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PREPAYMENT BEHAVIOUR OF DUTCH MORTGAGORS: AN EMPIRICAL ANALYSIS

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Discussion paper

Prepayment Behaviour of Dutch Mortgagors: An Empirical Analysis*

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Abstract

The booming Dutch mortgage market and the development of a promising secondary mortgage market in the Netherlands stress the need for an accurate mortgage prepayment model that incorporates typical Dutch market and contract characteristics. One of those typical Dutch features prescribes that each calendar year the mortgagor is allowed to prepay penalty-free 10 to 20 percent of the original loan amount. As a consequence, Dutch mortgagees suffer a loss when borrowers prepay their loans. This risk, once again, underlines the importance of a prepayment model that focuses on the Dutch market. To derive such model we use historical data on mortgages originated between January 1989 and June 1999. We estimate separate models for two popular redemption types: savings mortgages and interest-only mortgages. In both models we allow for suboptimal prepayment behaviour. The results clearly indicate that prepayment rates depend on interest rates and the age of the mortgage contract. Moreover, Dutch prepayment rates peak in the month December.

Keywords: mortgage prepayments, loan-level data, econometric model

JEL codes: D19, C23

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1. Introduction

The booming Dutch mortgage market and the development of a promising secondary mortgage market in the Netherlands stress the need for an accurate mortgage prepayment model that incorporates typical Dutch market and contract characteristics. To manage a mortgage portfolio properly, it is essential to understand how mortgagors prepay in today's economic environment and how prepayment will fluctuate as economic conditions change. If interest rates increase and people prepay then there is no problem; the prepaid principal can be reinvested at the new, more profitable rate. However, when interest rates increase, prepayment rates tend to slow down. Hence, lenders who based their funding on prepayment rates that turn out to be too high, need to attract additional funding against the prevailing, higher interest rates. Institutions that invest in mortgages, like the Dutch pension Fund for Public Employees (ABP), do not require additional funding. However, lower prepayment rates together with higher interest rates will lead to a market-value loss. Hence both lenders and investors suffer a loss in this situation.

On the other hand, when interest rates decrease, prepayment rates tend to increase. Prepayments in this economic situation always result in a loss for the lender or the investor, as the charged penalty is insufficient to cover the reinvestment costs. The exact size of the loss depends on the difference between the contract rate and the prevailing mortgage rate *and* on the part of the remaining balance that can be prepaid without penalty. In the Netherlands, the mortgagor is always allowed to prepay penalty-free each calendar year 10 to 20 percent of the original loan amount. As the remaining balance frequently decreases over time, the proportion that can be prepaid without penalty is often larger than 10% of the remaining balance. When a household moves, the mortgagor does not even have to pay any penalty at all!

From the above discussion it follows that the daily management of a mortgage portfolio requires a prepayment model that predicts future prepayments accurately. The prevailing approach to develop such a model is to isolate the determinants on the basis of historical information on prepayments and to extrapolate the resulting relationship into the future. Most of this empirical research is based on aggregated pool-level data. The mortgage pools analysed are mainly based on securutised American portfolios. For example, Kang and Zenios (1992) used observations of several hundred thousand Mortgage-Backed Securities over an eight-year period to estimate their empirical prepayment model. Golub and Pohlman (1994) included over 28 million historical prepayment rates to calibrate the Wharton prepayment model.[1] However, the aggregated pool-level data smooths out the individual loan characteristics that are behind the pool averages. In aggregation, much information is lost.[2] To avoid this problem, we use loan-level data kindly provided by The Pension Fund for Public Employees in The Netherlands (ABP). This dataset contains detailed information on a loan-by-loan level for all mortgages originated by ABP between January 1989 and June 1999. In total the dataset contains monthly information on approximately 45,000 interest-only mortgages and 70,000 savings mortgages. One of the few other studies using loan-level data is Abrahams (1997). Abrahams draws on historical prepayment data from 206,000 American individual loans. However, no details are provided on the quantitative model. Another study using loan-level data is Green and Shoven (1986), who elaborate in more detail on the proportional hazard model used in their research.

Our econometric approach builds on Green and Shoven (1986), by applying a proportional hazard prepayment model to quantify the relationship between prepayments and factors like the refinance incentive, seasoning, seasonality and burnout. We carefully define and quantify these factors. In particular we elaborate on the quantification of the refinance incentive, taking into account typical Dutch mortgage features. Relevant characteristics are the type of the mortgage, prepayment penalties and the Dutch tax regime. In this article we focus on two popular Dutch redemption types: the interest-only mortgage and the savings mortgage. The latter is a typical Dutch mortgage type that makes full use of the opportunities offered by the tax authorities in The Netherlands. We illustrate the quality of the models on the basis of in-sample predictions. Although we use Dutch data in the analysis, the methodology is generally applicable.

The remainder of this article is organised as follows. Section 2 gives an overview of the literature. Section 3 describes the mortgage market and contracts in the Netherlands. The prepayment model is described in Section 4. Section 5 describes the data used to estimate the model and Section 6 contains the results and illustrates model performance. Section 7 concludes.

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[1] Other, in this context interesting articles that make use of aggregate American mortgage portfolios include Brennan and Schwartz (1985), Clapp et al. (2000), Collin-Dufresne and Harding (1999), Hayre (1994), Hayre and Rajan (1995), Hayre et al. (2000), Huang et al. (1999), Jegadeesh and Ju (2000), Patruno (1994), Richard and Roll (1989), Singh and McConnell (1996).

[2] The difference between using transformations of aggregated data versus using aggregates of a transformation of the loan-level data can be substantial. A good example is the refinance incentive. When using pool-level data this is an unknown function of the ratio between the weighted average coupon rate and a refinance rate (See Jegadeesh and Ju, 2000). If these two rates are equal to each other then this approach concludes that there is no incentive for the mortgagors to prepay their loans. However, if the underlying mortgages are analysed on a loan-by-loan basis then you will find that about half of them have a contract rate that is lower than the average rate and hence are serious candidates for refinancing.

2. Modelling prepayment

The main difficulty in managing a mortgage portfolio lies within the prepayment behaviour of the mortgagor. The literature distinguishes between optimal prepayment and exogenous prepayment rules. Under optimal prepayments, the valuation proceeds as for any callable bond by starting at the maturity date of the contract and working backwards in time. At each point in time, the borrower prepays when the value of the mortgage, if left uncalled, exceeds the outstanding debt plus any transaction costs associated with refinancing it. Van Bussel (1998) applies this approach to Dutch mortgage contracts. The resulting prepayment behaviour depends only on the term structure of interest rates, thereby ignoring the individual characteristics of the borrower. These contingent claim techniques with endogenously determined termination are inappropriate for modelling observed prepayment numbers. Prepayment data on residential mortgages reveal that the prepayment option is frequently exercised when the prevailing mortgage rate is above the contract rate, while the mortgage is often not prepaid when it might be optimal to do so. Optimal call valuation models cannot explain this behaviour.

Valuation models in which prepayments are exogenously specified override this empirical shortcoming. Exogenous prepayment models can be divided into two categories. First, there are models that are based on endogenous models. These models take an optimal call model as a starting point and add exogenous calls that are unrelated to the interest rate. On the other hand, there are strictly empirical models, which do not assume any optimal behaviour. Instead, these models relate the observed prepayments to a set of explanatory variables.

Dunn and McConnell (1981a,b) acknowledged the non-optimal behaviour and incorporate it into a model in which prepayments are only interest rate driven with non-financial termination features. Dunn and McConnell add a Poisson-driven process to explain the non-optimal prepayments. Even though such exogenous terminations always increase the market value of the mortgage they are not necessarily irrational. Such behaviour is often due to personal circumstances, such as job relocation or change in family size.

The Brennan and Schwartz valuation model (1985) adopts Dunn and McConnell's approach to include suboptimal prepayment behaviour. Instead of using a one-factor interest rate model, as Dunn and McConnell do, Brennan and Schwartz use a two-factor model to value the mortgage and its prepayment option. They abstract from default, a possibility that is included in the model developed by Kau, Keenan, Muller and Epperson (1992). Alongside optimal termination behaviour they also use a Poisson process to include suboptimal termination decisions. None of these models addresses transaction costs - a shortcoming that does not hold for the models developed by Giliberto and Ling (1992) and Archer and Ling (1993). As well as considering prepayments that occur when the option is out-of-the-money, Archer and Ling (1993) recognize that many mortgagors fail to exercise the prepayment option when this would be optimal. Their results indicate that transaction costs account for the observed lags in exercising in-the-money prepayment options. Stanton (1995) explicitly modelled heterogeneity in prepayment costs and found that the transaction costs in the observed termination data are significantly higher than the explicit monetary costs associated with refinancing.

Strictly empirical exogenous models do not use optimality in characterizing prepayment behaviour. Instead, these models relate the observed prepayments to a set of explanatory variables. The literature on these models is extensive, see the references in the introduction. The prepayment decision is analysed by using models estimated from historical data. In these models, four main determinants are specified. The first and most important element that determines prepayment is the *refinancing incentive*. Homeowners tend to refinance the existing mortgage when the current mortgage rate is far enough under the contract rate. Secondly, not everybody will react immediately when faced with a prepayment opportunity. The most aware mortgagors will react and prepay their mortgage the first time a refinance incentive occurs. If the same refinance incentive occurs at a later stage, a smaller number of the remaining mortgagors will respond. The phenomenon of prepayment rates declining as mortgage pools age through interest cycles is known as *burnout*. The burnout effect is an aging effect, the older the pool of mortgages, the lower the prepayment rates. Thirdly, s*easoning* is also an aging factor but one with an opposite effect. When borrowers take out a new mortgage it is generally unlikely that the interest rate, family or employment circumstances change in the near future. The prepayment rates are therefore low at the beginning of a mortgage contract and increase gradually over time until they reach a stable or "seasoned" level.[3] Finally, *seasonality* measures the correlation between prepayment rates and the month of the year. This cyclical behaviour is highly linked with the cyclical behaviour in house sales. Homeowners' relocation tends to peak in the spring and summer and decline in the autumn and winter months.[4]

Macro-economic factors could be incorporated as well. A factor that is frequently mentioned is house prices. However, using the resulting prepayment model for forecasting would also require a model to describe house price fluctuations. This is not the focus of this paper and we follow the existing literature by including the four aforementioned factors: refinancing incentives, burnout, seasoning and seasonality.

