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Factors Affecting Mortgage Prepayment in Hong Kong

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Abstract

This paper presents a quantitative analysis of prepayment data based on the historical prepayment experience of two banks in Hong Kong. One of the most distinctive features of mortgages as an asset class is the existence of prepayment risk. Research in prepayment has matured into a coherent body of work that has a sound theoretical framework and consistent empirical validation. Previous research in prepayment has identified certain important causes for prepayment. However, most studies on prepayment were based on fixed-rate mortgages in the USA, while little work on variable-rate mortgages and even less work on prepayment in other countries has been conducted. In this paper, the prepayment pattern of variable-rate mortgages in Hong Kong are examined. Following the logic of the option-based/optimal model, certain variables have been identified for inclusion in an empirical model on prepayment. As variable-rate mortgages are the custom in Hong Kong, it is considered that there will not be a refinancing incentive with decreases in interest rates as in the case with fixed-rate mortgages. In this study, interest rates are however found to be an important determinant of prepayment, with prepayments sensitive to real interest rates and borrowers sensitive to the prospect of an increase in interest rates. The explanation proposed for this behaviour is consistent with findings in the field of quasi-rational and behavioural economics. It is thus considered fruitful to incorporate concepts from this field into mortgage prepayment research.

Keywords: Residential mortgages, prepayment, variable-rate mortgages, quasi-rational economics, behavioural economics.

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Introduction

One of the distinguishing features of mortgages as an asset class is the existence of prepayment risk, with the consequent asset valuation problems to investors that prepayment introduces. At a different level, the accuracy of prepayment estimates in a pool of mortgages may also affect the risk-return characteristics of mortgage backed securities issues. Research in prepayment has thus been prolific and has matured into a coherent body of work that has a sound theoretical framework and consistent empirical validation. Previous research in prepayment has largely completed the circumscription of causes for prepayment of Fixed Rate Mortgage generally with most studies conducted in the USA; but few studies on Variable Rate Mortgage have been conducted and even fewer studies exist on prepayment in countries other than the USA.

As contribution to this broader body of endeavour, this paper presents a quantitative analysis of prepayment data of Variable Rate Mortgages in Hong Kong. It is the purpose of this study to enhance the knowledge and understanding of prepayment behaviour, by examining the historical prepayment pattern of a sample of Variable Rate Residential Mortgages from two banks in Hong Kong and to attempt to identify causes of prepayment.[1] The paper commences with a brief review of important aspects of prepayment research that are viewed as necessary to locate the empirical research reported on in the broader body of prepayment research, and to order analysis leading to the identification and empirical analysis of variables that contribute to prepayment in Variable Rate Mortgages in Hong Kong. An empirical model which tests expected relationships between selected variables and prepayment

[1] Following an undertaking with the banks, we are unfortunately not presently at liberty to disclose descriptive statistics of the sample. This influenced other aspects of the research, as will be commented on below. Although the present sample provided was most useful, dates overlapped, and the sample contains only mortgages over a common time period.

identified in the brief review is then presented, based on the historical prepayment pattern of a sample of VRMs in Hong Kong. We then conclude.

A Selected Review of Mortgage Prepayment Literature

The research reported on in this paper examines prepayment patterns in variable rate mortgages (VRMs), and is thus atypical of the greater body of research on mortgage prepayment patterns and risks generally, as mentioned above. In order to understand the nature of differences in prepayment risks between VRMs and Fixed Rate Mortgages (FRMs), we briefly discuss a number of important concepts and principles that have developed in the study of mortgage prepayment. We firstly identify and selectively discuss the economic variables that are seen to influence mortgagors' prepayment decisions (*and also default decisions*), and point out some useful similarities between VRMs and FRMs that help to provide context for the study. Besides the variables that influence prepayment, two further significant developments in prepayment research that provide insight into the context of our study are also discussed. These are developments towards identifying appropriate functional forms to estimate prepayment, and prepayment research based on option-pricing methodology and optimal prepayment concepts.

Commonly Accepted Mortgage Prepayment Variables

Given the extent of the body of research on mortgage prepayment, little disagreement still exists about the variables that influence prepayment decisions with FRMs. Cunningham and Capone (1990) summarize these variables that have been found to be significant in previous studies on VRMs, and categorized these generally as mortgage related, property related, borrower related or macroeconomic. Table 1 presents their categorised summary of variables with VRM's and their expected relationship with prepayment; including interest rates, mortgage age, loan to value (LTV) ratio, borrower's age, mortgage payment to income (PTY) ratio, and the macro-economic factors Gross National Product and Real Income.

The research on these variables and their relationship with prepayment in FRMs is extensive (see for example Campbell and Dietrich 1983; Peter, Pinkus and Askin 1984; Vandell and Thibodeau 1985; Lea and Zorn 1986), and for the sake of brevity

will be treated as read. Interestingly, the variables that are seen to influence prepayment decisions were also found to influence borrowers' mortgage default decisions; given that prepayment and default decisions may be considered as substitutes because the expected sign between default and these variables are opposite to that of prepayment and the same variables. For example, LTV and PTY have opposite expected signs between default and prepayment decisions. This follows because with a high market

Table 1: Relationship of different variables to mortgage prepayment with VRMs

Variables	Expected Sign
Mortgage Characteristics:	
Mortgage Interest Rate	+
Mortgage Age	+
Property Characteristics:	
Loan to Value Ratio	-
Borrower Characteristics:	
Borrower Age	-
Mortgage Payment to Income Ratio	-
Marco Economic Conditions:	
GNP	+
Real Income	+

Source: Cunningham and Capone (1990)

value of the underlying asset relative to the debt outstanding, a borrower would not choose default but is instead expected to sell the asset and use the proceeds to pay the outstanding debt. By identical reasoning, if the market value of the asset is low, a borrower would choose default and thus invite the lender to foreclose. Similarly, when PTY increases because of say lower borrower income, borrowers' ability to continue the mortgage payment is affected, but whether a borrower would choose to default will also depend on LTV. These relationships hold despite the FRM contract, because asset values are influenced by changes in interest rates that occur exogenous to the FRM contract. The reasoning that supports these expected relationships is however also not confined to FRMs, but an additional layer of complexity is added with VRMs by making PTY also depended on interest rate movements as part of the VRM contract. With VRMs, changes in interest rates would directly affect borrowers' ability to service debt and thus PTY, and this may explain also a positive expected relationship between prepayment and interest rates with VRMs. If

borrowers are unable or unwilling to continue higher debt service payments at higher interest rates, it may be expected that borrowers may choose rather to sell the asset if LTV is high enough instead of defaulting. Prepayment in this condition is then a substitute for default.

