

Mortgage Lock-In, Mobility, and Labor Reallocation*

Julia Fonseca[†]

Lu Liu[‡]

March 2023

Abstract

We study the impact of rising mortgage rates on mobility and labor reallocation. Using individual-level credit record data and variation in the timing of mortgage origination, we show that a 1 p.p. decline in mortgage rate deltas (Δr), measured as the difference between the mortgage rate locked in at purchase and the current market rate, reduces moving rates by 0.68 p.p, or 9%. This effect is economically meaningful and implies that projected rate increases until 2033 will reduce moving by 25%. Moreover, we show that this relationship is nonlinear: once Δr is high enough, households' alternative of refinancing without moving becomes attractive enough that moving probabilities no longer depend on Δr . Lastly, we find that mortgage lock-in attenuates household responsiveness to shocks to employment opportunities, measured as MSA-level wage growth and instrumented with a shift-share instrument. The responsiveness of moving rates to wage growth is half as large for households who are more locked in (below-median Δr) than for those who are less locked in. We provide causal estimates of mortgage lock-in effects, highlighting unintended consequences of monetary tightening with long-term fixed-rate mortgages on mobility and labor markets.

Keywords: Mortgages, housing lock-in, mobility, labor reallocation, monetary tightening

JEL Codes: G21, G51, J62, R30, E58

*We thank John Campbell, Itamar Drechsler, Sasha Indarte, Greg Kaplan, Ben Keys, Adair Morse, David Musto, Nick Roussanov and Heidi Thyssen for helpful comments and discussions. Fonseca thanks Jialan Wang for help in creating the Gies Consumer and Small Business Credit Panel and the Gies College of Business for generously supporting this dataset. Peter Han and Yizhong Zhang provided excellent research assistance.

[†]Gies College of Business, University of Illinois Urbana-Champaign. Email: juliaf@illinois.edu

[‡]The Wharton School, University of Pennsylvania. Email: lliu1@wharton.upenn.edu

1 Introduction

Mortgage loans in the United States allow borrowers to lock in interest rates for up to 30 years. After broadly declining for decades and hitting record lows at the end of 2020, mortgage rates rose sharply in 2022 (Figure 1) and are projected to remain at higher levels. For households who have locked in low mortgage rates, these rate increases add an implicit financial cost to the cost of moving, as moving requires prepayment of the current mortgage and remortgaging at significantly higher mortgage rates. For instance, a 1 percentage point (p.p.) rise in rates increases the present value of future mortgage payments for the median borrower by around 27,000 USD, and annual payments by around 1,900 USD.¹

This implicit financial cost might have unintended consequences for household mobility and labor reallocation. A widely-cited concern is that this financial cost may “lock in” households, reducing housing market transactions and labor mobility (Ferreira et al., 2010).² On the other hand, if this financial cost is small relative to the benefit of moving, the real effects on mobility and labor reallocation may be relatively muted. In this paper, we provide causal evidence of the effect of mortgage lock-in on labor mobility. We do so by developing a simple theoretical framework relating mortgage rates to households’ moving behavior and using it to derive testable implications. We then take these predictions to the data using individual-level credit record data and exploiting plausibly exogenous variation in the timing of mortgage origination.

In our theoretical framework, we define the difference between the previously locked-in mortgage rate and current prevailing mortgage rate as the “mortgage rate delta” (Δr). A positive delta implies that there is a financial gain from remortgaging, while a negative delta implies a financial cost because the current mortgage rate is higher than the rate that was previously locked in. Households make a choice between three options: staying put (not refinancing or moving); refinancing; or moving and remortgaging at the current rate.³ The net benefit of remortgaging depends on the mortgage rate delta and loan balance, which determine the

¹This calculation assumes a remaining term of 20 years, an initial loan balance of 260,000 USD, a discount factor of 0.96, and a mortgage rate change from 4.5% (matching the median monthly mortgage payment of around 1,300 USD) to 5.5%. This ignores the option value of reducing payments again once interest rates decrease, which would lower the expected NPV.

²For discussions of this concern in the media, see, for instance, [Wall Street Journal, September 22, 2022](#), [Financial Times, January 12, 2023](#).

³We refer to the process of obtaining a new mortgage priced at current mortgage rates more generally as remortgaging, while we refer to prepayment and remortgaging of the existing loan more specifically as refinancing.

change in mortgage payments when remortgaging, and on a fixed cost of remortgaging. The net benefit of moving (ignoring the cost of remortgaging) depends on a moving shock and a fixed cost of moving.

Mortgage lock-in occurs when the benefit of remortgaging net of the remortgaging cost is negative, leading some households to stay put even though the net benefit of moving is positive. As a result, we predict an asymmetric relationship between moving and Δr . As long as the benefit of refinancing is smaller than the cost, an increase in Δr alleviates mortgage lock-in. Because it is costly to remortgage, lock-in can occur when mortgage rate deltas are positive, i.e. when current mortgage rates are lower than locked-in rates.⁴ Once the benefit of refinancing is greater than the cost, households' refinancing option becomes attractive and provides an outside option to capture the benefit from remortgaging without the need to move. From that point onward, the relationship between Δr and moving rates flattens, as moving only depends on fundamental moving shocks and the moving cost. Thus, our framework predicts a kink in the relationship between moving rates and Δr . Lastly, we predict that Δr attenuates household responsiveness to a given moving shock, such as an increase in wage income that can be obtained by moving. In other words, some households do not pursue higher-paid employment opportunities due to the financial cost imposed by mortgage lock-in.

To test these predictions, we employ a novel consumer credit panel dataset, the Gies Consumer and small business Credit Panel (GCCP), which allows us to measure locked-in mortgage rates and moving for millions of borrowers from 2010 to 2018.⁵ We measure households' mortgage rate deltas as the difference between the mortgage rate that the household locked in at the time of mortgage origination and the current mortgage rate. Our main empirical challenge is that a simple OLS regression of moving rates on household-specific mortgage rate deltas may be biased if, for instance, households choose to reduce their mortgage rate by buying points when they are less likely to move (Stanton and Wallace, 1998). To overcome this challenge, we use an instrumental variables (IV) research design and instrument household-specific mortgage rate deltas with the aggregate mortgage rate delta determined by current mortgage rates and average mortgage rates in the month of mortgage origination. We thus isolate the variation in mortgage rate deltas coming solely from the timing of mortgage origination, and control for zip code fixed effects, county \times year fixed effects, mortgage

⁴This is in contrast to predictions of negative home equity lock-in where lock-in kicks in below home equity levels of zero.

⁵The next revision of the paper will use data available up to and including 2022.

and borrower controls, and a zip code house price index.

