The Effect of Changing Mortgage Payments on Default and Prepayment: Evidence from HAMP Resets *

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Abstract

The Home Affordable Modification Program (HAMP) is a government-sponsored program to reduce the monthly mortgage payments of borrowers who are in danger of default. After five years of below-market interest rates, HAMP interest rates jump predictably, increasing annually in increments of up to one percentage point until they reach a pre-determined market rate. We identify the causal effect of increasing interest rates – and with them, monthly payments – on default (as well as on delinquency transitions and prepayment) with an event study design, comparing default rates immediately before and after rate reset times for loans that do and do not reset. Since the size of the interest rate reset is a kinked function of the difference between the subsidized interest rate and the market interest rate, we also identify the effect using a regression kink design (RKD). We find that a one percentage point rate increase led to a roughly 20 percent increase in the default hazard (e.g., from 0.6 percent per month to 0.72 percent per month). Our estimates imply that the payment reduction associated with a one percentage-point decline in the mortgage rate has a similar default-reducing effect as principal reduction in HAMP's Principal Reduction Alternative (as estimated by Scharlemann and Shore (2016)) at much lower cost.

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1 Introduction

The financial crisis involved widespread mortgage delinquency and foreclosures, rapid deterioration in mortgage-backed asset values, and tightening credit. Since then, economists and policymakers have debated which tools are best suited to stabilize mortgage borrowers, minimize losses on mortgage assets, and restore lending conditions. Mortgage modifications featuring payment reduction and principal reduction have been prominent tools in tackling mortgage delinquency, and their effectiveness has been widely debated.

Home prices peaked in 2005 following several years in which equity extraction and low-downpayment loans were common. Many borrowers entered the downturn with little home equity and found themselves with negative home equity – their unpaid balances exceeded the value of their homes – after home prices fell. Borrowers with low and negative equity were generally unable to refinance into lower mortgage rates (Agarwal et al., 2016). Recent research has shown that lowering mortgage payments could dramatically affect consumer spending during this period (Agarwal et al., 2015; Di Maggio et al., 2016), and consequently mitigate the macroeconomic impact of falling housing prices.

Tools for limiting mortgage default for struggling borrowers are important because rising levels of delinquency and foreclosure destabilized financial markets, mortgage servicers, banks, and local housing markets during the financial crisis. Beyond the large losses for mortgage lenders and investors, mortgage servicers were swamped with time-intensive delinquent mortgages and had to advance tax, insurance, and homeowner's association payments on behalf of delinquent borrowers (Cordell et al., 2008). Mortgage servicers were typically unwilling to offer meaningful mortgage modifications to help borrowers avoid default (Agarwal et al., 2011b,a; Adelino et al., 2013; Kruger, 2016). Local housing markets were affected when the blight associated with foreclosures spilled over onto neighboring properties (Anenberg and Kung, 2014; Mian et al., 2015; Ellen et al., 2013). Rising foreclosures and delinquencies also motivated the government rescue of Fannie Mae and Freddie Mac, one of the largest interventions of the financial crisis

(Frame et al., 2015).

In this environment, the government introduced the Home Affordable Modification Program (HAMP) in 2009 to avoid foreclosure and its spillover effects by reducing the mortgage payments of struggling homeowners. Despite mortgage losses that mounted in 2007, HAMP did not enroll a large number of borrowers until October 2009. Serious delinquencies (mortgages over 90 days delinquent or in the foreclosure process) peaked in 2010 at nearly 10 percent of outstanding mortgages. By the time the HAMP program was in place, one third of the 7.8 million foreclosures that would ultimately characterize the housing market downturn had already occurred (CoreLogic, 2017). One and a half million borrowers eventually participated in the HAMP program, and other research suggests that it may have reduced the default rate for its participants by 50 percent (Hembre, 2014). Given that the HAMP program is the first large government program to offer mortgage modifications during the deepest financial crisis since the Great Depression, this is a unique opportunity to learn and to inform future policy.

We examine the determinants of mortgage default and prepayment in the Home Affordable Modification Program. HAMP subsidizes mortgage investors and servicers to provide payment reduction to borrowers in danger of default, and in some cases also grants principal forgiveness. HAMP requires servicers to reduce monthly payments to reach an affordability target (31 percent debt-to-income ratio). This target is reached in part by reducing interest rates to as low as 2 percent for the first five years of the modification. After five years, interest rates jump annually by up to one percentage point per year until they reach a pre-determined market rate.

Mortgage payments affect borrowers' default decisions in two ways, characterized in the literature as "ability to pay" and "willingness to pay" (Gerardi et al., 2015). The impact of changing payments on borrowers' ability to pay is straightforward: borrowers may be unable to make their higher mortgage payment and, if they are unable to sell their home, may default. Defaults driven by economic shocks or payment changes in the presence of negative equity are often called "double-trigger" defaults (Elul et al., 2010; Foote et al., 2008). The impact of changing payments on borrowers' willingness to pay is subtler. A home with a mortgage is a call option; borrowers receive the difference between the home value and the mortgage balance if they are able to sell their home for a profit in the future. This option is out-of-the-money for borrowers with negative equity mortgages, who can only profit from selling their home if home prices appreciate. To maintain this call option, borrowers must pay their mortgage to avoid default. Higher monthly payments increase the cost of the call option and may reduce the number of borrowers willing to pay it. (For more complete treatment of the theory of strategic default, see, for example Campbell and Cocco (2015). For empirical evidence, see Ghent and Kudlyak (2011); Scharlemann and Shore (2016); Ganong and Noel (2017).)

We identify the causal effect of increasing the interest rate – and with it, the monthly payment – on transitions into delinquency, as well as defaults and prepayments.[1] We use an event study design, comparing transition rates immediately before, during, and after rate jumps at 60 months and 72 months. This approach is especially powerful because we can compare a control group of loans whose rates do not reset after 60 months and 72 months to our treatment group of loans that reset.

We also use a regression kink design (RKD) around each of these rate jump events. The size of the interest rate reset is a kinked function of the difference between the subsidized interest rate and the market interest rate. The interest rate increases by exactly one percentage point for those for whom the initial subsidized rate is more than one percentage point below the pre-determined market rate. The interest rate increases by the difference between the subsidized rate and the market rate when that gap is less than one percentage point. We can identify the causal effect of increasing the interest rate by comparing the interest-rate default gradient before, during, and after the reset for those with pre-reset interest rates that are more and less than one percentage point

[1] "Prepayment" occurs when a borrower repays the balance of his mortgage before it is due, usually through sale of the home or through refinance.

below the market rate.

We find that default increases permanently by approximately 20 percent following a 1 percentage point increase in the interest rate. Prepayment rates also increase permanently by roughly 50 percent from a very low level.

This paper is the first to use natural experiments to identify the causal effect of payment changes along the intensive margin (the magnitude of payment change) for borrowers in the context of mortgage modifications, addressing a question critical for optimal mortgage design (Eberly and Krishnamurthy, 2014; Piskorski and Tchistyi, 2017; Guren et al., 2017; Karamon et al., 2016). However, important related research has used interest rate resets to identify the causal effect of payment changes on default outside the context of mortgage modifications. Several of these studies have evaluated the rate changes following the financial crisis, when ARM loans largely reset downward and negative equity was widespread (Tracy and Wright, 2012; Fuster and Willen, 2015). Zhu et al. (2015) evaluate the impact of payment reductions on subsequent default using a regression discontinuity around the date of eligibility for the Home Affordable Refinance Program (HARP). Ehrlich and Perry (2015) use a regression discontinuity design, evaluating the default propensities of FHA borrowers who had access to lower fees for refinancing. They find that a 1 percent reduction in payment reduces default propensities by about 2.75 percent. Several researchers evaluating upwardly-resetting ARM loans leading up to the financial crisis find small effects, due in part to borrowers' ability to refinance out of the resetting loans (Ambrose et al., 2005; Pennington-Cross and Ho, 2010; deRitis et al., 2010). In the context we study, upwardly-resetting ARMs remain subsidized relative to prevailing mortgage rates, and the prepayment probabilities remain quite low throughout. Fang et al. (2015) estimate a structural model of default for ARM borrowers and consider a number of policy interventions, including higher- and lower-rate policies.[2]

[2] Researchers have also evaluated the performance of HELOCs as they approach their reset period, during which the loan converts from a revolving line of credit to a closed-end, amortizing loan with a higher monthly payment (Johnson and Sarama, 2015).

Existing research has also evaluated the impact of payment reduction on default in the context of mortgage modifications, both empirically (Haughwout et al., 2016; Agarwal et al., 2016) and using structural models (Hembre, 2014). Haughwout et al. (2016) use non-HAMP modifications to evaluate the impact of payment reduction on default; however, the servicers' method for determining payment reduction in these modifications is unobserved and therefore may be correlated with borrowers' outcomes. Agarwal et al. (2016) evaluate the effectiveness of HAMP modifications on the extensive margin (HAMP vs non-HAMP modifications). Because payment reduction in HAMP is completely determined by a borrower's pre-modification debt-to-income ratio, the causal impact of payment reduction on the intensive margin cannot be cleanly identified with this approach.

Apples-to-apples comparisons that evaluate the default-reducing efficacy of various changes to mortgage modifications are critical for optimal modification design. However, such comparisons have been absent to date because natural experiments that vary mortgage terms are rare; this paper makes such a comparison possible. Scharlemann and Shore (2016) use a natural experiment on HAMP borrowers to estimate the effect of principal reduction on default, exploiting variation in principal forgiveness among borrowers with identical payment reductions. In this paper, we use a different natural experiment on HAMP borrowers with similar data to estimate the effect of a rate – and therefore payment – change on default and prepayment.