[3] The American PSA (Public Securities Association) model is based on this idea. The PSA model assumes that the prepayment rates increase linearly during the first thirty months of the contract until they reach a 6% per year level, at which prepayment rates will remain constant.

[4] See for example Richard and Roll (1989).

Before describing the data and the econometric model, we first give an overview of the Dutch mortgage market in the next section.

3. The Mortgage Market in the Netherlands

The mortgage market in the Netherlands has become a highly dynamic market. Indicators are a substantial growth of the market, the increasing interest for the secondary market and the sharp increase in the variety of loan types. During most of the eighties the linear and annuity mortgages were the most popular mortgages types. At each payment date, total payment consists of an interest and a principal component. The principal component is fixed for a linear mortgage and hence total monthly payments decrease over time as interest payments decrease. In an annuity the total monthly payments are fixed. Initially the part related to interest payments is large whereas the principal payments are small. The reverse holds towards maturity. In the 1990s the life-insurance mortgages and savings mortgages became increasingly popular for their tax friendliness. Under such mortgages, no principal is repaid during the term of the contract. Instead, the borrower makes payments on a regular basis to the lender. These payments comprise interest on the mortgage loan and an investment or savings element. Upon maturity, the loan is repaid with the money saved in the investment or savings account. Since no repayments take place during the term of these contracts, the outstanding mortgage balance remains unimpaired. As a consequence, the interest costs to the mortgagor do not decline over the years. However, in the Netherlands these interest costs are tax deductible for the entire term of the contract. On the other hand, the return on the savings and investment accounts are, under certain conditions, not taxed. Hence, these products take optimal advantage of the tax system in The Netherlands.

The size of the lump sum payment at maturity of such saving-to-repay mortgages depends on the return of an agreed-upon investment benchmark. For a life-insurance mortgage, the profitability of the insurance company is used as the benchmark. In the event of disappointing economic performance these expected returns may not be realized, and the resulting lump sum payment is too small to repay the loan. This scenario would leave the mortgagor with a debt at the end of the term. On the other hand, more favourable economic conditions would leave the mortgagor with more money than expected, after repayment. This uncertainty is absent in the savings mortgage. With a savings mortgage, the monthly premium is determined such that at maturity enough capital is accumulated to pay back the entire loan. Moreover, the interest compensation on the savings account is equal to the interest cost of the corresponding loan. Hence, apart from the tax effects, a savings mortgage is comparable with an annuity mortgage. Whether a lender grants a fully amortizing annuity-mortgage or a savings mortgage will not substantially influence the periodical cash flows received. In the first case it consists of repayments plus interest while in the second case it is composed of savings premiums and interest. The remaining debt of a fully amortizing annuity-mortgage decreases with time. For a savings mortgage, the debt does not change during the maturity of the contract. However, savings premiums are collected during the life of such a mortgage contract and since the interest reimbursement on these premiums equals the mortgage rate, the outstanding balance of a savings mortgage is equal to the remaining debt of a comparable annuity mortgage at any moment in time.

In the second half of the 1990s, the interest-only and the investment mortgage became popular. No principal payments nor any periodic savings or investment premiums are required on an interest-only mortgage. Hence the regular payments only consist of interest. At the end of the term, principal repayment is achieved through the sale of the property, by taking out a new mortgage or by individual savings. Due to the higher credit risk, Dutch mortgagees never grant an interest-only loan that exceeds 75 percent of the foreclosure value of the underlying property. This 75 percent level is agreed upon by all Dutch mortgage suppliers and is set out in the Code of Conduct.[5]

The introduction of the investment mortgage was encouraged by the high returns on the Dutch stock market. With this new mortgage type the return on the investment account no longer relates to the mortgage rate or to the return of the insurance company. Instead it solely depends on the investment decisions made by the homeowner. Statistics Netherlands (1999) shows that in 1998 the market share of the investment mortgage already exceeded 50% of the newly issued mortgages.

More recently, so-called switch mortgages have become popular. Instead of choosing beforehand between a savings and an investment mortgage, mortgagors can switch between building up the principal amount through a savings account or by an investment account. Similar to a savings or an investment mortgage, the borrower does not pay back any principal during the term of the contract.

The Code of Conduct that regulates the maximum loan-to-foreclosure value for interest-only mortgages also prescribes minimum prepayment possibilities offered to Dutch mortgagors. As result, at least 10 percent of the initial principal can be prepaid within any full calendar year without penalties. Various lenders offer a larger percentage, such as 15 or 20 percent. Besides the annual partial penalty-free prepayment opportunity, situations exist in which complete prepayment is free of costs: the sale of the house, demise of the mortgagor, bankruptcy and the reception of a fire-insurance benefit. The only other instance that prepayment is free, is when

[5] Since October 1st, 1996, practically all mortgage suppliers subscribe to the non-binding interbank code of conduct for mortgage lending. This code is drawn up in co-operation with the government, consumers' associations and advisory bodies, and it prescribes minimum requirements regarding offer and contract conditions.

the mortgage rate is reset at the beginning of the next fixed-rate period. Dutch mortgages usually have a maturity of thirty years with the interest rate fixed for a period of between five and twenty years. At the end of each fixed-rate period the mortgage rate is reset to the prevailing market mortgage rate. Usually there are no caps or floors restricting the interest rate adjustments at the reset date so that the new contract rate is in conformity with the market rate.

Above the annual permitted prepayment, additional prepayments are settled at costs equal to the present value of the difference between the future monthly interest payments of a new contract and the existing mortgage. Sometimes an additional fixed amount between 250 and 500 guilders is added to this penalty. These "yield maintenance" penalties are in place to discourage prepayments.

Despite these discouraging costs, Dutch mortgagors frequently prepay their loan. This is illustrated in Table 1, which summarizes the recent developments on the Dutch mortgage market. As Table 1 shows, the market has grown enormously; between 1993 and 2000 the outstanding amount even more than doubled. In the same period, the amount issued per year even tripled. This sharp increase can be ascribed by the increase in both the average loan size and the number of newly issued mortgages. As Table 1 illustrates, a substantial part of the newly issued mortgages consists out of second lien mortgages and mortgages that replace existing loans. These large replacement numbers illustrate that, despite all costs, prepayment is an important feature when managing a Dutch mortgage portfolio.

Table 1: Overview Dutch mortgage market

	1993	1994	1995	1996	1997	1998	1999	2000
Amount Outstanding (Euro billions)	119	133	146	167	193	221	254	279
Amount newly issued (Euro billions)	21	27	26	38	49	60	78	70
Number of newly issued mortgages (thousands)	303	384	350	470	537	577	665	510
Of which								
Purchase home	65.3%	56.0%	64.0%	55.1%	52.3%	48.5%	49.2%	52.3%
Second mortgages				13.6%	11.4%	11.1%	21.9%	28.1%
	34.7%*	44.0%*	36.0%*					
Refinancing				31.3%	36.3%	40.4%	28.9%	19.6%
Average mortgage rate	7.5%	7.3%	7.1%	6.3%	5.8%	5.6%	5.1%	5.7%

*The numbers of 1993, 1994, and 1995 do not distinguish between second mortgages and refinancing.
Source: Statistics Netherlands

4. A prepayment model for the Dutch market

The empirical prepayment models summarized in Section 2 commonly specify four main determining factors: refinance incentive, burnout, seasoning and seasonality. The way in which the four factors are incorporated should reflect the characteristics of the underlying market. For example, due to the prepayment penalty included in Dutch contracts, the refinance incentive in the Netherlands must be defined differently than its American counterpart. In this section we specify the econometric model, which describes the four factors and incorporates the Dutch market characteristics.

The econometric model in this paper is based on Green and Shoven (1986) and Schwartz and Torous (1992) who use proportional hazard models. Differences stem from ensuring that the probabilities in the model are guaranteed to be between zero and one. The main element in the model is the so-called hazard rate, which represents the probability of prepayment for a mortgage in a specific month, given that it has not been prepaid at an earlier stage. Let h_{it} denote the hazard rate for mortgage *i* in month *t*:

$$h_{it} = h_0(age_t; J_1, J_2) * p(x_{it}; \tilde{J})$$

where $h_0(age_t; J_1, J_2)$ is the baseline hazard depending on the age of the mortgage (in months) in month *t* and the parameters J_1, J_2. The first parameter indicates the baseline-hazard for a mortgage that has just been originated, whereas the second parameter indicates how the baseline-hazard changes with an increase in the age of the mortgage. The function $p(x_{it}; \tilde{J})$ is the proportionality factor that depends on explanatory variables x_{it} and the parameters $\tilde{J}$. Given the explanatory variables, which will be defined later on, the parameters $\tilde{J}$ indicate the effect on the proportional hazard by a change in the related explanatory variable.