Our paper has three main sets of findings. First, our two-stage least squares estimate implies that a 1 p.p. increase in mortgage rate deltas leads to a 0.68 p.p. increase in moving rates, or 9% of the sample mean. This estimate suggests that the recent rise in mortgage rates will have substantial effects on future moving rates. In a back-of-the-envelope calculation, we use forward rates to project mortgage rates until 2033 and find that future mortgage rate rises should lead to a 1.9 p.p. decline in moving by 2033, or 25% of the sample mean.

Second, we show that the effect of Δr is indeed nonlinear. Our framework predicts that, once Δr is higher than the cost of refinancing, households' alternative to refinance without moving becomes attractive enough that moving probabilities become unrelated to Δr . We provide graphical evidence consistent with these predictions through a binned scatter plot of the relationship between moving rates and aggregate mortgage rate deltas, showing that the relationship between Δr and moving flattens at a level of Δr of around 1.8 p.p., broadly consistent with recent estimates (Andersen et al., 2020; Fisher et al., 2021) and survey measures (Keys et al., 2016) of refinancing costs, given a median loan balance of around 152,000 USD.

Third, consistent with our theoretical prediction, we find that low Δr attenuates household responsiveness to moving shocks such as higher-wage employment opportunities. We measure the availability of higher-wage employment opportunities using MSA-level wage growth, which we instrument using a shift-share instrument. We find that the slope of the relationship between local wage growth and moving rates is higher for borrowers with above-median aggregate Δr than for those with below-median aggregate Δr . This implies that borrowers who have locked in lower mortgage rates (and thus have lower mortgage rate deltas) move at lower rates in response to higher local wages. We estimate that, for borrowers with low aggregate mortgage delta, a one standard deviation increase in MSA-level wage growth increases within-MSA moving by 0.51 p.p., which is not significant at 5%. On the other hand, within-MSA moving increases by 1.21 p.p. for borrowers with high mortgage delta, and that estimate is significant at 1%. This suggests that mortgage lock-in modulates the geographical allocation of labor and leads to a mismatch between workers and jobs, as some households forego higher-paid employment opportunities due to the financial cost imposed by mortgage lock-in.

The two key identifying assumptions behind our IV research design are that (1) aggregate mortgage deltas are associated with household-specific mortgage deltas and (2) aggregate mortgage deltas only affect moving rates through their effect on household-specific mortgage

deltas. The latter would be violated if, conditional on controls, the timing of mortgage origination is related to moving rates through channels other than its effect on the aggregate mortgage delta. For instance, one potential concern is that financially sophisticated households are more likely to time their mortgage origination and may move at different rates than unsophisticated households. While the exclusion restriction is untestable, we conduct a range of robustness checks that support a causal interpretation of our findings.

First, we directly address the issue of market timing by exploiting increasingly narrow sources of variation in aggregate mortgage deltas. We show that our results are qualitatively identical and quantitatively larger when we include origination year, origination half-year, or origination quarter-year fixed effects. In the most stringent of these specifications—with origination quarter-year fixed effects—variation in aggregate mortgage deltas comes from monthly variation in aggregate mortgage rates within the same quarter of mortgage origination. This specification compares individuals who had a mortgage originated in, for instance, January with those with a mortgage originated in February or March of that same year. We also control for the timing of mortgage refinancing by including fixed effects for the year in which the household last refinanced. Combining origination date and last refinancing fixed effects, we compare households with similar refinancing and mortgage origination behavior, further alleviating concerns that our results might be driven by market timing.

We provide further indirect evidence in support of a causal interpretation of our results by conducting an event study. Using our theoretical framework, we generate dynamic predictions about the relationship between moving rates and average 30-year fixed mortgage rates and test those predictions in an event-study setting. Specifically, our framework predicts that moving rates of borrowers with sufficiently high mortgage rate differentials should not respond to declining mortgage rates, but should start decreasing once mortgage rates increase. We document that this pattern holds in the data using the period of declining mortgage rates in 2010–2012 and the sharp mortgage rate increase of mid-2013. Finally, our results are also quantitatively similar when we measure the present value of future mortgage payments in dollars rather than focusing on mortgage rate differentials.

We provide quantitative estimates of mortgage lock-in effects and highlight unintended consequences of monetary tightening in the presence of long-term fixed-rate mortgages. Our findings suggest that mortgage lock-in is likely to substantially impact housing and labor markets going forward.

1.1 Related Literature

Our paper contributes to a broader literature of how housing markets affect household mobility (Ferreira et al., 2010, 2012). While earlier studies found mixed evidence of negative home equity lock-in on labor mobility (e.g. Chan, 2001; Schulhofer-Wohl, 2012; Coulson and Grieco, 2013), more recent work shows that negative home equity reduces mobility, labor supply, wages, and job search intensity (Bernstein, 2021; Bernstein and Struyven, 2021; Gopalan et al., 2021; Brown and Matsa, 2020). Negative effects on mobility have also been documented due to property tax lock-in, caused by caps on property tax growth for incumbent owners (Wasi and White, 2005). Another source of lock-in are down-payment constraints (Stein, 1995; Genesove and Mayer, 1997; Andersen et al., 2022), and behavioral effects such as loss aversion and reference dependence (Genesove and Mayer, 2001; Engelhardt, 2003; Anenberg, 2011; Andersen et al., 2022), with evidence of households raising list prices and spending a longer time on the market to avoid losses relative to their previous purchase price.

Existing work by Quigley (1987) and Ferreira et al. (2010) shows that mortgage lock-in reduces household mobility using Panel Study of Income Dynamics (PSID) and American Housing Survey (AHS) data, respectively, in a broadly declining interest rate environment. We build on these findings to make progress along a number of dimensions. Similar to more recent work on home equity constraints (Bernstein, 2021; Bernstein and Struyven, 2021; Gopalan et al., 2021), we employ micro-level household panel data and use an IV strategy to allow for a causal interpretation. The granularity of our data allows us to document asymmetric effects of mortgage rate deltas on moving rates consistent with a simple model of household moving and remortgaging. We further provide evidence that a reduction in mortgage rate differentials reduces households' moving rates in response to higher-wage employment opportunities. We hence provide direct evidence that mortgage rate lock-in reduces labor reallocation.⁶

Our findings highlight a seeming trade-off between insurance provision and allocative efficiency.⁷ Fixed-rate mortgages provide insurance against interest rate increases, but can cause prolonged periods of mortgage lock-in when rates rise, especially in the US where the close

⁶Our findings are consistent with other quasi-experimental settings where alleviating household liquidity constraints improves moving and labor market matching (He and le Maire, 2021), and somewhat in contrast to e.g. Demyanyk et al. (2017).