In view of the general observations presented here about variables that affect prepayment and default decisions, research on prepayment with VRMs using Canadian data to examine prepayment experience is of general interest to Hong Kong, because the predominant mortgage contracts offered in Canada is also variable-rate.[2] Lea and Zorn (1986, 1989) examined the prepayment experience of 250 individual VRMs between 1979 and 1982 in Canada with a logit model. They found that the indirect utility of loan prepayment was negatively related to the rate of return on other investment assets, the loan prepayment penalty, and the cost of alternative types of shelter. They also found that borrowers were more likely to prepay the larger the increase in the mortgage interest rates, which they argued was consistent with the hypothesis that prepayment was a response to the payment shock of rising mortgage payments. They also concluded that prepayment was positively related to the difference between mortgage interest rate and return from alternative investment opportunities, reflecting the incentive to increase housing equity when the return to paying off a mortgage was relatively high. The return on alternative investment opportunities thus reflects the opportunity cost of prepayment. Prepayment utility was also positively related to the rate of appreciation in housing, equity buildup, and the underlying loan rate.

Lea and Zorn's research results suggest that the financial and nonfinancial inducements to prepayment seem quite similar for fixed-rate and variable-rate loans. Further light is shed on this proposition by Cunningham and Capone (1990), who compared concurrent default and prepayment experience on fixed-rate and variable-rate loans. By adding interactive terms to their model, in which fixed-rate and variable-rate loans were assigned with interactive dummy terms, they found that VRM prepayment was positively related to the slope of the yield curve, but to a lesser

2 Differences in detail exist, for example with respect to changes in interest rates. Typically with Canadian contracts the mortgage interest rate is adjusted at an interval of one year to five years, while

extent than those on fixed-rate loans. This indicates that interest-rate expectations affect fixed-rate borrowers more strongly than VRM borrowers. In addition, they found that VRM prepayments were negatively related to the various adjustment limitations (interst rate "caps") in the loan contract.[3]

There are additional important considerations with VRMs that require mention, however. In economies like Canada and Hong Kong, where FRMs are the exception and not the custom, refinancing would not be a directly defensible motive for prepayment. In the USA, where in addition to the ubiquitous FRMs, borrowers can choose a wide number of forms of mortgages from fixed-rate to variable-rate; borrowers have the opportunity to refinance a FRM into a VRM, and vice versa, depending on their expectation about interest rate movements and the shape of the yield curve. In fact, the share of FRMs and VRMs in total mortgage origination fluctuates depending on the state of interest rates. In periods of high interest rates, most mortgages originated are VRMs, while in periods when interest rate is low, borrowers prefer FRMs. In Huang and Xia (1996), it was estimated that two-thirds of VRM prepayment were related to refinancing decisions.

The relationships discussed above provide important background to the nature of our study. Our study proceeds from similar reasoning as presented, and concentrates cross-sectionally on a period of general residential real estate price rises. This means we are able to consider the influence of variables such as LTV on prepayment decisions rather than the more complex combination of LTV and PTY, particularly also because banks widely adopted conservative LTV preconditions for risk management and regulatory reasons during this period. For example, we expected that over our study period borrowers would choose to sell their property rather than default when unable or unwilling to continue debt service because the possibility to realize enough proceeds from sale of the assets to pay off outstanding mortgage debt existed throughout. It may be argued that this is supported by the low default rate experienced by banks in Hong Kong. In addition, interest rate movements in Hong

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in Hong Kong, the rate is tied to the prime lending rate, and borrowers will be given one month notice of any rate change. The new rate is usually effective in the period after the next payment.

[3] When such limits are reached, no further interest rate adjustment are possible, and VRMs are expected to behave like FRMs. Such limits obviously become valuable if interest rate movements

Kong are singular in that the level and term structure are exogeneously benchmarked through the currency board arrangements that dominate monetary policy, and may influence prepayment decisions in ways not generally foreseen in USA-based or other research.

Prepayment Functions

While the different variables that influence prepayment decisions and their relationships with the decisions have formed one avenue of prepayment inquiry, modeling prepayment decisions has formed another. Recent research aimed at modeling prepayment decisions invariably use the concept of a hazard function.

Hazard function logic is generally based on the length of a state or condition experienced by an agent, also referred to as the duration of a state, for example the length of an unemployment spell. Duration (or survival) models are used to analyze the length of time an individual or firm is in a certain state. The object in this case is the length of time a mortgage remains active. Underlying a duration model is a probability density function ***f(t)*** reflecting the probability of, say, a spell of unemployment having length ***t***. In our case, ***f(t)*** reflects the probability that a mortgage will remain active after a length of period ***t***. Most applications of duration models are such that the object of interest is, for example, the probability of ending a spell of unemployment, given that an individual has already been unemployed for a duration ***t***; or as in our case, the probability that a mortgage will be prepaid. Interest therefore focuses on the conditional probability of a mortgage being prepaid, given that the mortgage has not been prepaid for a period of ***t***, rather than the unconditional probability represented by ***f(t)***. This conditional density function, called the *hazard function*, is given by $\lambda(t)=f(t)/[1-F(t)]$ where ***F(t)*** is the cumulative density of ***t***. Estimation of duration is normally undertaken using maximum likelihood estimates. Each observation on a completed period of the state is entered into the likelihood function as ***f(t)*** and each observation on an uncompleted period is entered as ***[1-F(t)]***. Explanatory variables are incorporated into duration models by specifying how they affect the hazard function. The most popular way of doing this is to specify that the

