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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

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Abstract

We analyze the transmission of an interest rate shock to households in the context of a stress-test module. We examin standard mitigants, such as delays due to a future interest-rate-reset-date, tax deduction of the interest paid on mortgages, the amortization of different mortgage types and conjunctural factors. We also include the possibility of behavioral responses, where households can alleviate the effect of a shock by reducing debt using voluntary repayments. We estimate a Cragg log-normal hurdle model on loan-level data for the Dutch mortgage market. We simulate debt 30 years into the future under different scenarios for the development of the interest rate and simulating both contractual and voluntary amortization. This study finds a significant dampening role of voluntary repayments on the effects of an interest rate shock.

Keywords: transmission of interest rate shock; voluntary repayments, loan level data.

JEL codes: C01; C23; D14; E44; G21.

1. Introduction

We analyze the transmission of an interest rate (IR) shock to households within the context of a stress-test module. With normalizing monetary policy and interest rates increasing in different areas, like in the US, it is likely that also in Europe interest rates will soon increase. As interest rates have been low for a prolonged period, households face now relatively low payments on their debt, when compared with the past decades. Do increases in the interest rate translate into a direct and proportional increase of payments for households? For some, this could be the cases, but very

Preliminary results of this study have appeared in the Master Thesis "Behavioral responses and top-down stress test models: Do voluntary repayments alleviate the effect of a shock in the mortgage interest rate?" by Sigourney Zomer (July 2016), supervised by Mauro Mastrogiacomo at the VU University Amsterdam. Views expressed are those of the individual author and do not necessarily reflect official positions of De Nederlandsche Bank.

often borrowers are partly protected by a number of institutional features of the mortgage market. The extent of the pass through is an empirical matter, and we bring about detailed evidence using highly granular loan level data with quarterly frequency from the Netherlands, which are hardly available in other countries.

We analyze some standard mitigants, such as delays due to a future interest-rate-reset-date, tax deduction of the interest paid on mortgages, the amortization of different mortgage types and possible conjunctural factors (such as the decreasing IR in the last decade). We also include the possibility of behavioral responses, where households can alleviate the effect of a shock by reducing their debt using voluntary repayments. In most stress-test models, households are assumed to simply pay the increased payments and to default in case they cannot afford it. However, households could decide to partly immunize themselves from the IR risk by fixing the IR for a longer period or by repaying voluntarily (part of) their debt before maturity. So, we extend the static-balance-sheet approach in standard stress-test models of mortgage credit risk (Constâncio (2015)) introducing a household behavioral response. Standard models do not include a dynamic interaction between banks and the household sector's balance sheet (Bilston, Johnson, and Read (2015) and Sugawara and Zalduendo (2011)).

The transmission of an IR-shock is key to top-down macro stress-testing. It is especially interesting to focus on credit as systemic risk, since financial crises are almost always preceded by steep increases in leverage or debt-based financing (Mian and Sufi, 2010). However, most stress-test models struggle with the implementation of the pass-through to households. We show that the speed of transmission to households is an empirical matter, that depends on several institutional, contractual and behavioral factors that are country-specific. As for the Netherlands, imputations of the pass-through based on existing literature assumed full transmission in a period ranging between 5 to 8 years (DNB 2015, and DELFI model calibration). In this study, we show that transmission does actually never take place in full, and that it is highly concave, with the shock being quickly transmitted in the first 5 years after the shock, and more slowly thereafter.

This study relies on supervisory loan-level data, which cover around 85% of the total mortgage market. The information contained is extremely granular and detailed. Central Banks's survey data like the DHS in the Netherlands or the SHIW in Italy, also contain loan level data but suffer of the typical measurement error inherent to self-reported information.

Our strategy is to simulate the mortgage debt position of Dutch households 30 years into the future under different scenarios for the development of the IR, considering possible voluntary repayments, contractual conditions and fiscal incentives. For this purpose, we first estimate a Cragg log-normal hurdle model describing voluntary repayments behavior of households using data over the year 2014 (see Mastrogiacomo 2017). Using the estimated model, voluntary repayments are predicted for the simulation period recursively, where the repayments depend on several yearly updated variables among which the IR. Although the Dutch mortgage market is quite responsive to an IR-shock, voluntary repayments can reduce payments and dampen the effect of an IR-shock.

Our findings show that higher interest rates are associated with a higher probability of a decision to voluntarily repay. Also, borrowers with a higher interest-only share are more likely to repay. This is presumably due to the rising opportunity cost of saving when the mortgage interest rate increases. The increase in the mean gross mortgage payments caused by an immediate interest rate shock is, on average, 17.5 percentage points lower due to voluntary repayments. Large heterogeneity across households and scenario's must be acknowledged. In case of a shock after 5 years of low interest rates, the increase in the mean gross payment is lowered by 15.8 percentage points. The dampening role of voluntary repayments is higher when looking at the net payment and thus considering the mortgage interest rate deductibility (IRD). Voluntary repayments can also reduce the number of borrowers that, due to an interest rate shock, will have a MDSI (mortgage debt service ratio) ratio greater than or equal to 35%. Such a ratio has been considered as a critical threshold above which borrowers might default on their mortgages. The borrowers, who have a MDSI ratio in that "critical" range, seem to have significantly lower income, higher house values, higher outstanding debt levels, and higher LTV ratios.

Despite the advantages of voluntary repayments in reducing risks, it should be noted that at a macro-economic level these repayments could reduce consumption and thus slow down economic growth. This general equilibrium cost, within a stress-test module, is typically taken into account in the scenario itself as it is beyond the scope of such modules to directly account for it.

Policies that aim at increasing the resilience of households should be addressed to those who have more frequent interest rate resets, and a larger share of interest-only loans in their mortgage. Repaying the mortgage voluntarily appears to be more effective than fixing the interest rate for longer periods, as the fixation period has increased already substantially in the past.

The following section discusses the specifics of the Dutch mortgage market and some relevant policy measures. Section 3 describes the transmission of the IR within the model for voluntary repayments. The data and methodology are further described in Section 4. The results are presented in Section 5, and discussed in Section 6. The conclusions and policy implications are provided in the last section.

2. Dutch mortgage market

The asset prices crisis that started in 2009 had left by 2013 about 40% of mortgage owners in the Netherlands underwater. Due to the possible implications in terms of financial stability, the mortgage market underwent several changes. Starting from 2013, reforms were implemented to the generous interest rate deductibility (IRD) the Loan-to-Value (LTV) cap and to the amortization of newly issued mortgage loans. At the same time debt service to income (DSTI) norms were made sharper and the mortgage-default insurance (NHG – *Nationalehypotheekgarantie*) was extended to houses up to a transaction price of 350.000 Euro. The generosity of the IRD, the popularity of interest-only (IO) loans and the absence of a down-payment constraint, had contributed to a sharp increase in households' indebtedness. In an attempt to reduce it, the IRD was sobered down, IO-mortgages were made no longer eligible for the IRD (so their production for new costumers nearly stopped) and the LTV-cap was gradually reduced to 100%. Decreasing indebtedness makes households more resilient to an IR-shock, and all these measures aimed in that direction. However, the effect of sobering down the IRD is less clearly related to shock-resilience. Two opposite channels play a role. A price effect, accompanied to the reduction of the IRD, decreases the demand for debt, which in turn could bring down the price of borrowing and the upward pressure of high indebtedness on house prices. The stabilizing effect of taxes works in the opposite direction. A lower IRD will decrease the dampening of an IR-shock. Finally, the abolition of IO-loans acknowledges the role of the mortgage type in fueling indebtedness, but at the same time also its role in the transmission of a shock, as interest payments decrease in case of amortizing mortgages.

Relevant to this study is also the tax-exemption for gifts aimed at voluntary repayments. Outside the period 2013q3 - 2014q4 and 2017q1 to present, parents could donate to their children up to €53,016 tax free, under the condition that the gift was used for buying (or rebuilding) a house or to repay (part of) their mortgage (Rijksoverheid, 2016). In 2013q3 and starting again from 2017q1, this tax-exemption was lifted to €100,000. During our sample period, we observed intervals with and without such extended exemptions, thus providing additional heterogeneity to our voluntary repayment model.

3. Behavioral detail in top-down stress-test models, a literature review

Including behavioral responses is not common in stress-test modeling. Macro stress-testing is a multistage process (Foglia, 2009). Stress-tests consist typically of designing the adverse macroeconomic scenario, transforming the scenario into measures that affect the valuation of the banks' balance sheet elements, and applying the quantified effects to the banks' balance sheets. The macroprudential perspective has led to a fourth step that includes second-round effects through spill-over and contagion within and between financial sectors as well as interactions or feedback effects between the financial sector and the real economy (Henry & Kok, 2013). An example of a feedback effect is when an IR-shock increases the monthly costs of households, thereby decreasing their income available for other types of consumption. The decrease in disposable income after debt service may affect the aggregate demand and thereby the economy (Mishkin, 1996).

Commonly used adverse scenarios include an upward IR-shock, which could increase debt-servicing costs, an increase in the unemployment rate, which could lead to a loss in income; and a decrease in asset prices and/or house prices, which could increase the loss given default due to a lower value of collateral.[1]

An alternative would be the financial margin (FM) [2]. This is equal to disposable income minus basic living costs minus debt service expenditures, the latter being sensitive to the transmission of the IR-shock. In case the FM is negative, then the household is assumed to default. When stress-testing is done from the banks' perspectives, then subsequently the PDs and debts positions of the households can be used to calculate the weighted-average debt at risk[3] (DAR). This measure can then be compared to the banks' capital positions to assess whether they can absorb the adverse shocks. It is more interesting to look from the households' perspectives, since an IR-shock is first felt by the households.

The behavior of households can play an important role in this second step of the stress-test framework, because it could affect the transmission of an adverse scenario to the banks' balance sheet. For example, saving behavior of households prior to a negative income shock may determine whether a loan will become non-performing to a bank (Ampudia, van Vlokhoven, & Zochowski, 2014). In the stress-test model of Ampudia et al. (2014), households can draw on their liquid assets[4] in order to cover their debt payments. Bilston et al. (2015) estimated that at least one third of the households would avoid default in the stress-tests if they could draw on their liquid assets. Moreover, 75% of the households would avoid default when they were also able to sell less-liquid assets. As well, the respondents of the survey used by Ampudia et al. (2014) indicate that they sold assets, got a credit card, overdraft facility or some other loan, used savings, asked help from friends or relatives or left some bills unpaid in order to meet expenses when they are higher than their income.

4. Data and methodology

4.1 Data and descriptive evidence

The data used for this study are mortgage loan-level data (LLD) collected by De Nederlandsche Bank (DNB), the Dutch central bank. The data collection stems from the 100% transparency policy of the ECB requiring lending institutions to fill out the reporting template for Residential Mortgage-Backed Securities (RMBS)[5] in case they want to use securitized mortgages as collateral.

[1] These macro variables or scenarios are then linked to probabilities of default (PDs) and loss given defaults (LGDs) in the banks' loan portfolios. Typically, there are two methods to derive a probability of default of a household: by using an arbitrary threshold or a financial margin threshold (Bilston et al., 2015). The arbitrary threshold usually involves measuring total debt service payments to disposable income (income after tax) (DSI) and is set to a certain percentage (see e.g. Johansson and Persson (2006)). A household is then assumed to default when the measure for that particular household has a value above the threshold[1]. In this study, that focuses on mortgage debt only, a variant of the DSI could be used, namely the mortgage debt service to income (MDSI).

[2] Formula for the financial margin (FM): $FM_j = DI_j - BLC_j - DSE_j$, where DI, BLC, and DSE stand for respectively disposable income, basic living costs, and the debt service expenditures for household *j*.

[3] Formula for the debt at risk (DAR): $DAR = EAD \cdot LGD = \sum_j p_j(D_j - A_j)/\sum_j D_j$, where p_j, D_j, and A_j stand for respectively the probability of default, the outstanding debt and the value of eligible collateral of household *j*. The DAR is equal to the multiplication of the exposure at default (EAD), $EAD = \sum_j p_j D_j / \sum_j D_j$, and the loss given default (LGD), $LGD = \sum_j p_j(D_j - A_j)/\sum_j p_j D_j$.

[4] These liquid assets include the sum of deposits, investments in mutual funds, bonds, shares and managed accounts, the value of non-self-employment private businesses and other financial assets.

[5] For the RMBS template, see: https://www.ecb.europa.eu/paym/coll/loanlevel/transmission/html/index.en.html.

Table 1. Descriptive statistics LLD 2014Q4-2015Q4 and subsample

Descriptives statistics	2014Q4	2015Q4	Subsample
Types of loans* (distribution)			
Annuity	7.7%	10.5%	8.6%
Linear	1.4%	1.6%	1.4%
Savings	16.1%	15.8%	17.0%
Life insurance	9.1%	8.3%	9.3%
Interest-only	59.6%	57.9%	60.4%
Investment	4.1%	4.1%	3.3%
Other	2.1%	1.9%	-
Interest rate			
Interest rate - mean*	4.30%	4.04%	4.15%
Interest rate - median*	4.50%	4.20%	4.40%
Mean interest rate reset interval (in years)*	8.7	9.8	9.9
Debt at origination and current debt			
Mean number of loans per borrower	1.9	2.0	2.3
Mean debt at origination per loan*	98 200	100 100	90 300
Mean current outstanding debt per loan*	87 700	88 700	79 600
Mean debt at origination per borrower	191 100	195 600	211 100
Current outstanding debt per borrower	170 800	173 200	186 200
Interest-only (IO) share at origination (distribution)			
Full amortizing debt (IO-share = 0%)	20.9%	22.4%	13.7%
IO-share between 0% - 20%	3.7%	3.6%	4.8%
IO-share between 20% - 40%	8.8%	8.8%	10.9%
IO-share between 40% - 60%	19.8%	20.0%	23.6%
IO-share between 60% - 80%	9.5%	9.3%	11.2%
IO-share between 80% - 100%	3.6%	3.6%	4.5%
Full interest-only debt (IO-share is 100%)	33.6%	32.2%	31.3%
Property value			
Mean current value of property	290 100	286 200	316 900
Median current value of property	237 400	236 000	256 000
LTV ratio			
Mean LTV at origination	77.10%	81.1%	83.5%
Mean current LTV	71.19%	73.3%	76.1%
Share of underwater mortgages	19.32%	22.4%	22.2%
Total observations			
Number of loans*	5 740 114	5 990 957	84 943
Number of borrowers	2 948 408	3 067 040	36 336
Total number of borrowers (CBS data)	*3 560 000*	*3 527 000*	
Coverage	*82.8%*	*87.0%*	
Number of institutions	9	10	6

Notes: * indicates that the variable is a loan-level concept, while all other variables are borrower level-concepts. The latter differs from the former, because in most cases the borrower combines multiple loans for a mortgage. The subsample of borrowers is randomly drawn from the total population in 2015Q4, after which the 2014Q4 data is appended and the subsample is balanced out. Here the information of the subsample at 2015Q4 is presented.