Comparing the estimates from these two papers, we find that the payment change in this paper and the principal reduction from Scharlemann and Shore (2016) lead to a similar change in the default rate, but with payment reduction coming at a much lower cost to lenders. Scharlemann and Shore (2016) exploit natural variation in the amount of principal reduction in HAMP's Principal Reduction Alternative (PRA) program, reducing mortgage balances by 28 percent on average while holding total payments fixed. That paper finds that principal reduction reduced the default hazard by approximately

22 percent, a similar default change to the one induced by the payment change that we estimate here. While the default-reducing benefits of these two interventions are similar, payment reduction achieves this goal at much lower cost – roughly half the cost given our central assumptions – for all but the most extreme and pathological assumptions about loan duration and default.

2 HAMP Structure and Identification

The Home Affordable Modification Program (HAMP) was announced in 2009 as part of the Troubled Asset Relief Program (TARP). HAMP subsidizes servicers and lenders to modify the mortgages of struggling borrowers. HAMP servicers are required to send a letter to delinquent borrowers with information about HAMP.[3] Eligible borrowers must have a debt-to-income (DTI) ratio in excess of 31 percent, live in their home, and have an unpaid balance of no more than $729,750 for a single-family home. Applicants provide information about their income, which is needed to calculate their DTI. DTI measures the fraction of pre-tax income going to monthly first-lien mortgage payments, property taxes, homeowner's insurance, and dues for condominium or homeowner's associations.

2.1 HAMP Structure

Two modifications are commonly offered under HAMP: "standard" HAMP and HAMP PRA. This paper considers only standard modifications. Standard modifications were introduced first, were focused primarily on payment reduction, and were provided to more borrowers. As a result, the vast majority of modifications with histories longer than 60 months are standard modifications. Standard modifications reduce monthly payments to a level deemed affordable, specifically by reducing the borrower's DTI to 31 percent. This payment reduction is achieved by reducing the mortgage interest rate

[3] Non-delinquent borrowers are allowed to apply for HAMP as well, and will qualify for the program if deemed in danger of imminent default.

as needed, to no lower than 2 percent. If rate reduction is insufficient to meet the 31 percent DTI target, the mortgage term is extended as needed, to no longer than 480 months. If term extension is insufficient to meet the 31 percent DTI target, principal is forborne as needed to reach the payment target. (No interest or principal payments are made on this portion of the mortgage.)[4] Servicers use a net present value (NPV) model to compare the expected discounted cash flows lenders would receive with and without a modification.[5] To encourage participation in HAMP, the government provides subsidies to participating lenders.

Once borrowers are offered and accept the modification, they are given a three-month trial period during which they must stay current on their mortgage and produce any required documentation.[6] The mortgage modification becomes permanent after the trial period, at which point delinquency or foreclosure proceedings are terminated. If borrowers become more than 90 days delinquent on a permanent modification, they are dropped from the program (and our data).

Loan terms are set at the time the modification becomes permanent, and loan age is calculated relative to this date. Mortgage terms are unchanged for the first 60 months in the HAMP program. During that time, borrowers receive a $1,000 reduction in their

[4]HAMP PRA is similar to standard HAMP except that it includes principal forgiveness down to 115 percent or 100 percent loan-to-value (LTV) first, before reducing interest rates or extending the term to reach the DTI target.

[5]The NPV model estimates a default probability, prepayment rate, and recovery rate based on the borrowers' pre- and post-modification DTI and LTV, their FICO score and delinquency at the time of modification, their geography, and other variables. Updated FICO scores are pulled from credit bureaus. Government subsidies are included in lenders' NPV calculations. Servicers typically offer borrowers the option that yields the highest NPV to the lender, though they may use other objective criteria (e.g., do a HAMP PRA modification if it is better than no modification even if standard HAMP yields an even higher NPV).

While there will be selection into standard HAMP, HAMP PRA, and no modification based on the NPV model, the structure of the model is known to the econometricians (and is publicly available at www.hmpadmin.com) as are the loan-level variables used to calculate the NPV for each borrower who receives a HAMP PRA modification. As a result, we can correct for any selection stemming from the NPV model.

[6]If borrowers fail to produce this documentation or go delinquent during this period, they fail out of the trial modification. At this point, the mortgage reverts to its pre-modification terms and delinquency or foreclosure proceedings can continue; the borrower may also be evaluated for a non-HAMP modification.

mortgage balance after 12, 24, 36, 48, and 60 months in the program; borrowers receive another $\$5,000$ after 72 months (though this larger reduction was announced in late 2014 or early 2015, well into the modifications of many early participants) and then nothing thereafter.[7]

After 60 months in the program, interest rates reset. They increase each year (after 60, 72, 84 months, etc.) – by up to one percentage point per year – until they reach a pre-specified rate, the Primary Mortgage Market Survey (PMMS) rate at the time the borrower received the modification. Mortgages are recast at these interest rate jumps, so that principal payments fall somewhat as interest rates increase, and total payments increase by somewhat less than interest payments.

2.2 Identification

A standard approach for evaluating the mutually exclusive, absorbing (terminal) states of prepayment and default is to use a competing risks model (Deng et al., 2000; Fuster and Willen, 2015; Foote et al., 2010). This method allows researchers to account explicitly for the censoring that occurs when a loan exits the sample through one or the other absorbing state, and can be important when baseline rates are high. In this analysis, we evaluate default and prepayment separately, using logit models. Our exit rates through either path are low and the frequency with which we evaluate the outcomes is high, so exits do not affect the population in any period. We also do not have an exclusion restriction that would allow us to estimate complementarity or substitution between these exit paths. (In other words, we cannot tell whether defaulting borrowers would have prepaid had that option been available.) Therefore we evaluate the outcomes separately for computational ease and clarity of presentation. The low baseline exit rates ensure that this simplification

[7]These reductions are not received by borrowers who prepay their mortgages before "earning" these reductions. The annual balance reductions have no direct, high-frequency impact on the default decision before and after they are earned, since the amount received by borrowers upon default ($0) is independent of the "earned" balance. However, annual balance reductions provide a substantial incentive to delay prepayment until after the balance reductions have been "earned."

does not affect the substance of our results.

Identification comes from two sources: from variation in loan age, comparing outcomes just before, during, and just after the reset, and from variation in rate step-up size, comparing borrowers with different rate step-up sizes around the time of reset.

Loan age variation is relatively straightforward to exploit. Rate resets come into effect after the 60th/72nd month, so higher amounts are owed in the 61st/73rd month. The effect of this reset is apparent as borrowers who do not make these higher payments become delinquent in the 62nd/74th month.

The size of the interest rate step-up is a function of the "rate gap," the difference between the PMMS rate at the time the borrower receives the modification and the borrower's post-modification rate. The size of the reset is the lesser of one percentage point or the rate gap, the amount needed to reach the PMMS rate. Figure 1 shows that loans with rates above the PMMS rate – with negative rate gaps – will not experience a rate change; loans with moderately high interest rates – with initial post-modification rates below, but less than one percentage point below, the PMMS rate – will experience a "partial" rate change of less than one percentage point, bringing their new interest rate to the PMMS rate; only loans with rate gaps larger than one percentage point receive a full reset. When exploiting this high-frequency variation in loan age, we compare the time-series pattern of delinquency for loans receiving a full reset (the treatment group) to loans receiving partial resets or no reset (the control group). Because the rate step-up reflects a predictable change in the borrower's stream of payments that was known at the time of modification, the borrower's wealth does not change discretely due to the change in rate.

We also use a regression kink design (RKD) to formally compare borrowers with different rate step-up sizes around the time of reset. Figure 2 shows that the size of the rate step-up is a kinked function of the rate gap. For borrowers with negative rate gaps who receive no step-up, on the margin the initial rate has no effect on the size of their step-up size (zero); for borrowers with rate gaps greater than one percentage point with full step-ups, on the margin the initial rate has no effect on the size of their initial step-up (one percentage point). On the margin, the initial rate affects only the step-up size for borrowers with rate gaps between zero and one percentage point who receive a partial step-up. For these borrowers, increasing their initial mortgage rate reduces the size of the rate increase. We can therefore identify the effect of the reset by comparing the default gradient with respect to the rate gap in the high and low regions (where that gap does not affect the reset size) to the middle region (where that gap determines the reset size). The differences between these gradients identifies the magnitude of the effect of the reset on default.

3 Data

Data are from the Making Home Affordable data program and are publicly available. We primarily rely on the "loan modification" files from the first-lien modification program, which record modification characteristics and performance. We use monthly pulls of this file from October 2012 to January 2017. Each monthly file contains information about the loan at the time of modification, as well as the current status of the loan (e.g., still in program, already defaulted, already prepaid). Data include the month of last paid installment (LPI), the last month through which the borrower is current.[8] Delinquency states and transitions can be calculated by comparing changes in LPI from month to month.

We use CoreLogic MSA-level price indexes to update the value of the home monthly. Where the borrower's MSA is not available, we use the state-level home price index. We use a standard fixed-rate mortgage formula to advance the amortizing portion of the

[8]Note that this last paid installment is not the calendar month in which the most recent payment was received. Instead, it captures the gap between obligations and payments to date. A borrower who misses one payment and then makes typical payments thereafter without a catch-up payment will show an LPI one month behind the current month in every month. The LPI will advance by one month as they make the "March" payment in April, and then make the "April" payment in May.

unpaid balance, and calculate the updated LTV each month as the ratio of the total unpaid balance (amortizing portion and forbearance) and the updated home value.

Table 1 describes the pre-reset mortgage terms of the loans we study. While our sample includes 1.3 million loans that have aged to 36 months, the variation of interest comes from the 488,000 loans with a sufficient loan age (at least 60 months) to experience the first mortgage reset and the 270,000 loans with sufficient loan age (at least 72 months) to experience the second reset. The loans that reach reset are described in Table 2, which shows how the mortgage terms change after the first (60 month) and second (72 month) reset. Note that most loans in the sample begin the modification with a 2 percent interest rate that increases to 3 percent after 60 months, and to 4 percent after 72 months.