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bring them into consideration, and are thus expected to be considered by borrowers in prepayment decisions.

effect of such "regressors" is to multiply the hazard function by a scale factor, producing what is called the proportional hazard specification. Formally, this is written as $\lambda(t)=\phi(x,\beta)\lambda o(t)$ where $\lambda o(t)$ is the part of the hazard function that depends on t, and $\phi(x,\beta)$ is the scale factor that depends on a Vector x of explanatory variables and a Parameter Vector β

There is however not agreement about most appropriate (or indeed "correct") functional form and estimation methods in prepayment modelling, a field which has also generated substantial research. There is a wealth of empirical research on prepayment functions with many studies using different specifications and estimation methods, and there is certainly not consensus about how best to proceed. A familiar type of hazard model specification is the Accelerated Failure Time Model (AFTM) as adopted by VanderHoff (1996).[4] The AFTM provides direct estimates of the explanatory variables's effects on mortgage age. The period from mortgage origination to mortgage maturity is designated as T. The vector of covariates X determines the probability that prepayment occurs at time t, prior to T, as specified by the cumulative density function:

$$F(t; X) = Pr(T, t; X). \qquad (1)$$

The density function is

$$f(t: X) = dF(t: X)/dt. \qquad (2)$$

The survival function is the probability that the loan remains current at time t:

$$S(t: X) = 1 - F(t; X \qquad (3))$$

The conditional density function of prepayment at time t (conditional on continuation in previous period) is given by the hazard function:

$$h(t; X) = f(t; X)/S(t; X). \qquad (4)$$

The AFTM provides estimates on how the elements of $\boldsymbol{X}$ affect the distribution of $\boldsymbol{t}$. VanderHoff's empirical model analyzes both prepayments and defaults with the interaction of the covariates and the binary variable ***DEF***:

$$\boldsymbol{Ln\ AGE_{t,j} = BX_{t,j}(1\text{-}DEF_{t,j}) + BX_{t,j}(DEF_{t,j}) + e_{t,j}} \qquad \boldsymbol{(5)}$$

where $\boldsymbol{AGE_{t,j}}$ is the number of months from loan origination to prepayment or default or censor for mortgage $\boldsymbol{j}$, $\boldsymbol{X_{t,j}}$ is a vector of mortgage, house and macroeconomic variables, and $\boldsymbol{DEF_{t,j}}$ is a dummy variable which is equal to $\boldsymbol{0}$ if mortgage $\boldsymbol{j}$ either is censored or prepays at time $\boldsymbol{t}$ and equals $\boldsymbol{1}$ if mortgage $\boldsymbol{j}$ defaults at time $\boldsymbol{t}$.

Predictably, there is substantial disagreement about functional form. In a survey article, for example, Dickinson and Andrea (1994) offer the observation that the prepayment relationship for cross-sectional data is not linear when measured against the difference between the contract loan rate and the refinancing rate for fixed-rate mortgages. A logistic function or another specification that generates an S-curve shape instead is appropriate, and maximum likelihood estimation is required. Furthermore, a generalized least-squares covariance adjustment is appropriate if the underlying data is a collection of pools.

The prepayment decision model first used in Green and Shoven (1986), followed and expanded by Schwartz and Torous (1989, 1992) provided robust and consistent prepayment estimation results based on the proportional hazard approach. Green and Shoven analyzed the termination experience of 4,000 individual loans in California from 1975 to 1982, using this methodology. For each loan, Green and Shoven estimated a "lock-in" variable as the *difference* between a loan's book value and market value divided by an approximate house price. The only other predictor variable employed was the loan age base-line, which exhibited a nonlinear relationship with prepayment. After controlling for age, the probability of prepayment was found to be negatively related with the size of the lock-in. The probability of prepayment was also found to be negatively related to the size of the

[4] A less common approach in model specification and estimation method as used in Cunningham and Capone (1990) is the multinomial logit model.

lock-in for above-market-rate loans, and positively related to lock-in for below-market-rate loans.[5] [6]

Options-based methodology and Optimal Prepayment

A brief description of hazard function approaches help to introduce further aspects of research into prepayment decisions, noteably research based on options pricing methodology. In early attempts at modeling prepayment (see for example Dunn and McConnell 1981), the right to prepay a fixed rate mortgage was modeled using logic similar to that applying to investors exercising a call option, and a rich literature thus also developed in this vein (see Hall 1985). Briefly, the financial decision to terminate a mortgage is viewed as the outcome of the borrower's analysis of a variety of interest-rate and refinancing-cost expectations, while a non-financial decision to terminate is seen to be motivated by demographic or macroeconomic factors. Also, the borrowers decision depends on whether the existing loan carries a fixed or an adjustable rate. The option-based model forms the theoretical framework which frames the analysis of a borrower'sdecision to prepay based on financial variables. The decision is modeled as a call option given the borrower's right to pay off the remaining balance, a known amount, at any time before maturity. With such characteristics the mortgage can be valued like a callable bond. In various studies (for example Hall, 1985; Chen and Ling, 1989), it was found that the option-based model produced unbiased estimates of actual mortgage yields; while Follain, Scott and Yang (1992), used the option-based model to construct the prepayment behaviour of a pool of fixed-rate mortgages. They found that the spread between the current market interest rate and the coupon rate of the mortgage pool was the most important determinant in a prepayment function, but also that the relationship between the spread and prepayment appears to be nonlinear. The spread was shown to depend upon the expected holding period of the borrower, transaction costs, the volatility of interest rates, the type of mortgage contracts available, and more. However, the

[5] An above-market-rate loan generally means borrowers have the incentive to refinance which will increase the probability of prepayment; while a below-market-rate loan meant that there is no financial incentive to refinance, and the probability of prepayment would decrease.