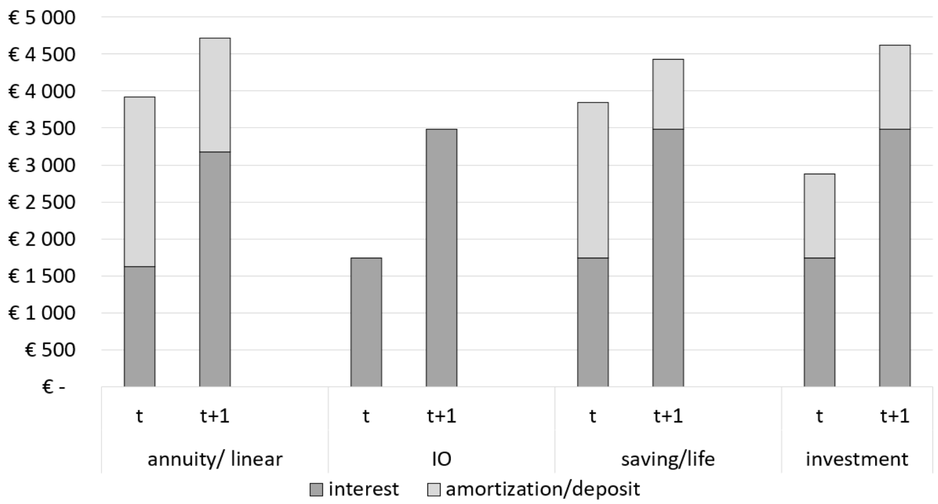
In addition to the mortgages used for securitization, DNB also receives data on all other mortgages in the portfolios of reporting institutions. The quarterly reported data was first collected in 2012Q4. The data used here cover the periods 2014Q4 and 2015Q4. The dataset on 2015Q4 covers over 85% of the total Dutch mortgage market. Table 1 presents descriptive statistics on the data of

2014Q4 and 2015Q4. We also show how the two datasets relate to the 2015Q4 subsample that we take to extrapolate debt to the future.

The dataset contains information on each loan covering both loan characteristics and borrower characteristics. Each separate borrower can be identified and tracked over time when he or she sticks with one bank. As can be derived from Table 1, the mean number of loans per borrower equals two. The dataset includes a variety of loan characteristics, such as the date of origination, the maturity date, the IR, the debt at origination, the current outstanding debt, the type of loan, whether or not the IR is fixed for the whole term and, if not, the IR reset date and interval, and more.

The most common types of loans in the Netherlands were the linear, annuity, savings, life insurance, investment and IO-loans. Together those loans make up for around 98% of the loans in the 2015Q4 data. Remarkable is the relatively high amount of IO-loans. Over 75% of the borrowers have a positive share of IO-loans. Around 30% of the borrowers have full IO-mortgages and just over 20% have full amortizing mortgages. This means that over 45% of the borrowers combine an IO-loan with other types of loans. An IR-shock will fully pass through the payments of IO-loans, partly in those of amortizing loans. This evident in Figure 1, where fictive loans, that mature in 30 years and with a principal of €100.000, experience an increase in the IR from 3%, 5 years after origination of the loan, to 6% in year 6.

Figure 1: Effect of an interest rate shock in *t+1* on yearly net mortgage payments (interest plus amortization), different loan types



Notes: Interest rates increases from 3% in *t* to 6% in *t+1*. Principal is equal to €100.000 for all loans and *t* is equal to 5 years after origination of a loan that matures in 30 years. Payments are net, mortgage interest rate is deducted with a marginal tariff equal to 42%.

The figure shows two interesting elements. First, when the IR increases, products such as annuities or saving loans 'adapt' the amortization such that the overall impact of the shock is reduced. Second, we show the effect on net periodic payments. The presence of IRD implies that when more IR is paid a higher tax-rebate will be received. So, while in this example net payments double for the IO-loans, they increase only by 15% for a saving loan. The presence of IRD and amortization thus reduced the transmission of an IR-shock. Also Figure 1 assumes that the households are affected immediately by the shock. In reality, Dutch households have a mean IR reset interval of about 10 years. This amplifies the effect of amortization even more, as after 10 years less interest is being paid.

Figure 2: Debt by interest rate bucket and rest year

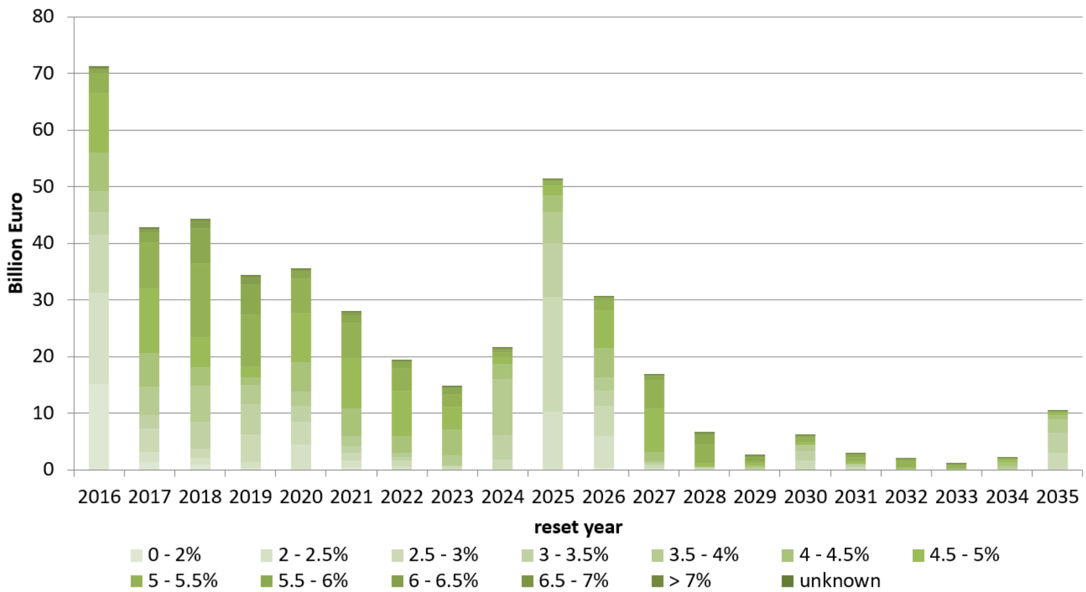


Figure 2 shows that in 2015Q4 most debt would reset after 5 years, also it shows that most loans resetting before have an IR above 5%. From a stress-test perspective, this is an interesting fact. The European Banking Authority (EBA), coordinates the EU-wide stress-test exercise. This aims at assessing the resilience of financial institutions to adverse market developments, as well as to contribute to the overall assessment of systemic risk. The severe scenario for the IR-shock that EBA had set for the Netherlands at that time, implied an increase of the IR to 6%. This means that, for most households subject to the immediate shock, the increase in IR would be less than 1%, which partly explains the low losses resulting from the Netherlands (EBA, 2016). This shows how conjunctural factors, such as the decreasing interest rates of the last decade, can accidentally contribute to dampen the effect of an IR-shock as well.

To further illustrate the effect of voluntary repayments on the reduction of the pass-though, we work with a subsample of borrowers in the main 6 Dutch banks, that is randomly drawn from the LLD 2014q4-2015Q4. The subsample consists of almost 85,000 loans for 36,336 borrowers. As the randomization is carried on at borrower level and only for the main banks, the subsample does not replicate perfectly loan-level characteristics, but all variables have mean values that do not differ significantly.

4.2 Set up of the scenarios analysis

We model the development in yearly payments per loan, and aggregate these by borrower, for a simulation period of 30 years. In a baseline scenario ("scenario S0") there is no IR-shock and no voluntary repayments. That is, the IR is assumed to be constant and the positions of households are calculated in a deterministic way. Then two additional scenarios ("scenario S1" and "scenario S2") are modeled in which two IR-shocks are applied to the balance sheets of the households. In scenario S1, the IR-shock is immediate. The level of the shocked IR, that will replace the original interest rate per loan at the first interest reset date, depends on the original LTV ratio, whether the borrower participates in the mortgage-default insurance, and the length of the interest rate reset interval.

The increases in the interest rate vary from 250 to 300 basis points on top of the interest rate observed at the end of 2015. The longer the interest rate reset interval and the higher the original LTV, the higher the (shocked) interest rate that banks request to new customers. An overview of the newly applied interest rates is presented in Table 2.

Table 2. Interest rates used for shock, model input

Interest rate reset interval	NHG	LTV ≤ 65%	65 < LTV ≤ 85 %	85 < LTV ≤ 95%	LTV > 95%
0 to 5 years (250 bp increase)	4.61%	4.64%	4.83%	5.30%	5.47%
5 to 10 years (280 bp increase)	5.07%	5.14%	5.33%	5.76%	5.96%
Above 10 years (300 bp increase)	5.58%	5.66%	5.84%	6.26%	6.47%

Notes: NHG is the national mortgage guarantee. If the borrower participates in this guarantee, then those rates are applied to the loans depending on the interest rate reset interval. LTV stands for the Loan-to-Value ratio at origination of the loan.

Regarding scenario 2, the same interest rates will be applied from the year 2020 onwards. Again, the specific interest rate reset date per loan determines when the interest rate will be replaced. For the period from 2016 to 2020, interest rates are applied that are equal to 40% of the shocked interest rates as shown in Table 2, close to those observed in 2015. Whether or not a specific loan enjoys this low interest rate depends on the first interest rate reset date after year 2015. For example, if the first interest reset date is 2021, in that year the interest rate of that specific loan will increase towards the level of the shocked rates. However, if the reset date is 2019, then the loan will enjoy the lower interest rate for a period equal to the reset interval (say 10 years). In all scenarios, the interest rate reset interval is kept constant as well as the IRD.

Households do not voluntarily repay (part of) their debt in scenarios 0, 1, and 2. Allowing the households to make voluntary repayments results in scenarios 3, 4, and 5 (homologous to as in scenarios 0, 1, and 2, respectively). In this way, it can be assessed whether voluntary repayments alleviate the effects of a mortgage interest rate shock.

Notice that we assume that borrowers respect their mortgage contract and do not modify their present debt. We can calculate the yearly interest expenses and repayment (in case of an annuity loan) or deposit (in case of a savings, life-insurance or investment loan) using the available loan level information[6].

For each loan type, the net payment is calculated by taking into account the interest rate deductibility (IRD). The level of IRD depends on the current income level. However, here an average rate of 42% is used because of the lack of data on current income[7]. This means that 58% of the total interest expense is used as the net interest expense. The net payment is derived by adding the debt repayment or deposit (if any) to the net interest expense.

4.2.1 Voluntary repayments model

In order to include voluntary repayments in the interest rate stress-test model, we must describe the voluntary repayments behavior of households. Voluntary repayments in the year 2014 are used as input for estimating the model. As these are not directly observed but must be elicited looking at the first difference of the current principal we maintaining a minimum of €2,000 as this was then common to most banks because of administration costs. This means that the observed voluntary repayment (y_i) for borrower i can de denoted as:

$$y_i = \begin{cases} y_i^* & if\ y_i^* \geq L \\ 0 & if\ y_i^* < L \end{cases}, \tag{1}$$

where y_i^* denotes the latent variable, and L the lower limit, which is here equal to €2,000.

The voluntary repayments variable is a limited dependent variable, since it is a strictly positive continuous variable. Each borrower does or does not voluntarily repay. In the first case the variable takes on a continuous positive random value, while in the latter case the variable is equal to zero. Corner solution models are used when the dependent variable is of this type of data. In this case, the corner is zero.

For the voluntary repayments model, two decisions must be modeled: the extensive margin (whether or not the borrower repays) and the intensive margin (in case that the borrower repays, how much will he or she repay). The participation equation for a voluntary repayment can be denoted by:

$$w_i = \begin{cases} 1 & if\ y_i > 0 \\ 0 & if\ y_i = 0 \end{cases}, \tag{2}$$

where w_i is equal to 1 if a voluntary repayment is observed ($y_i > 0$) for borrower i and equal to 0 if borrower i does not make a voluntary repayment ($y_i = 0$). The Tobit model (Tobin, 1958), an often-used corner solution model, uses a single mechanism for the participation decision ($w_i = 0$ or $w_i = 1$) and the amount decision (size of y_i given $y_i > 0$). This means that the coefficients of the regressors explaining the participation decision and the amount decision can only have the same sign. That is, a particular variable cannot have a positive effect on the participation decision

[6] See appendix B for the formulas for calculating the yearly payments per loan type.

[7] In the period 2018-2021, the IRD will be reduced to a maximum of 38%. However, this measure has been taken after the end of our sample period.

and a negative effect on the amount decision. The Cragg log-normal hurdle model (Cragg, 1971) relaxes this assumption by allowing different mechanisms for the two decisions. This is a two-part model, where a probit regression is used to estimate the model for the participation decision (part I) and a OLS regression is used on $\ln(y_i)$ for the amount decision (part II). In this case we can denote y_i as follows:

$$y_i = w_i \cdot y_i^* = I(x_i'\gamma + v_i > L) \cdot \exp(x_i'\beta + u_i), \quad (3)$$

where x_i is a vector of explanatory variables, γ and β denote the coefficients for the participation and amount decision respectively, v_i and u_i are the error terms of the participation and amount decision respectively, and $I(.)$ is an indicator function. The error terms, v_i and u_i, are normally and independently distributed with both mean zero and standard deviations 1 and σ^2 respectively. The terms are assumed to be independent from each other. The explanatory variables (x_i) are the same in both parts of the model and include the following borrower-level variables: the debt-weighted share of IO-loans, the interest rate, the age of the borrower, age squared, a dummy indicating whether the mortgage is underwater, i.e. the loan value is higher than the house value, an interaction term between age and the underwater dummy, a dummy indicating whether the borrower participates in the NHG guarantee, and the current LTV.