The baseline hazard contains the seasoning effect, which refers to the gradual increase in prepayment speeds until a reasonably steady-state speed is reached (Hayre, Chaudhary and Young, 2000). The traditional approach to modelling the seasoning process is to assume that the seasoning curve reflects an *S*-shaped relation between the prepayment rate and the mortgage age. When the mortgage is recently originated, it is highly unlikely that it will be prepaid in the near future. Similarly, the likelihood that the family or employment circumstances change within a short time span is rather small. Moreover, changing homes is a major undertaking with high transaction costs and most home purchases are therefore followed by a settling-in period. Consequently, prepayments associated with newly originated mortgages are initially quite small, and increase gradually during the so-called ramp-up period. After this ramp-up period, the housing turnover likelihood will stabilize at its natural or ”seasoned” level. It could be argued that loans which are used to refinance already existing mortgages season faster than loans taken out to finance the purchase of a house because many of the elements that determine seasoning (*e.g.* a new born-baby, increased income, divorce) are already developed to some extent in a refinanced loan. However, as pointed out by Hayre *et. al.* (2000), this view is not universally held. Homeowners who plan to move in the near future are most likely not interested in starting the procedure of applying for a new mortgage and paying the corresponding transaction costs. These transaction costs can be very high, especially in the Netherlands where the homeowner must pay a yield maintenance penalty. This penalty is not in place when the mortgagor moves. Hence, a homeowner who has plans to move in the near future will probably not refinance his mortgage until after the move. The refinancing of a mortgage can thus be read as a signal that the mortgagor does not intend to move in the near future. Therefore the S-shaped seasoning curve should hold for both purchase loans and refinancing loans and as such the following specification serves as the baseline hazard:

$$h_0(age_t; J_1, J_2) = 1/(1+\exp(-J_1 - J_2 age_t))$$

The specification is chosen in such a way that a positive parameter value indicates that the hazard rate increases with the age of the mortgage until the seasoned level is reached.

The proportionality factor contains the other relevant factors in determining prepayments. Before elaborating on these factors the specification of the proportionality factor must be introduced:

$$p(x_{it}; \tilde{J}) = \exp(-\exp(-\tilde{J}' x_{it}))$$

Again, the parameters indicate the direction of the effect of an increase in an explanatory variable. The functional forms for $h_0(age_t; J_1, J_2)$ and $p(x_{it}; \tilde{J})$ guarantee that the hazard rate h_{it} is in between zero and one. The hazard rate is also known as the Single Month Mortality rate (= *SMM*), which, in turn, relates to the well-known Conditional Prepayment Rate (*CPR*) as *CPR* = 1- (1-*SMM*)^{12}. Once the hazard rate and its components are defined, we can estimate the parameters by maximizing the log-likelihood. For a sample of *N* mortgages starting in month t_i and lasting for T_i months, the log-likelihood reads as follows (see Jenkins, 1995):

$$\log-\text{likelihood} = \sum_{i=1}^{n} \sum_{t=t_i}^{t_i+T_i} \left[y_{it} \log \frac{h_{it}}{(1-h_{it})} + \log(1-h_{it}) \right] \quad (4)$$

where y_{it} is 1 if mortgage i is prepaid in month t and zero otherwise. Consequently, the first term of the equation only differs from zero if mortgage i is prepaid in month t. The second term contributes to the log-likelihood in all months. Hence, if no prepayment occurs, the chosen specification forces the parameters to be chosen such that the Single Month Mortality is as close to zero as possible. On the other hand, when a mortgage is prepaid, the log-likelihood is equal to log(h_{it}). And as a result of maximizing the log-likelihood, this corresponds with a value of h_{it} that is as close to one as possible.

Before being able to estimate the parameters, the variables that are included in x_{it} must be specified. It should come as no surprise that these variables are chosen to describe the pillars on which most prepayment models are built: refinance incentives, seasonality and burn-out. The seasoning factor is already included in the baseline hazard.

In determining the refinance incentive, we assume that a homeowner who considers replacing the mortgage with a new loan has to borrow an amount equal to principal outstanding on the existing mortgage plus the after-tax prepayment penalty. As the marginal tax rate is not observed we have to determine it. Details can be found in Appendix A. Computation of the before-tax prepayment penalty involves several steps. First, a yield maintenance penalty is computed as the present value of the difference between the future interest payments of a new mortgage and the existing contract. Administration costs are added to this yield maintenance penalty in order to yield the before-tax prepayment penalty. Together with the marginal tax rate this yields the after-tax prepayment penalty. For refinancing to be attractive, the effect of a lower mortgage rate has to outweigh the consequences of a higher debt level. To determine this we calculate the present value of the future monthly payments when the mortgage is left uncalled and compare this with the present value of a newly taken out mortgage.[6] The refinance incentive is positive when the present value of the mortgage, if left uncalled, exceeds the present value when refinanced. In all other situations the refinance incentive equals zero. Details on the computation of the refinance incentive for different mortgage redemption types can be found in Appendix B. For several redemption types, and a special case of the quantification of the refinance incentive, Charlier (2001) presents graphical representations of it.

The above defined refinance incentive incorporates the after-tax penalty Dutch borrowers must pay when refinancing their mortgagor. This penalty, however, is not in place when the mortgagor moves. The value of this '*moving option*' increases with

[6] Note that mortgagors can choose a fixed-interest rate period that differs from the remaining fixed-interest rate period on the current mortgage. However, this leads to the question regarding the choice of period. This requires a separate investigation from which we abstract for the moment.

decreasing interest rates. The tendency to move house when interest rates are low is strengthened by the fact that the mortgagor's income can service a larger debt, which enables him to buy a bigger house.

In the absence of refinancing incentives, home sales are the main driver for prepayments.[7] In the Netherlands, these home sales are primary a consequence of the desire to "move up" to a larger or more expensive house. Relocation is of much less importance in this small country. Accepting a new job, for example, generally implies that the individual simply changes his commuting route rather than his residence. People in their mid-thirties and forties are considered the most likely candidates for upgrading. To capture this we include the age of the corresponding mortgagor as well as the square of his age in the proportionality factor. [8] Moreover, we included a dummy variable to capture the higher likelihood that an apartment-owner considers upgrading, as opposed to the owner of a single family home.

The seasonality factor is accounted for by including a constant term and dummies for each month of the year. This is related to the fact that relocation tends to peak in the spring and summer months and declines in the autumn and winter months. For identification of the parameters we have to normalize one of the seasonality coefficients at zero. In this paper we set the coefficient related to the month of August to zero because the average prepayment rate in August is roughly equal to the annual average. This implies that all other seasonality dummies must be interpreted relative to August.

The next variable included in our model captures the burnout effect. Burnout is a consequence of changes in the composition of the mortgage pool as the mortgagors who are willing and able to refinance leave the pool at faster rates than other mortgagors.[9] As a result, the proportion of 'slow prepaying mortgagors' becomes larger over time. As such, part of the burnout effect is already absorbed in our model through our definition of the other variables, *e.g.* apartment owners are expected to prepay faster than single-family homeowners. However, this is already absorbed by the dummy variable for the underlying property. Consequently, the probability that the mortgage of an apartment-owner is still in the pool at month t is smaller than that of a mortgage of a single-family homeowner. Hence, rather than explicitly modelling the changing composition of the pool, we opted for a burnout variable which indicates an increasing or decreasing likelihood of individual mortgage refinancing in a particular month. In this paper, the burnout variable is defined as the refinance incentive in the current month minus the maximum

[7] Dutch homeowners can rollover their mortgage loan when moving to a new house. Consequently, the lock-in effect, which refers to the damping effect on the likelihood of moving for those who have loan rates below current mortgage rates, is not relevant in the Netherlands.
[8] For scaling purposes we use the age in years divided by 10 and its square.
[9] See Hayre (1994).

refinance incentive in the past. A negative value shows that the mortgagor did not take advantage of an earlier, more profitable opportunity. Based on this knowledge, the prepayment expectation for such a mortgagor should be adjusted downwards. Hence, we expect to observe a positive parameter corresponding with this burnout variable.

Another variable included in our analysis is the number of subsidized parts. Some mortgagors receive part of their mortgage subsidized by the government. If the mortgage is prepaid the subsidy might be lost. Therefore subsidized parts could lead to lower prepayment rates. In addition, if the mortgage consists of several (non-subsidized) parts then prepayment of a single part might be affected by the presence of the other parts. Therefore we include the number of other parts as well. Finally, we include time dummies to account for the media effect. These dummies would also pick-up increasing relocations, if present.

5. Data

The data, required to estimate the parameters in the prepayment model, are kindly provided by ABP. The dataset contains information on a loan-by loan level of all mortgages originated between January 1989 and June 1999. This number exceeds 100,000 mortgages. As a consequence, the dataset is too large to use all individual mortgages in the log-likelihood specification of our model. Rather than using all mortgages, a randomly selected subsample of approximately 4,000 mortgages is utilized. By selecting this subsample it is required that its characteristics correspond with the main characteristics of the full sample. For example, the fraction of mortgages originated in each year should match, and for each origination year, the fraction of mortgages that is prepaid in the subsample should match the fraction in the full sample. Tables 2 and 3 show how well the subsamples of 1,940 savings mortgages and 2,037 interest-only mortgages match the characteristics of the complete dataset. The reported numbers add up to 100% for both the full sample and the subsample. The interpretation is the following: of the total amount of savings-mortgages originated as of 1989, 5.48 percent (full sample) was originated in 1992 and has not prepaid whereas 7.02 percent was also originated in 1992 but already has prepaid. Hence 12.50 percent of the originated amount as of 1989 was originated in 1992. Of this 12.50 percent, 44 percent has not prepaid whereas 56 has.

When constructing the data, four savings mortgages were dropped due to incomplete information on the history of the related mortgage rates. For the same reason, 31 interest-only mortgages were left out. Definitions and summary statistics on the variables used in the application are presented in Table 4.