[6] Furthermore, the effect of the lock-in was found to be larger in the second half of the sample; indicating that below-market financing lessened the probability of prepayment dramatically, after the 1978 Wellenkamp court decision which precluded lenders from enforcing due-on-sale clauses for any reason other than increased default risk. This decision allowed a below-market-rate loan to be assumed even if the underlying property was sold.

prepayment option embedded in a mortgage contract has also proved to be more complicated than a financial option. As noted in Hall (1985),

1. The mortgage option is not transferable separately from the underlying mortgage;
2. The values of the option and the underlying property are not perfectly correlated, so maximizing the return on the property may not imply the same strategy as maximizing the return on the option;
3. The possibility of nonoptimal exercise reduces the value of the option to the borrower and increases the value of the underlying mortgage to the lender; and
4. The prepayment option is not priced explicitly but is paid for in a premium over the rate on a noncallable loan, an origination fee, or some combination of the two.

To account for these complications, the option-based model of prepayment assumes the borrower maximizes the sum of *nonhousing wealth* plus *housing wealth* in each payment period (usually per month) by exercising a termination option or renewing the options with the monthly principal and interest payment. An example which takes these factors into account in an option-based model is VanderHoff's (1996) model. In VanderHoff's model, housing wealth equals the borrowers housing equity plus the market value of the mortgage, so that:

HOUSING WEALTH = MORTVAL + EQUITY + PAYOPT + DEFOPT (6);

with equity represented by:

EQUITY = HOUSE VALUE - MORTGAGE BALANCE. ***(7)***

The value of the mortgage includes the net market value of a noncallable bond ***(MORTVAL)***, and the prices of the prepayment option ***(PAYOPT)*** and default options ***(DEFOPT)***. The value of ***MORTVAL*** is:

MORTVAL = MORTGAGE BALANCE - PV OF PAYMENTS, ***(8)***

with ***PV OF PAYMENTS*** the present value of mortgage payments over the expected life of the mortgage evaluated at the current market interest mortgage rate. The prices of the options depend on the risk free interest rate, the volatility of interest rates, the volatility of house prices and the term to maturity of the mortgage.

VanderHoff`s paper presents analyses of the probabilities of prepayment or default for both fixed-rate mortgages and adjustable-rate mortgages. The effect of interest rates on prepayment is reflected in ***MORTVAL,*** with the relationship between ***MORTVAL*** and prepayment for fixed-rate mortgages and adjustable-rate mortgages expected to be in opposite directions. For instance, it is expected that with fixed-rate mortgages prepayment is positively related to ***MORTVAL,*** as market rates decrease; and for adjustable-rate mortgages prepayment is negatively related to ***MORTVAL,*** as market rates increase. These expectations are confirmed in VanderHoff's empirical estimates.[7] Greater uncertainty in house prices and mortgage interest rates were expected to increase the likelihood of prepayment and default, since the values of the prepayment and default options are positively related to the volatility of mortgage interest rates and house prices. VanderHoff however does not estimate the values of the prepayment and default options.[8]

The introduction of volatility and uncertainty about future interest rate movements and house price behaviour has enhanced empirical models to analyse the decision of prepayment and default considerably, and has also been supported by considerable refinement and testing. For example, Deng (1997) incorporates a binomial mean-reverting interest rate model into the estimation of the value of the prepayment option and conducts two tests, one with the assumption of a stochastic term structure and one with an assumed deterministic term structure. It was found that an important difference in outcome between the different term structure assumptions was clear when comparing the two models' respective predicted cumulative prepayment rates. The predicted cumulative prepayment rates are higher in the model using a stochastic

[7] The values of ***MORTVAL***, ***EQUITY*** and ***PAYMENT*** were calculated from the loan data of a private company that originated the loans supplemented with data on mortgage interest rates and local house price indices.

[8] VanderHoff does however offer an approach to calculate risks associated with prepayment and default options. The standard deviation of a five-year moving sample of house price appreciation rates was used as proxy to measure risk for the default option; while the standard deviation of the five-year

term structure, and the difference in predicted prepayment rates also increases as the predicted time span increases. This behaviour of the predicted prepayment rates is consistent with the basic tenets of option pricing - that the value of an option is a increasing function of time.

There are also concerns about aspects of the options-based prepayment model, however. It was discovered that many mortgage borrowers frequently appear to behave suboptimally with respect to the exercise of their mortgage prepayment options, with some choosing not to prepay when the call options were well into-the-money, whilst some chose to prepay when the call options were out-of-the-money. For example, many FRMs originated at high interest rates are still active even though current interest rates are much lower, and many mortgages originated with a lower than current rate have been prepaid. In order to account for apparently suboptimal prepayments patterns in mortgages, the recent trend in prepayment modeling has shifted away from optimal call valuation models, in favour of models in which prepayment behaviour is specified based on empirical estimation. These strictly empirical valuation models typically rely on exogenously estimated hazard functions to account for prepayment behaviour. Some researchers had commented that these empirical models are vulnerable due to their heavy reliance on historical data, and are somewhat unsatisfying to the financial economist in that borrower prepayment behaviour is passively accepted without rational economic explanation (Archer and Ling 1993). Other researchers were also unsatisfied with the fact that the proportional hazard model assumes that past attributes of the environment do not influence present behaviour, and it is argued that this factor is relevant in newly issued mortgages (see Kang and Zenios 1992).. With historical mortgages that were active and prepaid during a long history of interest rate variations, this may lead to gross overestimation of prepayment rates under less volatile interest rate regimes.