In each month, we define borrowers as being in one of five mutually exclusive states: current, 30-to-60 days (1 month) delinquent, 60-to-90 days (2 months delinquent), default, and prepay.[9] The default and prepayment states are absorbing; loan performance is not monitored after the borrower leaves the program. Table 3 shows the Markov delinquency transition matrix for the 23 million observations (on 1.3 million loans with loan ages above 36 months) in our sample. While roughly 3 percent of loans go delinquent each month, nearly one-third of loans that are one month delinquent cure and only roughly

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[9] Borrowers are considered current if they are fewer than 30 days delinquent; they are current at least through the month before the reporting period (if payment is due January 1, borrower did not pay their January payment and missed their February 1 payment). Borrowers are considered 30-to-60 days delinquent if they are at least two payments behind (they have missed through March 1 but have not yet missed April 1). Borrowers are considered 60-90 days delinquent if they are three payments behind (they have missed payments through April 1 but have not yet missed May 1).

A borrower can remain one month delinquent indefinitely by making regular payments without additional catch up payments. A borrower can transition from two months delinquent to one month delinquent by making one catch-up payment, or transition to being current by making two catch-up payments. Servicers are required to disqualify borrowers if they miss their fourth payment, or are "delinquent by the equivalent of three full monthly payments at the end of the month in which the last of the three delinquent payments was due."

After being disqualified from HAMP, the borrower may be evaluated for an additional non-HAMP modification, or foreclosure proceedings may be initiated. We do not have loan-level performance data following disqualification, so the eventual disposition of disqualified HAMP modifications is unobserved. We refer to falling out of the program as "default" or "re-default," but borrowers falling out of HAMP do not necessarily permanently default – their mortgage could be repaid in full outside of HAMP or they could receive a deeper modification from their lender. (Making Home Affordable, 2014) We call this default.

one-sixth progress to become two months delinquent. Furthermore, less than 20 percent of loans that are two months delinquent default in the next month. This pattern suggests that delinquent loans do not typically proceed immediately from new delinquency straight to default. This informs our approach of looking at transitions into delinquency and not merely on the default and prepayment rates. Figure 3 is a histogram showing the distribution of loans among rate gap categories at the time of the first rate reset. Most loans receive two full rate resets.

4 Results

4.1 Delinquency and Default

4.1.1 Results with Temporal Variation

Figure 4 shows the key result using an event study design (comparing delinquency transitions immediately before, during, and after the loan age associated with the first rate reset).[10] This figure breaks out results separately for each of three groups of borrowers based on the size of their initial rate reset at the referenced step-up: no rate reset; partial (less than one percentage point) reset; and full (one percentage point) reset. To summarize, delinquency and default jump at loan ages associated with resets, but only for loans scheduled to reset at those times.

The top left panel of Figure 4 shows the expected result that new delinquencies spike in month 62 for borrowers who experience a rate step-up after month 60; borrowers without a rate step-up appear unaffected. While some of the new delinquency spike reverts after this first month, the rate of new delinquencies remains elevated from the pre-reset level by roughly 10 percent for loans that receive a full rate reset. However, the default rate (top right panel) increases by roughly 10 percent in the graphs. Patterns

[10]Note that the rate resets go into effect after the 60th and 72nd months, so that higher payment amounts are due in months 61 and 73. For borrowers who fail to pay the higher amount, the account will go into delinquency in months 62 and 74.

for the second reset are similar (middle two panels), with the notable exception that all three rate categories appear to experience a temporary bump in new delinquencies at the time of the step-up, perhaps reflecting some confusion about the $5,000 balance reduction that accrues to all borrowers in that period. The pattern in new delinquencies pulls through to default only for those with a full rate step-up.

These results are also apparent in regression form in Table 4. Regressions are shown separately for the same two outcomes from Figure 4. These logit regressions include dummy variables and interactions to separately identify temporal effects for groups based on eligibility to receive step-ups of various sizes: no initial step-up; partial initial step-up; full initial step-up and partial second step-up; two full step-ups; and step-ups on loans with principal forbearance (which, all else equal, imply a lower payment increase).[11] The regressions show transitory "during" effects for the first step-up at 62 months, permanent "after" effects after the first-step up after 62 months, transitory "during" effects for the second step-up at 74 months, and permanent "after" effects after the second step-up at 74 months. The omitted category is the time period encompassing months 57-61 – the months prior to the first reset – so that the coefficients can be interpreted as changes relative to this pre-reset baseline. The regression also includes a dummy variable for the period encompassing months 69 to 80 (coefficient not displayed) so that coefficients on the second reset variables can be interpreted as changes from this second-pre-reset baseline.[12]

Table 4 shows a 37 to 43 percent spike in new delinquency (top panel) during the first

[11]The baseline regressions shown in Table 4 include calendar date dummies and additional borrower and loan characteristic controls, including the natural log of borrower income, the natural log of the borrower's updated mortgage balance, the borrower's credit score at the time of modification, updated loan-to-value ratios (using MSA-level single family price indexes from CoreLogic), an indicator variable for GSE loans, and an indicator for single family properties.

[12]We use the first month in which a borrower can become delinquent following the new payment change (month 62 for the first reset and month 74 for the second) to measure the "during" period, the effect of the reset on new delinquencies in the month it takes effect. A borrower failing to pay their higher payment in month 61 will not show up as newly delinquency until month 62). Because a borrower must be more than three months delinquent to default, we measure default "during" the reset as occurring two months later, in month 64 for the first reset and month 76 for the second.

rate reset for those who experience a full rate reset. (Our monthly probabilities of new delinquency and default are sufficiently low that we approximate the percentage change in the monthly hazard of our dependent variable using the percentage change in log likelihoods shown in the regression results.) New delinquency remains 11 to 15 percent elevated in the months following the first reset (which we label as the permanent effect). There is little or no evidence of elevated delinquency for loans that do not experience a reset. The effect on default (bottom panel) is even larger, showing a 35 to 42 percent spike in default during the first rate reset for those who experience a full rate reset, with a 18 to 25 percent "permanent" elevation in default rates in the months following the reset. Again, there is little or no evidence of elevated default for loans that do not experience a reset. The results for the second reset are broadly consistent but are slightly noisier due to smaller sample sizes and higher collinearity between cohort, calendar time, and loan age effects.

In Appendix A.2 we repeat the analysis in Table 4 to show that our results are robust to a variety of time and borrower controls. Table A1 uses only calendar date controls. Table A2 includes no controls other than those shown in the table. Table A3 includes calendar date controls, cohort controls, and all borrower- and loan-level controls. Results are robust across these specifications. However, eliminating calendar date and borrower-level controls affects the precision and magnitude of the estimate for default following the second step-up. We suspect this reflects collinearity between calendar time and the second reset. The majority of loans in the sample subject to the second step-up reached the 72nd month in late 2016, when the economy was quite strong and the overall level of defaults was quite low.

4.1.2 Results Exploiting Kinked Rate Step-Up Function

Section 2.2 shows that the size of the step-up after months 60 and 72 is a kinked function of the "rate gap," the difference between the PMMS rate at the time of modification and the initial modification rate. Where Section 4.1.1 exploited fine variation in loan age with coarse comparisons of rate step-up categories, Section 4.1.2 exploits fine variation in step-up size (determined by the rate gap) with coarse comparisons of loan age categories.

Figure 5 provides a graphical representation of rate gap effects around the first rate step-up after month 60 and month 72. As with previous figures and tables, results are shown for two transitions around the first and second reset: new delinquency rate for the first step-up (top left panel), default rate for the first step-up (top right panel), new delinquency rate for second step-up (bottom left panel) and default for second step-up (bottom right panel). The x-axis in all figures is the rate gap, the difference between the PMMS rate at the time of modification and the initial modification rate. When this gap is negative, the borrower gets no step-up; when the gap is between zero and one percentage point, the size of the step-up is equal to the size of the rate gap; when the gap exceeds one percentage point, the rate step-up is one percentage point. Results are based on logistic regressions that control for cohort and calendar age, showing logit coefficients for rate gap separately by each of three loan age dummies for each reset: before the reset (months 57-60/69-73), during the reset (month 62/74), and after the reset (months 63-68/75-80).

The top left panel of Figure 5 shows that before the step-up (the blue line), the relationship between the rate gap and default is roughly linear. On the left side of the graph (where the rate gap is negative, and rates don't reset), the relationship between the rate gap and the delinquency coefficients is similar before, during, and after the time of reset. The before, during, and after lines diverge for rate gaps between zero and one, the region in which increasing rate gaps pass through to larger resets. For rate gaps greater than one, when the reset is a full one percentage point regardless of the rate gap, the gaps between the before, during, and after coefficients stay roughly constant, as expected. This is consistent with the idea that default is affected by the rate reset and not by the loans' age directly.

These kink-based graphical results imply that the full percentage-point reset has a roughly 40 percent transitory effect and a 20 to 25 percent permanent effect on new delinquency, consistent with our regression results. We show similar figures for delinquency and default during the second reset, but the statistical power of these data-intensive kink-based exercises is too weak to draw reliable inference, particularly for the low-frequency default event. These kink-based results are broadly consistent with the results exploiting temporal variation in Section 4.1.1.

4.2 Prepayment

Prepayment occurs either when borrowers sell their house and move or when they refinance. Figure 6 shows that the prepayment rate increases dramatically after each reset. The baseline rate of prepayment is quite low, reflecting both the difficulty of refinancing for lower-credit borrowers and the deep rate subsidy that makes such refinances undesirable for borrowers. For borrowers with deep rate subsidies, prepayments likely reflect moves rather than refinances. While prepayment rates rise around the first reset, prepayments remain relatively rare; the incentive to refinance remains muted even after the first reset. For most borrowers, rates rise from 2 percent to 3 percent, still well below contemporaneous market mortgage rates. Prepayment rates increase dramatically after the second reset, when rates for most mortgages rise from 3 to 4 percent, close to prevailing market rates. Prepayment is concentrated among borrowers with shorter remaining mortgage terms, and we suspect that most prepayments reflect refinances into longer-duration products with lower payments, because market rates were competitive with the post-reset rates during much of this time period. The $5,000 incentive borrowers earn after six years in the program likely delays refinances until after the second reset.