⁷These distortionary effects have been documented in studies on rent control, which can provide insurance against rent price increases, but reduce allocative efficiency of housing (Glaeser and Luttmer, 2003; Favilukis et al., 2023).

to 30-year average fixation length is a relative outlier in international comparison (Badarinza et al., 2016; Liu, 2022). Reduced mobility and a reduction in housing market turnover can lead to a greater mismatch between employees and jobs and between households and houses or locations. Understanding the unintended consequences of monetary tightening with fixed-rate mortgages should further help inform mortgage market design (Piskorski and Tchistyi, 2010; Campbell, 2012; Campbell et al., 2021; Guren et al., 2021; Liu, 2022). The paper raises the importance of alternative housing market policies such as mortgage assumability and portability, which provide a way to alleviate the distortionary effects of mortgage lock-in and are common in many other countries, but not widely available in the US (Quigley, 1987; Lea, 2010; Berg et al., 2018; Madeira, 2021).

Our work further relates to monetary policy pass-through and the role of the mortgage market (Scharfstein and Sunderam, 2016; Beraja et al., 2019; DeFusco and Mondragon, 2020; Di Maggio et al., 2020; Fuster et al., 2021; Agarwal et al., 2023), with an emphasis on the effects of monetary tightening, and the role of past mortgage rates (Berger et al., 2021; Eichenbaum et al., 2022). More broadly, our paper also relates to studies of the effect of monetary policy on the allocation of labor across occupations, firms, and sectors (e.g. Faia et al., 2021; Jasova et al., 2021; Guerrieri et al., 2021; Singh et al., 2022; Bergman et al., 2022). We complement these works by focusing on how interest rates affect mobility and the geographical allocation of labor through the mortgage lock-in channel.

The remainder of the paper is structured as follows. Section 2 outlines the conceptual framework using a simple model of household moving and refinancing. Section 3 introduces the data and empirical strategy. Section 4 presents the main results and section 5 provides additional results and robustness checks. Section 6 concludes.

2 Theoretical Framework

2.1 A Simple Model of Household Moving and Remortgaging

Household Problem. Households live for two periods and are endowed with a house and mortgage loan of size L . The mortgage interest rate r_1 is fixed for both periods but households have the option to prepay after period one and remortgage, to obtain interest rate r_2 in period two. Households maximize their lifetime utility, which is linear in consumption. For notational simplicity, there is no discounting. At the end of period one, households face stochastic interest rate and moving shocks and, upon realization of these shocks, make decision $\mathbb{D} \in \{S, R, M\}$, which affects outcomes in period two. Households choose between

three actions: staying put ($\mathbb{D} = S$); refinancing ($\mathbb{D} = R$); or moving ($\mathbb{D} = M$). A simplifying assumption is that households move into a similarly sized house, such that L stays the same, and there is no loan repayment in period two.⁸

Moving requires households to pay a moving cost κ^m , and to prepay the existing loan, and take out a new loan at rate r_2 , at cost κ^r . Refinancing requires households only to pay the cost to remortgage, κ^r .

Households earn income Y_t , pay mortgage payment M_t , and consume C_t in each period $t \in \{1, 2\}$. The mortgage payment in period one is $r_1 \cdot L$. The mortgage payment in period two is:

$$M_2 = \begin{cases} r_1 \cdot L, & \text{if } \mathbb{D} = S \\ r_2 \cdot L, & \text{if } \mathbb{D} \in \{R, M\}, \end{cases} \quad (1)$$

i.e. households are protected from interest rate changes in the second period, but they need to remortgage in order to obtain the mortgage rate r_2 . Mortgage rates in period two are stochastic and follow a random walk:

$$r_2 = r_1 + \epsilon, \text{ where } \epsilon \sim \text{i.i.d. } \mathcal{N}(0, \sigma_\epsilon), \quad (2)$$

In period two, households also face a stochastic moving opportunity in the form of a potential shock to income η that they can realize if they move, and the realization of the shock is known before decision \mathbb{D} needs to be made. The moving shock is i.i.d. normally distributed with mean 0 and standard deviation σ_η . Denote Y the initial income level. Households obtain $Y_1 = Y$ in period one. Income in period two is given by

$$Y_2 = \begin{cases} Y, & \text{if } \mathbb{D} \in \{S, R\} \\ Y \cdot (1 + \eta), & \text{if } \mathbb{D} = M, \text{ where } \eta \sim \text{i.i.d. } \mathcal{N}(0, \sigma_\eta). \end{cases} \quad (3)$$

⁸Given the short time frame of two periods, there is no option value of waiting for the refinancing and moving decisions, but one can generalize the meaning of refinancing and moving benefits to incorporate a notion of option value, e.g. using the framework by [Agarwal et al. \(2013\)](#). This framework would likely result in scaling of household optimality conditions but would preserve model predictions qualitatively.

Households solve the following optimization problem:

$$\max_{\mathbb{D}} U = C_1 + C_2 \quad \text{s.t. budget constraint } \Lambda \quad (4)$$

where

$$\Lambda = \begin{cases} C_1 + C_2 = 2Y - 2r_1L, & \text{if } \mathbb{D} = S \\ C_1 + C_2 = 2Y - (r_1 + r_2)L - \kappa^r, & \text{if } \mathbb{D} = R \\ C_1 + C_2 = (2 + \eta)Y - (r_1 + r_2)L - \kappa^r - \kappa^m, & \text{if } \mathbb{D} = M. \end{cases} \quad (5)$$

Household Decision Rules. Comparing total consumption (i.e., the sum of period one and period two consumption) when refinancing ($\mathbb{D} = R$) and subtracting total consumption when staying put ($\mathbb{D} = S$) gives

$$(r_1 - r_2)L - \kappa^r \equiv \Delta rL - \kappa^r, \quad (6)$$

i.e. the net benefit of refinancing can be represented as the mortgage rate delta (Δr) scaled by the loan balance, less the cost of refinancing. Using equation 2, equation 6 can be further simplified to $\epsilon L - \kappa^r$, which we will use further below.

Similarly, comparing the budget constraint when moving ($\mathbb{D} = M$) and subtracting the budget constraint when staying put ($\mathbb{D} = S$) gives

$$\eta Y + \Delta rL - \kappa^r - \kappa^m, \quad (7)$$

i.e. the net benefit of moving and remortgaging is the sum of the moving benefit (change in income if moving) and benefit from remortgaging, less the cost of remortgaging and moving.

We can define the following useful conditions: when

$$\Delta rL - \kappa^r \geq 0, \quad (8)$$

the household is a *potential refiner*, as the benefit of remortgaging is greater or equal to the cost of remortgaging; in other words, the option to refinance is in the money. In a world without moving concerns, household would find it optimal to refinance.