The first part of the model is estimated over the whole subsample and is specified as:

$$\Pr(y_i > 0|\boldsymbol{x}_i) = \Phi(\boldsymbol{x}_i\boldsymbol{\gamma}), \quad (4)$$

where $\Phi(.)$ is the cumulative distribution function of the standard normal distribution. The marginal effect of each variable is given by:

$$\frac{\partial \Pr(y_i>0|x_i)}{\partial x_{ij}} = \gamma_j \phi(\boldsymbol{x}_i\boldsymbol{\gamma}), \quad (5)$$

where $j = 2, .., k+1$ for the k explanatory variables, $j = 1$ is not considered since it is a constant.

The second part of the model is only estimated over those borrowers that have made a voluntary repayment $(y_i > 0)$ and is specified as:

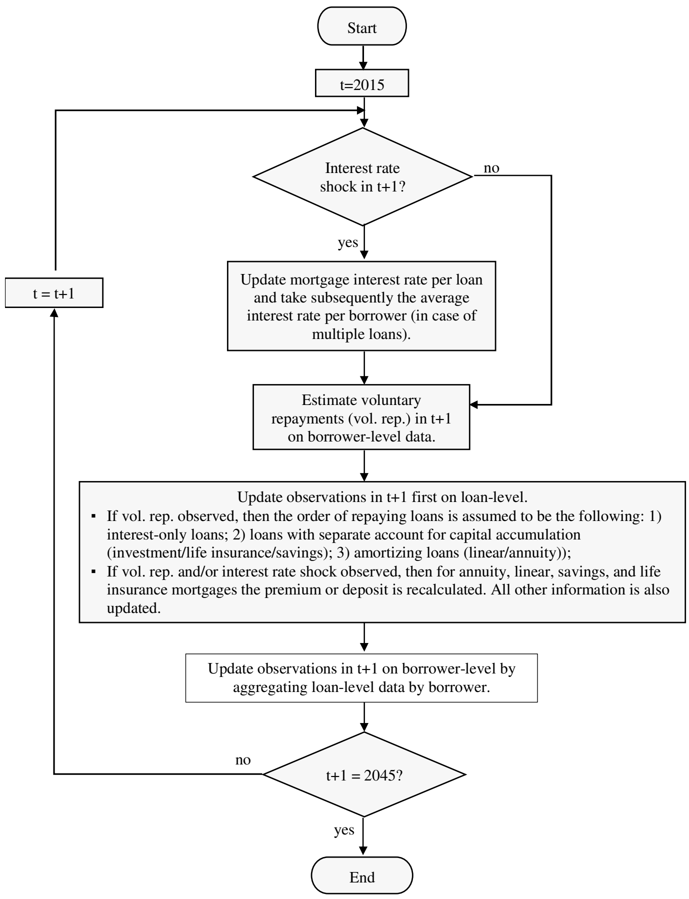
$$\ln(y_i) = x_i\beta + u_i, \qquad y_i > 0. \quad (6)$$

These equations are estimated for both the full subsample and different groups of borrowers depending on their IO-share. The latter is done as voluntary repayments are likely most relevant to borrowers with high IO-shares and the voluntary repayments behavior of these groups may differ. The borrowers with full IO-mortgages do not make any contractual debt repayment during the whole term of the mortgage. By estimating the model on different groups, the error terms in both parts of the model are allowed to differ between the groups. There are six groups of borrowers defined: borrowers with an IO-share between (i) 0% up to 10%; (ii) 10% up to 30%; (iii) 30% up to 50%; (iv) 50% up to 70%; (v) 70% up to 90%; and (vi) 90% up to and including 100%.

4.2.2 Method of simulation

We used a model in which the voluntary repayments are recursively predicted every year using the updated balance sheet positions per borrower starting from the year 2015. In order to derive these positions, the yearly contractual position per loan are updated first (see above). The first step is thus to calculate the positions per loan and aggregate them per borrower for the years up to and including 2015 in a deterministic way. That is, up to that year there are no voluntary repayments and thus no stochastic component. Then for the subsequent year, the average interest rate[8] per borrower is determined. Additionally, the IO-share, age of the borrower, LTV ratio, and underwater dummy are updated (see overview in Figure 3).

Figure 3. Flow chart of simulation method



These variables are used as input for the six estimated voluntary repayment models[9], that depend on borrowers' IO-share, and determine whether a borrower will make a voluntary repayment and its' size. As this is a stochastic process we simulate this process for 100 iterations[10], and in each

[8] The average interest rate per borrower is calculated by dividing the total sum of interest expenses by the total sum of outstanding debt per borrower. This means that it is a weighted average.

[9] The six models, for the different IO shares, are used instead of the model for the full sample in order to grant some degree of heterogeneity in the simulation.

[10] We have carried out all estimations and robustness checks with 100 draws. The preferred specification was also carried out with 1000 draws, and we found no differences in the results worth mentioning.

we compare the predicted probability a random draw from a uniform distribution. After, the amount of the voluntary repayment is determined. Next, the balance sheet items of the loans are separately updated again for the next year. This process is repeated every year until the end of the simulation period is reached, i.e. year 2044[11]. For the simulation it is assumed that the house prices stay constant, while the income of the borrowers increase yearly with 2%. When the borrower reaches his or her pension age[12], it is assumed that the income is equal to 70%[13] of his or her last earned income before reaching the pension age. After that, the income stays constant at this level.

5. Results

5.1 Estimation results of the voluntary repayments model

The results from estimating Part I and Part II of the Cragg log-normal hurdle model on the full subsample are presented in Table 3. The estimation results of the models for the six different groups of borrowers, who differ with respect to their IO-share, can be found in appendix C. In this section we will comment on the differences between the estimation results of the model of the full sample and of the different groups of borrowers depending on their IO-share, where relevant. In the first subsection we discuss the results regarding Part I of the model, which models the participation decision, while we describe the results of part II of the model, which involves the decision about the amount, in the second subsection.

5.1.1 Part I of the model

Part I of the model is a probit model for the borrower' s decision to voluntarily repay or not using data on the whole subsample of borrowers. The explanatory variables in the model are the IO-share at origination, the average interest rate per borrower, the age of the borrower, age squared, a dummy indicating whether the mortgage is underwater (which equals 1 if the mortgage is underwater, i.e. the loan value is higher than the house value, and 0 otherwise), an interaction term between age and the underwater dummy, a dummy indicating whether the borrower participates in NHG guarantee, the current LTV ratio, time to maturity and to the next interest rate reset. These are all borrower-level variables[14].

Regarding the IO-share, the estimated coefficient is positive and significantly different from zero. This means that a higher IO-share is associated with a higher probability that a borrower will choose to voluntarily repay. A positive sign is expected, because when the IO-share is higher, the borrower contractually repays relatively less debt over the term of the mortgage and a voluntary repayment may be warranted more. If a borrower has a full position in IO loans, i.e. the IO-share is 100%, then no contractual debt repayments are scheduled for the whole term of the loan.

The estimated coefficient for the average interest rate per borrower is positive and significantly different from zero. Ideally, one would like to correct for the difference between the saving-interest-

[11] An order of repayment is assumed in case a borrower has multiple loans. IO loans are repaid first, then: investment loans, life insurance loans, savings loans, linear loans, and lastly, the annuity loans. We assume that the borrower can voluntarily repay free of charge

[12] Due to a transition of the retirement age from 65 years to 67 years, the actual retirement age is dependent on the date of birth (Belastingdienst, 2016). If a borrower is born before the year 1947, the borrower will retire at the age of 65. When born in the years 1947 to 1953, the retirement age is 66 years. If the borrower is born in the year 1953 or later, then the borrower retires on the age of 67.

[13] All policies together, the state pension (AOW) and private pension, aim to provide retirees with an income of 70% of the last earned income.

[14] We have thus transformed variables such as "time to next interest rate reset" of "time to maturity" from loan-level to borrower-characteristics. We refer in both cases to the date being pertinent for the earliest event.

rate and the mortgage-interest-rate, in order to pick up the effect of the arbitrage that one could make by voluntarily repay. The former rate is not available, and imputing it using macro data would boil down to subtracting a constant from the latter, which would in turn not improve the explanatory power of our model. The estimated coefficient shows that the opportunity cost for saving increases in the mortgage interest rate. Thus, the coefficient represents the positive effect of a change in mortgage interest rate on the probability to voluntarily repay, while holding all other things constant (among which the unobserved savings-interest-rate).
As our simulation will be based on draws from the empirical distribution from the error term, we bring additional heterogeneity in the model by looking at 6 different subgroups in separate regressions. The IO-share is an obvious (and highly statistically significant) predictor in our model, as those who fully amortize are a lot less likely to voluntarily repay, while for those with a fully IO mortgage, such repayments are the only way to amortize. This suggests that different types of repayers should be defined by the different levels of the IO-share. Remarkably, when estimating the model for the six different groups of borrowers depending on their IO-share, the estimated coefficient for the average interest rate is higher when the IO-share of the group is higher (see Table C.1). The estimated coefficient for the group with the largest IO-shares is substantially higher compared to the other groups. This indicates that the effect of a mortgage interest rate change is the largest for those borrowers who have relatively high IO-shares. Alternatively, we could have estimated one model with interactions terms among the groups identifiers and the dependent variables, but this would have reduced the borrower-type-heterogeneity in the simulation that is based on the different draws of the error term of each separate model.
A lower effect for the group of borrowers with the lowest IO-share is intuitive, since those borrowers have the largest share of amortizing loans or loans with pledged savings or investment accounts. In case of amortizing loans, it is relatively less relevant to voluntarily repay in anticipation of an interest rate increase, since the outstanding debt, over which interest is paid, already decreases every period due to the contractual repayments. That is, the interest rate arbitrage is lower for those loans. Contrary, there are no periodic contractual debt repayments for IO-loans and the interest is paid over the total debt at origination.

The age of the borrower is included in three variables of the model: a linear term and a squared term, in order to test for possible non-linearities between repayments and age, and a term that is multiplied by the underwater dummy, in order to check whether being underwater has differential impact at different ages. This is relevant because younger borrowers, who are more likely to be underwater, are also those who have had less time to save for voluntary repayments. The age of the borrower has on average an overall negative impact on the participation decision, considering all channels. That is, the older the borrower, the lower the probability that the borrower decides to voluntarily repay. There is a positive coefficient for the age variable and a negative coefficient for the age squared variable, which suggests a diminishing positive effect of age on the decision to voluntarily repay. The estimated coefficient for the age variable multiplied by the underwater dummy is positive and significantly different from zero. An older borrower with an underwater mortgage is more likely to voluntarily repay. This can be explained in different ways. Think for instance at older borrowers having saved more, and thus being more likely to have the means for a voluntary repayment. Also, one could think at the fact that it may become more important to a borrower to be mobile and thus be able to sell the house without incurring a residual debt. It could be that a borrower wants to downsize in terms of living space when he or she becomes older or that he or she wants to move to another place to spend his or her retirement.

Table 3. Estimation results for voluntary repayments model: part I (probit) and part II (log-normal hurdle)

	Part I: Probit			**Part II:** Log-normal hurdle
Dep. var.: Vol. rep. dummy	Coeff.	ME	**Dep. var.:** Vol. rep. if vol. rep. > 0	Coeff.
Share IO	0.140***	0.0233***	Share IO	-0.170***
Interest rate – deposit rate	3.799***	0.624***	Interest rate – deposit rate	-6.385***
Age	0.022***	-0.001***	Age	0.00752
Age squared	-0.0003***		Age squared	-0.00002
Underwater	-0.519***	-0.0570***	Underwater	-0.465**
Age times underwater	0.00549**		Age times underwater	0.00969**
NHG	-0.246***	-0.0601***	NHG	-0.390***
Current LTV	-0.0028***	-0.0005***	Current LTV	0.00123
Time to maturity	0.0129***	0.00315***	Time to maturity	0.0220***
Time to reset	0.0137***	0.00284***	Time to reset	0.00198
Constant	-1.548***		Constant	8.887***
Number of observations	23444	23444	Number of observations	3279
Log likelihood	-9205		R-squared	0.052
Pseudo R-squared	0.0238		Log likelihood	-48996
			Sigma u	1
			Log likelihood two-part	-49946
			Pseudo R-squared	0.0247

Notes:***, **, and * indicate that the estimated coefficient is significantly different from zero on a 1%, 5%, or 10% level respectively. Standard errors are in parentheses. Share IO stands for the share of interest-only (IO) debt in the total debt per borrower; underwater is a dummy, which equals 1 if the outstanding debt for a certain borrower is larger than the value of his house and 0 otherwise; NHG is a dummy indicating whether the borrower has a NHG insurance; and current LTV stands for the current Loan-to-Value ratio per borrower. Dep. var. stands for dependent variable. In part I of the model, the dependent variable is equal to a voluntary repayments dummy, which equals 1 if a borrower has made a voluntary repayment and 0 if the borrower has not made a voluntary repayment. Part I of the model is estimated using data on the whole subsample in 2014. In part II of the model, the dependent variable is equal to the voluntary repayments in case these are positive, i.e. a borrower has made a voluntary repayment. That is, model part II is estimated over those borrowers of the subsample that has made a voluntary repayment in 2014. Coeff. and ME stand for coefficient and mean marginal effect respectively. See formula (5) in section 4.2.2 for calculation of the ME.

Regarding the underwater dummy, which equals 1 in case the current LTV is higher than 100% and 0 otherwise, the estimated coefficient for the regular term is significant and has a negative sign. The mean marginal effect, which also takes into account the interaction term with age, is negative and significant. This means that a borrower that has an underwater mortgage is associated with a lower probability of a positive participation decision. An opposite result is expected, where borrowers with underwater mortgages are more likely to make a voluntary repayment. Those borrowers cannot sell their house and move without being left with a residual debt, i.e. those borrowers are more immobile. Noteworthy, the group of borrowers with the highest IO-shares show a significantly positive coefficient for the regular underwater term. However, since the estimated coefficient for the interaction term with age is negative, the mean marginal effect of a mortgage being underwater is still negative for that group as well.