Table 5 shows these results in regression form, showing a 32 to 52 percent increase in prepayment rates after the first reset and a 45 to 60 percent increase after the second reset. These results are confined to borrowers whose rates actually increase at months

60 and 72.

These prepayment results are also apparent using the kink-based procedure we used in Section 4.1.2 (Figure 7). While baseline prepayment rates are too low around the first reset to yield robust results (left panel, Figure 7), prepayment rates are higher at the second reset, and kink-based results are readily apparent (right panel). For the second reset, on the left side of the graph (where the rate gap is below one and rates don't reset), the relationship between the rate gap and the prepayment coefficients is similar before, during, and after the time of reset. The before, during, and, after lines diverge as the rate gap increases from one to two, the region in which increasing rate gaps pass through to larger resets. For rate gaps greater than two, where the reset is a full percentage point regardless of the rate gap, the gaps between the before, during, and after coefficients stay roughly constant, as expected.

Figure 8 and Table 6 show that prepayment rates were much higher for government-sponsored entity (GSE) mortgages than for non-GSE mortgages. This reflects the fact that Home Affordable Refinance Program (HARP) mortgages and other streamlined refinances were available to GSE borrowers, but not to non-GSE borrowers; we believe that these differences in access explain the roughly three-fold difference in prepayment between GSE and non-GSE mortgages. After the second reset, the absolute level of prepayment was above 2 percent per month for GSE mortgages. Despite these dramatic differences in prepayment rates, the rates of new delinquency were very similar for GSE and non-GSE modifications. This provides suggestive evidence that access to GSE refinances did not materially divert borrowers who might otherwise go delinquent.

5 Cost Comparison and Conclusion

Scharlemann and Shore (2016) document that the principal forgiveness component of HAMP PRA (keeping monthly payments constant but replacing less generous rate reduction and term extension with principal forgiveness averaging 28 percent of the mortgage balance) led to a roughly 20 percent reduction in the default hazard. In this paper, we show that a one percentage point rate increase has a similar impact, increasing the default hazard by roughly 20 percent. This allows us to compare the costs of these two different methods of achieving a roughly 20 percent reduction in default: reducing the principal balance by 28 percent (holding payments fixed) and reducing the interest rate (and with it, the monthly payment) by one percentage point.

We compare the total discounted costs over ten years of these two different approaches to reducing the default hazard, for a given set of default, prepayment, and discounting assumptions (Table 7). The default and prepayment rates we use in this exercise are drawn from HAMP data.[13] The cost of a one percentage point rate reduction over 10 years in this example is 5.6 percent of the balance, with a cost of 1 percent of the balance per year for loans that have not yet defaulted or prepaid discounted back to the current period.[14] The cost of a 28 percent balance reduction in this example is 11.9 percent of the balance, with a cost that is 28 percent of the balance at the time of prepayment for loans that eventually prepay (or after 10 years for loans that never default), discounted back to the present.[15]

While the exact costs of rate reduction and principal reduction vary depending on the assumed values, payment reduction is cheaper except in cases with pathological and counterfactual default assumptions. The cost of principal reduction can only be reduced by a high eventual default rate; however, this reduces the cost of payment reduction as well by reducing the number of years during which a payment reduction subsidy must be

[13]Default and prepayment rates for six years are estimated as averages for all borrowers receiving standard HAMP; default and prepayment rates in years seven to ten are assumed to be the same as those from year six. We assume a discount rate of 4 percent, and that principal reduction totals 28 percent of the principal balance.

[14]Note that this cost would be 10 percent absent default or prepayment with a discount rate of zero, but is lower since loans receive no subsidy after default or prepayment and these subsidies are received in future years and must be discounted back to the present.

[15]The cost of principal reduction is zero for loans that eventually default, because the reduced principal would never have been paid with or without principal reduction.

paid. For principal forgiveness to be a cheaper form of default reduction, borrowers must stay in the program for many years without default (receiving the payment reduction subsidy) but then default eventually (making principal forgiveness free). This pattern of highly delayed but eventual default is the opposite of what we see in the data, with default rates falling precipitously over time.

Given the similar default-reducing effects of rate and principal reduction in the amounts we considered here, this exercise shows that rate reduction reduces default at lower cost than principal reduction.

In making this cost comparison, we implicitly make a number of assumptions. First, we assume symmetry in the impact of rate increases and rate reductions. Our estimates of the default-increasing effect of a payment increase may not correspond exactly to the default-reducing effect of a payment decrease. Theory provides no obvious guide about the likely size or sign of any bias. Second, we assume the effects we observe will be persistent. The effects we estimate appear persistent during the six to eight months following reset, but we cannot rule out the possibility that the effect of a rate increase may wane in the longer term.

While these results apply to the troubled borrowers participating in the HAMP program, the effects we estimate may not generalize to the population at large. Borrowers applied to the HAMP program precisely because it offered payment reductions, so this group may be particularly sensitive to changes in payment.

Despite these limitations, this paper provides strong evidence that the level of monthly payments is important in borrowers' default decisions. This information will help lenders and policymakers design mortgage modifications to limit the macroeconomic and financial stability impacts of systemic housing downturns.

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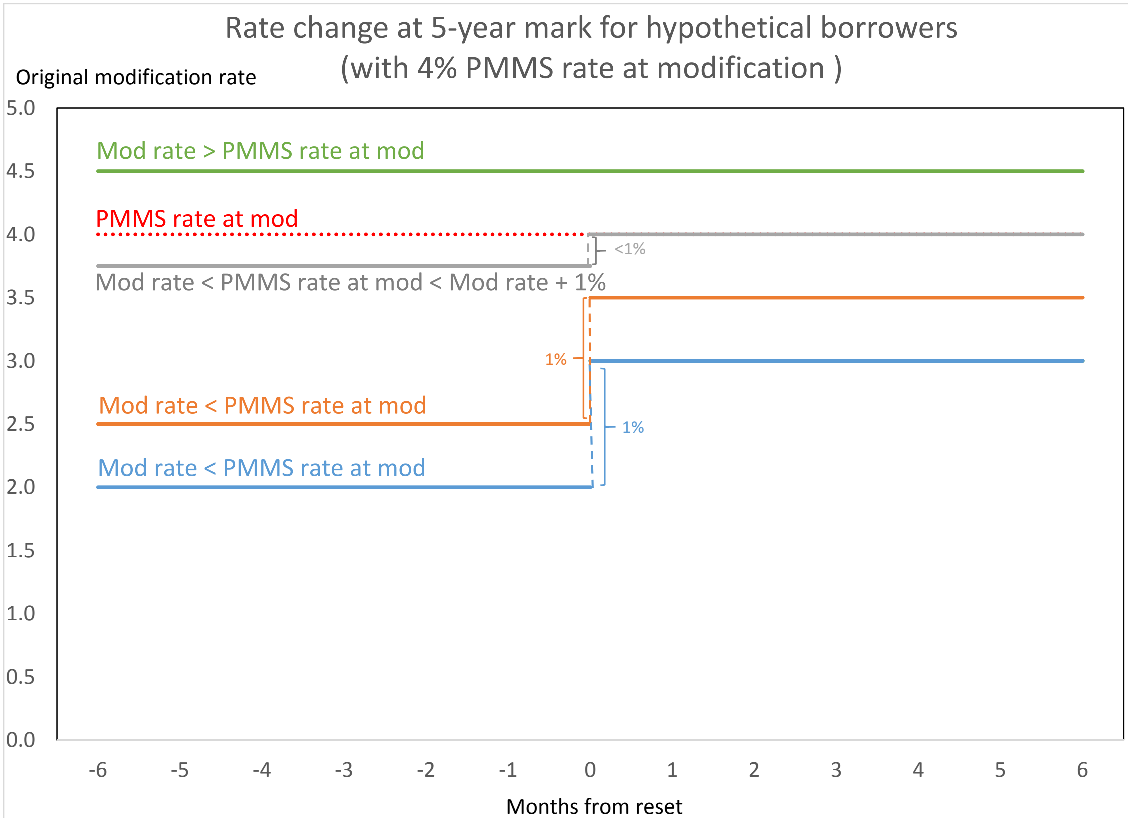
Figure 1: Graphical Representation of Rate Step-Up



Note: This figure illustrates the change in rate experienced by borrowers with different modified mortgage rates as they pass through the 60th month in the program. The red dotted line (PMMS rate at mod) shows the maximum rate to which a mortgage modified to a below-market rate will adjust. Modifications that result in an above-market rate will not face rate step-ups at the 60th month (green line). Borrowers with modified mortgage rates less than one percentage point below the PMMS rate at the time of modification will face a partial step-up, as they hit the rate cap (grey line). Borrowers with modified mortgage rates greater than one percentage point below the PMMS rate at the time of modification will face a full percentage-point rate step-up (orange and blue lines), regardless the size of the rate subsidy.