When

$$\eta Y - \kappa^m \geq 0, \quad (9)$$

the household is a *potential mover*, i.e. in a world where the household does not have a mortgage, the household would move since the income benefit from moving is greater or equal to the cost of moving.

Solving the household's optimization problem yields the following optimal household decision rules:

$\mathbb{D}^* = S$, iff:

$$\Delta rL - \kappa^r < 0 \quad \wedge \quad \eta Y + \Delta rL - \kappa^m - \kappa^r < 0, \quad (10)$$

$\mathbb{D}^* = R$, iff:

$$\Delta rL - \kappa^r \geq 0 \quad \wedge \quad \eta Y - \kappa^m < 0, \quad (11)$$

$\mathbb{D}^* = M$, iff:

$$\eta Y - \kappa^m \geq 0 \quad \wedge \quad \eta Y + \Delta rL - \kappa^m - \kappa^r \geq 0. \quad (12)$$

Household Groups. To build intuition for households' decision rules, we can divide households into five different (mutually exclusive, collectively exhaustive) groups, by splitting them by their potential mover and potential refinancer status.

Group 1 (Non-Marginal Stayers):

$$\Delta rL - \kappa^r < 0 \quad \wedge \quad \eta Y - \kappa^m < 0. \quad (13)$$

These households are neither potential movers nor potential refinancers, and clearly find it optimal to just stay put ($\mathbb{D}^* = S$).

Group 2 (Refinancers):

$$\Delta rL - \kappa^r \geq 0 \quad \wedge \quad \eta Y - \kappa^m < 0. \quad (14)$$

These households are potential refinancers, but not potential movers, meaning their net benefit of moving without remortgaging is negative. This implies that $\eta Y + \Delta rL - \kappa^m - \kappa^r < \Delta rL - \kappa^r$, such that households are better off exercising the refinancing option, without moving (thus $\mathbb{D}^* = R$).

Group 3 (Non-Marginal Movers):

$$\Delta rL - \kappa^r \geq 0 \quad \wedge \quad \eta Y - \kappa^m \geq 0. \quad (15)$$

These households are potential movers and potential refinancers, and clearly find it optimal

to move and remortgage ($\mathbb{D}^* = M$).

What about households who are potential movers, but not potential refinancers? Ideally, these households would like to port their current mortgage when moving or assume an existing mortgage, as they want to move, but not refinance. In the absence of such mortgage policies, their behavior depends on whether the net moving benefit or net refinancing cost dominates, i.e. whether $\eta Y + \Delta r L - \kappa^m - \kappa^r \gtrless 0$. We can split this group of households into the following two sub-groups.

Group 4 (Marginal Movers):

$$\Delta r L - \kappa^r < 0 \quad \wedge \quad \eta Y - \kappa^m \geq 0 \quad \wedge \quad \eta Y + \Delta r L - \kappa^m - \kappa^r \geq 0 \quad (16)$$

These households move marginally ($\mathbb{D}^* = M$), as the net benefit of moving and remortgaging is positive (last condition above), even though households pay a net penalty to remortgage, meaning the moving net benefit is large enough to prevent mortgage lock-in.

Group 5 (Marginal Stayers):

$$\Delta r L - \kappa^r < 0 \quad \wedge \quad \eta Y - \kappa^m \geq 0 \quad \wedge \quad \eta Y + \Delta r L - \kappa^m - \kappa^r < 0 \quad (17)$$

These households do not move ($\mathbb{D}^* = S$), as the net benefit of moving and remortgaging is negative. They are households with *mortgage lock-in*, in the sense that the financial cost of remortgaging marginally prevents them from moving despite the net benefit of moving without remortgaging being positive.

The decision rules of these household groups lead to the optimal decision rules to stay, refinance or move in equations 10 to 12.

Share of Stayers, Refinancers and Movers. Recall that households i are heterogeneous in moving shocks η_i , with cumulative distribution function $F(\eta_i)$ and density $f(\eta_i)$, and interest rate shocks ϵ_i , with cumulative distribution function $G(\epsilon_i)$ and density $g(\epsilon_i)$ (we were able to omit the i subscript until here). There is a unit mass of households. Denote λ^j , with $j \in \{S, R, M\}$, the share of stayers, refinancers and movers, respectively, such that $\sum_{j \in \{S, R, M\}} \lambda^j = 1$.

Using condition 9, we can define a cutoff value η^* above which a household would be considered a potential mover:

$$\eta^* = \frac{\kappa^m}{Y}. \quad (18)$$

Similarly, using condition 8, we can define a cutoff value ϵ^* above which a household would be considered a potential refiner:

$$\epsilon^* = \frac{\kappa^r}{L}. \quad (19)$$

Lastly, using condition 7, we can define a household-specific cut-off value η_i^{**} (for a given value of ϵ_i) above which the joint moving and remortgaging net benefit is weakly positive:

$$\eta_i^{**} = \frac{\kappa^m + \kappa^r - \epsilon_i L}{Y}. \quad (20)$$

As a result, we obtain the fraction of stayers ($\mathbb{D}^* = S$) following equation 10 as:

$$\lambda^S = \iint_{\{(\eta_i, \epsilon_i): \eta_i < \eta_i^{**} \cap \epsilon_i < \epsilon^*\}} f(\eta_i)g(\epsilon_i)d\eta_i d\epsilon_i, \quad (21)$$

and the fraction of households who are refiners ($\mathbb{D}^* = R$) as:

$$\lambda^R = \iint_{\{(\eta_i, \epsilon_i): \eta_i < \eta^* \cap \epsilon_i \geq \epsilon^*\}} f(\eta_i)g(\epsilon_i)d\eta_i d\epsilon_i. \quad (22)$$

To determine the fraction of movers ($\mathbb{D}^* = M$), we need to consider which of the two conditions in equation 12 is binding, i.e. whether η_* or η_i^{**} is greater:

$$\lambda^M = \iint_{\{(\eta_i, \epsilon_i): \eta_i \geq \max\{\eta^*, \eta_i^{**}\}\}} f(\eta_i)g(\epsilon_i)d\eta_i d\epsilon_i. \quad (23)$$

2.2 Model Predictions and Simulation

We use the model to derive predictions regarding the comparative statics of moving. First, we are interested in household moving decisions with respect to changes in their mortgage rate delta, $\Delta r_i = \epsilon_i$.