Other researchers have incorporated the effect of past interest rate variations into proportional hazards modeling to estimate prepayment, and have demonstrated that the proportional hazards model is capable of handling time-varying variables (Schwartz and Torous 1989, 1992). For present purposes it is instructive to relate

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moving sample of market mortgage interest rates was used as proxy to measure risk for the prepayment option.

how Schwartz and Torous proceeded. They adopted a proportional hazard prepayment function similar to Green and Shoven's, while their baseline function indicated that prepayments increased gradually until a loan pool reached six years of age and then leveled off. They also identified three significant positive covariates. The difference between loan contract rate and the long-term Treasury rate, lagged three months, approximated the monetary incentive to refinance, while this variable was also cubed to allow prepayments to accelerate at greater rate spreads. Third, the ratio of the actual pool balance to the balance implied by scheduled payments captured a pool's prepayment history. If the ratio was high, few terminations occurred, indicating that the level of prepayment activity was relatively low, so borrowers who faced relatively low refinancing costs remained in the pool and prepayment elasticity was high. In general therefore, there is evidence that hazard functions is a robust methodology that can incorporate the influence of sophisticated causal variables, and are thus not equivalent to simple reduced form estimation logic.

Despite some encouraging results from option-based prepayment research, there is nevertheless criticism of these models from researchers pursuing different methodologies. For example, Dickinson and Andrea (1994) comment that despite their theoretical superiority, option-based prepayment functions do not explain prepayment experience as well as simple econometric models do, and that more work is required to improve the option-based model's ability to incorporate exogeneous variables that affect financial and non-financial decisions to prepay.

An Empirical Model of Variable Rate Mortgage Prepayment: A Hong Kong Study

The above selection hardly reflects the width of prepayment research, or the depth to which various aspects have been explored. It does however give an indication of the range of issues associated with prepayment research, and in particular the issues of concern and variables that are important when considering prepayment decisions in Variable Rate Mortgages. The primary objective of the empirical part of the research reported here is then to test a prepayment model for VRMs, and in particular test a number of relationships between prepayment behaviour and selected prepayment

variables using OLS regression analysis. The estimated prepayment model is based on monthly prepayment records of a sample of residential mortgages obtained from two banks in Hong Kong, with prepayment records measured in constant prepayment rates. The data cover the period January 1988 to May 1994.[9]

To commence and following the logic of the option-based/optimal model on mortgage prepayment, we include a number of variables which may be interpreted as proxies for option positions in the property, the mortgage and the borrowers'overall wealth. Where considered necessary we explain peculiarities in Hong Kong institutions and market factors that might influence expected relationships between prepayment and the selected variables. The variables selected are general but also are considered to be important for all types of borrowers. Our choice of variables was however constrainted by the fact that borrower-specific, property-specific and mortgage-specific information was not made available for confidentiality reasons. Consequently we were unable to include certain variables (such as the effect of seasoning) in our model, because the sample prepayment rates reflect only the *aggregate* prepayments from the bank's mortgage portfolio. The model estimates of our empirical model should thus be interpreted as the estimated effects of these variables on aggregate prepayment behaviour.

The regression model of prepayment is specified as:

$$CPR = f[VOL, REHS, DUM, (UOP, DOP)/(RUOP, RDOP)]. \qquad (9)$$

The variables chosen for our model are briefly as follows:

CPR - the monthly prepayment record, the dependent variable
VOL - the monthly sale & purchase agreements recorded in the land registry
DUM - a dummy variable to indicate the period before and after September 1991 in our sample of observations.
REHS - monthly returns of the Hang Seng Index to reflect alternative returns offered in the general investment environment
UOP/DOP - the expected increase/decrease in monthly mortgage payment from a nominal interest rate increase/decrease
RUOP/RDOP - the expected increase/decrease in monthly mortgage payment from a real interest rate increase/decrease

[9] The sample period covers a period of steady price rises in Hong Kong's residential property market,

In addition to estimating the effects of these variables on prepayment, we are also interested in comparing prepayment reaction to nominal and real interest rates, to include for the effect of Hong Kong's interest rate regime on prepayment. Therefore we present two alternative specifications, one model using nominal interest rates (UOP, DOP) and the other using real interest rates (RUOP, RDOP).

Turnover of the Housing Market ***(VOL)***

Embedded in all mortgage contracts is the provision that when the mortgaged property is sold, the whole of the remaining balance of the mortgage loan becomes due (the "due-on-sale" clause). The sale of a mortgaged property would thus cause the prepayment of a mortgage. The turnover of any housing market can be approximated by the number of sale and purchase transactions,[10] with a higher volume of S & P agreements recorded simply meaning more properties sold with underlying mortgages thus becoming due. Further, when borrowers seek to maximize returns on investment in the mortgaged property, an important expected determinant of prepayment behaviour is also the condition of the housing market. We thus view transaction volume in the market as a proxy for market conditions, and expect that borrowers are more likely to sell the underlying property and maximize the investment return when market conditions are favourable.[11] Therefore, we can expect that the condition of the housing market as proxied by VOL to be an important determinant of borrowers' prepayment decisions. We thus would expect prepayment ***(CPR)*** and the number of S & P agreements ***(VOL)*** to be positively related.

Changes in the Interest Rate Spread ***(DUM)***

Typical residential mortgage custom in Hong Kong is to relate variations in mortgage interest rates in contracts to changes in the prime rate by a spread, with mortgage rates contractually adjustable with a short notification period during the contract. So when

briefly interrupted by concerns over the Tiananmen Incident in June 1989.

[10] In Hong Kong, this may be accurately represented by the number of Sale and Purchase Agreements recorded with the Land Registry.