The estimated coefficient for NHG participation is negative and significant. A negative sign is expected, since voluntary repayments are less warranted in case the borrower has a NHG insurance, because participation insures that the mortgage suits the borrower's income and helps in case of financial difficulties. In the worst case, NHG could forgive the residual debt that is left after selling the house for a price lower than the mortgage value. The negative effect of NHG participation on the decision to voluntarily repay debt could be due to moral hazard, which is often connected to insurances in economic theory (see e.g. Arrow (1963)). That is, a borrower voluntarily repays less, because he or she is (partly) insured and thus not repaying will have no or less severe consequences. On the other hand, NHG participation is only possible under certain conditions regarding the mortgage[15], which may be the reason that voluntary repayments are less warranted to begin with and thereby explaining the negative effect of NHG participation.

The estimated coefficient for the current LTV variable has a negative sign. This means that a borrower is less likely to decide to voluntarily repay if the current LTV is higher. Like for the underwater dummy, here also a positive effect is expected. It may be more warranted to voluntarily repay if the LTV is higher and reduce the LTV ratio, in order to increase the borrower's mobility. From the banks' perspective, a positive effect would be beneficial, since a lower LTV results in a lower or no LGD in case the borrower defaults on its mortgage.

We have included also time to maturity and to the next interest rate reset. Those who are further away from maturity or from the reset date are more likely to repay.

We also attempted including a dummy for self-employment into the voluntary repayments model. Since the self-employed do not automatically save for their pension, it could be that the self-employed save for their pension through their house or mortgage by voluntarily repaying their debt earlier. Through lowering the LTV ratio, they may receive a positive net difference when selling their house, which could provide for extra resources during retirement. However, the estimated coefficients for the self-employment dummy are not significantly different from zero. Therefore, it seems that being self-employed does not have a (profound) effect on voluntary repayments behavior. Because there is a substantial amount of missing values regarding the self-employment dummy, we use the model without this dummy as explanatory variable as our baseline.

5.1.2 Part II of the model

Part II of the model is a log-normal model for the decision how much to voluntarily repay, in case the borrower has already determined that he or she is going to make a voluntary repayment. This model is estimated using data on those borrowers that have made a voluntary repayment in 2014. Furthermore, the same explanatory variables are used as in Part I of the model. Here the estimation results of the model for the full subsample is shown, while in appendix C the estimation

[15] For example, currently, only mortgages up to €245,000 (including all additional costs such as notary fees and transfer taxes) are applicable for NHG participation (NHG, 2016). For a complete overview of requirements for NHG participation, see: https://www.nhg.nl/V-N/Voorwaarden-en-normen.

results of the models for the six different groups of borrowers, who differ with respect to their IO-share, can be found.

The estimated coefficient for the IO-share variable is negative and significantly different from zero. That is, a higher IO-share is associated with a lower voluntary repayment, while the number of repayments increases in the IO-share. So, a borrower makes a repayment more often, but the amount of each repayment is lower. This result could appear counterintuitive at first sight. But those with larger IO-shares are elderly borrowers, who typically have lower outstanding debt. For them the necessity to voluntary repay is thus lower. For a similar reason an opposite effect of the difference between the interest rate and the deposit rate is also found between the participation decision and the decision on the amount with respect to the interest rate. The estimated coefficient for the interest rate is negative in the second part of the model. While the interest rate variable has a positive effect on the participation decision, the variable has a negative effect on the size of the voluntary repayment. Again, the group of those with a higher interest rate has typically originated the loan in the past, has interest rates have been steadily decreasing. Those borrowers are likely to repay a lower amount because their debt is lower, but more often have the means to repay. The overall effect of age is not significant. Age though has a positive effect when interacted with the underwater dummy. An older borrower with a mortgage that is underwater is associated with a larger voluntary repayment, than a borrower of the same age with a mortgage that is not underwater. This finding does make sense, because voluntary repayments reduce the LTV ratio and may make the mortgage "above" water again. This will increase the mobility of the borrower, which may be especially relevant for older borrowers, as explained earlier.

The direct effect of the underwater dummy on the size of the voluntary repayment is negative. This means that a borrower with an underwater mortgage is associated with a lower voluntary repayment. This is unintuitive, because voluntary repayments may be more warranted for those borrowers than for borrowers that have an above water mortgage. However, as noted before, the underwater dummy has a positive effect when interacted with age.

NHG participation has a negative effect on the size of the voluntary repayment. This make sense, since NHG could forgive the residual debt that is left after selling the house and thus it may be less necessary to voluntarily repay. That is, borrowers may show moral hazard. However, due to the requirements for NHG participation, among which an upper limit to the debt amount, it may also be the case that voluntary repayments are less warranted. After all, NHG participation ensures that borrowers engage in a mortgage that is compatible with their income. Lastly, the current LTV has a positive coefficient. This is intuitive, because those borrowers could benefit most from earlier repayments since their debt levels are relatively high (compared to the house value), which could increase the borrower's mobility. From the banks' perspective, a positive effect is beneficial, since a higher voluntary repayment reduces the LTV, which in turn results in a lower or no LGD in case the borrower defaults on its mortgage. The last significant variable in the model is time to maturity. This suggests that borrowers with the most recent loan being further away from maturity make larger voluntary repayments.

5.2 Simulation results

By comparing the results of the different scenarios in terms of payments and mortgage debt service to income (MDSI) ratios, the effect of an interest rate shock on the households is assessed as well as the dampening role of voluntary repayments. In section 5.2.1, the predicted voluntary repayments for the simulation are discussed. The effects on respectively the payments and the MDSI ratios are presented in respectively sections 5.2.2 and 5.2.3.

Table 4. Predicted voluntary repayments over the simulation using the estimated model

		S3 No IR-shock		**S4 Immediate IR-shock**		**S5 IR-shock after 5 years**	
		Absolute	Relative	Absolute	Relative	Absolute	Relative
Number of vol. rep. over the simulation		92 685	4.2%	113 488	5.1%	105 917	4.8%
Number of vol. rep. by type of loan							
- Annuity mortgage		2 436	2.6%	2 502	2.2%	2 462	2.3%
- Linear mortgage		486	0.5%	434	0.4%	500	0.5%
- Interest-only mortgage		80 572	86.9%	101 469	89.4%	93 728	88.5%
- Savings mortgage		5 302	5.7%	5 284	4.7%	5 386	5.1%
- Life insurance mortgage		2 622	2.8%	2 640	2.3%	2 608	2.5%
- Investment mortgage		1 267	1.4%	1 159	1.0%	1 233	1.2%
		34 321	40.7%	36 433	43.2%	35 424	42.0%
Number of loans with nonzero vol. rep.							
Number of borrowers with nonzero vol. rep.		30 915	85.7%	32 333	89.6%	31 574	87.5%
Total sum of vol. rep. (in billion €)		1.40	8.0%	1.59	9.1%	1.52	8.7%
Size of vol. rep.	mean	€ 15 067		€ 13 981		€ 14 395	
	median	€ 9 738		€ 8 944		€ 9 191	
Average number of vol. rep.							
- by loan		1.1		1.3		1.3	
- by borrower		2.6		3.1		2.9	
Cumulative vol. rep.							
- by loan	mean	€ 16 576		€ 18 835		€ 18 098	
	median	€ -		€ -		€ -	
- by borrower	mean	€ 38 720		€ 43 997		€ 42 275	
	median	€ 27 227		€ 32 975		€ 31 270	

Notes: IR and vol. rep. stand for respectively interest rate and voluntary repayment. The relative value of the number of voluntary repayments over the simulation is taken over all instances that a voluntary repayment could have occurred. The relative values for the number of voluntary repayments by loan type indicate the distribution of the number of voluntary repayments over the loan types. The relative values of the number of loans and borrowers with nonzero voluntary repayments represent respectively how many loans and borrowers show a voluntary repayment. Lastly, the relative value for the total sum of voluntary repayments gives the ratio of the total sum of voluntary repayments over the total sum of outstanding debt in 2015.

5.2.1 Predicted voluntary repayments

Some descriptives on the predicted voluntary repayments by scenario are displayed in Table 4. The number of voluntary repayments during the whole simulation is higher in the scenarios with an interest rate shock, scenario 4 (“S4”; immediate interest rate shock) and 5 (“S5”; interest rate

shock after 5 years of low interest rates), compared to the scenario 3 ("S3") in which there is no interest rate shock. This is probably mostly driven by the estimated positive effect that the interest rate has on the decision to voluntarily repay or not. In scenario 3, there are voluntary repayments in 4.2% of all instances when the borrowers could have decided to voluntarily repay. This percentage is equal to 5.1% in scenario 4. Furthermore, around 85%-90% of the voluntary repayments are applied to the IO-loans, which is also due to the modeling assumption regarding the order of repayment, i.e. voluntary repayments are first applied to IO-loans. Around 85% of the borrowers in scenario 3 show a voluntary repayment in the simulation, while this is higher for the scenarios with an interest rate shock, 89% and 87% for scenarios 4 and 5 respectively.
The size of the voluntary repayment is on average lower in the scenarios with an interest rate shock compared to S3, which is in first instance driven by the estimated negative effect of the interest rate on the 'amount' decision. Then, due to different patterns of voluntary repayments under the different interest rates, the LTV, share IO and underwater dummy are affected. For example, the LTV decreases due to earlier voluntary repayments, thereby reducing the size of the repayment in subsequent years. A lower IO-share will result in a lower voluntary repayment.
Even though the mean size of a voluntary repayment in the scenarios with an interest rate shock is lower, the higher number of voluntary repayments results in a higher total sum of voluntary repayments in scenarios 4 and 5. Over the whole simulation period, around 8% of the outstanding debt, as measured in 2015Q4, is voluntary repaid in the scenario with no interest rate shock and 9% in the scenarios with an interest rate shock.

5.2.2 Effect on borrowers' payments

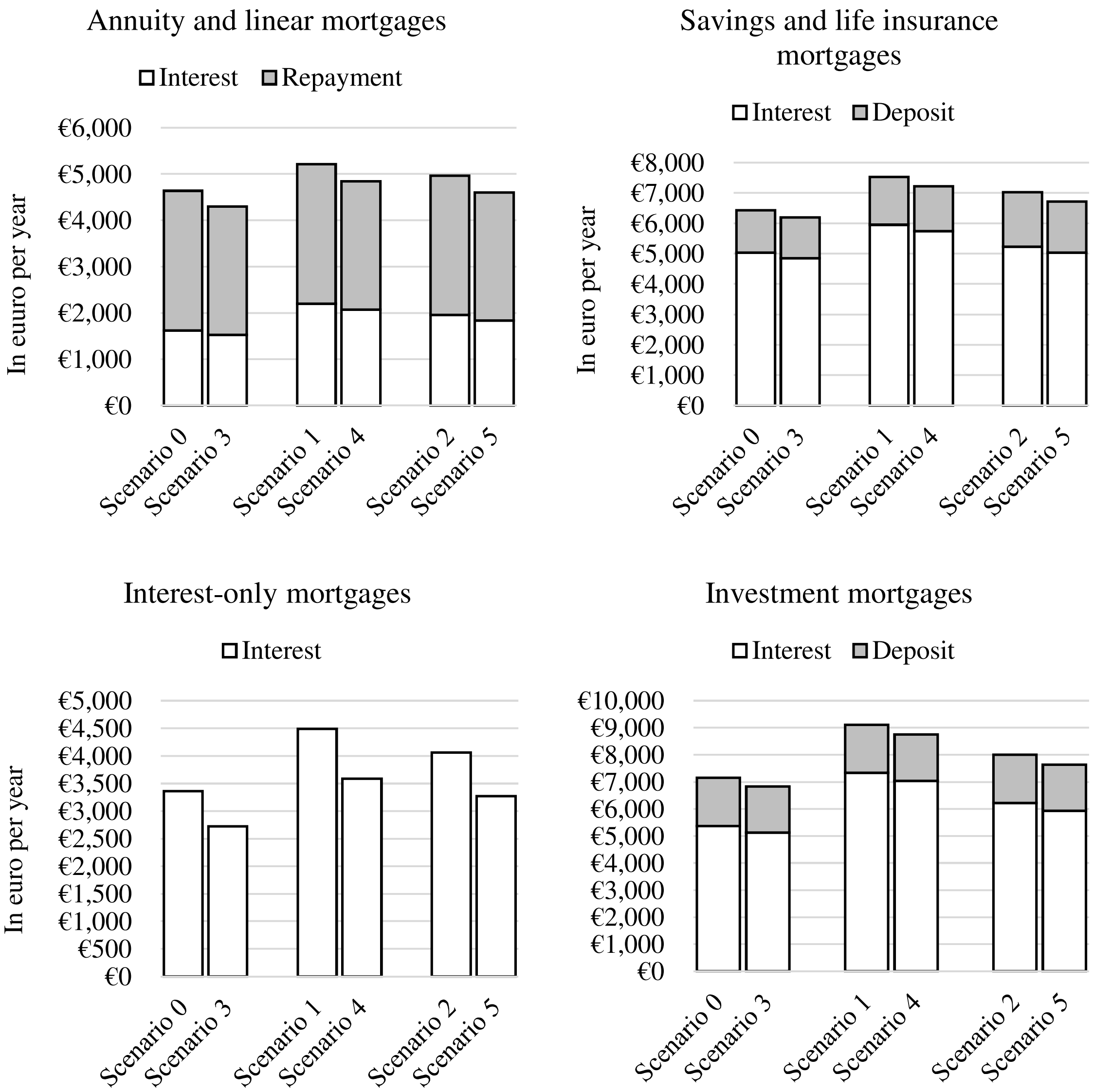
In Figure 4, the mean gross payments of the simulations under the six different scenarios are displayed by loan type. The increases in payments with and without voluntary repayments are all significantly different from zero, though this difference is the largest for the IO-loans.

For this loan type, the voluntary repayments lower the payments on average by around 20% when an interest rate shock is applied and around 19% in case there is no interest rate shock. The largest effect of including voluntary repayments for IO-loans is due to the fact that most voluntary repayments are applied to these loans (over 85% of the voluntary repayments are applied to IO-loans; see Table 4). After all, the borrower is assumed to use a voluntary repayment first for repaying IO-loans before addressing other types of loans. For investment loans, savings and life insurance loans, and annuity and linear loans, the effects of including voluntary repayments are respectively a decrease in payments of around 3.9% – 4.7%, 3.7% – 4.3%, and 7.2% – 7.5%.