Proposition 1 *Moving is strictly increasing in Δr_i , up to a cutoff value of $\Delta r^* = \frac{\kappa^r}{L}$. Above the cutoff value Δr^* , moving is weakly increasing in Δr_i .*

Proof of Proposition 1: An increase in ϵ_i reduces the cutoff value of η_i^{**} (equation 20), which raises the fraction of movers λ^M as long as $\eta_i^{**} \geq \eta^*$. $\eta_i^{**} \geq \eta^*$ holds as long as $\kappa^r \geq \epsilon_i L$, meaning as long as $\Delta r_i \leq \frac{\kappa^r}{L} = \Delta r^*$. Once $\eta_i^{**} < \eta^*$ and η^* becomes binding for

moving, moving only depends on moving fundamentals, i.e. households move if $\eta_i \geq \frac{\kappa^m}{Y} = \eta^*$, regardless of further increases in Δr_i . \square

Observation on Refinancers. For households who are not potential movers ($\eta Y - \kappa^m < 0$), an increase in Δr increases the number of refinancers (group 2), as non-marginal stayers (group 1) turn into refinancers.

Next, we are interested in how moving responds to a given moving shock η , when the degree of lock-in as measured by $\Delta r_i = \epsilon_i$ differs.

Proposition 2 *For any given interval $[\eta, \bar{\eta}]$ ($\bar{\eta} > \eta$) and $[\underline{\epsilon}, \bar{\epsilon}]$ ($\bar{\epsilon} > \underline{\epsilon}$), $\lambda_{\{[\eta, \bar{\eta}], [\underline{\epsilon}, \bar{\epsilon}]\}}^M \leq \lambda_{\{[\eta, \bar{\eta}], [\underline{\epsilon}+x, \bar{\epsilon}+x]\}}^M$, where $x < +\infty$.*

To see this, consider the difference between households who are potential movers and who actually move. The share of potential movers (PM) is:

$$\lambda^{PM} = \iint_{\{(\eta_i, \epsilon_i): \eta_i \geq \eta^*\}} f(\eta_i)g(\epsilon_i)d\eta_i d\epsilon_i. \quad (24)$$

For any given interval $[\eta, \eta + x]$ where $x < +\infty$, $\lambda^{PM} \geq \lambda^M$, i.e. for any given interval of η , there is a weakly positive share of households who are locked in (i.e. for whom $\Delta r_i \leq \frac{\kappa^r}{L} = \Delta r^*$), such that the number of potential movers is weakly greater than the number of actual movers. We also know that the share of households who are locked in is weakly decreasing in Δr_i , such that the share of movers is weakly increasing in Δr_i .

This yields the following predictions.

Prediction 1: Non-Linear Relationship between Moving and Δr_i . *The relationship between moving and Δr_i is nonlinear: moving is increasing in Δr_i for marginal households for whom an increase in $\Delta r_i L - \kappa^r$ relaxes the moving and remortgaging constraint. It is flat for households for whom $\Delta r_i L \geq \kappa^r$.*

Prediction 2: Non-Linearity at $\Delta r_i > 0$. *With a strictly positive cost of refinancing $\kappa^r > 0$, the increasing relationship between Δr_i and moving flattens out at $\Delta r_i > 0$.*

The moving conditions suggest that moving is only beneficial if the net benefit of moving without remortgaging ($\eta_i Y - \kappa^m$) is positive. While $\Delta r_i L - \kappa^r < 0$, households pay a net penalty to remortgage. However, as soon as $\Delta r_i L - \kappa^r = 0$, households have the outside option to refinance to capture the financial benefit of lower interest rates (meaning higher mortgage rate deltas). That means that the probability of moving is increasing in $\Delta r_i L$

and hence Δr_i up to a point. Once $\Delta r_i \geq \frac{\kappa^r}{L} = \Delta r^*$, moving only depends on whether $\eta_i \geq \frac{\kappa^m}{Y} = \eta^*$. We should hence see a flattening in the relationship between Δr_i and moving for $\Delta r_i \geq \frac{\kappa^r}{L} > 0$, with costly refinancing ($\kappa^r > 0$).

Lastly, we expect a lower Δr_i to tighten the moving and remortgaging constraint for any given level of the moving shock η_i .

Prediction 3: Moving Rate w.r.t η_i and Δr_i . *A lower Δr_i (i.e. a greater degree of lock-in) weakly reduces the probability of moving for any given level of the moving shock η_i relative to a higher Δr_i .*

Model Simulation. In the empirical analysis, we exploit variation in Δr_i . To map the model to our empirical findings, we simulate predictions for household moving behavior based on the model. To capture dimensions of household heterogeneity in the data, we further assume heterogeneity in refinancing (k^r) and moving cost (k^m), and calibrate the income level and income shock (Y, σ_η), initial interest rate level and shock (r_1, σ_ϵ) to match stylized features of the data, with further detail provided in Appendix Section B.

Figure B5 in the appendix illustrates Predictions 1 and 2, while Figure B6 illustrates Prediction 3.⁹

3 Data and Empirical Strategy

3.1 Data

Our main dataset is the Gies Consumer and small business Credit Panel (GCCP), a novel panel dataset with credit record data on consumers and small businesses from Experian, one of the three major national credit reporting agencies in the United States. The GCCP consists of a one percent random sample of individuals with a credit report, which is linked to alternative credit records from Experian’s alternative credit bureau, Clarity Services, and to business credit records for individuals who own a business.¹⁰

We use data on mainstream consumer credit records between 2010 and 2018 and, given

⁹Figure B7 provides a simplified simulation with a greater range of positive wage shocks, which illustrates that the moving gap between high and low Δr_i households widens, but once the wage shock η_i is sufficiently large, the wage shock dominates and the share of locked-in households becomes very small, such that the moving gap narrows again.

¹⁰See Fonseca (2023) for a discussion of the link between mainstream and alternative credit records in the GCCP and Fonseca and Wang (2022) on the link between consumer and business credit records.

our focus on the effect of interest rates on mortgage rate lock-in, we restrict attention to consumers with positive mortgage balances. These records include detailed credit attributes and tradelines of each individual, including debt levels for all major forms of formal debt such as mortgages, student loans, and credit cards. The data also includes individuals’ credit scores and payment history, as well as bankruptcies and other public records. The GCCP also has information on mortgage interest rates from Experian’s Estimated Interest Rate Calculations (EIRC) enhancement, which provides interest rate estimates based on balance, term, and payment information. In addition, the dataset includes basic demographics such as zip code of residency, age, gender, marital status, and employment status. We define moving at time t as having a different zip code of residency at time $t + 1$ than at time t .¹¹

We supplement these data with county-level employment and wages from the Quarterly Census of Employment and Wages (QCEW), average 30-year fixed mortgage rates from the Federal Reserve Bank of St. Louis, and a house price index at the zip code level from the Federal Housing Finance Agency.