Table 1: Summary statistics: modification characteristics

	N ('000s)	Median	Mean	SD	Min	Max
Unpaid balance ('000s)	1,342	$ 194	$ 218	$ 123	$ 0	$ 1,891
Modified mortgage rate	1,342	2.0 %	2.9 %	1.5 %	0.4 %	15.1 %
Modified mortgage term (months)	1,342	324	353	83	36	636
Has principal forbearance	1,342	0.00	0.29	0.45	0.00	1.00
Amount of forbearance ('000s)	390	$ 41	$ 60	$ 61	$ 0	$ 1421
Premodification debt to income ratio	1,341	44 %	46 %	12 %	5 %	200 %
Original postmodification LTV ratio	1,295	121 %	133 %	53 %	40 %	400 %
Fannie Mae or Freddie Mac Loan	1,342	0.00	0.46	0.50	0.00	1.00
Single-family property	1,342	1.00	0.97	0.17	0.00	1.00

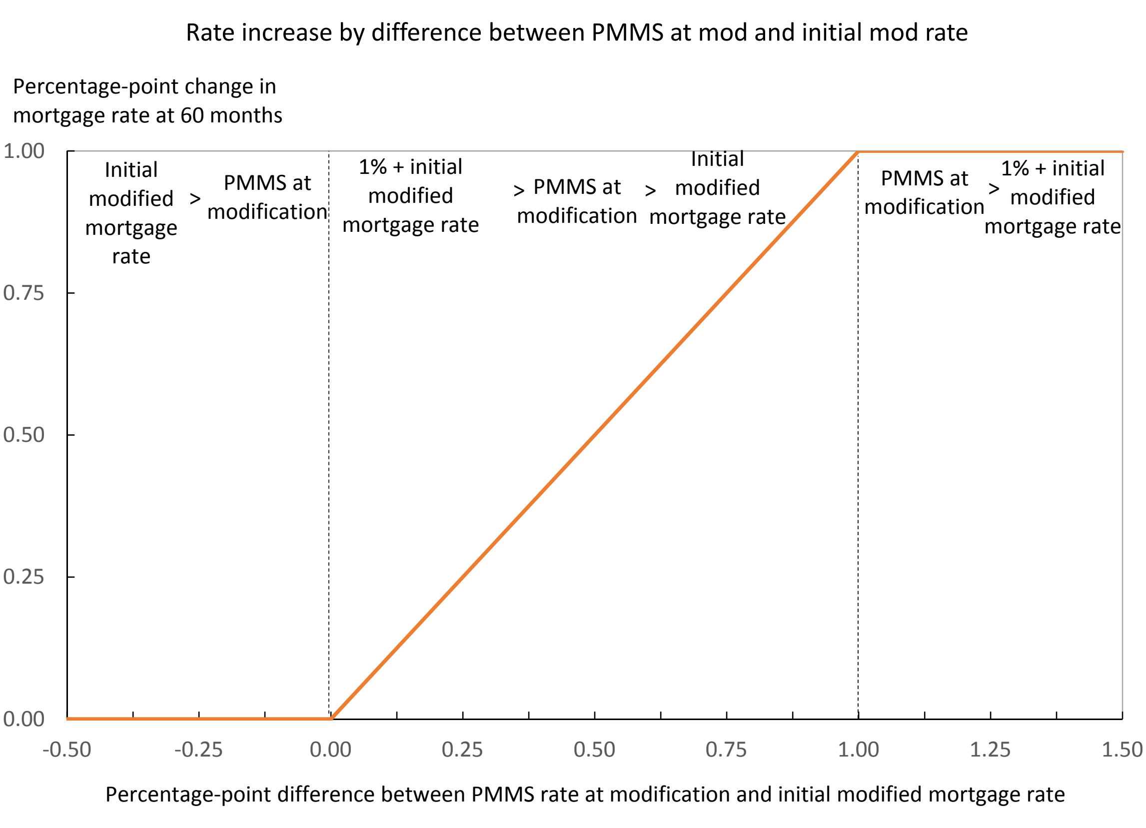
Note: This table shows summary borrower and mortgage characteristics for all loans that have remained in the HAMP program for at least 36 months, subject to the minimal quality control filters described in the data appendix.

Table 2: Summary statistics: Characteristics at first and second resets

	First reset (loan age = 60)					
	N ('000s)	Median	Mean	SD	Min	Max
Unpaid balance at rate reset ('000s)	488	$ 202	$ 223	$ 117	$ 4	$ 1,559
Original modified mortgage rate	488	2.0 %	2.6 %	1.2 %	1.0 %	15.1 %
Rate after reset	488	3.0 %	3.5 %	1.0 %	1.5 %	15.1 %
Remaining term at reset (months)	488	276	312	82	60	576
Has principal forbearance	488	0.00	0.36	0.48	0.00	1.00
Amount of principal forbearance ('000s)	174	$ 48	$ 67	$ 65	$ 0	$ 1,378
Fannie Mae or Freddie Mac loan	488	1.00	0.53	0.50	0.00	1.00
Single family property	488	1.00	0.96	0.19	0.00	1.00
	Second reset (loan age = 72)					
	N ('000s)	Median	Mean	SD	Min	Max
Unpaid balance at rate reset ('000s)	270	199	218	113	4	1,085
Original modified mortgage rate	270	2.0 %	2.5 %	1.1 %	1.0 %	12.5 %
Rate after reset	270	4.0 %	4.3 %	0.6 %	2.0 %	12.5 %
Remaining term at reset (months)	270	276	308	81	48	564
Has principal forbearance	270	0.00	0.38	0.48	0.00	1.00
Amount of principal forbearance ('000s)	102	$ 52	$ 71	$ 68	$ 0	$ 790
Fannie Mae or Freddie Mac loan	270	1.00	0.56	0.5	0.0	1.0
Single family property	270	1.00	0.96	0.2	0.0	1.0

Note: This table shows summary borrower and mortgage characteristics at the time of rate reset for all loans that have remained in the HAMP program at least 60 months (for the first reset) and 72 months (for the second reset), subject to the minimal quality control filters described in the data appendix. Unpaid balance is calculated using the standard amortization schedule for fixed-rate mortgages.

Figure 2: Graphical Representation of Kink Design



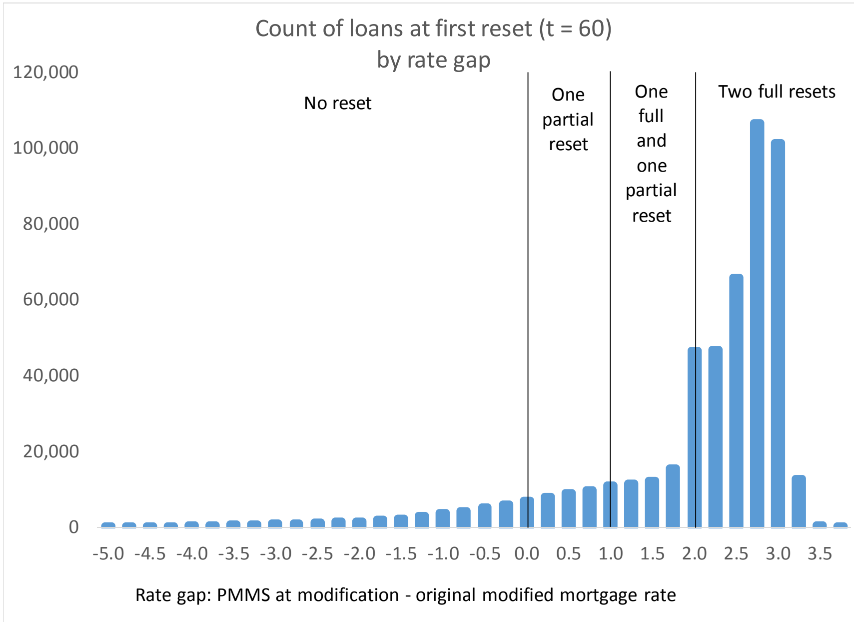
Note: The figure illustrates the slope of rate changes faced by borrowers at reset, by the gap between their modified mortgage rate and the market rate (PMMS rate) at the time of modification. Where the rate gap is negative (the modified mortgage rate exceeds the market rate, far left of the figure), borrowers' rates remain unchanged at 60 months. As the rate gap increases and becomes positive (moving from left to right) the rate adjustment at reset increases until the rate gap hits one percentage point. All loans with rate gaps higher than one percentage point (loans falling in the far right portion of the figure) receive a one percentage point rate increase 60 months after modification.

Table 3: Delinquency Transitions

Delinquency status at month t	Delinquency status at month t+1					
	Current	$30-60$ days DQ	60+ days DQ	Defaulted	Prepaid	Total
Current	19,741,381	661,101	0	0	85,138	20,487,620
	(96.4%)	(3.2%)	(0.0%)	(0.0%)	(0.4%)	(100%)
$30-60$ days DQ	497,099	878,797	272,809	0	6,112	1,654,817
	(30.0%)	(53.1%)	(16.5%)	(0.0%)	(0.4%)	(100%)
60+ days DQ	88,976	88,564	256,486	94,232	2,844	531,102
	(16.8%)	(16.7%)	(48.3%)	(17.7%)	(0.5%)	(100%)
Total	20,327,456	1,628,462	529,295	94,232	94,094	22,673,539
	(89.7%)	(7.2%)	(2.3%)	(0.4%)	(0.4%)	(100%)

Note: This table shows the average rate of transition between stages of delinquency for loans that have remained in the modification for at least 36 months."Current" loans are those that are fewer than 60 days past due (or fewer than 30 days "delinquent," where delinquency begins on the first day the second payment is missed). 60+ days DQ includes loans that are between 90 and 120 days past due. Loans are disqualified from the program when they are 120 days past due (or 90 days delinquent). Numbers in parentheses represent the probability a loan in the category identified by the line in month t will fall in the delinquency category identified by the column in month t+1; rows sum to 100 percent.

Figure 3: Distribution of Rate Gaps



This graph illustrates the distribution of loans among rate gap categories at the time of the first rate reset. The rate gap is measured as the percentage-point difference between the PMMS rate at the time of modification and the modified mortgage rate before the rate reset. Negative values reflect loans with modified mortgage rates greater than the PMMS rate at the time the mortgage was modified. These loans do not see their payments increased at the time of the reset.