When comparing the payments under scenarios 0, 1, and 2, we can derive the effect of the interest rate shocks[16] in case no voluntary repayments are allowed. As can be seen from the figures, the mean relative increase in payments is the highest for IO-loans, which show an increase of 33.5% and 20.8% for respectively an immediate interest rate shock and an interest rate shock after 5 years.

[16] The interest rate shock effect under no voluntary repayments can be derived by comparing scenarios 0 and 1 (an immediate shock) and scenarios 0 and 2 (a shock after 5 years).

Figure 4. Mean gross payments per loan type per scenario (loan-level)

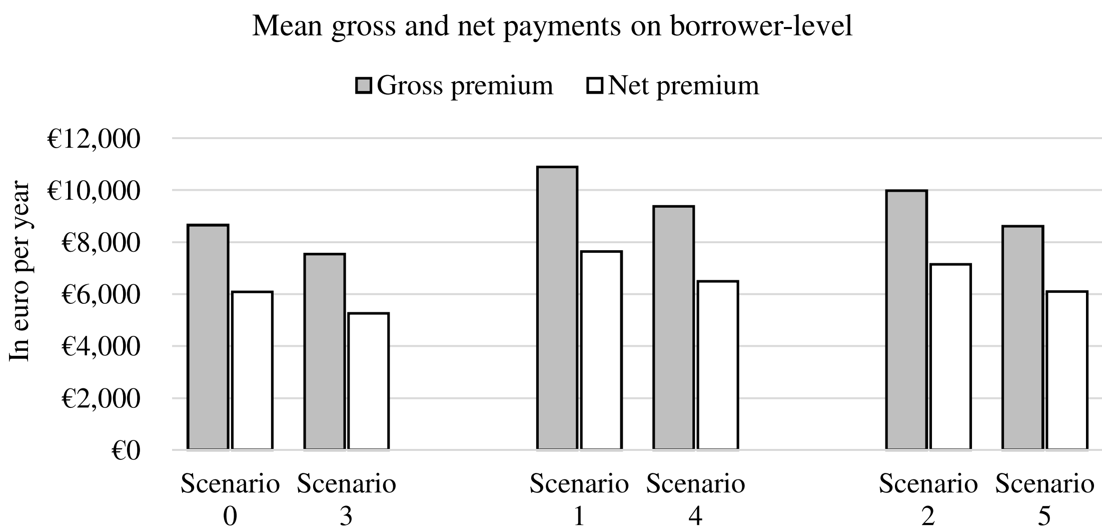


Notes: The differences in payments with and without voluntary repayments are significantly different from zero in all instances and for all loan types at a 1% level. This is assessed using a t-test. Scenario 0 and 3 are the scenarios respectively with and without voluntary repayments in case there is no IR-shock. Scenario 1 and 4 are the scenarios respectively with and without voluntary repayments in case there is an immediate IR-shock. Scenario 2 and 5 are the scenarios respectively with and without voluntary repayments in case there is an IR-shock after 5 years of low IRs.

The relative increase is second highest for investment loans: 27.4% and 12.0% respectively for scenarios 1 and 2. The effect for annuity and linear loans is the lowest, 12.4% and 7.1% respectively, while the effects for savings and life insurance loans are respectively an increase of 17.2% and 9.3%.

When looking at the combined effect of an interest rate shock and voluntary repayments, the payments of IO-loans increase on average with 6.7% and decrease with 2.8% in case of an immediate interest rate shock and interest rate shock after 5 years respectively, compared to the payment under the baseline scenario (S0). This is substantially lower than the situation where borrowers are confronted with an interest rate shock and no voluntary repayments are allowed. For the other types of loans, the mean combined effects for an immediate shock and a shock after 5 years are respectively: 22.4% and 6.7% increases for investment loans; 12.3% and 4.5% increases for savings and life insurance loans; and a 4.3% increase and a 0.9% decrease for annuity and linear loans. Thus, including voluntary repayments reduces the impact of an interest rate shock, when taking scenario 0 as starting point. That is, the mean increase of the payments due to an immediate shock and a shock after 5 years are lower when including voluntary repayments, respectively: 26.8 and 23.6 percentage points lower for IO-loans, 5.0 and 5.2 percentage points for investment loans, 4.9 and 4.7 percentage points for savings and life insurance loans, and 8.1 and 8.0 percentage points for annuity and linear loans.

Figure 5. Mean gross and net payments per borrower per scenario over the whole simulation period



Notes: To derive the mean gross and net payments as presented here, first the mean gross and net payments per borrower over the whole simulation period are calculated. Subsequently, the mean is taken of all mean payments per borrower. Scenario 0 and 3 are the scenarios respectively with and without voluntary repayments in case there is no interest rate shock. Scenario 1 and 4 are the scenarios respectively with and without voluntary repayments in case there is an immediate interest rate shock. Scenario 2 and 5 are the scenarios respectively with and without voluntary repayments in case there is an interest rate shock after 5 years of low interest rates.

Figure 5 shows the mean yearly gross and net payments per borrower under the six different scenarios. The difference between the gross and net payments is that for the latter the interest rate deductibility (IRD) is taken into account, which effectively lower the interest expense to the borrowers. Net payments fluctuate less under the different interest rate scenarios than the gross payments. The gross payments are quite responsive to a shock in the interest rate. Only looking at the effect of an interest rate shock, the yearly gross payments increase on average by 25.9% (€2,240) and 15.3% (€1,325) for respectively an immediate shock or a shock after 5 years of low interest rates (see Table 5).

Table 5. Mean effects of an interest rate shock and allowing voluntary repayments on the gross and net payments per borrower

	Gross premium		Net premium	
	Absolute	Relative	Absolute	Relative
Immediate interest rate shock				
Combined effect of IR shock and allowing vol. rep.	€ 723	8.4%	€ 411	6.8%
Effect of the interest rate shock	*€ 2,240*	*25.9%*	*€ 1,554*	*25.6%*
Effect of allowing voluntary repayments	*€ -1,517*	*-13.9%*	*€ -1,144*	*-15.0%*
Interest rate shock after 5 years of low interest rates				
Combined effect of IR shock and allowing vol. rep.	€ -42	-0.5%	€ 17	0.3%
Effect of the interest rate shock	*€ 1,325*	*15.3%*	*€ 1,063*	*17.5%*
Effect of allowing voluntary repayments	*€ -1,367*	*-13.7%*	*€ -1,046*	*-14.6%*

Notes: IR and vol. rep. stand for respectively interest rate and voluntary repayments. The effect of an interest rate shock is determined by comparing the payments of scenarios 1 and 0 for an immediate shock and scenarios 2 and 0 for a shock after 5 years. The effect of allowing voluntary repayments is determined by comparing the payments of scenarios 4 and 1 for an immediate shock and scenarios 2 and 5 for a shock after 5 years.

For the net payments, the average increases equal 25.6% (€1,554) and 17.5% (€1,063) respectively. This means that in relative terms the increase due to an immediate shock is lower for net payments compared to gross payments, but the relative increase is higher when caused by a shock after 5 years of low interest rates. Compared to the baseline scenario (S0), the effect of an interest rate shock is substantially lower when voluntary repayments are allowed. The combined effect equals an 8.4% increase of the gross payment in case of an immediate shock and a 0.5% decrease in case of a shock after 5 years. In the latter case, the decreasing effect of voluntary repayments on the gross payments is larger than the increasing effect of the interest rate shock. In any case, the dampening effect of voluntary repayments on the transmission of an upward shock in the interest rates on the gross payments is substantial. The same holds for net payments. Though, the stabilizing role of IRD results in a lower relative increase in net payments when the borrowers are confronted with an immediate shock. This is driven by a lower relative impact of the interest rate shock and a higher relative impact of allowing voluntary repayments. The net payments show on average an increase of 0.3% in case of a shock after 5 years, while the gross payments decrease by 0.5% under the same interest rate scenario. This is due to the IRD, where the borrower cannot fully benefit from the period of low interest rates when looking at the net payments and therefore the interest rate scenario has a relative larger impact. Furthermore, the dampening effect of voluntary repayments is relatively larger, around 1 percentage point, for net payments than gross payments.

Figure 6, Figure 7, and Figure 8 display the development of the yearly mean gross and net payment per borrower over the simulation period. In the scenarios where there is no shock to the interest rates (S0 and S3; see Figure 6), gross payments decrease, because the number of loans that have reached maturity increase in the simulation year, thereby lowering the payments per borrower.

Figure 6. Mean gross and net payment per borrower over the simulation period in case of no interest rate shock, with and without allowing voluntary repayments

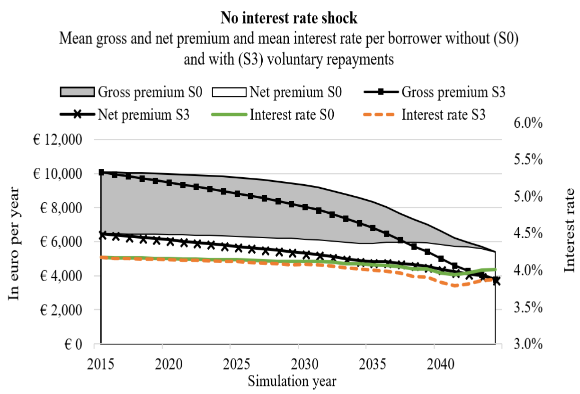


Figure 7. Mean gross and net payment per borrower over the simulation period in case of an immediate interest rate shock, with and without allowing voluntary repayments

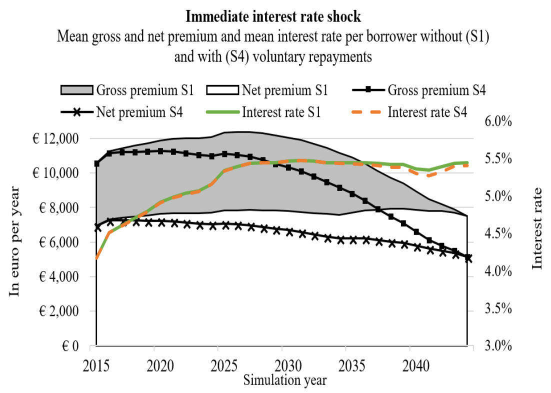
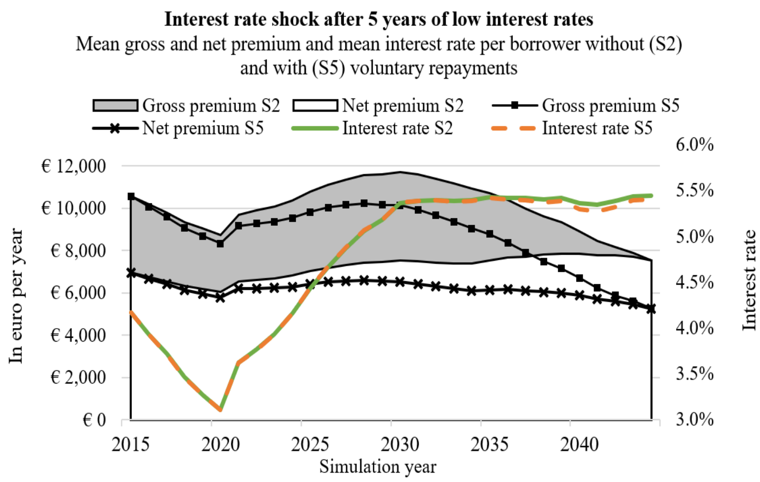


Figure 8. Mean gross and net payment per borrower over the simulation period in case of an interest rate shock after five years of low interest rates, with and without allowing voluntary repayments



The gross and net payments converge over the simulation period due to the expiration of the IRD, 30 years after the origination of the mortgage. The IR per loan is constant over the simulation period, but the average IR per borrower does slightly decrease over time due to the changing composition of the mortgage portfolio, which is a result of loans reaching their maturity. Lastly, the slight divergence of the average interest rate[17] is driven by voluntary repayments, which alter the interest expenses and outstanding debt per borrower. The mean gross and net payment decrease relatively more with voluntary repayments, indicating the decreasing effect of voluntary repayments on the per-period payments. In 2044, the mean gross and net payment under the scenario with voluntary repayments are almost €1,600 lower.

Figure 7 displays the yearly mean gross and net payments for an immediate IR-shock. As can be seen from the average IR, it takes some years before the shock is transmitted to most borrowers. The mean interest rate increases sharply until approximately year 2025 and flattens afterwards. Correspondingly, the mean gross payment under the scenario without voluntary repayments also increases. The mean gross payment under the scenario with voluntary repayments, shows a clear increase in 2015 and reaches its maximum in year 2020 after which the gross payment more or less declines again. At the end of the simulation period in year 2044, the difference between the gross payments of the scenarios with and without voluntary repayments reached €2,400, while the difference between the net payments is slightly less than €2,400. On a monthly basis, voluntary repayments lower payments up to €200 on average. The mean yearly payments over the simulation period under the scenario of a shock to the IR after 5 years of low interest rates are shown in Figure 8.

The initial period of low interest rates results in an average interest rate that declines up to year 2020, after which there is a sharp increase again until year 2030. In 2044, the average interest rates are around the same level of the average interest rate under the scenario with an immediate shock in the same year. Contrary to the previously discussed interest rate scenario, the borrowers can here benefit from low interest rates before being confronted with a shock. Again, the responsiveness of the mortgage portfolio, though with some lag, to changes in the current interest rates can be clearly seen from this figure. Similarly, as for the average interest rate, the gross payments display evident fluctuations. The net payments on the other hand fluctuate less, indicating the stabilizing role of the IRD. At the end of the simulation period, voluntary repayments reduced the mean gross and net payment by around €2,250.