Table 2: comparison of subsample with full sample for savings mortgages

Origination Year	Full sample Not Prepaid	Subsample Not Prepaid	Full sample Prepaid	Subsample Prepaid
1989	0.82%	0.84%	0.87%	1.04%
1990	2.39%	2.22%	3.36%	3.29%
1991	3.72%	3.92%	5.40%	5.33%
1992	5.48%	5.21%	7.02%	6.70%
1993	7.11%	7.07%	7.06%	6.51%
1994	7.75%	7.74%	6.05%	6.96%
1995	7.24%	7.24%	4.03%	4.52%
1996	8.80%	8.40%	3.11%	3.33%
1997	7.82%	7.75%	1.56%	1.76%
1998	6.83%	6.62%	0.45%	0.36%
1999	3.11%	3.21%	0.02%	0.00%

Table 3: comparison of subsample with full sample for interest-only mortgages

Origination Year	Full sample Not Prepaid	Subsample Not Prepaid	Full sample Prepaid	Subsample Prepaid
1989	1.21%	1.47%	0.13%	0.24%
1990	0.24%	0.20%	0.05%	0.00%
1991	0.32%	0.07%	0.18%	0.21%
1992	1.47%	1.28%	0.88%	0.83%
1993	2.35%	2.85%	1.50%	1.35%
1994	3.72%	3.68%	2.07%	2.55%
1995	4.75%	4.38%	2.05%	1.88%
1996	9.46%	9.49%	3.21%	3.40%
1997	12.54%	13.09%	3.13%	3.40%
1998	26.59%	25.60%	2.39%	2.23%
1999	21.52%	21.36%	0.27%	0.46%

Figures 1 through 8 indicate the unilateral relationship between the factors and the CPR. These figures are based on those values or buckets for the explanatory variables for which at least 500 observations are available. Figures 1 through 4 relate to the relationships for savings mortgages, Figures 5 through 8 relate to interest-only mortgages. Figure 1 illustrates a clearly positive relationship between the CPR and the age (seasoning) of a savings mortgage. This positive relation is, less obvious when looking at an interest-only mortgage (Figure 5). Figures 2 and 6 show the seasonal pattern. It holds for both savings mortgages and interest-only mortgages that the prepayment rates are relatively high in April, the summer months and December. The main difference between both redemption types is that the summer-peak occurs in July for savings mortgages while the prepayment on interest-only mortgages seems to peak in June. The December effect we observe for both redemption types might be caused by tax effects: if a mortgage is prepaid, the

Table 4: Definition of Variables and Summary Statistics					
		Savings mortgages		Interest-only mortgages	
Variable	Definition	# obs	Mean	# obs	Mean
Age	Age of the mortgage in months	96,609	33.11	51,713	23.74
Refinance	Refinance incentive/1000	22,130 74,479	0 1.33	7,064 44,649	0 1.95
Burnout	Burnout, see main text	96,609	–0.48	51,713	–0.39
Agemortgagor, Agemortgagor2	Age of the mortgagor (and its square) in years divided by 10	96,609	3.54 12.99	51,713	4.53 21.95
Dflat	Dummy equal to 1 if the collateral is an apartment	1,936	0.070	2,006	0.064
Djan,..,Ddec	Dummy equal to one if the datapoint is related to the specific month of the year	8,022 8,087 8,166 8,367 8,283 8,466 8,568 7,555 7,640 7,714 7,825 7,916	Djan=1 Dfeb=1 Dmar=1 Dapr=1 Dmay=1 Djun=1 Djul=1 Daug=1 Dsep=1 Doct=1 Dnov=1 Ddec=1	4,224 4,313 4,427 4,595 4,767 4,960 5,143 3,639 3,753 3,849 3,958 4,085	Djan=1 Dfeb=1 Dmar=1 Dapr=1 Dmay=1 Djun=1 Djul=1 Daug=1 Dsep=1 Doct=1 Dnov=1 Ddec=1
Notherparts	Number of other parts in the mortgage	53,057 37,301 5,941 310	0 1 2 3	935 900 171	0 1 2
Nsubsidy	Dummy equal to one if subsidized parts are present for the particular mortgage	87,020 9,589	0 1	1,999 7	0 1
Dyear92,.., Dyear99	Dummy equal to 1 if the datapoint is related to the specific year	5,559 8,542 11,176 13,487 14,990 15,527 15,184 8,199 3,954	Dyear92=1 Dyear93=1 Dyear94=1 Dyear95=1 Dyear96=1 Dyear97=1 Dyear98=1 Dyear99=1 All other origination years	595 1,506 2,883 4,367 6,815 10,146 14,033 10,441 927	Dyear92=1 Dyear93=1 Dyear94=1 Dyear95=1 Dyear96=1 Dyear97=1 Dyear98=1 Dyear99=1 All other origination years

related costs are tax deductible, which might be an incentive to prepay the loan in the last month of the fiscal year (which coincides with the calendar year).[10] Figures 3 and 7 show the positive relationship between the prepayment rate and the refinance incentive. This relation seems to be stronger for savings mortgages than for interest-only mortgages.

Finally, the relationship between the age of the mortgagor (divided by 10) and the CPR is plotted in Figures 4 and 8. As these figures illustrate, this relation is humped-shaped; the prepayment rate is relatively low during the early adult-years of the mortgagor, increases during his thirties and forties and decreases again afterwards. This corresponds with our hypothesis regarding upgrading. The humped shape relation is much more obvious for savings mortgages than it is for interest-only mortgages. Due to differences like this we opted for estimating separate models for savings mortgages and interest-only models. The estimation results are presented in the next section.

6. Results

This section presents the results of the prepayment model developed for the Dutch Market. Recall that in this paper we estimate a separate prepayment model for both the savings mortgage and interest-only mortgage. Moreover, for both of these redemption types we specified two models, either excluding or including burnout. The empirical outcomes of the resulting four prepayment functions are presented in Table 5.

The first column in Table 5 contains the explanatory variables and indicates whether a variable belongs to the baseline hazard function or to the proportionality factor. The next two columns contain the parameter estimates, and the corresponding standard errors (in parentheses), for the savings mortgages. Column two excludes burnout, whereas column three includes it. Time dummies are only included for 1992 through 1999 because the observations in earlier origination-years are insufficient to identify separate year dummies for 1990 and 1991.

[10] One might expect that this peak in December is caused by mortgagors who exercise the option to prepay 10 to 20% within a calendar year without paying a penalty. However, the plots are solely based on mortgages that are completely prepaid. Hence, curtailments cannot cause this December peak.

Figures for savings mortgages

Figure 1: relationship between the CPR and the age of the mortgage (time)

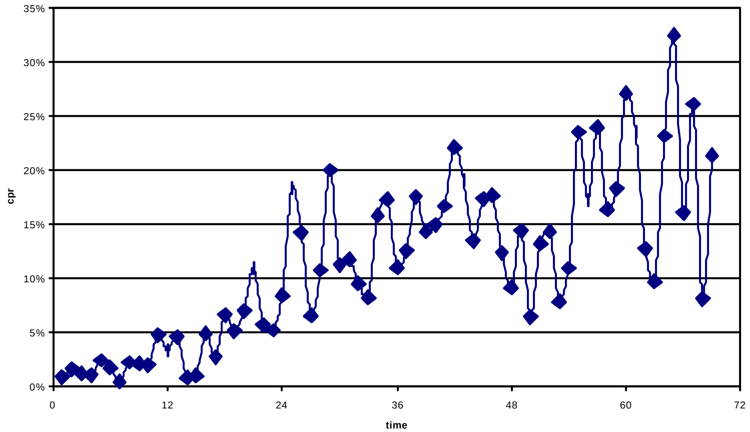


Figure 2: relationship between the CPR and the month of the year

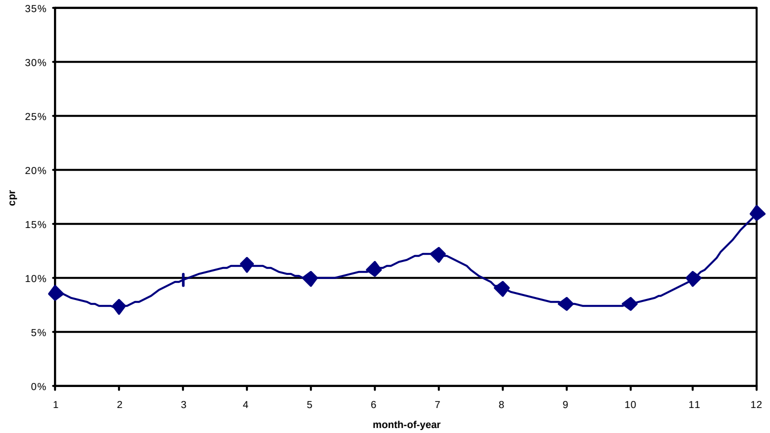


Figure 3: relationship between the CPR and the refinance incentive

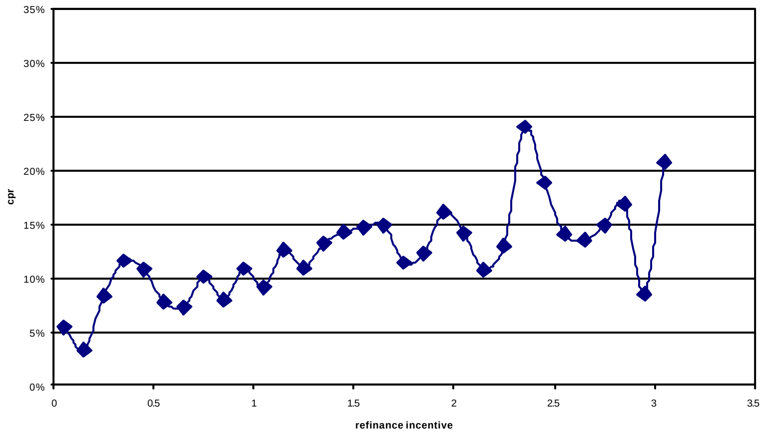
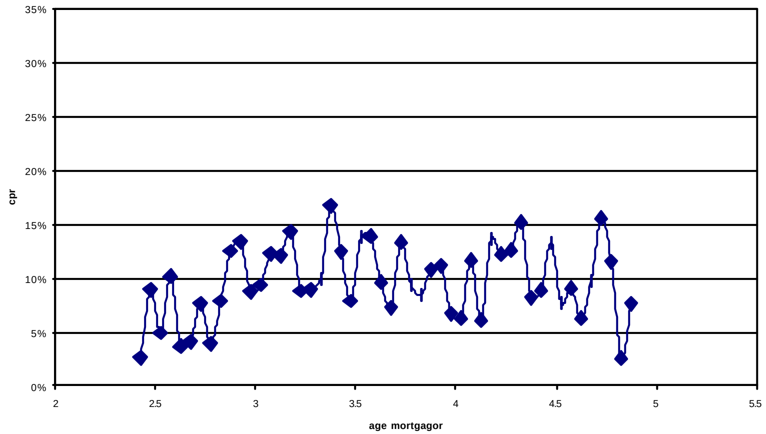