Figure 4: Delinquency and Default at First and Second Resets (by rate category)

Note: The top two panels of this chart show the pattern of transitions into delinquency and default in the months around the first reset, which occurs after month 60. The spike in new delinquencies among borrowers with a full rate reset occurs in month 62, when borrowers who miss their first higher payment become overdue (left panel). A surge in defaults occurs two months later, as some newly delinquent borrowers fail to cure (right panel). The second row shows the second reset. The surge in new delinquencies occurs in month 74 and the surge in defaults appears in month 76. The bottom row shows the full history of transitions into new delinquency and default for each of the rate categories: loans affected by the first reset (orange, red, green, and grey), loans affected by both resets (red, green, and grey), and loans that are unaffected by either (blue). Bars indicate the volume of loans falling in each category.

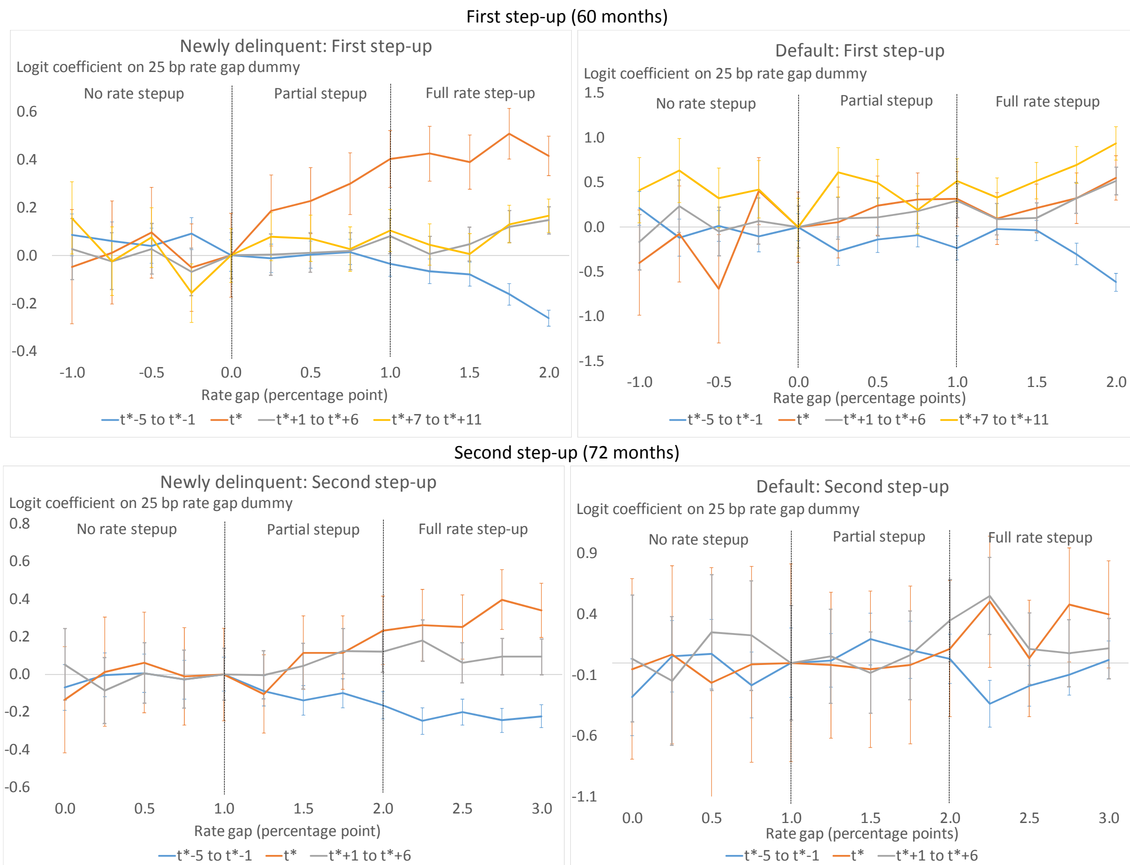
Table 4: Delinquency and Default (by rate gap categories)

Control variables	Calendar date dummies and all non-time controls				
Dependent variable	**New delinquency**				
Sample	All current loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset (loanage = 62)	-0.041	0.146***	0.372***	0.385***	0.434***
	(0.035)	(0.038)	(0.026)	(0.014)	(0.015)
After first reset (loanage [63, 68])	0.065***	0.099***	0.149***	0.115***	0.112***
	(0.020)	(0.022)	(0.017)	(0.009)	(0.010)
During second reset (loanage = 74)	0.150***	0.163***	0.218***	0.486***	0.461***
	(0.051)	(0.055)	(0.041)	(0.018)	(0.020)
After second reset (loanage[75,80]	0.046	0.036	0.109***	0.154***	0.132***
	(0.031)	(0.033)	(0.025)	(0.012)	(0.013)
Observations (loan-months)	7,730,909				
R^2	0.0128				

Dependent variable	**Default**				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset (loanage = 64)	-0.001	0.313***	0.346***	0.417***	0.356***
	(0.088)	(0.091)	(0.068)	(0.037)	(0.0437)
After first reset (loanage [65,70])	0.023	0.101*	0.183***	0.247***	0.212***
	(0.050)	(0.057)	(0.042)	(0.024)	(0.0278)
During second reset (loanage = 76)	0.002	0.026	-0.003	0.450***	0.465***
	(0.147)	(0.170)	(0.120)	(0.049)	(0.0557)
After second reset (loanage [77,82])	-0.017	0.196**	0.107	0.295***	0.333***
	(0.090)	(0.099)	(0.071)	(0.034)	(0.038)
Observations (loan-months)	6,931,367				
R^2	0.0114				

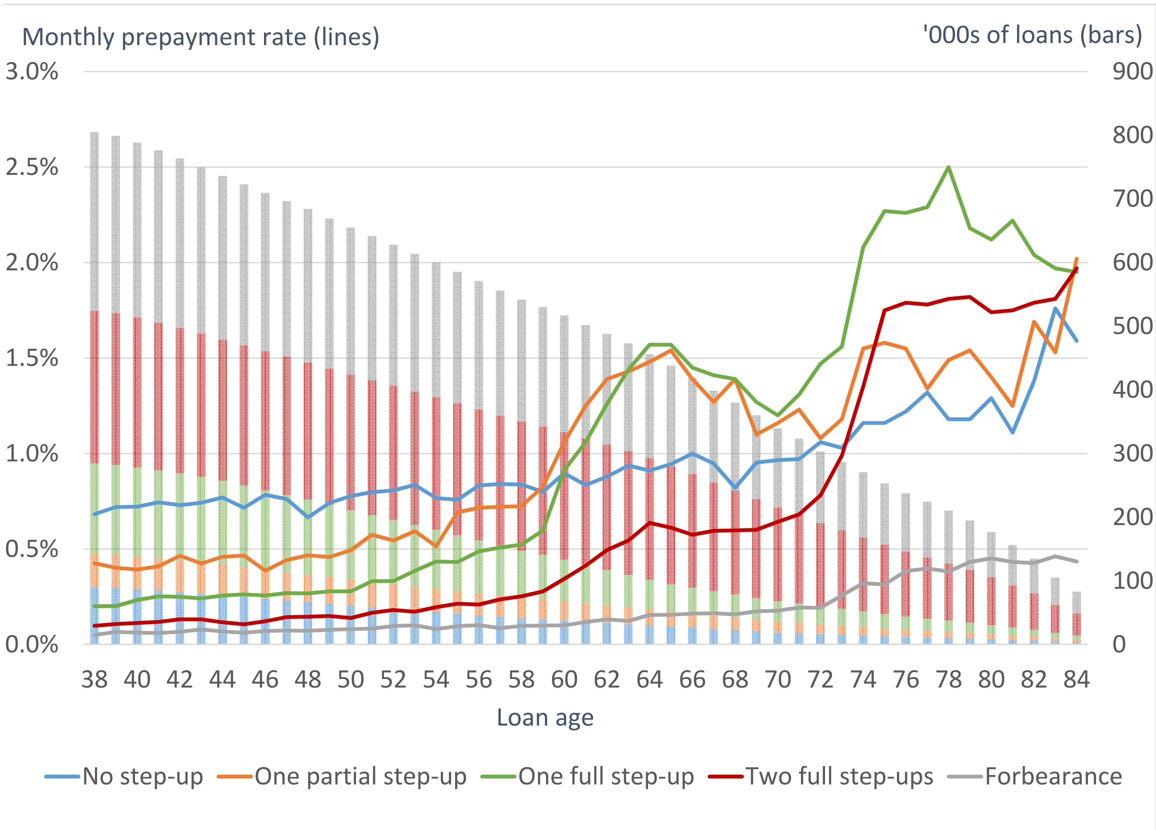
Note: This table shows the results of interest for two logistic regressions with the same basic structure. In the top panel, the dependent variable is transitions into delinquency, and the sample consists of loans where this value is defined: loans that are current in period t-1 and either current (taking on the value of 0) or delinquent (taking on the value of 1) in period t. The loans in the top panel are between 57 and 80 months postmodification. In the bottom panel, the dependent variable is default, which is an absorptive state. Because default among those with payment shocks occurs two months later than delinquency, the sample in this panel is shifted back by two months, and consists of loans between 59 and 82 months postmodification. Each regression consists of interactions between five time-indicator variables and five rate categories. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. Both regressions include calendar date dummies and controls for observable loan and borrower characteristics, including outstanding unpaid balance, credit score at modification, remaining term, whether the loan is a GSE loan, whether the property is a single-family or multifamily unit, the borrower's loan-to-value ratio, and the borrower's income at modification.