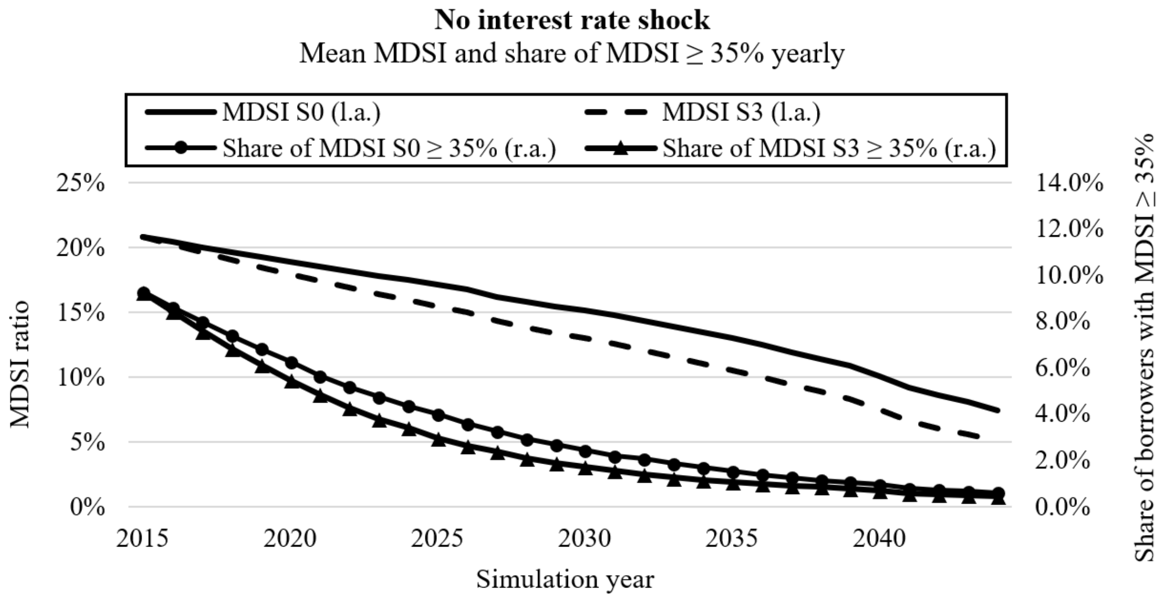
5.2.3 Effect on MDSI ratios

Figure 9 presents the mean MDSI ratios and the shares of borrowers who have a MDSI greater than or equal to 35%[18] for the scenarios where there is no interest rate shock. The decreasing pattern in both the mean MDSI ratios and the shares of borrowers with a MDSI ratio greater than or equal to 35% is driven by the decreasing gross payments over the simulation period (due to mortgages reaching their maturity) and the yearly increasing income. The mean MDSI ratio equals around 21% in 2015 and almost linearly declines to 7.5% under the scenario without voluntary repayments and 5% under the scenario with voluntary repayments. In 2015, the share of borrowers with a MDSI ratio greater than or equal to 35% is around 10% and declines yearly until it reaches

[17] The average interest rate per borrower is calculated through dividing the sum of interest expenses by the sum of outstanding debt.
[18] This is a common threshold in most studies that identify households at high default risk.

around 0.5% in 2044. Allowing for voluntary repayments reduces the share slightly, with a maximum difference of around 1 percentage point reached in year 2025.

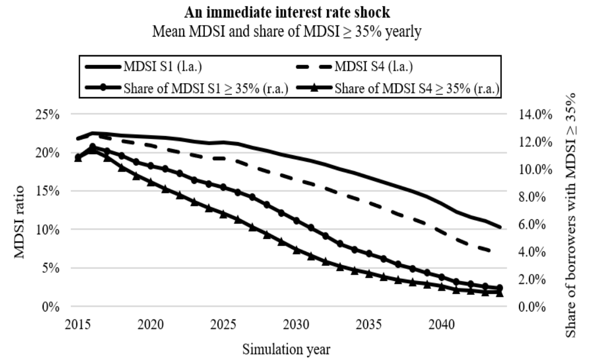
Figure 9. Mean MDSI ratio per borrower and share of borrowers with a MDSI ratio equal to or above 35% over the simulation period in case of no interest rate shock



Notes: l.a. and r.a. stand for respectively left axis (MDSI ratios) and right axis (share of borrowers with MDSI equal to or above 35%. The MDSI ratios are based on the gross payments. The differences in MDSI ratios and shares of borrowers with MDSI ratios equal to or greater than 35% between the scenarios with and without voluntary repayments are significant at a 1% level.

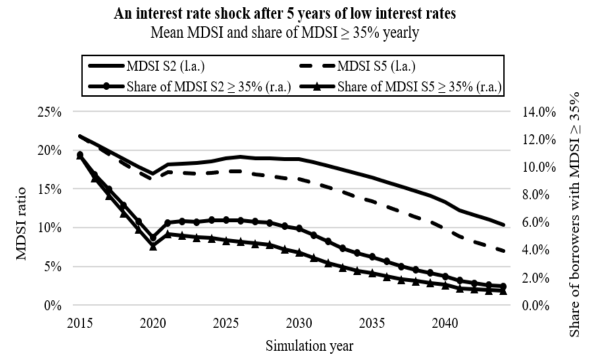
The mean MDSI ratios and the shares of borrowers with a MDSI ratio greater than or equal to 35% under the interest rate scenario where there is an immediate shock are presented in Figure 10. Both measures show a maximum in 2016. The mean MDSI ratio and the share decline to respectively 10.3% and 1.3% under the scenario without voluntary repayments in 2044 and respectively 6.8% and 1% in case voluntary repayments are allowed. These values are larger than when there is no shock to the interest rates. Additionally, compared to the scenarios where there is no shock, allowing voluntary repayments results in a relatively larger difference in the mean MDSI ratio and the share of borrowers that have a ratio greater than or equal to 35%. The difference is at maximum equal to 3.7 percentage points in 2042 for the mean MDSI ratio and for the share the maximum difference of 2.2 percentage points is reached in 2027. Thus, allowing for voluntary repayments has a larger impact when looking at the measures that are traditionally used for identifying probabilities of default of households.

Figure 10. Mean MDSI ratio per borrower and share of borrowers with a MDSI ratio equal to or above 35% over the simulation period in case of an immediate interest rate shock



Notes: l.a. and r.a. stand for respectively left axis (MDSI ratios) and right axis (share of borrowers with MDSI equal to or above 35%. The MDSI ratios are based on the gross payments. The differences in MDSI ratios and shares of borrowers with MDSI ratios equal to or greater than 35% between the scenarios with and without voluntary repayments are significant at a 1% level.

Figure 11. Mean MDSI ratio per borrower and share of borrowers with a MDSI ratio equal to or above 35% over the simulation period in case of an interest rate shock after five years of low interest rates



Notes: l.a. and r.a. stand for respectively left axis (MDSI ratios) and right axis (share of borrowers with MDSI equal to or above 35%. The MDSI ratios are based on the gross payments. The differences in MDSI ratios and shares of borrowers with MDSI ratios equal to or greater than 35% between the scenarios with and without voluntary repayments are significant at a 1% level.

Figure 11 shows the effects of an interest shock after 5 years of low interest rates on the mean MDSI ratio and share of borrowers that potentially will default. For both the mean MDSI ratio and the share a sharp decrease until 2020 is observed, after which there is a sharp increase in the subsequent year. From 2021 onwards both measures flatten and start to decrease after year 2030 again. In 2044, the mean MDSI ratio and share of borrowers with a MDSI ratio equal to or greater than 35% are equal to respectively 10.3% and 1.3% under the scenario without voluntary repayments and 7% and 1% under the same interest scenario with voluntary repayments. These values are comparable to the values observed for the same year under the interest rate scenario with an immediate shock. Though the development in these values over the simulation period differ substantially. That is, the mean MDSI ratios with and without voluntary repayments are below 20% from 2017 onwards in case the shock kicks in after 5 years, while in the scenario with an immediate shock the same ratios will be under 20% starting from respectively 2029 and 2023 for the scenarios with and without voluntary repayments.

In the context of MDSI ratios, it is especially interesting to look at the group households that starts with a MDSI ratio below 35%, but experiences a MDSI ratio with a value equal to or greater than 35% at least one year during the simulation period when being confronted with an interest rate shock, see Table 6. All borrowers who started with a MDSI ratio below 35% stay below this threshold when there is no interest rate shock applied during the simulation. However, when there is an immediate interest rate shock or an interest rate shock applied after 5 years, there are some households that will cross the 35% threshold, even though they started with a MDSI below this threshold. That is, this group of households (the "critical" group) is pushed over the critical threshold due to the interest rate shocks.

Around 90% of the borrowers have a MDSI ratio below 35% in the simulation when the interest rates are assumed to be constant. For the scenarios with an interest rate shock, around 86% and 88% of the borrowers stay below the critical threshold during the simulation when they are confronted with respectively an immediate shock and a shock after 5 years. For the borrowers that started with a ratio equal to or greater than 35% (ranging from 9% to 11% for the different interest rate scenarios), allowing voluntary repayments reduces the group that at least one year in the simulation also has a MDSI ratio equal to or above the 35% threshold, while it increases the group that has a ratio below the threshold during the whole simulation.

The "critical" group consists of 3.1% of all borrowers in case of an immediate interest rate shock, where the voluntary repayments reduce this group to 2.7%. The group is smaller in case the shock is implemented 5 years after the start of the simulation, respectively 1.5% and 1.1% of the borrowers for the scenario without and with voluntary repayments. The "critical" group of households under the scenario with a shock after 5 years is a subgroup of the "critical" group in case of an immediate shock. For both interest rate scenarios, allowing for voluntary repayments reduces the size of the "critical" group by 0.4 percentage points.

In Table 7, the "critical" group, like in the interest rate scenario with an immediate shock, is compared to all other borrowers and to the borrowers who stay below the 35% threshold during the whole simulation. As can be derived from the table, the "critical" borrowers are somewhat younger than those borrowers who stay below the 35% threshold, while the share of pensioners, i.e. borrowers that have a retirement age at the start of the simulation, is somewhat larger.

Table 6. Distribution of borrowers regarding changes in MDSI ratios over the simulation

	No interest rate shock		Immediate interest rate shock		Interest rate shock after 5 years of low interest rates	
Voluntary repayments allowed	No	Yes	No	Yes	No	Yes
Distribution of borrowers regarding changes in MDSI						
Borrower starts with a **MDSI < 35%** and keeps a **MDSI < 35%** during the simulation	90.7%	90.7%	86.1%	86.5%	87.7%	88.0%
Borrower starts with a **MDSI < 35%** and has a **MDSI ≥ 35%** at least one year during the simulation	0.0%	0.0%	3.1%	2.7%	1.5%	1.1%
Borrower starts with a **MDSI ≥ 35%** and has a **MDSI ≥ 35%** at least one year during the simulation	8.6%	8.4%	10.4%	10.2%	10.0%	9.7%
Borrower starts with a **MDSI ≥ 35%** and has a **MDSI < 35%** during the whole simulation	0.6%	0.8%	0.4%	0.6%	0.8%	1.2%

Note: In this table the distribution of borrowers is shown for the different categories of MDSI ratios over the simulation under the six different scenarios. All percentages in the same column sum up to 100%, i.e. all borrowers can be grouped into one of the categories.

Table 7. Differences in mean characteristics of the "critical" group and "non-critical" group

Mean characteristics	"Critical" group	All other borrowers	Difference with "critical" group	Borrowers who stay below 35% threshold	Difference with "critical" group
Age of the borrower (in years)	47.9	48.6	-0.7	49.5	-1.6 ***
Share of pensioners	12.6%	10.1%	2.5% **	10.9%	1.7%
Income	€ 52,029	€ 61,327	€ -9,298 ***	€ 63,810	€ -11,781 ***
House value	€ 356,703	€ 286,351	€ 70,352 ***	€ 283,757	€ 72,946 ***
Debt at origination	€ 353,363	€ 224,127	€ 129,236 ***	€ 212,576	€ 140,787 ***
Current outstanding debt	€ 323,843	€ 200,666	€ 123,178 ***	€ 190,519	€ 133,325 ***
LTV at origination	100.6%	83.9%	16.7% ***	81.8%	18.8% ***
Current LTV	96.4%	76.2%	20.2% ***	73.4%	23.0% ***
Interest rate	3.53%	4.20%	-0.67% ***	4.1%	-0.6% ***
Interest-only share at origination	53.4%	53.7%	-0.2%	55.7%	-2.3% *
Current interest-only share	56.5%	56.8%	-0.3%	58.8%	-2.3% *
N	682	21,283		18,902	

Notes: The "critical" group is defined as those borrowers for which an immediate interest rate shock pushes them over the 35% MDSI threshold, where before the simulation they had a MDSI of below 35%. This group is compared with two other groups separately. Firstly, the "critical" group is compared to all other borrowers (which include borrowers with a MDSI higher or below 35%), and secondly the "critical" group is compared to that group of borrowers that have a MDSI below 35% before and during the simulation. The (mean) characteristics are based on data of year 2015. The difference in characteristics are tested on significance using a t-test. ***, **, and * indicate that the difference in characteristic is significant on a 1%, 5%, or 10% level respectively.

The income of the "critical" borrowers is significantly lower than the income of the other borrowers, while the house value, debt at origination, and current outstanding debt is significantly higher. The difference in the debt values is relatively larger than that of the house value resulting in significantly higher LTV ratios of the "critical" borrowers at both the origination and current date. Remarkably, the "critical" borrowers have significantly lower interest rates on their mortgages, while the IO-share at origination and the current shares do not significantly differ.

6. Discussion

In this study, the debt positions of households are simulated under three different interest rate scenarios. One scenario involves an interest rate shock after 5 years, instead of immediately. Since it is uncertain how long the interest rates will stay (historically) low, it is interesting to check empirically the robustness of changing the timing of the shock in the stress-test model. As an additional sensitivity analysis, scenarios where there is a shock after 3 and 10 years are evaluated as well. The results[19] indicate that in case of a shock after 3 years, the mean yearly gross and net payments are respectively around 3.5% or €350 and 2.6% or €190 higher compared to the scenario where there is a shock after 5 years. When voluntary repayments are introduced, the mean gross

[19] The (complete) computations are available from author on request.

and net payment are respectively 3.3% or €280 and 2.3% or €140 higher. Voluntary repayments reduce the gross and net payment relatively more. This is due to a higher amount of voluntary repayments[20] in this instance compared to the situation where there is a shock after 5 years, which is driven by a higher average interest rate. The borrowers can now only benefit 3 years from the low interest rates, instead of 5 years. This can also be seen from Figure 12. The mean yearly average interest rate reaches its minimum of around 3.5% in 2018, while in the scenario with a shock after 5 years a minimum of 3.1% is reached in year 2020.