[11] Over the time period covering our sample, residential properties in Hong Kong were frequently held mostly for their short and near term investment performance and relatively less for long term use, resulting in active turnover. This was largely confirmed in the survey of residential mortgages in Hong Kong by the Hong Kong Monetary Authority in 1995, where the average age of most mortgages was found to be less than two years (HKMA 1995).

the prime rate changes, mortgage interest rates would adjust accordingly with a short lag, both for active and new contracts. The spread is thus an important indicator in considerations affecting mortgage decisions, both for existing and new mortgages. Excluding credit risk, the size of the spread for new contracts varies with competitive conditions between banks and other risks in lending perceived by banks at the time of contracting, but generally the spread is maintained at approximately the same level by banks in normal circumstances. The spread between the prime rate and new residential mortgages was maintained around 1.25% between January 1988 and September 1991, but then widened to around 1.75% for newly originated mortgages thereafter. The widening of the spread partly reflected an increase in risk perceived by banks in mortgage lending, as the residential property market became more volatile and credit risk concentration became a subject of regulatory concern.[12] Mortgages that were originated before then would thus enjoy a lower rate than mortgages originated after that date. We expect that this change in spread would deter those with a smaller spread mortgages to prepay their mortgages, because they would lose the benefit of a lower rate if a new mortgage was to be negotiated.

A dummy variable is used in the prepayment model to indicate the period before and after the generally changed mortgage interest rate spread in September 1991. We expect that the dummy variable to have a negative sign, because borrowers with a lower spread mortgage (pre-September 1991) are expected to be less susceptible to mortgage rate changes in decisions to prepay than borrowers with a higher spread mortgage. The negative dummy is consistent with prepayment behaviour observed for fixed rate mortgages, where prepayment is expected to respond positively with lower interest rates, and negatively with interest rate increases as refinancing opportunities are less attractive. In sum, we expect a decrease in prepayment with increases in the spread.[13]

[12] A collection of additional factors might however also explain a weakening effect of mortgage rates on prepayment decisions during the period of observation. First, as banks perceived an increased risk of lending, they became more cautious in mortgage loan application through a general reduction in LTV ratios to 70% (partly following regulatory pressure), and consequently lower amounts that can be borrowed. A smaller loan would mean a smaller monthly payment required, and the effect of interest rate changes on monthly payments would also be smaller compared to larger loans at a higher LTV ratio. Second, banks in this period also increased prepayment penalties and other transaction costs, and this also would function to weaken the effect of mortgage interest rate on prepayment behaviour.

[13] There is market information covering a later period to support this expectation. Our reasoning suggests that we would similarly expect an increase in prepayment if the spread is to decrease for newly originated mortgages, and this was exactly the response of borrowers to the decrease in spread in

*Returns from Alternative Investment (**REHS**)*

When deciding to prepay but without considering sale of the property, borrowers would need to come up with the required funds to pay off the remaining loan balance. The funds may come from another loan or it may be the result of the borrower's adjustment of her investment portfolio of which the mortgaged property is a component. [14] For borrowers not subject to wealth constraints, prepayment may be the result of portfolio adjustment as borrowers seek to maximize portfolio returns. In each period, borrowers will compare the returns of all the assets in the portfolio, and the cost of funding the portfolio. For our purposes, comparative returns can be approximated by a broadly based investment index, like the Hang Seng Index of the Hong Kong Stock Exchange. HSI returns can thus also be regarded as the opportunity cost of prepayment. Therefore, we would expect prepayment to be negatively related to the returns from the general investment environment, proxied by returns from investing in the HSI.

*Prepayment Option Values **(UOP and DOP) (RUOP and RDOP)***

As explained, the option to prepay a mortgage loan is similar to a call option. Borrowers can exercise the prepayment option at any time during the term of the mortgage, as such it is an American-type option. It is valuable to the borrower because it allows a borrower to terminate the mortgage loan under favourable conditions. As mentioned in previous sections, favourable conditions arises from borrowers selling the underlying property, when mortgage interest rates and returns from alternative investments align in particular ways. These factors were found to be significant in explaining prepayment pattern in studies reviewed earlier, and thus indicate that borrowers have largely acted rationally in exercising prepayment options.

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the mortgage price war in the second half of 1995. As banks competed for market share in the mortgage market, some banks lowered the spread from 1.75% to around 0.5%, and some even offered mortgage rate at zero spread. These lower spreads were offered mainly to new mortgages, without adjusting the spread on existing mortgages. The offer of lower spread caused a significant increase in prepayments for existing mortgages as borrowers captured savings in interest payment from refinancing.

[14] We argue that the probability that the funds would come from another loan at a lower interest rate is relatively small, given that mortgage and other lending rates are generally determined competitively in Hong Kong.

The prepayment option for variable-rate mortgages gives the borrowers an escape route, when faced with rising interest rates which would translate in higher period mortgage repayments. We believe borrowers are more concerned about the prospect of possible interest rate increases in exercising the prepayment option, than with possible losses from not refinancing when interest rates decline,[15] because the potential loss from increases in interest rates could result in default with comparatively more serious consequences. To test the proposition that borrowers are more concerned about the effect of future interest rate increases than the lost benefit from interest rate decreases when exercising the prepayment option, we calculated the expected effect to the borrowers from interest rate increases and the expected effect from interest rate decreases. For our purposes the expected effect to the borrowers from interest rate increase ***(UOP)*** can be quantified as the expected increase in mortgage payments in each period due to the increase in interest rates in each period; while the expected effect from interest rate decreases ***(DOP)*** can be quantified similarly as the expected decrease in mortgage payments in each period due to the decrease in interest rates.

To calculate the expected cost or benefit from prepayment resulting from interest rate uncertainty, it was necessary to model interest rate uncertainty. The underlying model of uncertainty of interest rates was derived following Rendleman and Bartter's (1980) approach. To determine the parameters for the expected future distribution of interest rates, we needed to estimate the mean and variance of the distribution of interest rates. These were estimated using the log of interest rate ratios of the last twelve months. With the mean and variance estimated in this way we could generate a model of the future movements of interest rates.