Figure 5: Kink Graphs



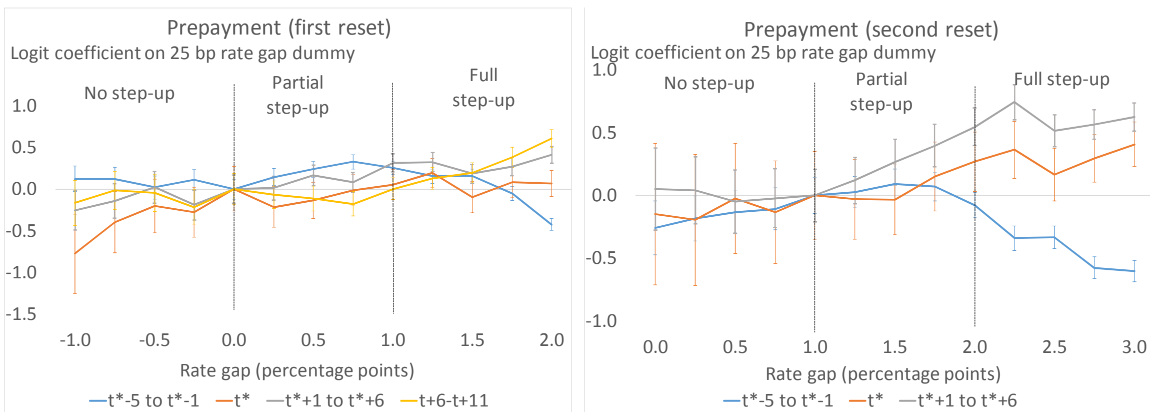
These panels illustrate the shape of the response to the rate step-up in 25 bps rate-gap bins for broad time intervals. In the panels on the left, transition to delinquency is the dependent variable, and in the panels on the right, default is the dependent variable. The top panels show behavior around the first step up (the sample includes months 57 through 73) and the bottom panels show behavior around the second step up (the sample includes months 69 through 80). Each panel plots the results from a logistic regression of the dependent variable on broad time intervals interacted with dummies reflecting 25 basis-point rate gap intervals. The broad time intervals are t*-5 to t*-1, t*, t*+1 to t*+6, t*+7 to t*+11 (first reset only), where t* indicates the month where the response is expected to occur (e.g., month 64 for new delinquency during the first reset). The coefficient for each broad time interval is set to 0 at the highest rate gap for which no payment change occurs for each rate reset (rate gap = 0 for the first reset and rate gap = 1 for the second).

Figure 6: Prepayment at First and Second Resets (by rate category)



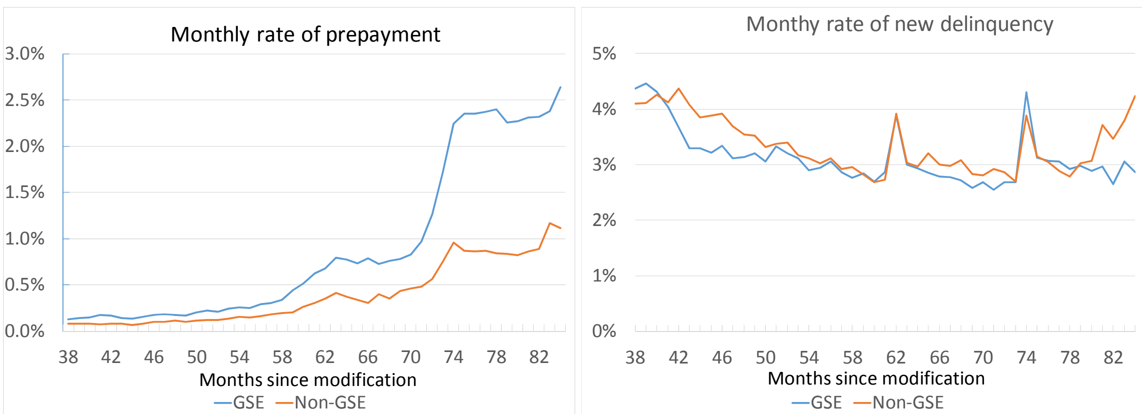
Note: This panel shows the pattern of transitions into prepayment in the months surrounding the first and second resets, which occurs after month 60 and 72, respectively. The pattern is broken out by rate category: loans affected by the first reset (orange, red, green, and grey), loans affected by both resets (red, green, and grey), and loans that are unaffected by either (blue). Bars indicate the volume of loans falling in each category.

Figure 7: Prepayment Kink Analysis



These panels illustrate the shape of the prepayment response to the rate step-up in 25 bps rate-gap bins for broad time intervals. The panel on the left shows the behavior around the first rate reset (the sample includes months 57 through 73) and the second shows behavior around the second reset (the sample includes months 69 through 80). The broad time intervals are t*-5 to t*-1, t*, t*+1 to t*+6, t*+7 to t*+11 (first reset only), where t* indicates the month where the response is expected to occur (e.g., month 64 for prepayment during the first reset). The coefficient for each broad time interval is set to 0 at the highest rate gap for which no payment change occurs for each rate reset (rate gap = 0 for the first reset and rate gap = 1 for the second).

Figure 8: Prepayment by Investor Type, for Loans with Two Full Step-ups



Note: This figure shows average prepayment rates (left panel) and new delinquency rates (right panel), by loan age, separately for GSE and non-GSE loans. Only loans with at least two full step-ups are included in the graphed sample. GSE loans are better able to prepay throughout the program, and the difference between the prepayment rates of GSE and non-GSE prepayment rates expands (though remains proportional) as rates become less subsidized for borrowers facing resets. The new delinquency rates for the two groups remains roughly equal, suggesting that the relative quality of the pools remains constant despite higher sample attrition among the GSE loans. Data for loan ages after the second reset is sparse and the divergence in the two populations after the second reset is not statistically meaningful.

Table 5: Prepayment (by rate gap category)

Dependent variable Sample	Prepayment All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset (loanage = 64)	0.062	0.283***	0.511***	0.346***	0.068
	(0.063)	(0.058)	(0.042)	(0.035)	(0.076)
After first reset (loanage [65,70])	0.037	0.234***	0.520***	0.435***	0.319***
	(0.037)	(0.035)	(0.026)	(0.022)	(0.042)
During second reset (loanage = 76)	0.070	0.204**	0.378***	0.647***	0.276***
	(0.088)	(0.079)	(0.050)	(0.027)	(0.064)
After second reset (loanage [77,82])	0.058	0.040	0.314***	0.603***	0.452***
	(0.051)	(0.049)	(0.031)	(0.018)	(0.036)
Observations (loan-months)	8,479,955				
R^2	0.0792				

Note: This table shows the results of interest for a logistic regression where the dependent variable is prepayment. The loans in the sample are between 57 and 80 months postmodification. The regression consists of interactions between five time-indicator variables and five rate categories. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. The regression includes calendar date dummies and controls for observable loan and borrower characteristics, including outstanding unpaid balance, credit score at modification, remaining term, whether the loan is a GSE loan, whether the property is a single-family or multifamily unit, the borrower's loan-to-value ratio, and the borrower's income at modification.

Table 6: GSE Interaction with Prepayment

Dependent variable	**Prepayment**				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.030	0.278**	0.340***	0.249***	-0.025
	(0.086)	(0.112)	(0.087)	(0.070)	(0.107)
After first reset	-0.145***	0.073	0.265***	0.157***	0.024
	(0.053)	(0.072)	(0.055)	(0.046)	(0.062)
During second reset	-0.014	0.165	0.292***	0.436***	0.125
	(0.124)	(0.150)	(0.103)	(0.058)	(0.100)
After second reset	-0.288***	-0.147	0.057	0.155***	0.067
	(0.077)	(0.096)	(0.067)	(0.041)	(0.061)
GSE x during first reset	-0.041	-0.139	0.073	-0.009	-0.009
	(0.126)	(0.131)	(0.099)	(0.080)	(0.152)
GSE x after first reset	-0.107	-0.095	0.021	0.068	0.155*
	(0.073)	(0.080)	(0.060)	(0.049)	(0.083)
GSE x during second reset	-0.060	-0.105	-0.038	0.124*	0.075
	(0.176)	(0.177)	(0.118)	(0.065)	(0.130)
GSE x after second reset	0.209**	-0.070	0.027	0.265***	0.261***
	(0.102)	(0.110)	(0.073)	(0.042)	(0.074)
Observations (loan-months)	8,479,955				
R^2	0.0802				

Note: This table shows the results of interest for a logistic regression where the dependent variable is prepayment. The loans in the sample are between 57 and 80 months postmodification. The regression consists of interactions between five time-indicator variables and five rate categories, for both GSE and non-GSE loans. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. The regression includes calendar date dummies and controls for observable loan and borrower characteristics, including outstanding unpaid balance, credit score at modification, remaining term, whether the property is a single-family or multifamily unit, the borrower's loan-to-value ratio, and the borrower's income at modification.

Table 7: Cost Comparison: Rate Reduction vs. Principal Forgiveness

Discount rate	4%
Rate reduction	1%
Principal forgiveness	28%

Year	Default rate	Prepayment rate	Share remaining	Present value of rate reduction	Present value of principal forgiveness
0	14.6%	0.4%	100.0%	1.0%	0.1%
1	10.8%	1.0%	85.0%	0.8%	0.2%
2	7.6%	1.8%	75.0%	0.7%	0.3%
3	5.5%	2.5%	68.0%	0.6%	0.4%
4	4.4%	3.8%	62.6%	0.5%	0.6%
5	3.8%	7.4%	57.5%	0.5%	1.0%
6	2.4%	9.5%	51.0%	0.4%	1.1%
7	2.4%	9.5%	44.9%	0.3%	0.9%
8	2.4%	9.5%	39.6%	0.3%	0.8%
9	2.4%	9.5%	34.9%	0.2%	0.7%
10	2.4%	9.5%	30.7%	0.2%	5.8%
Total				5.6%	11.9%

The table presents a simple calculation comparing the expected cost of two modifications that deliver approximately the same reduction in default probability: 28 percent principal forgiveness (with payment unchanged) and a one percentage point rate reduction (which reduces payments). The default and prepayment rates are derived from the HAMP data. The dicount rate is 4 percent. The present value of the rate reduction is calculated as the discounted value of 1% of the share of the unpaid balance remaining in the pool (100 percent in the first period). The present value cost of principal forgiveness is calculated as the principal forgiveness share (28%) times the expected value of prepayments in each period (since the payment is unchanged through this policy, by construction, losses are realized only when the loan prepays). The present value after 10 years is shown in bottom row of the table.

