mortgages across and within sectors of the mortgage market.

As discussed in the section on home sales, housing turnover may be defined as the ratio of existing (single-family) home sales to single-family housing stock. This definition makes the relationship of housing turnover rates to prepayment speeds very clear. Hence, Salomon Brothers has performed a careful analysis of housing turnover rates over the past 15 years, leading to a deeper understanding of the factors that affect home sales and to a model that may be used to project turnover rates into the future under different interest rate scenarios. This Appendix outlines the latter, which forms a submodel of the Salomon Brothers prepayment model.

We believe that explicitly modeling home turnover rates offers a number of advantages. It leads to a more dynamic and realistic depiction of the evolution of turnover and hence prepayment rates over time, capturing in particular the path dependence of such rates. For example, if a sudden and sustained rise in mortgage rates occurs, an initial drop in home sales (and hence in speeds) will take place, but eventually pent-up demand and a gradual adjustment to the higher mortgage rates will lead to a pickup in sales and in speeds (as happened, for example, in the first half of the 1980s). The model also allows easier sensitivity testing; for example, what happens if for a given level of interest rates, home inflation is significantly different from historical norms? Finally, an explicit projection for the housing turnover rate furthers our goal of increasing the transparency of the prepayment model; users can determine for themselves if they agree with the model’s projections for home turnover rates along given interest rate paths.

Factors Affecting Housing Turnover

Demographics and population mobility, as well as macroeconomic and social factors all combine to influence home sales:

• **Affordability.** This refers to the home buyer’s ability to make a monthly mortgage payment. Affordability can be approximated by the ratio of median income to the median monthly mortgage payment on a median home.

Affordability is often cited as an important predictor of home sales, and correctly so. However, the effect of affordability is subtler than first appears, in that home sales depend not only on the current affordability of housing, but also on the recent history of affordability. For example, when mortgage rates rallied after hitting all-time highs above 16% in 1981-82, the pickup in home sales was immediate. Turnover averaged 4.85% and 5.02% in 1983 and 1984, respectively, although affordability was still quite low by historical standards, with rates still several hundred basis points above mean 1970s levels. It is likely that pent-up demand for housing from prospective buyers who could not afford a house in 1981-82 was a factor.

• **Desirability.** Another socioeconomic factor that helps explain historical variations in turnover is the desirability of homeownership. We use this term in a general sense, to include a perception of the likely economic return from buying a home and a perception as to whether it is currently prudent to do so.

In our model the variable influencing this desirability is the prospective inflation in home prices, for which a good proxy might be a weighted average of nominal home price changes in recent years. High levels of price inflation, which tend to lower the **real** (inflation-adjusted) mortgage interest rate are acknowledged in the literature as a key factor behind the sharp rise in turnover rates from 1973 to 1978, which bucked the sustained drop in affordability during the same period.[23]

Another important influence on housing activity is the level of co**nsumer confidence**. However, although using this variable would improve the historical fit of our model, we have chosen not to use it, as we do not want to attempt to predict it's levels going forward.

The Estimation of Turnover

Our analysis has thus shown that there are two intersecting populations of prospective buyers or movers: those who desire to buy or trade up and those that can afford to do so. The basic behavioral assumption behind the model is that the turnover rate is determined by the size of the intersection of these two groups. The size of the groups depends upon the levels of desirability and affordability, respectively. We capture these levels with two factors, an **affordability factor** that depends upon the median income, median home price and mortgage rates, as described above, and a **desirability factor** that incorporates the effects of home price inflation. The model also accounts for pent-up demand, or the lack of demand due to past interest rates, by carrying forward an affordability "deficit" or "surplus" from previous periods.

For our projections, we make the assumption that income and home prices change at the same rate over time; hence, changes in affordability are just a function of changes in mortgage rates.

A discussion of the model's fit to actual data as well as its predictions for various interest rate scenarios is included in the section on home sales (see Figure 3 and accompanying commentary). As shown there, the model manages to capture historical variations quite well and also provides realistic projections of the impact of interest rate changes on future housing turnover levels.

[23] See, for example, *Urban Economics*, E.S. Mills and B.W. Hamilton, Scott Foresman and Company, Chapter 10.