Figure 4: relationship between the CPR and the age of the mortgagor



Figures for interest-only mortgages

Figure 5: relationship between the CPR and the age of the mortgage (time)

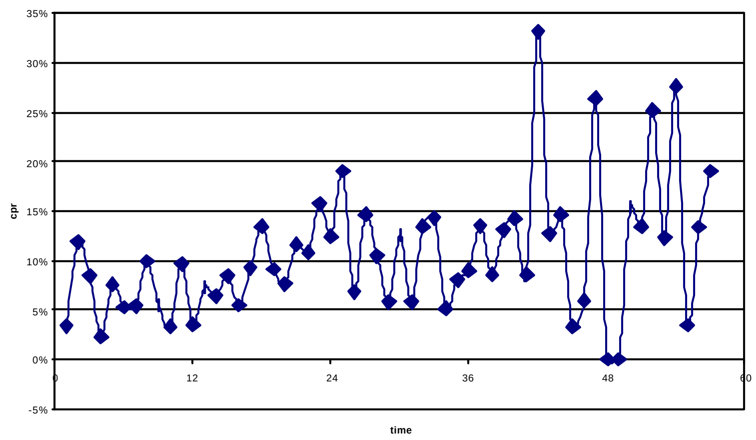


Figure 6: relationship between the CPR and the month of the year

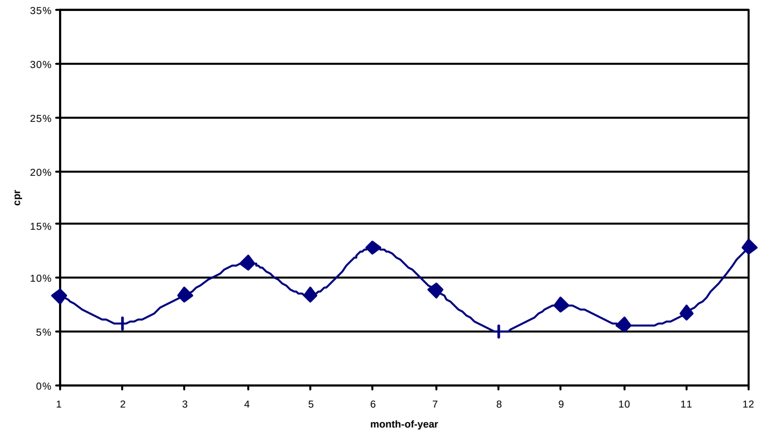


Figure 7: relationship between the CPR and the refinance incentive

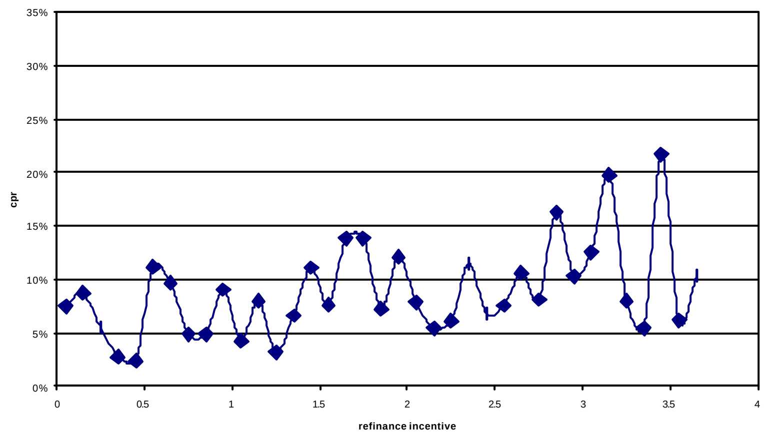


Figure 8: relationship between the CPR and the age of the mortgagor

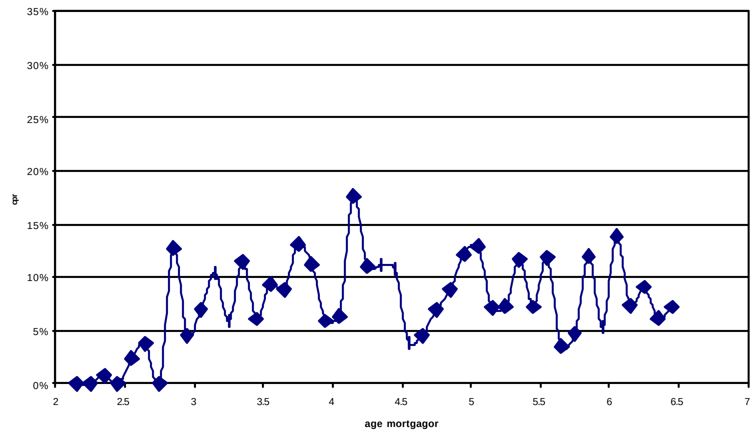


Table 5: Estimation results (standard errors in parentheses)[a]

		Savings mortgage		Savings mortgage		Interest only		Interest only	
	Variable	Estimates		Estimates		Estimates		Estimates	
Baseline	Age	0.132**	(0.021)	0.121**	(0.015)	0.125	(0.063)	0.124**	(0.036)
Prop	Refinance	0.021*	(0.011)	–0.011	(0.012)	0.018*	(0.009)	–0.001	(0.009)
Factor	Burnout			0.106**	(0.018)			0.095**	(0.024)
	Djan	–0.071	(0.043)	–0.090*	(0.045)	0.016	(0.067)	0.001	(0.070)
	Dfeb	–0.097*	(0.044)	–0.107*	(0.045)	–0.020	(0.066)	–0.030	(0.069)
	Ddec	0.128**	(0.040)	0.133**	(0.041)	0.213**	(0.061)	0.220**	(0.064)
	Dflat	0.097**	(0.032)	0.093**	(0.033)	–0.019	(0.051)	–0.019	(0.054)
	Notherparts	0.009	(0.016)	0.005	(0.016)	–0.016	(0.020)	–0.018	(0.021)
	Nsubsidy	–0.061	(0.033)	–0.042	(0.034)				
	Agemortgagor2	–0.005	(0.017)	–0.008	(0.017)	0.006	(0.007)	0.005	(0.007)
	Agemortgagor	–0.027	(0.126)	–0.004	(0.132)	–0.074*	(0.067)	–0.061	(0.070)
	Dyear92	0.022	(0.141)	0.026	(0.147)				
	Dyear93	0.122	(0.125)	0.139	(0.131)				
	Dyear94	0.264*	(0.122)	0.341**	(0.128)				
	Dyear95	0.254*	(0.121)	0.322*	(0.126)	0.190*	(0.077)	0.207**	(0.080)
	Dyear96	0.345**	(0.120)	0.410**	(0.126)	0.231**	(0.071)	0.254**	(0.074)
	Dyear97	0.420**	(0.120)	0.502**	(0.125)	0.324**	(0.067)	0.360**	(0.069)
	Dyear98	0.472**	(0.119)	0.572**	(0.125)	0.353**	(0.065)	0.376**	(0.067)
	Dyear99	0.509**	(0.121)	0.607**	(0.127)	0.424**	(0.065)	0.446**	(0.067)
Log–Lik		–4400.53		–4370.03		–2212.98		–2198.99	

** means significant at the 1% level; * means significant at the 5% level

[a] All models contain a constant term in both the Basline hazard and the proportionality factor. The proportionality factor contains dummies for each month where August is the reference month. We only report the results for the significant month dummies.

Columns four and five refer to the prepayment functions for interest-only mortgages. The difference again consists of either excluding or including burnout. For interest-only mortgages we could only identify year dummies as of 1995.

As illustrated in Table 5, the parameters belonging to most year dummies are significant at the 5% level and also formal chi-square tests illustrate that the models, which incorporate the year dummies, are preferred to models without them. This is attributed to the media effect, meaning that intermediaries urge people more to prepay their mortgages.

Due to the chosen specification, the baseline hazard has an S-shaped curve. For the four models, the baseline hazard is equal to 0.99 after 53, 60, 40 and 46 months, respectively. This implies that a pool of Dutch mortgages seasons rather quickly; within 4 to 5 years the seasoned level is reached.

When considering the results for the models without an explicit burnout variable (columns two and four of Table 5), the effect of the refinance incentive is significantly positive. This implies that Dutch borrowers are sensitive to interest fluctuations and that they do prepay their mortgages when financially attractive opportunities appears.

However, this relationship between prepayment speeds and the prevailing refinance incentives becomes insignificant when we take the burnout variable into consideration. This is illustrated in the third and fifth column of Table 5. These columns present the results for the savings mortgage and interest-only mortgage, respectively, including a separate burnout variable. Recall that burnout is defined as the prevailing refinance incentive minus the maximum refinance incentive in the past. The corresponding positive coefficient, which is significant at a 1% level, indicates that past refinance incentives play an important role in explaining current prepayment rates. For example, mortgagors who have not had the opportunity to refinance their loan at attractive rates in the past are more likely to prepay when this opportunity appears in the future. On the other hand, individuals who did not act in the past when attractive refinance rates appeared, tend to respond equally passively when similar opportunities come along.

For savings mortgages, the parameters related to the month dummies (seasonality) are individually insignificant, except for the months January, February and December. In January and February prepayments are lower than those in August (the reference month) whereas they are higher in December. For the other months, the SMM does not differ from the SMM for August. Interest-only mortgages prepay more in the month December. The January and February effects are not present. In all models, the coefficient related to December is the largest positive. This implies that prepayments are largest in December.