A Appendix

A.1 Data appendix

We restrict the sample to observations with a loan term of more than ten years at time of modification; loans with shorter terms will pay off in full prior to the reset periods of interest. Most analyses consider loans only after they have been in the program for at least 36 months. While we have data on modifications that became permanent from July 2009 (first cohort) to May 2015, we effectively consider only cohorts with modification dates on or before September 2012 (last cohort with 36 months of data).

We drop loans with conflicting or missing data across monthly files. Occasionally LPIs jump forward and then revert from month-to-month in the data files, and we correct these post-dated values; we believe they reflect data errors as LPI cannot move backward. The HAMP data records default separately from LPI date, so we throw out loans for which default data conflicts with LPI data (e.g., loans that are persistently more than 4 months delinquent or loans that advance through 5-, 6-, and then 7-months delinquency but are not recorded as defaulted; these loans are typically identified as defaulted eventually, but we have no way to know which data entry errors led to this problem). Roughly 2 percent of defaults are subject to this problem, though these defaults are not disproportionately clustered around our reset windows. We also eliminate a small number of loans with temporally impossible delinquency patterns. We encounter extreme values in the data, some of which likely reflect data entry errors rather than true mortgage characteristics. We exclude from the sample loans where the loan-to-value ratio at modification exceeds 400 percent and where the borrower's pre-modification debt to income ratio exceeds 150 percent.

A.2 Robustness tests

Table A1: Robustness test: Calendar date dummies, no borrower or loan characteristic controls

Dependent variable Sample	New delinquency All current loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.041	0.150***	0.374***	0.387***	0.433***
	(0.035)	(0.038)	(0.026)	(0.014)	(0.015)
After first reset	0.065***	0.104***	0.155***	0.117***	0.109***
	(0.020)	(0.022)	(0.017)	(0.009)	(0.010)
During second reset	0.152***	0.164***	0.222***	0.487***	0.461***
	(0.051)	(0.055)	(0.041)	(0.018)	(0.020)
After second reset	0.051	0.042	0.118***	0.161***	0.134***
	(0.031)	(0.033)	(0.025)	(0.012)	(0.013)
Observations (loan-months)	7,730,909				
R^2	0.0095				

Dependent variable. Sample	Default All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.005	0.315***	0.351***	0.415***	0.351***
	(0.088)	(0.091)	(0.068)	(0.037)	(0.0437)
After first reset	0.007	0.098*	0.184***	0.238***	0.197***
	(0.050)	(0.057)	(0.042)	(0.024)	(0.0278)
During second reset	0.001	0.025	-0.002	0.448***	0.455***
	(0.147)	(0.170)	(0.120)	(0.048)	(0.0557)
After second reset	-0.020	0.190*	0.106	0.286***	0.308***
	(0.090)	(0.099)	(0.071)	(0.034)	(0.038)
Observations (loan-months)	6,931,367				
R^2	0.00461				

Dependent variable Sample	Prepayment All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	0.068	0.284***	0.517***	0.363***	0.083
	(0.063)	(0.058)	(0.042)	(0.035)	(0.076)
After first reset	0.062*	0.239***	0.531***	0.466***	0.346***
	(0.037)	(0.035)	(0.026)	(0.022)	(0.042)
During second reset	0.077	0.206***	0.376***	0.649***	0.280***
	(0.088)	(0.079)	(0.050)	(0.027)	(0.064)
After second reset	0.073	0.056	0.316***	0.615***	0.488***
	(0.051)	(0.049)	(0.031)	(0.018)	(0.036)
Observations (loan-months)	8,479,955				
R^2	0.0532				

Note: This table shows the results of interest for a logistic regression where the dependent variables in the top, middle, and bottom panels are new delinquency, default, and prepayment, respectively. The loans in the sample are between 57 and 80 months postmodification. The regression consists of interactions between five time-indicator variables and five rate categories. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. The regression includes no additional controls.

Table A2: Robustness test: No controls

Dependent variable	**New delinquency**				
Sample	All current loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.061*	0.120***	0.373***	0.339***	0.404***
	(0.035)	(0.038)	(0.026)	(0.014)	(0.015
After first reset	0.022	0.045**	0.136***	0.042***	0.055***)
	(0.020)	(0.022)	(0.016)	(0.009)	(0.010
During second reset	0.109**	0.124**	0.173***	0.439***	0.411***)
	(0.051)	(0.054)	(0.041)	(0.018)	(0.020
After second reset	0.003	-0.010	0.063**	0.108***	0.081***)
	(0.031)	(0.033)	(0.025)	(0.012)	(0.013
Observations (loan-months)			7,730,917		)
R^2			0.0019		

Dependent variable	**Default**				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.083	0.221**	0.350***	0.295***	0.258***
	(0.087)	(0.091)	(0.067)	(0.036)	(0.0434)
After first reset	-0.097*	-0.027	0.144***	0.079***	0.0783***
	(0.050)	(0.057)	(0.042)	(0.023)	(0.0267)
During second reset	-0.082	-0.050	-0.083	0.376***	0.375***
	(0.147)	(0.170)	(0.120)	(0.048)	(0.0554)
After second reset	-0.245***	-0.044	-0.133*	0.030	0.0508
	(0.090)	(0.098)	(0.071)	(0.033)	(0.0369)
Observations (loan-months)			7,648,930		
R^2			0.00218		

Dependent variable	**Prepayment**				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	0.100	0.325***	0.540***	0.428***	0.129*
	(0.063)	(0.058)	(0.042)	(0.035)	(0.076)
After first reset	0.094**	0.285***	0.552***	0.532***	0.391***
	(0.037)	(0.035)	(0.026)	(0.021)	(0.041)
During second reset	0.122	0.251***	0.425***	0.708***	0.338***
	(0.088)	(0.079)	(0.050)	(0.027)	(0.064)
After second reset	0.171***	0.157***	0.423***	0.730***	0.604***
	(0.051)	(0.048)	(0.031)	(0.017)	(0.036)
Observations (loan-months)			8,480,356		
R^2			0.0511		

Note: This table shows the results of interest for a logistic regression where the dependent variables in the top, middle, and bottom panels are new delinquency, default, and prepayment, respectively. The loans in the sample are between 57 and 80 months postmodification. The regression consists of interactions between five time-indicator variables and five rate categories. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. The regression includes calendar date dummies and no additional controls.

Table A3: Robustness test: Calendar date dummies and cohort, borrower, and loan-level controls

Dependent variable	New delinquency				
Sample	All current loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.051	0.136***	0.361***	0.376***	0.424***
	(0.036)	(0.038)	(0.026)	(0.015)	(0.016)
After first reset	0.044**	0.079***	0.128***	0.095***	0.091***
	(0.022)	(0.024)	(0.019)	(0.013)	(0.014)
During second reset	0.140***	0.152***	0.208***	0.475***	0.451***
	(0.052)	(0.055)	(0.041)	(0.018)	(0.020)
After second reset	0.025	0.015	0.088***	0.133***	0.110***
	(0.032)	(0.035)	(0.027)	(0.015)	(0.016)
Observations (loan-months)	7,730,909				
R^2	0.0128				

Dependent variable	Default				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.037	0.277***	0.309***	0.382***	0.321***
	0.088)	(0.092)	(0.069)	(0.039)	(0.0452)
After first reset	-0.052	0.027	0.108**	0.173***	0.138***
	0.056)	(0.062)	(0.049)	(0.034)	(0.0372)
During second reset	-0.036	-0.013	-0.041	0.413***	0.427***
	0.148)	(0.170)	(0.121)	(0.050)	(0.057)
After second reset	-0.090	0.123	0.035	0.223***	0.261***
	0.093)	(0.102)	(0.075)	(0.041)	(0.045)
Observations (loan-months)	6,931,367				
R^2	0.0114				

Dependent variable	Prepayment				
Sample	All loans				
	No rate stepup	Partial rate stepup	One full stepup + partial stepup	Two full rate stepups	Forbearance
During first reset	-0.049	0.174***	0.396***	0.241***	-0.040
	0.064)	(0.058)	(0.043)	(0.036)	(0.077)
After first reset	-0.197***	0.001	0.281***	0.207***	0.086*
	0.041)	(0.040)	(0.032)	(0.028)	(0.045)
During second reset	-0.046	0.089	0.263***	0.532***	0.162**
	0.089)	(0.080)	(0.051)	(0.028)	(0.065)
After second reset	-0.178***	-0.196***	0.080**	0.367***	0.214***
	0.054)	(0.052)	(0.036)	(0.025)	(0.041)
Observations (loan-months)	8,479,955				
R^2	0.0794				

Note: This table shows the results of interest for a logistic regression where the dependent variable is prepayment. The loans in the sample are between 57 and 80 months postmodification. The regression consists of interactions between five time-indicator variables and five rate categories, for both GSE and non-GSE loans. The time-indicator variables are: during first reset, after first reset, before second reset (output not shown), during second reset, after second reset. The period before the first reset (months 57 through 61 for the top regression) is the omitted category. The regression includes calendar date dummies and controls for observable loan and borrower characteristics, including outstanding unpaid balance, credit score at modification, remaining term, whether the property is a single-family or multifamily unit, the borrower's loan-to-value ratio, and the borrower's income at modification. In addition to the controls included in our baseline regression, this specification includes cohort controls.