Let x be a measure of refinancing incentive. Assume that, for a given x, the likelihood of a refinancing varies from person to person. Let θ be a parameter that characterizes a mortgagor's propensity to refinance, and let

$p(x;\theta)$ = the probability of a refinancing, given x and θ.

Let $f_o(\theta)$ = initial probability distribution of θ across the population of borrowers.

If x_1 = refinancing incentive in month one, then the refinancing rate in month one will be

$\overline{p_1}$ = average of $p(x_1;\theta)$ across the distribution of θ

$$= E[p(x_1;\theta)] \int_{-\infty}^{\infty} p(x_1;\theta)f_o(\theta)d\theta$$

Evolution of the Distribution of θ

Mortgagors with a higher propensity to refinance will leave the population at a faster rate. The survival rate in month one of a "type θ" mortgagor is $[1-p(x_1;\theta)]$, and it follows that the new distribution of θ at the end of month one is

$$f_1(\theta)=A_1(x_1)(1-p(x_1;\theta))f_o(\theta),$$

where $A_1(x_1)$ is a normalizing constant given by

$$A_1(x_1) = \left[\int_{-\infty}^{\infty}(1-p(x_1;\theta))f_o(\theta))d\theta\right]^{-1}.$$

Repeating this argument, it can be seen that if x_n is the refinancing incentive in month n, then the refinancing rate in month n will be

$$\overline{p_n} = \int_{-\infty}^{\infty} p(x_n;\theta)f_{n-1}(\theta)d\theta$$

(A1)

where $f_{n-1}(\theta)$ is the distribution of at the beginning of the month. The distribution of θ at the end of the month is given by

$$f_n(\theta) = A_n(1-p(x_n;\theta))f_{n-1}(\theta)$$

$$= A_n(1-p(x_n;\theta))(1-p(x_{n-1};\theta))...(1-p(x_1;\theta))f_o(\theta) \qquad \text{(A2)}$$

$$= A_n\, Q_n\, f_o(\theta), \text{ say}$$

where $Q_n = (1-p(x_n;\theta))(1-p(x_{n-1};\theta))...(1-p(x_1;\theta))$

and A_n is a normalizing constant given by

$$A_n = \left[\int_{-\infty}^{\infty} Q_n f_o(\theta) d\theta \right]^{-1}$$

• **Burnout.** Note that, from Equation (2), as the population undergoes refinancings, the population distribution will shift towards those with the lowest propensities to refinance (or highest survival likelihoods). Hence, even for a constant refinancing incentive, the refinancing rate will decline, at a rate proportional to the average across θ of the cumulative survival factor Q_n (note the similarity to the traditional Wall Street practice of modeling burnout using some sort of pool factor).

Changes in Intrinsic Propensities: The Media Effect

Thus far, we have assumed that, for any given mortgagor, the basic propensity to refinance remains unchanged, that is an individual's does not change. The evidence from the refinancing waves of 1991-93 suggests that borrowers, propensity to refinance does change. The combination of media publicity about low mortgage rates and resulting refinancing opportunities, proactive originators, and dormant changes in personal circumstances (for example, improved credit or equity) can lead to a distributional change in θ.

This phenomenon, which has been labeled the "media effect", can be modeled as a second influence in the evolution of the probability distribution $f_n(\theta)$. Thus, each month, the distribution of θ across the population can change because of two factors:

(1) Refinancings removing faster refinancers from the population at a faster rate ("Burnout"). This will lead a decline in the average propensity to refinance.

(2) A migration of some borrowers from "slower" to "faster" categories ("media effect"), leading to an increase in the average propensity to refinance. The migration rate can be a function of the history of interest rates, and a variety of ways exist to implement the effect on the distribution of θ.

Note: A simple version of this framework, in which θ can take only two values (so that mortgagors are either "slow" or "fast"), has been discussed in more detail in a previous Salomon Brothers publication.[24]

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[24] See "A Simple Statistical Framework for Modeling Burnout and Refinancing Behavior," Lakhbir Hayre, *Journal of Fixed Income*, December 1994.