When considering upgrading (represented by Dflat, Agemortgagor and Agemortgagor2) we conclude that for savings mortgages, mortgagors living in an apartment prepay more than those not living in an apartment. The relationship between the age of the mortgagor and the SMM can take on different shapes depending on the model. However, the coefficients are estimated imprecisely and performing tests whether the coefficients related to Agemortgagor and its square are zero simultaneously cannot reject this hypothesis at the 5% significance level.

The year dummies are generally significantly positive which implies that the prepayment rates have been rising over the years, *ceteris paribus*.

Statistical tests favour the models including burnout. In addition, we also compare the models by looking at the in-sample predictions for the SMM-s with the realizations of the SMM-s. The results are presented in Figures 9 through 12. We conclude that, despite the statistically significant difference in the parameter estimates, the models with and without burnout are similar in terms of the prediction of the in-sample SMM's.

Figure 9: In-sample performance of the model excl. burnout for savings mortgages

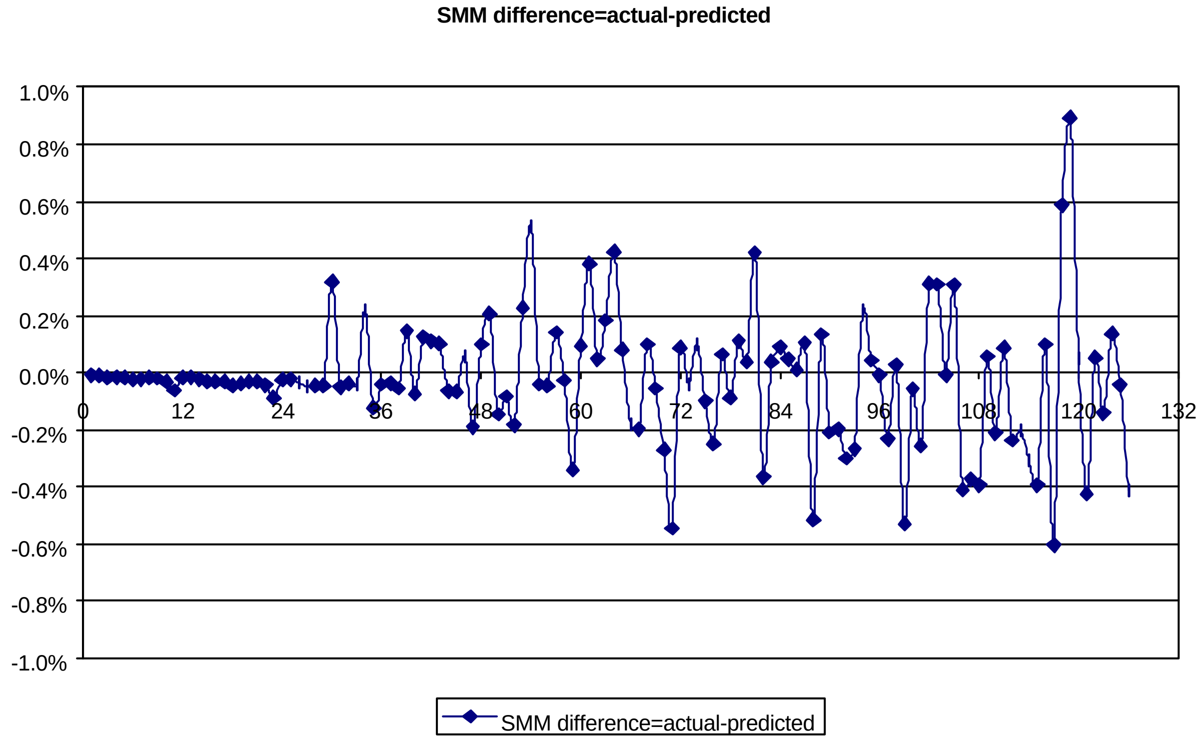


Figure 10: In-sample performance of the model incl. burnout for savings mortgages

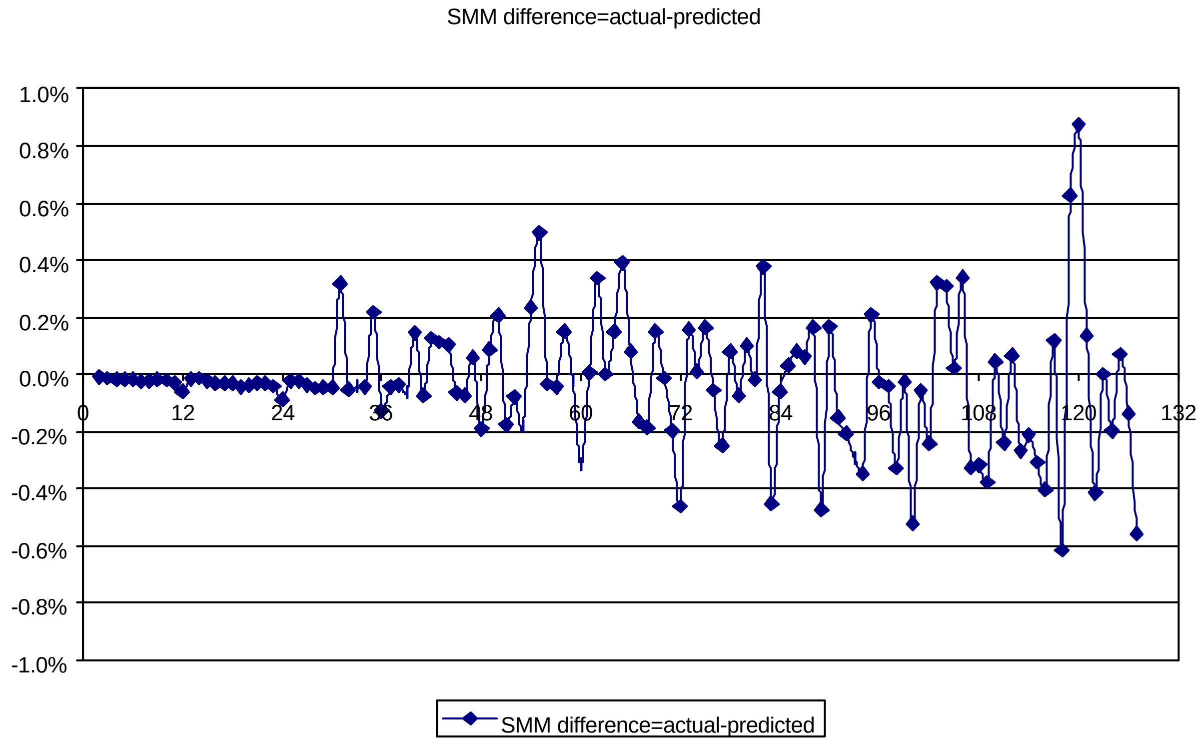


Figure 11: In-sample performance of the model excl. burnout for interest-only mortgages

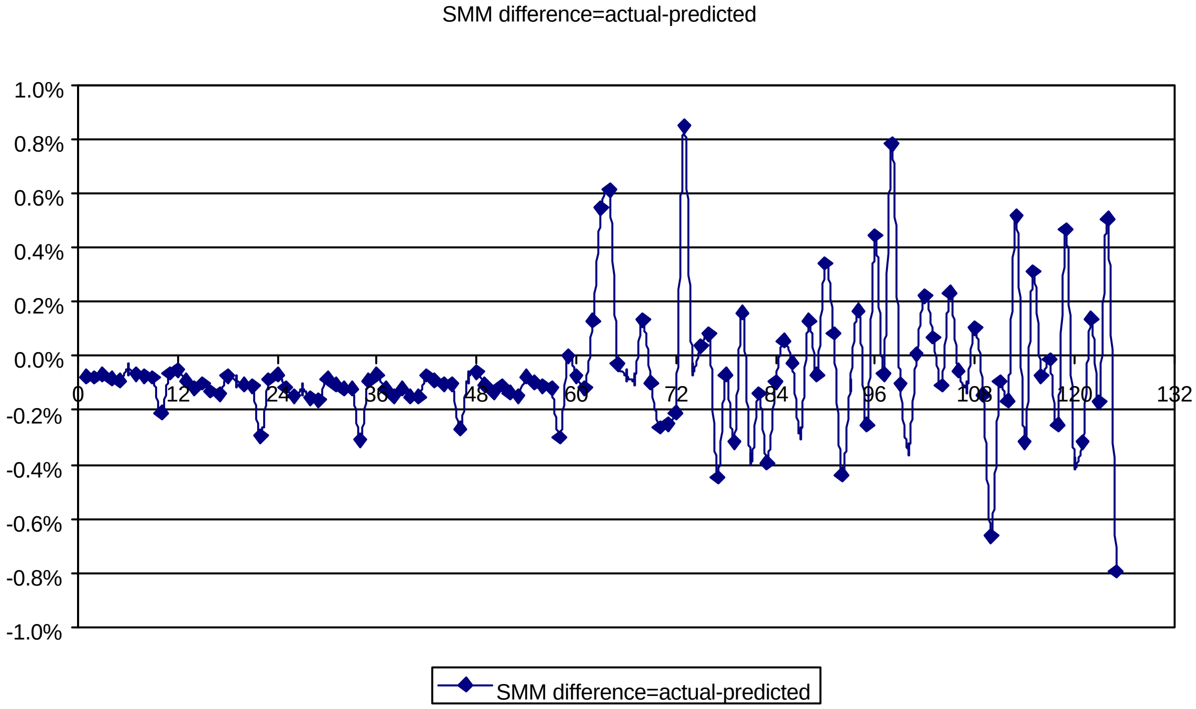
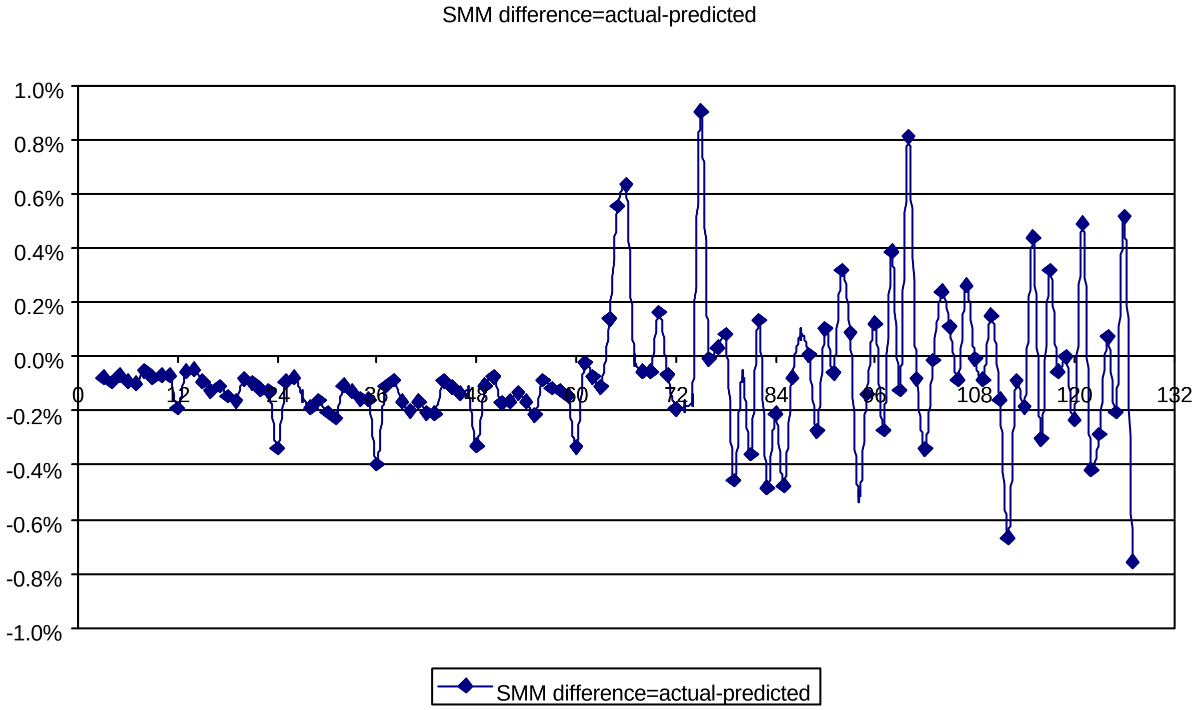