Figure 12. Mean gross and net payment per borrower over the simulation period in case of an interest rate shock after 3 years of low interest rates, with and without allowing voluntary repayments

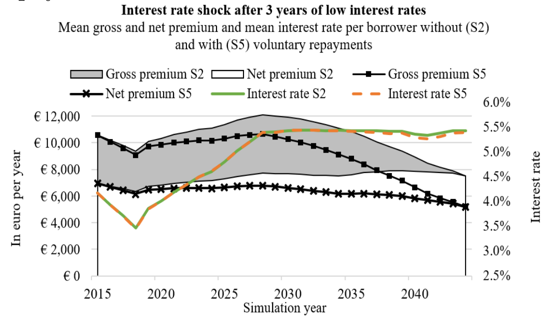
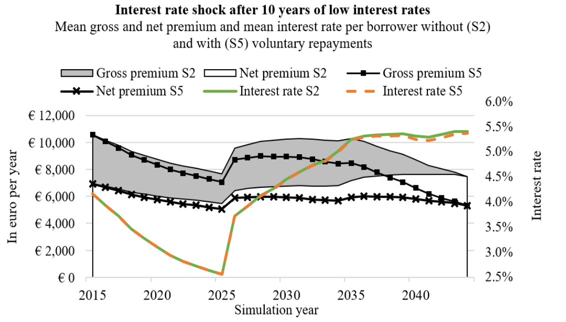


Figure 13. Mean gross and net payment per borrower over the simulation period in case of an interest rate shock after 10 years of low interest rates, with and without allowing voluntary repayments



Contrary, the mean gross and net payment under the scenario where the shock kicks in after 10 years are lower than those in case of a shock after 5 years. The mean gross and net payment is respectively reduced by 8.3% or €830 and 6.3% or €450 in case of no voluntary repayments and respectively 8.0% or €690 and 5.8% or €350 in case voluntary repayments are allowed. The payments are relatively less reduced when allowing for voluntary repayments, because the number and total sum of voluntary repayments are lower due to the longer period of low interest rates when borrowers are confronted with a shock after 10 years. As can be seen from Figure 13, the yearly average interest rate reaches an even lower minimum of around 2.6%.
Another behavioral response of households that may be relevant in this context, is fixing the interest rate for a longer period, i.e. increasing the interest rate reset interval. The effects of such a response is evaluated by running additional scenarios where all borrowers increase the reset interval by 3 and 10 years.

There are mixed results regarding the effects of a 3-year increase in the reset interval (see also Figure D.1 and Figure D.2). The mean yearly gross and net payments with and without voluntary repayments show minor differences, compared to the original situation, in the range from -0.5% to 0.2% or, in values, –€44 to €18. So, the payment could increase or decrease a little. However, looking at the scenario where there is a shock after 5 years, then the mean gross and net payments with and without voluntary repayments clearly increase. That is, when voluntary repayments are not allowed, the mean yearly gross and net payments increase with respectively 3.9% or €389 and

[20] The number of voluntary repayments is higher (0.1 percentage point) and the total sum of voluntary repayments, as percentage of the total outstanding debt in 2015, is 0.2 percentage point higher.

3.2% or €232; and the increases are equal to respectively 3.4% or €295 and 2.7% or €167 in case voluntary repayments are allowed. These results are driven by two dynamics. Firstly, by fixing the interest rates for 3 years longer, the average interest rate is lower for at least the first three years of the simulation period for the scenario with an immediate shock, but higher for the scenario with a shock after 5 years. In the latter scenario, the borrower can benefit less from the low interest rate scenario before the shock, as can be seen comparing Figure D.2 with Figure 5.5. Secondly, increasing the reset interval could lead to higher shocked interest rates for a borrower, since the shocked interest rates are dependent on, among other things, the reset interval (recall Table 2). Eventually, compared to the original results (see section 5), the average interest rate is lower up until year 2028 for the scenario where there is an immediate shock, but higher for almost the entire simulation period in case of a shock after 5 years.

The effects of increasing the interest rate reset interval for 10 additional years show similar results as when the reset interval is increased by 3 years, though in case of a 10-year increase the results are more extreme (see Figure D.3 and Figure D.4). That is, in case there is an immediate shock to the interest rate, the mean yearly gross and net payment are reduced by 4.9% or €538 and 3.1% or €234 respectively in case there are no voluntary repayments, and by respectively 5% or €472 and 3% or €198 when voluntary repayments are allowed. On the other hand, when there is a shock after 5 years of low interest rates, the mean yearly gross and net payments increase with respectively 3.8% or €378 and 3.6% or €259 in case of no voluntary repayments and respectively 3.4% or €289 and 3.2% or €194 when voluntary repayments are included. The yearly average interest rate is 0.25 percentage points higher on average in the simulation under the scenario of a shock after 5 years when the interest rate reset interval is fixed for 10 additional years compared to the situation where the reset interval equals the level stated in the mortgage contract, while this is on average 0.2 percentage points lower under the scenario of an immediate shock. Even though the interest rate is kept constant for a longer period, shielding the borrower for an interest rate shock for this time period, the effect of an increase in the shocked interest rate, due to the longer reset interval, is higher. Whether or not fixing the interest rate for a longer time is beneficial to the borrower in terms of the size of the payment seems to be dependent on the interest rate scenario. Of course, the development of the interest rates is uncertain ex-ante and increasing the reset interval will protect a borrower against upward interest rate shocks.

This study only evaluates an adverse interest rate scenario. As a next step, this satellite model can be inserted in the larger stress-testing framework, where also feedback effects to the economy and the financial sector are included. Changes in the interest rate and in the repayment-behavior will namely impact prices and debt at the same time, thus affecting macroprudential measures such as the LTV-ratios. Within a stress-test framework, these concerns are dealt with in the scenario that typically imposes an adverse development of prices. This is relevant here, since the IR-shocks increase the yearly mortgage payments and thereby decrease the income available for other types of consumption. Eventually, the economy can also be affected when borrowers reduce their consumption in order to be able to pay the higher mortgage payments. As well, when more data become available, information on current income or savings can be included into the voluntary repayments model, thereby taking into account (part of) the resources that borrowers can use to make voluntary repayments.

7. Conclusions and policy implications

In this paper, we have presented a stress-test satellite model, where households are confronted with a mortgage interest rate shock and a behavioral detail is included. That is, the role of voluntary repayments in alleviating the effects of an interest rate shock is evaluated. In order to do so, first a model is estimated describing voluntary repayments behavior. This model is used in the simulation to predict voluntary repayments. In the end, the role of voluntary repayments in the transmission of a shock in the mortgage interest rate is assessed by comparing the results of the simulation under different interest rate scenarios where borrowers are allowed to voluntarily repay with the results where the borrowers are not allowed to voluntarily repay.

There seems to be a clear relation between the mortgage interest rate and the decision of borrowers to voluntarily repay. Higher interest rates are associated with a higher probability of a positive decision to voluntarily repay. This is presumably due to the rising opportunity cost of saving when the mortgage interest rate increases. Looking at the predicted voluntary repayments in the simulation, it can be seen that the total sum of voluntary repayments is higher in the scenarios with a shock in the interest rates.
The results indicate that the Dutch mortgage market is quite responsive to interest rate shocks in the short run, though these are never fully transmitted to households. Eventually, mortgage payments, both gross and net, decrease through voluntary repayments. The dampening role of voluntary repayments in the transmission of an interest rate shock is larger when the interest rate scenario is more adverse. The increase in the mean gross payment caused by an immediate interest rate shock is 17.5 percentage points lower due to voluntary repayments. In case of a shock after 5 years of low interest rates, the increase in the mean gross payment is lowered by 15.8 percentage points. The dampening role of voluntary repayments is even higher when looking at the net payment and thus considering the interest rate deductibility (IRD). Voluntary repayments can also reduce the number of borrowers that due to an interest rate shock will have a MDSI ratio greater than or equal to 35%. Such a ratio has been considered as a critical threshold above which borrowers might default on their mortgages. The borrowers, who have a MDSI ratio in that “critical” range, seem to have significantly lower income, higher house values, higher outstanding debt levels, and higher LTV ratios. Policies that aim to increase the resilience of households regarding the mortgage debt should be directed to those borrowers. Indeed, lowering the cap on the LTV ratio is warranted based on these results.

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Appendices

A. Description of loan types

Below a table is presented that contains descriptions of the most common types of mortgage loans in the Netherlands.

Table A.1. Description of different types of loans

Loan type	Description
Annuity loan	The annuity loan is characterized by constant monthly payments, that consist of both debt repayments and interest expenses. In the beginning of the term of the loan, the interest expense makes up for the larger part of the monthly payment. As every month the borrower repays a part of the debt, the residual debt decreases as well as the interest expense part of the monthly payments. This means that the debt repayment share of the monthly payment increases over the term of the loan.
Linear loan	This loan type is characterized by constant monthly debt repayments. The interest expense is added to the monthly debt repayment. The total monthly payments decrease over the term of the loan, since the interest expense will decrease due to the fact that the residual debt will be lower every month when a part of the debt is repaid.
Interest-only loan	For the interest-only (IO) loan, the total debt is repaid at once at the maturity date of the loan. The monthly payment only consists of the interest expense and is calculated over the total debt at origination.
Savings loan	For this type of loan, no repayment is done during the term of the loan. The monthly interest expense is calculated based on the total debt at origination and is therefore constant over the whole term in case the interest rate stays constant for that period. A savings account is pledged to this loan, into which additional periodic payments are made. The return on the savings account is equal to the interest rate. The periodic payments are determined such that at the maturity date the total debt will be repaid in full using the savings account. The periodic payments into the savings account are constant given a constant interest rate.
Life insurance loan	The life insurance loan is comparable to the savings loan in the sense that no repayment is done during the term of the loan and monthly interest expenses are calculated over the total debt at origination. Differently, a life insurance is pledged to the loan, for which the borrower makes periodic payments. The periodic payments are saved and/or invested such that at maturity (part of) the total debt of the loan can be repaid from the insurance. With this type of loan it may be uncertain whether the insurance is sufficient to repay the loan back fully at maturity. Typically, the insurance also pays out when the insured passes away.
Investment loan	For this type of loan, the borrower pays a payment every month. This payment consists of the interest expense and an investment deposit. From the investment deposit a fee is subtracted and the remaining is invested in stocks by the lender (or a third party). All investments over the whole term of the loan together are supposed to yield an amount equal to the total debt of the loan, such that upon maturity the investment account can be used to fully repay the loan at once. The investment deposit is calculated based on the assumed or notional Return on Investment (ROI) taking into account the investment fee. Because the debt is only repaid at maturity, the interest expense is calculated over the total debt at origination.

Note: In this study linear loans are treated as annuity loans, and life insurance loans as savings loans for simplicity. We expect no substantial differences from this approach, since the amount of linear loans in the Netherlands is rather small (around 2%) and life insurance and savings loans are comparable in their characteristics.

B. Formulas for calculation of contractual mortgage payments

Below the formulas are listed which are used for calculating the contractual payments per each loan type.

Annuity and linear loans

Below the formulas for the yearly payment, interest expense, debt repayment, (residual) debt level, net interest expense, and net payment are presented. Firstly, the annuity payment is calculated, which stays constant over the whole term of the loan in case the interest rate does not change and there is no voluntary repayment.

$$Annuity_t = Premium_t = \left(\frac{i}{(1-((1+i)^{-(t_T-t_0)}))}\right) \cdot D_0 \tag{B.1}$$

$$Interest\ expense_t = i \cdot D_t \tag{B.2}$$

$$Debt\ repayment_t = annuity_t - interest\ expense_t \tag{B.3}$$

$$D_t = D_{t-1} - debt\ repayment_t \tag{B.4}$$

$$Net\ interest\ expense_t = interest\ expense_t \cdot (1 - IRD) \tag{B.5}$$

$$Net\ premium_t = debt\ repayment_t + net\ interest\ expense_t, \tag{B.6}$$

where i stands for the interest rate, t_0 for the year of origination, t_T for the year of maturity, i.e. $(t_T - t_0)$ is the residual length of the loan, D_0 for the debt at origination, and IRD for the rate of income tax at which the interest expense can be deducted. The subscript t stands for year t, where year 0 and T are respectively the year of origination and year of maturity. Formula B.1 is used for calculating the annuity at origination date, which stays constant afterwards when there are no changes in the interest rate or voluntary repayments. In case there is an interest rate change or voluntary repayment, the annuity needs to be recalculated. Then the i will be replaced by a new interest rate, D_0 will be replaced by the residual debt level minus (if any) the voluntary repayment, and $(t_T - t_0)$ will be replaced by the residual length to maturity, see formula B.7 below. As well, the voluntary repayment is subtracted from last period's residual debt, after which the debt repayment is subtracted in order to derive the residual debt of the subsequent period, see formula B.8.

$$Annuity_t = \left(\frac{i}{(1-((1+i)^{-residual\ length}))}\right) \cdot (D_{t-1} - vol.rep._t) \tag{B.7}$$

$$D_t = D_{t-1} - vol.rep._t - debt\ repayment_t, \tag{B.8}$$

where $vol.rep._t$ and $residual\ length$ stand for respectively the voluntary repayment made at the beginning of year t and the residual length of the loan in years to maturity.