We report summary statistics for the final sample in Table 1. The average mortgage loan balance is 205,480 USD, the average remaining loan term is 21 years, and the average mortgage rate is 5.10%. The average Δr is 1.04%, with the distribution shown in Appendix Figure A1. Moreover, in Appendix Figure A2, we show average mortgage rates by quartile of the distribution, as well as average 30-year fixed mortgage rates.

3.2 Empirical Strategy

3.2.1 Baseline

Define household i ’s mortgage rate delta at time t , Δr_{it} , as the difference between the mortgage rate that the household locked in at purchase time $p(i)$, $r_{ip(i)}$, and the current mortgage rate, r_t :

$$\Delta r_{it} = r_{ip(i)} - r_t \tag{25}$$

Consider a model that relates household moving rates to mortgage rate deltas:

¹¹Note that, since we define moving as a forward-looking variable, our main dependent variable is not defined for the last year of available data, 2018. In future revisions, we will use data up to 2022.

$$\mathbb{I}[\text{moved}]_{it} = \alpha + \beta X_{it} + \gamma \Delta r_{it} + \varepsilon_{it}, \quad (26)$$

where i is a household, t is the year of observation, X_{it} is a vector of controls, and γ is the causal effect of mortgage rate lock-in on moving rates.

The key challenge that our empirical strategy seeks to overcome is that OLS estimates of Equation (26) will be biased if moving rates are correlated with unobserved determinants of mortgage rate deltas. One concern is that household choices and characteristics might be related to both their propensity to move and their mortgage rate. For instance, households may choose to purchase points in order to reduce their mortgage rate when they anticipate that they are unlikely to move.

We estimate the effect of mortgage rate lock-in on moving rates by instrumenting household-specific mortgage rate deltas with the aggregate mortgage rate delta determined by current (annual) mortgage rates and mortgage rates in the month of mortgage origination:

$$\text{Aggregate } \Delta r_{it} = r_{p(i)} - r_t, \quad (27)$$

where $r_{p(i)}$ is the average 30-year fixed mortgage rate in the month of household i 's home purchase and r_t is the average 30-year fixed mortgage rate at time t . We thus isolate the variation in mortgage rate lock-in coming solely from the timing of mortgage origination.

The first stage of this instrumental variables (IV) research design takes the form:

$$\Delta r_{it} = \delta_{z(i)} + \kappa_{c(i)t} + \gamma \text{Aggregate } \Delta r_{it} + \beta X_{it} + \varepsilon_{it}, \quad (28)$$

where $\delta_{z(i)}$ are zip code fixed effects, $\kappa_{c(i)t}$ are county \times year fixed effects, and X_{it} includes the log mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. We double cluster standard errors at the county and origination-month-year throughout.

We estimate the following second-stage equation using two-stage least squares:

$$\mathbb{I}[moved]_{it} = \delta_{z(i)} + \kappa_{c(i)t} + \gamma \widehat{\Delta r}_{it} + \beta X_{it} + \varepsilon_{it}, \quad (29)$$

where $\widehat{\Delta r}_{it}$ represents predicted mortgage rate deltas from estimating the first stage Equation (28).

The two key identifying assumptions are that (1) aggregate mortgage deltas are associated with household-specific mortgage deltas and (2) aggregate mortgage deltas only affect moving rates through their effect on household-specific mortgage deltas. The first assumption is empirically testable. Our first stage F-statistic exceeds 1,000, indicating a strong instrument.

The second assumption would be violated if, conditional on controls, the timing of mortgage origination is related to moving rates through channels other than its effect on the aggregate mortgage delta. For instance, one concern is that financially sophisticated households might be more likely to time their mortgage origination and may have different moving propensities than unsophisticated households. While the exclusion restriction is untestable, we conduct a range of robustness checks that support a causal interpretation of our findings.

First, we directly address the issue of market timing in Section 5.1 by exploiting increasingly narrow sources of variation in aggregate mortgage deltas. We show that our results are qualitatively identical and quantitatively larger when we include origination year, origination half-year, or origination quarter-year fixed effects. In the most stringent of these specifications—with origination quarter-year fixed effects—variation in aggregate mortgage deltas comes from monthly variation in aggregate mortgage rates within the same quarter of the house purchase. For instance, this specification compares individuals who had a mortgage originated in, say, January with those with a mortgage originated in February or March of that same year. Conditional on observables, it seems plausible that households cannot perfectly time their mortgage origination or predict the current level of mortgage rates within the span of a quarter.

Second, we also control for the timing of mortgage refinancing by including fixed effects for the year in which the household last refinanced. By combining origination date and last refinancing fixed effects, we compare households with similar refinancing and mortgage origination behavior, further alleviating concerns that our results might be driven by market timing.

Third, we provide indirect evidence in support of a causal interpretation of our results in

Section 5.2 by conducting an event study. Using our theoretical framework, we generate dynamic predictions about the relationship between moving rates and average 30-year fixed mortgage rates and test those predictions in an event-study setting. Specifically, our framework predicts that moving rates of borrowers with sufficiently high mortgage rate differentials should not respond to declining mortgage rates, but should start declining once mortgage rates increase. We document that this pattern holds in the data using the period of declining mortgage rates in 2010–2012 and the sharp mortgage rate increase of mid-2013.

3.2.2 Interaction With Employment Opportunities

Our theoretical framework suggests that mortgage rate lock-in also modulates households’ responsiveness to shocks to the monetary benefit of moving, such as shocks to employment opportunities. To generate shocks to employment opportunities, we instrument local wage growth using a shift-share IV that interacts past industry-level wage shares with aggregate industry-level wage growth.

Let $w_{\ell t}$ denote wage growth in area ℓ in year t . We can write:

$$w_{\ell t} = \sum_k z_{\ell k} g_{\ell k t},$$

$$g_{\ell k t} = g_{k t} + \tilde{g}_{\ell k t},$$

where $z_{\ell k}$ is the wage share of industry k in area ℓ , and $g_{\ell k t}$ is the wage growth of industry k in area ℓ in year t . The latter has two components: $g_{k t}$, the national wage growth of industry k , and $\tilde{g}_{\ell k t}$, the idiosyncratic component of wage growth for industry k in area ℓ in year t .

We instrument w_{ℓ} using a [Bartik \(1991\)](#) instrument:

$$b_{\ell t} = \sum_k z_{\ell k} g_{k t}.$$

The instrument exploits the fact that past local industry wage shares are pre-determined and that industry-level wage growth at the national level is plausibly exogenous to local-area wage growth.

For a household residing in county c , we define a local area ℓ as the MSA to which county c

belongs.¹² We construct industry wage shares $z_{\ell k}$ using data from 2007, three years prior to the start of our sample.