Figure 12: In-sample performance of the model incl. burnout for interest-only mortgages



7. Conclusions

In the Netherlands, mortgage contracts are commonly only partially callable. Within a calendar year, only 10 to 20 percent of the initial loan can be prepaid without costs. Additional prepayments are settled at costs equal to the present value of the difference between future payments of a new mortgage and the existing contract. The option to partially prepay the mortgage penalty free results in a loss for the morgagee. This prepayment risk has been the topic of many studies. Most of these models, however, focus on the American market and are based on pool information only. In this paper, we developed a prepayment model that incorporates the characteristics of both the Dutch market and Dutch mortgage contracts. Moreover, the parameters are estimated by using a dataset that contains detailed information on a loan-by-loan basis.

In this paper, a prepayment model is developed for both savings mortgages and interest-only mortgages. The parameter estimates indicate that the likelihood that a savings-mortgage will be prepaid increases with the age of the mortgage. Models excluding burnout also lead to a positive relations between prepayments and the refinance incentive. However, when burnout is included the direct effect of the refinance incentive disappears and is taken over by burnout. The seasonality dummies indicate that prepayments are higher in the month December, which reflects both a holiday and a tax effect. For savings mortgages we also find lower prepayment rates for the months January and February. People with a savings mortgage living in an apartment also prepay more frequent than other people. This is attributed to the upgrading effect: young people usually start in an apartment moving to a larger house as their family situation changes and their income increases. Similar conclusions hold for the interest-only model. However, the magnitude of the effect on prepayment rates is different and the upgrading effect is less prevalent.

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Appendix A: Construction of the marginal tax rate[11]

The marginal tax rate is an important variable in our definition of the refinance incentive. Unfortunately, the provided database does not contain this information on a loan-by-loan level. But based on the general tax rules that applied to Dutch inhabitants in the nineties, a fair estimate of marginal tax rates can be made by applying three steps:

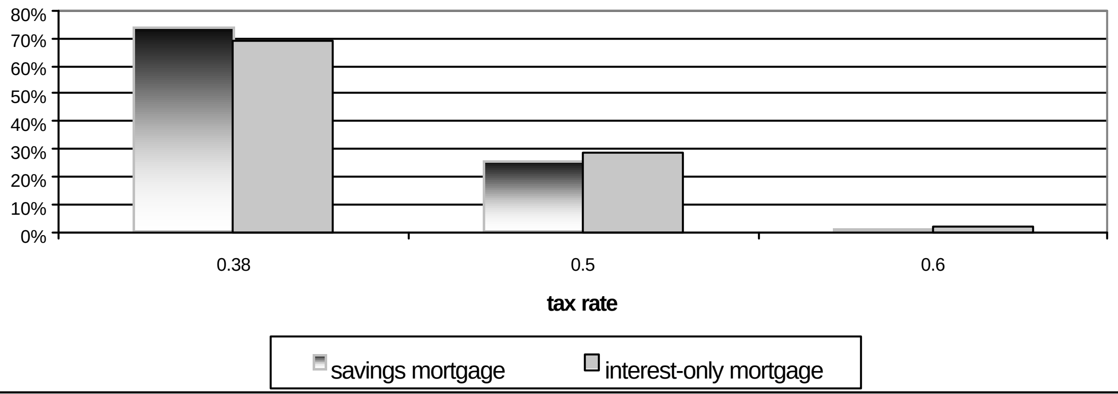
1. Determine the total mortgage amount at origination. This includes all mortgage parts, irrespective the mortgage type of the part.
2. Divide this amount by 3.5 to obtain the gross-annual income at origination. The factor 3.5 is a rough indication of the maximum mortgage a household can obtain. Although this factor depends on the prevailing interest rates, we keep it fixed for simplicity.
3. Based on the tax regime in the origination year we determine the marginal tax rate. We keep this fixed over time.

Steps 1 and 2 are straightforward. Step 3 requires more details on the Dutch tax system. First of all, the Dutch tax system involves a tax-exempt amount. Deducting this from the gross annual income yields the taxable income. The Dutch tax system is progressive. Taxable income up to the first threshold is taxed at approximately 38%. The remaining part of taxable income between threshold 1 and threshold 2 is taxed against 50% and any taxable income above threshold 2 is taxed at 60%. The tax-exempt amount depends on job and family characteristics. We assume that the tax-free amount is equal to the amount applicable to a single person household with a job. This amount changes over time, as do the thresholds and the tax rates. We have data from the tax authorities as of 1992. Values for these variables 1989 through 1991 are constructed by extrapolation using the relative changes from 1992 to 1993.

The results are summarized in Figure 13. As illustrated by this figure , the vast majority of the mortgagors in our dataset fall in the lowest tax-bracket. This holds irrespective of the chosen redemption type.

[11] The discussion focuses on the situation from 1989 through 1999. The tax system has been changed in January 2001. The change does not affect the tax deductibility of mortgage interest payments but it does affect the construction of the marginal tax rate.

Figure 13: distribution of marginal tax rate



Appendix B: Mathematical Details

In this appendix we provide details on the computation of the refinance incentive for Dutch mortgagors. The incentives are discussed for the three most common types of mortgages, *i.e.* an annuity, a savings mortgage and an interest-only mortgage. To provide the details we introduce the following notation:

t: end-of-month (just after regular payment) at which refinancing is considered

c: *monthly* interest rate currently paid on the mortgage

m: prevailing *monthly* interest rate used to discount cash flows. This is also the refinancing rate.

y: prevailing *monthly* interest rate used to compute the prepayment penalty

N: remaining number of months for which c is fixed (as of time t)

L: remaining life of the mortgage (in months as of time t)

S_{t+i}: remaining principal at time t+i, i=1,..,L

S_0: initial principal

τ: tax rate

α: fraction of the initial principal S_0 that can be prepaid without penalty.

$PMT(S_t,c,L)$: monthly payment (principal plus interest) as of month t+1 on an annuity with remaining principal S_t, interest c and a remaining life of L.

$PV_{interest}(S_t,c,m,L,N)$: present value of the interest payments on a mortgage with a remaining principal of S_t, a coupon of c, a discount rate of m, a remaining life of L and a period for which c is fixed of N months.

$PV_{redemption}(S_t,c,m,L,N)$: present value of the redemption payments on a mortgage with a remaining principal of S_t, a coupon of c, a discount rate of m, a remaining life of L and a period for which c is fixed of N months

For some mortgage originators, the interest rate used in the computation of the prepayment penalty, y, is equal to the refinancing rate m. Charlier (2001) provides more details on this. However, mortgages originated by ABP before June 1999, y is based on the number of months equal to the current fixed-rate period rather than the *remaining* number of months for which c is fixed.