Savings and life insurance loans

For this type of loans, there is no periodic debt repayment, instead there are periodic deposits on a savings account that is pledged to the loan. This deposit stays constant in case there is no interest change or voluntary repayment. The periodic interest payment is based on the debt at origination. The relevant formulas are listed below.

$$Savings\ deposit_t = (D_0 \cdot i)/\left((1+i)^{(t_T - t_0)} - 1\right) \tag{B.9}$$

$$Interest\ expense_t = i \cdot D_0 \tag{B.10}$$

$$Premium_t = savings\ deposit_t + interest\ expense_t \tag{B.11}$$

$$Savings\ account_1 = savings\ deposit_1 \tag{B.12}$$

$$Savings\ account_t = savings\ acount_{t-1} + savings\ deposit_t \cdot (1+i)^n \quad \forall\, t > 1 \tag{B.13}$$

$$Net\ premium_t = savings\ deposit_t + interest\ expense_t \cdot (1 - IRD), \tag{B.14}$$

where i stands for the interest rate, t_0 for the year of origination, t_T for the year of maturity, i.e. $(t_T - t_0)$ is the length of the loan, D_0 for the debt at origination, IRD for the rate of income tax at which the interest expense can be deducted, and n for the vintage of the loan, i.e. how old the loan is in years. The subscript t stands for year t, where year 0 and T are respectively the year of origination and year of maturity. If there is no interest change or voluntary repayment, the savings deposit only needs to be calculated once and stays constant over the whole term of the loan. However, if there is a voluntary repayment or a change in the interest rate, then the savings deposit needs to be recalculated taking into account the amount already saved and what this amount would be at the maturity, because it accumulates interest over the residual length of the loan, see formula B.15 below. The interest expenses will also be calculated over the debt at origination (D_0) minus the cumulative voluntary repayments ($cum.vol.rep.$). Additionally, the savings account balance will be calculated using formula B.17 after an interest change.

$$Savings\ deposit_t = \left(\left(D_0 - acc.vol.rep._t - \left(savings\ acount_{t-1} \cdot (1+i)^{residual\ length}\right)\right) \cdot i\right) / \left((1+i)^{residual\ length} - 1\right) \tag{B.15}$$

$$Interest\ expense_t = i \cdot (D_0 - cum.vol.rep._t) \tag{B.16}$$

$$Savings\ account_t = savings\ acount_{t-1} \cdot (1+i) + savings\ deposit_t, \tag{B.17}$$

where the residual length equals the time in years before the maturity of the loan will be reached.

Investment loans

Similarly, as for the savings and life insurance loans, the borrower does not repay debt during the term of the loan in case of an investment loan. Instead, a yearly deposit is made into a capital account, which is invested by the lending institution or a third party. All deposits together should yield an amount equal to the debt level at maturity. The yearly deposit stays constant over the whole term of the loan regardless of an interest rate change. The formulas used for calculating the balance sheet items of the investment loan are listed below.

$$Investment\ deposit_t = \frac{D_0}{(1 + RoI - inv.fee)^{(t_T - t_0)}} \Big/ \left(\frac{1 - (1 + RoI - inv.fee)^{-1^{(t_T - t_0)}}}{1 - (1 + RoI - inv.fee)^{-1}}\right) \tag{B.18}$$

$$Interest\ expense_t = i \cdot D_0 \tag{B.19}$$

$$Premium_t = investment\ deposit_t + interest\ expense_t \tag{B.20}$$

$$Net\ premium_t = investment\ deposit_t + interest\ expense_t \cdot (1 - IRD) \tag{B.21}$$

where, in addition to the notation already previously used, RoI and inv. fee stand for respectively the Return on Investment and investment fee, both entered in the formula as percentages. In this study, the fictional percentages of 8% RoI and 1.75% investment fee are used.

A voluntary repayment will change the amount of the yearly investment deposit as well as the interest expense. The investment deposit will be recalculated using formula B.22. The interest expense will decrease, because the interest will be paid over the debt at origination minus the (cumulative) voluntary repayment.

$$Investment\ deposit_t = \frac{(D_0 - cum.vol.rep._t)}{(1+RoI-inv.fee)^{(t_T-t_0)}} / \left(\frac{1-(1+RoI-inv.fee)^{-1^{(t_T-t_0)}}}{1-(1+RoI-inv.fee)^{-1}}\right). \tag{B.22}$$

Interest-only loans

The borrower will only make yearly interest payments in case of an IO-loan. The interest payment will be made of the debt level at origination, since there are no periodic debt repayments. The debt level over which interest is paid will only decrease in case of a voluntary repayment. The interest expense will also change when the interest rate will be altered. The relevant formulas for the IO loans are listed below.

$$Premium_t = i \cdot D_0 \tag{B.23}$$

$$Net\ premium_t = i \cdot D_0 \cdot (1 - IRD), \tag{B.24}$$

where the same notations apply as in the previous formulas.

C. Estimation results of the voluntary repayments model for different interest-only groups

The results from estimating Part I and Part II of the Cragg log-normal hurdle model on the six different groups of borrowers, who differ with respect to their IO-share, can are presented here. The estimation results regarding Part I of the model, which models the participation decision, are presented in Table C.1, while the results of part II of the model, which involves the decision regarding the amount, are presented in Table C.2.

Table C.1. Estimation results for voluntary repayments model part I: Probit model for the decision to voluntarily repay or not

	(1) 0% I-O		(2) 20% I-O		(3) 40% I-O		(4) 60% I-O		(5) 80% I-O		(6) 100% I-O	
VARIABLES	Coeff.	ME	Coeff.	ME	Coeff.	ME	Coeff.	ME	Coeff.	ME	Coeff.	ME
Interest rate	-1.455	-0.302	0.758	0.190	4.664*	0.952*	4.330**	0.957**	5.669**	1.217**	22.260***	5.258***
	(2.259)	(0.469)	(3.847)	(0.966)	(2.563)	(0.523)	(2.151)	(0.475)	(2.460)	(0.528)	(5.010)	(1.159)
Age	0.043***	-0.0004	-0.024	-0.003***	-0.021	-0.002***	-0.029	-0.003***	0.046*	-0.002***	0.228***	-0.002
	(0.015)	(0.0005)	(0.029)	(0.001)	(0.020)	(0.0006)	(0.018)	(0.0006)	(0.027)	(0.0006)	(0.067)	(0.001)
Age squared	-0.0005***		7.26e-05		6.85e-05		0.0002		-0.0006**		-0.002***	
	(0.0002)		(0.0003)		(0.0002)		(0.0002)		(0.0002)		(0.0006)	
Underwater	-0.732***	-0.081***	-1.049***	-0.062**	-0.961***	-0.062***	-0.663***	-0.052***	-0.419	-0.053***	2.201**	-0.038
	(0.272)	(0.019)	(0.394)	(0.030)	(0.233)	(0.014)	(0.244)	(0.015)	(0.340)	(0.020)	(0.932)	(0.052)
Age times underwater	0.008		0.018*		0.015***		0.009*		0.003		-0.043**	
	(0.007)		-0.01		(0.006)		(0.005)		(0.007)		(0.018)	
NHG	-0.236***	-0.049***	-0.175**	-0.044**	-0.280***	-0.057***	-0.293***	-0.065***	-0.051	-0.011	-6.52e-05	-1.54e-05
	(0.049)	(0.010)	(0.077)	(0.019)	(0.048)	(0.010)	(0.047)	(0.010)	(0.081)	(0.018)	(0.178)	(0.042)
Current LTV	0.0004	8.74e-05	-0.003*	-0.0007*	-0.002	-0.0003	-0.004***	-0.0009***	-0.002	-0.0003	-0.005*	-0.001*
	(0.0009)	(0.0002)	(0.002)	(0.0004)	(0.001)	(0.0002)	(0.001)	(0.0002)	(0.001)	(0.0003)	(0.002)	(0.0006)
Constant	-1.746***		0.323		-0.133		0.251		-1.965***		-7.817***	
	(0.383)		(0.735)		(0.509)		(0.474)		(0.732)		(1.935)	
Number of observations	5,343	5,343	1,899	1,899	5,708	5,708	5,973	5,973	3,716	3,716	805	805
Log likelihood	-2021		-857.9		-2126		-2395		-1453		-341.8	
Pseudo R-squared	0.028		0.024		0.035		0.029		0.018		0.069	

Notes: Share IO stands for the share of interest-only (IO) debt in the total debt per borrower; underwater is a dummy, which equals 1 if the outstanding debt for a certain borrower is larger than the value of his house and 0 otherwise; NHG is a dummy indicating whether the borrower has a NHG insurance; and current LTV stands for the current Loan-to-Value ratio per borrower. Coeff. and ME stand for coefficient and the mean marginal effect respectively. See formula (5) in section 4.2.2 for calculation of the ME. The dependent variable is equal to a voluntary repayments dummy, which equals 1 if a borrower has made a voluntary repayment and 0 if the borrower has not made a voluntary repayment. The model is estimated using data on the whole subsample in 2014.

Table C.2. Estimation results for voluntary repayments model part II: Log-normal hurdle model for the size of the voluntary repayment

VARIABLES	(1) 0% I-O	(2) 20% I-O	(3) 40% I-O	(4) 60% I-O	(5) 80% I-O	(6) 100% I-O
Interest rate	-3.603	-4.694	-2.589	-14.620***	-8.294*	-2.827
	(4.337)	(6.193)	(4.098)	(3.308)	(4.463)	(8.640)
Age	0.002	-0.112**	0.027	-0.01	-0.021	-0.066
	(0.033)	(0.055)	(0.032)	(0.032)	(0.056)	(0.160)
Age squared	3.45e-05	0.001*	-0.0003	0.0002	6.21e-05	0.0004
	(0.0003)	(0.0006)	(0.0003)	(0.0003)	(0.0005)	(0.001)
Underwater	-0.234	-0.818	0.001	-0.905**	-1.228*	-1.557
	(0.571)	(0.678)	(0.379)	(0.426)	(0.631)	(2.095)
Age times underwater	0.006	0.008	-0.006	0.019*	0.025*	0.04
	(0.014)	(0.016)	(0.009)	(0.010)	(0.013)	(0.042)
NHG	-0.379***	-0.287**	-0.429***	-0.410***	-0.221	-0.363
	(0.094)	(0.125)	(0.076)	(0.077)	(0.149)	(0.295)
Current LTV	0.003	0.007***	0.006***	0.002	0.002	-0.002
	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.004)
Constant	9.431***	11.830***	8.370***	10.060***	10.580***	11.850***
	(0.803)	(1.308)	(0.806)	(0.815)	(1.479)	(4.525)
Number of observations	702	331	740	863	506	137
R-squared	0.035	0.055	0.060	0.065	0.036	0.053
Log likelihood	-1047	-466.5	-991.3	-1169	-759.0	-205.0
Sigma u	1.082	1.003	0.929	0.942	1.093	1.113
Log likelihood two-part	-9704	-4412	-9925	-11550	-6992	-16528
Pseudo R-squared two-part	0.018	0.023	0.027	0.021	0.009	0.035

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Notes: Share IO stands for the share of interest-only (IO) debt in the total debt per borrower; underwater is a dummy, which equals 1 if the outstanding debt for a certain borrower is larger than the value of his house and 0 otherwise; NHG is a dummy indicating whether the borrower has NHG insurance; and current LTV stands for the current Loan-to-Value ratio per borrower. The dependent variable is equal to the voluntary repayments in case these are positive, i.e. a borrower has made a voluntary repayment. That is, the model is estimated over those borrowers of the subsample that has made a voluntary repayment in 2014.

D. Behavioral response: increasing the interest rate reset interval

Below the figures of the mean gross and net payment over the simulation period are presented for the scenarios where borrowers are confronted with an interest rate shock and they increase the interest rate reset interval. Figure D.1 and Figure D.2 show the results when the borrowers increase the reset interval with 3 years, while Figure D.3 and Figure D.4 show the results of increasing the reset interval with 10 years.

Figure D.1. Mean gross and net payment per borrower over the simulation period in case of an immediate interest rate shock and increasing the interest rate reset interval with 3 years, with and without allowing voluntary repayments

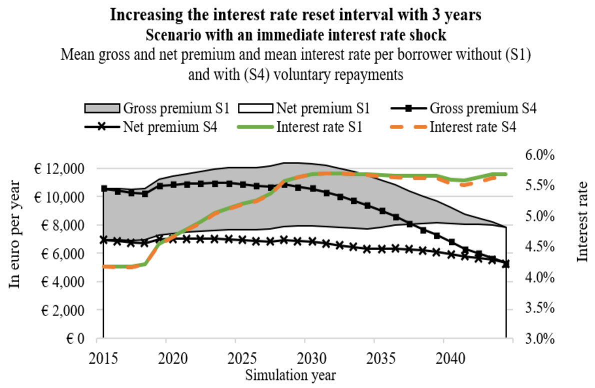


Figure D.2. Mean gross and net payment per borrower over the simulation period in case of an interest rate shock after five years of low interest rates and increasing the interest rate reset interval with 3 years, with and without allowing voluntary repayments

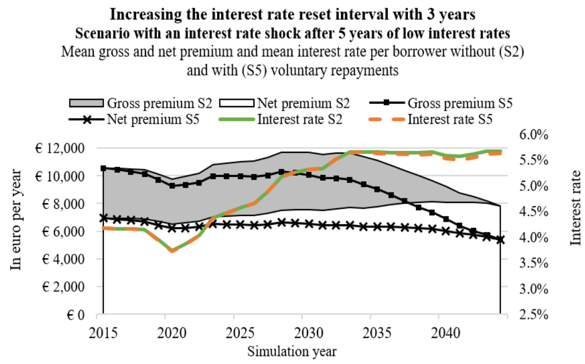


Figure D.3. Mean gross and net payment per borrower over the simulation period in case of an immediate interest rate shock and increasing the interest rate reset interval with 10 years, with and without allowing voluntary repayments

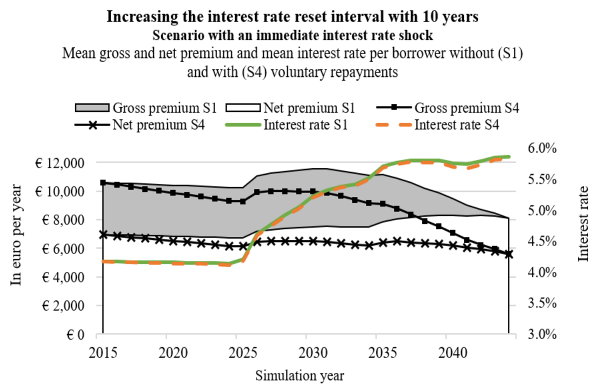
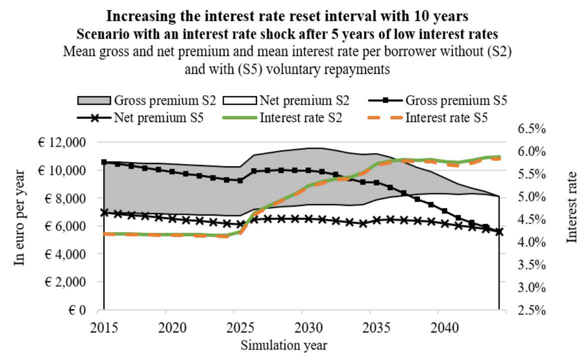


Figure D.4. Mean gross and net payment per borrower over the simulation period in case of an interest rate shock after five years of low interest rates and increasing the interest rate reset interval with 10 years, with and without allowing voluntary repayments



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