We estimate the following second-stage regression using two-stage least squares:

$$\mathbb{I}[\text{moved within MSA}]_{it} = \delta_{l(i)} + \kappa_t + \gamma \widehat{w}_{l(i)t} + \beta X_{it} + \varepsilon_{it}, \quad (30)$$

where $\widehat{w}_{l(i)t}$ represents fitted values from the first stage regression. In order to test whether the responsiveness of moving to local wage growth varies with the degree of mortgage rate lock-in, we estimate Equation (30) separately for borrowers with aggregate mortgage deltas above or below the sample median.

4 Main Results

We begin by estimating the effect of mortgage rate lock-in on moving rates. We then explore how moving responds to shocks to employment opportunities and how that relationship changes with the degree of mortgage lock-in.

4.1 Mortgage Rate Lock-In and Moving Rates

One of the key predictions of our framework is that mortgage rate deltas affect moving rates up to a point and, from that point onward, there is no relationship between the two variables (Prediction 1). Our framework also predicts that the kink point happens in the strictly positive region of Δr (Prediction 2). We provide graphical evidence consistent with these predictions through a binned scatter plot of the relationship between moving rates and aggregate mortgage rate deltas, which we report in Figure 2. As our framework predicts, there is a kink in the relationship between aggregate mortgage rate deltas and moving rates in the strictly positive region of aggregate deltas. The kink point is at a level of around 1.8 p.p., broadly consistent with recent estimates (Andersen et al., 2020; Fisher et al., 2021) and survey measures (Keys et al., 2016) of refinancing cost, given a median loan balance of around 152,000 USD.

Table 2 reports estimates of the effect of mortgage rate differentials on moving rates. We report the OLS estimate in column 1, which shows a positive correlation between household-

¹²An alternative would be to construct the instrument by leaving out the effect of county c , but this adjustment has been found to be unimportant in the classic Bartik setting (Goldsmith-Pinkham et al., 2020; Borusyak et al., 2022).

specific mortgage rate deltas and moving rates. In column 2, we report the first-stage estimate of Equation (28). We find that a 1 p.p. increase in the aggregate mortgage rate delta is associated with a 0.53 p.p. increase in the household-specific mortgage rate delta. The first stage F-statistic is above 1,000, suggesting that the aggregate mortgage rate delta is a strong instrument. Column 3 reports the two-stage least squares estimate of Equation (29). We estimate that a 1 p.p. increase in mortgage rate deltas leads to a 0.68 p.p. increase in moving rates (or 9% of the sample mean). This effect is higher than the OLS estimate of column 1, suggesting that the latter is downward biased.¹³

This estimate suggests that the recent rise in mortgage rates will have substantial effects on future moving rates. To quantify this effect, we project future mortgage rates using 10-year treasury rates 1-, 2-, and 10 years forward and assuming a constant mortgage rate spread between 30-year fixed-rate mortgage rates relative to 10-year treasury spot rates.¹⁴ Using projected rates, we then project the distribution of mortgage deltas using the 2018 distribution of locked-in mortgage rates and projected average mortgage rates, and plot the actual and projected time-series of average mortgage deltas in Figure 3.¹⁵ This back-of-the-envelope calculation suggests that, between 2020 and 2033, the average household-specific mortgage delta will decline by 2.8 p.p. Our estimates imply that this should lead to a 1.9 p.p. (0.68×2.8) decline in moving, or 25% of the sample mean.¹⁶

4.2 Interaction With Employment Opportunities

Next, we test the third prediction of our model: that mortgage rate deltas attenuate the sensitivity of moving rates to a moving shock. We explore how mortgage lock-in affects labor reallocation, by studying the response of moving rates to employment opportunities, and how this response varies with the degree of mortgage rate lock-in. We start by illustrating our main findings with a binned scatter plot of the relationship between within-MSA moving rates and predicted MSA-level wage growth in Figure 4. Consistent with our theoretical prediction, we find that the slope of this relationship is higher for borrowers with above-

¹³OLS estimates might be downward biased if, for example, financially sophisticated borrowers are able to lock in lower mortgage rates (leading to lower mortgage rate deltas) and are more likely to move than unsophisticated borrowers.

¹⁴We set the constant mortgage rate spread to 168 b.p. This equals the average spread between 30-year fixed-rate mortgage rates and 10-year treasury rates over the 1990–2022 period, which has remained broadly stable.

¹⁵Future revisions will use the 2022 mortgage rate distribution for this exercise.

¹⁶This is against the backdrop of an already declining secular trend in interstate migration ([Kaplan and Schulhofer-Wohl, 2017](#)).

median aggregate Δr than for those with below-median aggregate Δr . This implies that borrowers who have locked in lower mortgage rates (and thus have lower mortgage rate deltas) move at lower rates in response to higher local wages.

Table 3 reports estimates of Equation (30) separately for borrowers with below-median (columns 1–3) and above-median aggregate mortgage rate delta (columns 4–6). Columns 1 and 3 report OLS estimates and show no significant correlation between wage growth and moving for borrowers with high or low aggregate Δr . Columns 2 and 4 report first-stage estimates, with F-statistics of around 20 for both groups of borrowers. Columns 3 and 6 report estimates of Equation (30). For borrowers with low aggregate mortgage delta, a one standard deviation increase in wage growth increases within-MSA moving by 0.51 p.p., which is not significant at 5% (column 3). On the other hand, within-MSA moving increases by 1.21 p.p. for borrowers with high mortgage delta, and that estimate is significant at 1%.

In appendix Table A1, we show that these results are robust to excluding borrowers who are past the kink point of the relationship mortgage rate deltas and moving rates. Specifically, we re-run this analysis excluding from the high aggregate Δr group those borrowers with aggregate $\Delta r > 2\%$. If anything, we find that the difference between borrowers who are more vs. less locked in is even starker in this setting, with the responsiveness of moving rates to wage growth being three times as large for households with high aggregate Δr than for those who with low aggregate Δr (column 6 vs column 3).

These results imply that mortgage rate lock-in modulates borrowers’ response to employment opportunities, with borrowers who have locked in lower rates being less likely to move in response to rising wages. This suggests that mortgage lock-in meaningfully affects the geographical allocation of labor, with some households foregoing higher-paid employment opportunities due to the financial cost imposed by lock-in.

5 Additional Results and Robustness

5.1 Robustness to Market Timing

In this section, we address the concern that the timing of mortgage origination might affect moving rates through channels other than its effect on aggregate mortgage rate deltas. We do so by using increasingly narrow sources of variation in origination timing by including origination year, origination half-year, or origination quarter-year fixed effects in Equation (29). In the most stringent of these specifications, with origination quarter-year fixed effects, we compare individuals who had a mortgage origination in the same quarter of the same

year, exploiting only monthly variation in average 30-year fixed mortgage rates within a quarter. Conditional on observables, households plausibly cannot perfectly time their mortgage origination or predict the current level of mortgage rates within the span of a quarter.