Real Interest Rates

In deriving the prepayment option values from interest rate uncertainty, we used nominal interest rates. It should also be considered, however, that borrowers are

concerned about real interest rates and presumably do not suffer from money illusion. For example, if nominal rates remain unchanged but inflation decreases, borrowers will be suffering from money illusion if they did not exhibit any incentive to prepay because there is real benefit from prepayment. To test whether borrowers suffer from money illusion, we used real interest rates instead of nominal rates to calculate the option values. The expected increase ***(RUOP)*** and the expected decrease ***(RDOP)*** in option values are calculated in the same way as ***UOP*** and ***DOP*** except that real interest rates are used in the calculations instead of nominal interest rates. We consider also an additional difference that arises in the modeling of uncertainty for real rates. As nominal interest rates cannot be negative, we model uncertainty by a multiplicative random walk and assume a lognormal distribution. Because real interest rates can be positive and negative, we use an additive random walk instead to generate uncertainty and assume a normal distribution.

Empirical Results and Discussion

Below we present two set of regression results, with one set using nominal interest rates and the other with real interest rates (Tables 2 and 3).

Following the logic of the option-based/optimal prepayment model, we were able to identify certain variables which were critical in influencing borrowers' prepayment decisions for VRMs in Hong Kong. Consistent with previous empirical research, the model estimates indicate that the most important determinants are conditions in the housing market proxied by the turnover ***(VOL)*** and the effect and expected future increase in mortgage interest rates ***(DUM, UOP)***. In contrast to other studies where mortgage interest rates were found to be the most important determinant of prepayment, however, the present empirical estimates indicate that the effect of interest rates are not as significant as the housing market conditions. This behaviour is quite logical because the effect of interest rates on prepayment for variable-rate mortgages is less important as in the case for fixed-rate mortgages.

[15] The lost benefit here derives from the situation where after borrowers have exercised the prepayment option interest rates decline further, and borrowers have to incur a second set of transaction costs to capture the benefits of even lower interest rate.

Table 2: Estimates of Prepayment Model Using Nominal Interest Rates

Variable	Parameter Estimate	Standard Error	T -Values	Prob > |T|
INTERCEP	14.538	1.679	8.655	0.0001
VOL	0.0014	0.00013	10.423	0.0001
REHS	-12.2008	7.6963	-1.585	0.1173
DUM	-7.5860	1.3572	-5.589	0.0001
UOP	1.4923	0.5506	2.710	0.0084
DOP	-1.0019	0.5990	-1.673	0.0988

Adj R-sq	0.6183
Root MSE	4.3425

Durbin-Watson D	1.681
(For Number of Obs.)	77
1st Order Autocorrelation	0.156

Table 3: OLS Estimates of the Prepayment Model Using Real Interest Rates

Variable	Parameter Estimate	Standard Error	T -Values	Prob > |T|
INTERCEP	13.3132	2.6204	5.081	0.0001
VOL	0.0012	0.0001	9.863	0.0001
REHS	-14.0915	7.3971	-1.905	0.0608
DUM	-8.4765	1.3478	-6.289	0.0001
RUOP	0.0056	0.0013	4.154	0.0001
RDOP	-0.0017	0.0014	-1.163	0.2489

Adj R-sq	0.6445
Root MSE	4.1909

Durbin-Watson D	1.917
(For Number of Obs.)	77
1st Order Autocorrelation	0.038

All the variables tested in the model have the expected sign. Prepayment is related positively to the turnover of the housing market ***(VOL)***, and negatively to the returns from alternative investment which is proxied by the returns of the Hang Seng Index

(REHS). The dummy variable confirms that the change in spread had segregated borrowers with mortgages originated before October 1990 from mortgages originated thereafter. Borrowers with lower spread mortgages would thus have a lower incentive to prepay than borrowers with higher spread even though they are in a similar situation. Therefore, the prepayment threshold will be lower for the period after October 1990 with all else equal. In addition to having the expected signs, the level of confidence of the model as a whole is quite satisfactory. Most of the variables have a high level of significance. The regression also confirms our expectation that future interest rate increases is the more dominant factor in prepayment decisions. The DW and R-sq test statistics as reported in the results are also quite satisfactory.

Some results do warrant further analysis, though. One such result is the fact that the model using real rates has a better fit than that using nominal rates. This is possibly explicable by the fact that for a long period in 1993 there was no variation in nominal interest rates, and consequently there was no expected increase or decrease in mortgage payments for that period. It may however also indicate that borrowers were basing their prepayment decisions not just on how nominal interest rates are changing, but also on the effect of inflation on the real cost of borrowing (and thus that inflationary expectation may be an important factor). However, both models display a consistent pattern that an expected increase is more significant than an expected decrease in interest rates. This pattern is also consistent with option pricing theory in which the option value is derived from a possible future increase of the underlying variable.

Further economic rationale for the differing reaction to nominal and real interest rates, and the asymmetrical reactions to interest rate movements can be found in the field of quasi-rational and behavioural economics, drawing in particular on research conducted by Shafir, Diamond, and Tversky (1997). According to them economic transactions can be represented either in nominal or in real terms, with the nominal representation simpler, more salient, and sufficient for the short run. They further contend that people are generally aware that there is a difference between real and nominal values, but because at a single point in time, or over a short period, money is a salient and natural unit, people often think of transactions in predominantly nominal terms. Consequently, the evaluation of transactions often represents a mixture of

nominal and real assessments, which gives rise to money illusion. Shafir, et al further suggest that money illusion is interpreted as a bias in the assessment of the real value of economic transactions, induced by a nominal evaluation. Reliance on a nominal evaluation is however not strategic or motivational in nature, rather, it is due to the ease, universality, and salience of the nominal representation. The strength and persistence of this bias is likely to depend on several factors, notably the relative salience of the nominal and real representations, and the sophistication and experience of the decision maker.