In the following we assume end-of-month monthly payments and we assume that a mortgage is refinanced with a new mortgage of the same originator. The costs involved are 500 Dutch guilders (tax deductible). This is usually less than the costs involved when switching to a different originator. In addition to the definitions above we define fc: fixed cost when refinancing with a new mortgage of the same originator

B1. Refinance incentive for an annuity

For an annuity mortgage, monthly payments are determined from the following relationship:

$$\mathrm{PMT}(S_t, c, L)\sum_{j=1}^{L}\frac{1}{(1+c)^j} = S_t \Leftrightarrow \mathrm{PMT}(S_t, c, L) = S_t\frac{c}{1-(1+c)^{-L}}$$

These payments include both interest and redemption. To determine S_{t+i} use that

$$\mathrm{PMT}(S_t, c, L)\sum_{j=1}^{L-i}\frac{1}{(1+c)^j} = S_{t+i}$$

And hence

$$S_{t+i}(S_t, c, L) = S_t\frac{1-(1+c)^{-(L-i)}}{1-(1+c)^{-L}} = S_t\frac{(1+c)^L-(1+c)^i}{(1+c)^L-1}$$

To determine whether refinancing is profitable we need three ingredients:

1. Prepayment penalty. This is put first because it will be financed by increasing the principal of the mortgage after refinancing. The penalty depends on the present value of interest payments under c compared to y for the N periods.
2. Present value of interest payments including tax benefits plus the present value of the principal payments both without refinancing (using c) and with refinancing (using m and increasing the principal due to the prepayment penalty).
3. Difference in the time-t value of the principal remaining at t+N.

Ad 1.

The prepayment penalty is equal to $\mathrm{Max}(0, PV_{interest}(\max(0, S_t-\alpha S_0), c, m, L, N) - PV_{interest}(\max(0, S_t-\alpha S_0), y, m, L, N))$

Now

$$\begin{aligned}
&PV_{interest}(S_t, c, m, L, N) \\
&= \sum_{i=0}^{N-1}\frac{cS_{t+i}(S_t, c, L)}{(1+m)^{i+1}} = \frac{cS_t}{1-(1+c)^{-L}}\sum_{i=0}^{N-1}\frac{1-(1+c)^{-(L-i)}}{(1+m)^{i+1}} \\
&= \mathrm{PMT}(S\ \ , c, L)\left[\sum_{i=0}^{N-1}\frac{1}{(1+m)^{i+1}} - (1+c)^{-L}\sum_{i=0}^{N-1}\frac{(1+c)^i}{(1+m)^{i+1}}\right]
\end{aligned}$$

$$=\begin{cases} PMT(S_t,c,L)\left[\dfrac{1-(1+m)^{-N}}{m}-(1+c)^{-L}\dfrac{1-\left(\dfrac{1+c}{1+m}\right)^N}{m-c}\right], m\neq c \\ PMT(S_t,m,L)\left[\dfrac{1-(1+m)^{-N}}{m}-(1+m)^{-L-1}N\right], m=c \end{cases}$$

Ad 2.

$PV_{interest}$ is defined in ad 1. To determine the present value of the principal payments we first have to determine the redemptions in periods t+i, i=1,..,L

Redemption

$$= PMT(S_t,c,L) - cS_{t+i}(S_t,c,L) = \frac{cS_t}{1-(1+c)^{-L}}(1+c)^{-(L-i)} = PMT(S_t,c,L)(1+c)^{-(L-i)}$$

$$PV_{redemption}(S_t,c,m,L,N)$$
$$= PMT(S_t,c,L)(1+c)^{-L}\sum_{i=0}^{N-1}\frac{(1+c)^i}{(1+m)^{i+1}}$$
$$=\begin{cases} PMT(S_t,c,L)\left[(1+c)^{-L}\dfrac{1-\left(\dfrac{1+c}{1+m}\right)^N}{m-c}\right], c\neq m \\ PMT(S_t,m,L)\left[(1+m)^{-L-1}N\right], c=m \end{cases}$$

Ad 3.

The time-t value of the remaining principal at time t+N is equal to $S_{t+N}(S_t,c,L)/(1+m)^N$ when not refinanced and $S_{t+N}(S_t+(1-\tau)*(penalty+fc),m,L)/(1+m)^N$ when refinanced.

Adding the three together leads to the following results:

Value without refinancing:

$(1-\tau)\ PV_{interest}(S_t,c,m,L,N)+ PV_{redemption}(S_t,c,m,L,N)+S_{t+N}(S_t,c,L)/(1+m)^N$

Value with refinancing:

$(1-\tau)PV_{interest}(S_t+(1-\tau)*(penalty+fc),m,m,L,N)+PV_{redemption}(S_t+(1-\tau)*(penalty+fc),m,m,L,N)+$
$S_{t+N}(S_t+(1-\tau)*(penalty+fc),m,L)/(1+m)^N$

B2. Refinance incentive for a savings mortgage

For a savings mortgage the gross (before tax) monthly payments are equal to the monthly payments for an annuity (with same principal, interest rate and time to maturity). The difference stems from two sources. Firstly, the split up of the monthly payments is different for tax reasons. In The Netherlands, interest payments are tax deductible whereas principal payments are not. Secondly, the principal payments are not deducted from the initial principal but they are placed on a savings account. These “principal payments” are referred to as savings premia. As the principal does not decrease, the tax authorities allow deduction of interest payments based on the initial principal. However, for the originator the remaining balance decreases as it is equal to the initial principal minus the value in the savings account. Therefore, parts of the “interest payments” are added to the savings account as well (to generate a return on this account that is equal to the interest rate on the mortgage). In this way part of the principal payments are deductible in addition to the regular interest payments on an annuity. For the originator the cash flow schedule is the same as in an annuity. The savings premium is determined in such a way that, at maturity, the savings account is equal to the principal and it is used to redeem the mortgage.

In addition to the definitions for an annuity, define

SA_t: amount of capital built up in the savings account at time t (right after the regular monthly payment)

SP: premium that is monthly added to the savings account

Because the principal is fixed, the monthly interest payments are equal to cS_0. To determine SP, use that the discounted premia together with SA_t should be equal to the time-t value of the principal, i.e. $S_0(1+c)^{-L}$. Hence

$$SP(S_0, SA_t, c, L)\sum_{j=1}^{L}\frac{1}{(1+c)^j} + SA_t = S_0(1+c)^{-L}$$

$$\Leftrightarrow SP(S_0, SA_t, c, L) = (S_0(1+c)^{-L} - SA_t)\frac{c}{1-(1+c)^{-L}}$$

$$\Leftrightarrow SP(S_0, SA_t, c, L) = (S_0 - SA_t(1+c)^{L})\frac{c}{(1+c)^{L}-1}$$

Now we can determine $PV_{interest}$ and PV_{premia}.

$$PV_{interest}(S_0, c, m, N) = cS_0\sum_{i=1}^{N}\frac{1}{(1+m)^i} = cS_0\frac{1-(1+m)^{-N}}{m} = \frac{c}{m}S_0(1-(1+m)^{-N})$$

$$PV_{premia}(S_0, SA_t, c, m, L, N) = SP(S_0, SA_t, c, L)\sum_{i=1}^{N}\frac{1}{(1+m)^i} = SP(S_0, SA_t, c, L)\frac{1-(1+m)^{-N}}{m}$$

Ad 1.

The prepayment penalty now is equal to

$$PV_{interest}((1-\alpha)S_0, c, m, N) - PV_{interest}((1-\alpha)S_0, y, m, N) = \left(\frac{c}{m} - \frac{y}{m}\right)(1-\alpha)S_0(1-(1+m)^{-N})$$

Note that this is positive if c is larger than y.

Ad 2.

Follows from the penalty and the expression for PV_{premia}. When refinancing, S_0 should be replaced by $S_0+(1-\tau)*(penalty+fc)$.

Ad 3.

To correct for differences in the savings account at t+N we need an expression for the savings account at time t+N, given the savings account at time t and the premia that will be paid in periods t+1,.., t+N.

Using the same argument as in Ad 1, it holds that

$$SP(S_0, SA_t, c, L)\sum_{j=1}^{L-N}\frac{1}{(1+c)^j} + SA_{t+N} = S_0(1+c)^{-(L-N)} \Leftrightarrow$$

$$SA_{t+N} = S_0(1+c)^{-(L-N)} - SP(S_0, SA_t, c, L)\frac{1-(1+c)^{-(L-N)}}{c} \Leftrightarrow$$

$$SA_{t+N}(S_0, SA_t, c, L, N) = (1+c)^{N-L}\left(S_0 - SP(S_0, SA_t, c, L)\frac{(1+c)^{L-N}-1}{c}\right)$$

Adding the three together leads to the following results:

Value without refinancing:

$(1-\tau)PV_{interest}(S_0,c,m,N)+ PV_{premia}(S_0,SA_t,c,m,L,N)+(S_0-SA_{t+N}(S_0,SA_t,c,L,N))/(1+m)^N$

Value with refinancing:

$(1-\tau)PV_{interest}(S_0+(1-\tau)*(penalty+fc),m,m,N)+PV_{premia}(S_0+(1-\tau)*(penalty+fc),SA_t,m,m,L,N)$ $+(S_0+(1-\tau)*(penalty+fc)-SA_{t+N}(S_0+(1-\tau)*(penalty+fc),SA_t,m,L,N))/(1+m)^N$

B3. Interest-only mortgage

For an interest-only mortgage it holds that $S_t=S_0$ for all t. $PV_{interest}$ equals the expression as presented for a savings mortgage.

Ad 1.

As the interest payments are equal to the interest payments for a savings mortgage, the penalty is equal to the penalty as specified in ad 1. of section B2.

Ad2.

Now only $PV_{interest}$ matters. When refinancing, S_0 should be replaced by $S_0+(1-\tau)*(penalty+fc)$.

Ad 3.

Without refinancing, the remaining principal at t+N is equal to $S_0/(1+m)^N$. When refinancing it is equal to $(S_0+(1-\tau)*(penalty+fc))/(1+m)^N$. The difference is just the time-t value of the penalty and the fixed costs, after taxes, i.e. $(1-\tau)*(penalty+fc)/(1+m)^N$.

Adding the three together leads to the following results:

Value without refinancing:

$(1-\tau)\ PV_{interest}(S_0,c,m,N)+S_0/(1+m)^N$

Value with refinancing:

$(1-\tau)\ PV_{interest}(S_0+(1-\tau)*(penalty+fc),m,m,N)+(S_0+(1-\tau)*(penalty+fc))/(1+m)^N$