In the empirical estimates of the prepayment model, we found that prepayment decisions are better represented with real interest rates than in nominal rates. Therefore, there seems to be no bias/money illusion induced by a nominal evaluation. This may be attributed to the fact that both real rates and nominal rates are presented saliently in borrowers' prepayment decision. Borrowers are aware of inflation and its impact as inflation is regarded as an important economic indicator and is widely reported and discussed in the media. Borrowers are also able to assess the impact of inflation as mortgage borrowers are predominantly middle-class and well-educated. Despite the fact that prepayment decisions are better represented in real rates in our empirical model, it is likely that prepayment decisions do not correspond to either the real or the nominal rates but, rather, to a mixture of the two.[16] Accordingly, prepayment decisions may correspond to the interaction of the changes in the real and nominal rates. This question warrants further investigation, and may lead to better modeling of prepayment decisions.

In our empirical estimates of the prepayment model, we also found that the prospect of interest rate movement have differing effects on prepayment decision. As expected, the prospect of an interest rate increase will spur prepayment, while the prospect of an interest rate decrease will discourage prepayment. However, prepayments seem to be more sensitive to the prospect of an interest rate increase than to a decrease, as we expected. The parameter estimates and level of significance are both higher for interest rate increases than for nterest rate decreases. Following Benartzi and

[16] For example, a person who receives a 2 percent raise in salary in times of 4 percent inflation does not react as he would to a 2 percent raise, or to a 2 percent cut, in times of no inflation. Rather, this person's reaction to the real loss is tempered by the nominal gain (see Shafir, et al, 1997).

Thaler(1995) and Thaler et al(1997), this asymmetric reaction is consistent with two behavioural concepts: mental accounting and loss aversion. Loss aversion refers to the fact that people tend to be more sensitive to decreases in their wealth than to increases. Empirical estimates find that losses are weighted about twice as strongly as gains (Tversky and Kahneman [1992]). Mental accounting is the set of (implicit or explicit) cognitive activities that individuals and households engage in to serve the same function that regular accounting serves in an organization. Thaler et al(1997) puts forward that mental accounting determines both the framing of decisions and the experience of the outcomes of these decisions. An individual who frames decisions narrowly will tend to make short-term choices rather than adopt long-term policies. Also, an individual who frames past outcomes narrowly will evaluate gains and losses frequently. In general, narrow framing of decisions and narrow framing of outcomes tend to go together, and the combination of both tendencies defines a myopic individual.

The frequency in which an individual will evaluate the outcome of an investment will thus affect attitude to risk. An individual who is prepared to wait a long time before evaluating the outcome of an investment as a gain or a loss will find a risky investment more attractive than another investor (equally loss averse, but more myopic) who expects to evaluate the outcome soon. When the frequency of evaluation is high, the probability of observing a loss is also higher. Therefore, a myopic individual has a very low level of risk tolerance. In our empirical estimates, we found prepayment decisions to be more sensitive to the prospect of an interest rate increase than to a decrease. Following mental accounting concepts, this can be interpreted as loss averse behaviour, because an increase in interest rates will mean higher monthly payments for borrowers, with higher monthly payments then meaning a reduction of wealth for the borrower; and following similar logic, a decrease in interest rates will mean lower monthly payments and thus more wealth.

A more fundamental question for variable-rate mortgage borrowers, however, is why prepayment decision should be related to variations in interest rate at all. It is perfectly logical for fixed-rate mortgage borrowers to refinance the outstanding balance at lower interest rates, but for variable-rate mortgages there is technically no such motivation. Given that interest rates are likely to fluctuate up as well as down

over the remaining term of a mortgage, borrowers that choose to prepay when interest rates increase risk the loss of benefitting if interest rates decrease in the future. With prepayment decisions seemingly related to variations in interest rates comes the suggestion that borrowers only care about the impact of immediate interest rate changes and short-term choices, and have little concern for long-term interest rate trends. Futhermore, given periodic mortgage payments, borrowers are also continuously reminded of any gains and losses from interest rate changes. This combination of narrow framing of decisions and narrow framing of outcomes fits the description of myopic behaviour.

Conclusion

One of the objectives in conducting an analysis of prepayment data in Hong Kong was to test the various established relationships surrounding mortgage prepayment decisions and to determine whether prepayment behaviour in Hong Kong exhibited any difference from expected behaviour. Our analysis showed that borrowers in Hong Kong largely exercised their prepayment option in the manner consistent with expectations. However, we express due caution in interpreting the results achieved, as the study is subject to a number of limitations. Firstly, the prepayment data only represents the prepayment behaviour of the borrowers of two banks in Hong Kong, and the findings may thus differ with a larger sample drawn from more banks. In addition, much information that is borrower-specific, property-specific and loan-specific and which may shed light on prepayment behaviour was not available for inclusion in our model. Secondly, we were not in a position to adopt more sophisticate estimation methods, such as the hazard function approach or the logit model for our analysis of prepayment data, as we were not privy to the individual history of each loan. Nevertheless, we also believe that the simplicity and ease of interpretation of the OLS method did not obscure the importance of the findings of our analysis. Thirdly, although the binomial representation of interest rate movements may be criticised for being too simple, it has proven elsewhere to be very useful in modeling interest rates and other financial assets (Nelson and Ramaswamy, 1990). Possibly the strength of this research lies in the direction suggested for future research on prepayment of VRMs particularly, but all mortgages in general. As mentioned in the review, many borrowers did not exercise their prepayment as predicted by the option-

based/optimal model. Such non-optimal/irrational behaviour has received relatively little attention in the real estate finance research literature, but in explaining our findings of asymmetrical prepayment behaviour with interest rate movements we have drawn attention to the potential ability of concepts from the field of quasi-rational and behavioural economics to explain non-optimal behaviour in the exercise of options. We believe there are grounds in prepayment research to incorporate further these concepts.

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