We supplement this analysis by also controlling for refinancing behavior. We do so by including fixed effects for the year in which the household last refinanced. By combining origination date and last refinancing fixed effects, we compare households with similar refinancing and mortgage origination behavior, further alleviating concerns that our results might be driven by market timing.

Appendix Table A2 reports the results of this exercise, with column 1 reporting our baseline estimate. Across columns 2–5, we see that coefficients become larger as we control for origination timing and remain significant at 1%, suggesting that our baseline estimate is a conservative estimate of the effect of mortgage lock-in. One interpretation of the fact that coefficients become larger is that, to the extent that omitted variables influence both origination timing and moving rates, they introduce a downward bias in our estimates. This would be the case if, for instance, financially sophisticated households are more likely to time the market to lock in lower rates (leading to lower aggregate mortgage rate deltas) and are more likely to move than unsophisticated households.

5.2 Event Study

In order to further support a causal interpretation of our findings, we use our framework to derive dynamic predictions of how borrowers should respond to changing mortgage rates and test those predictions in an event-study setting. Specifically, our framework predicts that moving rates of borrowers with sufficiently high mortgage rate differentials—high enough that they are in the region of Δr where the relationship between Δr and moving is flat—should not respond to declining mortgage rates. That is because declining mortgage rates will further increase their mortgage rate deltas but, since those are already high enough that there is no longer a relationship between mortgage rate deltas and moving, there should be no moving response to declining rates.

On the other hand, once mortgage rates increase, mortgage rate deltas will decrease. This will push at least some borrowers into the region where there is a positive relationship between Δr and moving rates. Thus, our model predicts that, once mortgage rates increase, moving rates should decrease.

We test this prediction through an event study, exploiting the period of declining mortgage

rates in 2010–2012 and the sharp increase in rates in mid-2013 (Figure 1). We focus on the group of borrowers who were past the kink point in mortgage rate deltas, after which there is no relationship between moving rates and deltas, at the start of our sample period. To alleviate the endogeneity concerns discussed in Section 3, we use aggregate mortgage rate deltas—our instrumental variable—to select this group of consumers. Specifically, we restrict attention to consumers with aggregate Δr in 2010 greater or equal to 2 p.p., based on the graphical evidence of Figure 2 suggesting that this is approximately equal to the kink point.

We estimate the following event-study specification for this group of borrowers:

$$\mathbb{I}[\text{moved}]_{it} = \delta_z + \sum_{\tau=2010}^{2017} \gamma_\tau \mathbb{I}[t = \tau] + \beta X_{it} + \epsilon_{it}, \quad (31)$$

where δ_z are zip code fixed effects and the vector of controls X_{it} includes mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Our coefficients of interest are γ_τ , which show the evolution of moving rates across years.

We report coefficient estimates and 95% confidence intervals of Equation (31) in Appendix Figure A3, with 2013 as the omitted category. As our model predicts, we see no effect of declining mortgage rates between 2010 and 2012 in the moving rates of this group of borrowers. But after the rate rise of mid-2013, moving rates start declining and are statistically distinguishable from their 2013 baseline from 2015 to 2017.

5.3 Placebo Check: Refinancing and Employment Opportunities

One potential concern with the analysis of Section 4.2 is that MSA-level wage growth, instrumented by our shift-share instrumental variable, could function as a shock to variables other than moving rates, such as income levels. In this section, we provide further evidence that (instrumented) local wage growth is a moving shock.

To do that, we analyze a related household decision for which our model generates starkly different predictions: the decision to refinance. Our model predicts that refinancing rates should not increase with the monetary benefit of moving. In fact, since moving provides households with an alternative way to realize the same option value as refinancing, our framework predicts that the refinancing rates of households with high mortgage rate deltas decline with the magnitude of the wage growth shock. We illustrate this prediction in Appendix Figure B8, which plots simulated refinancing rates against the moving shock for

different levels of mortgage deltas.

We test this prediction by estimating Equation (30) with a dummy for refinancing as the dependent variable. As in Section 4.2, we start with a binned scatter plot of the relationship between refinancing rates and predicted MSA-level wage growth in Appendix Figure A4. As our model predicts, we see no relationship between refinancing rates and predicted wage growth for borrowers with below-median aggregate mortgage deltas and a negative relationship for those above the median.

We report two-stage least squares estimates of Equation (30) with refinancing as the dependent variable in Appendix Table A3. Consistent with the graphical evidence discussed above, we see that the two-stage least squares estimate of the effect of wage growth on refinancing is indistinguishable from zero for borrowers with low aggregate Δr (column 3) and negative and significant for those with high aggregate Δr (column 6). This evidence is consistent with our interpretation of instrumented MSA-level wage growth as a shock to within-MSA moving rates.

5.4 Robustness to Present Value of Mortgage Payments

Next, we show that our results are robust to focusing on changes in the present value of mortgage payments (ΔPVM) rather than on interest rate differentials. This measure, which we describe in detail in Appendix C, captures how changes in interest rates affect the present value of all mortgage payments and more closely maps to the dollar effect of varying mortgage rates.

We report estimates of Equation 29 with ΔPVM as the explanatory variable and find results that are consistent with our baseline findings, even in terms of magnitudes. We find that a \$1,000 increase in ΔPVM leads to a 0.04 p.p. increase in moving (column 4). This implies that a one standard deviation (\$45,897) increase in ΔPVM increases moving by 1.84 p.p. ($\$45,897 \times 0.04$). Similarly, our baseline estimate suggests that a one standard deviation (1.97 p.p.) increase in Δr leads to a 1.34 p.p. increase in moving.

5.5 Housing Market Liquidity

We expect mortgage lock-in to affect housing market turnover and hence liquidity in the market, as a decrease in the mortgage rate delta raises the financial cost of buying and selling a house with a mortgage. We test whether mortgage lock-in affects housing market liquidity using data from Realtor.com Economic Research, which provides aggregated information

on the number of active listings, average listing price, and median days on the market for all MLS-listed for-sale homes at monthly frequency.¹⁷ We create county-by-year averages of aggregate Δr and merge them with county-level annual averages of the Realtor.com database. We then regress variables relating to housing market liquidity on average aggregate Δr and include county and year fixed effects.

The regression results are presented in Table A5 in the Appendix. Controlling for county-level fixed effects, the log number of active listings (Column 1) and median days on the market (Column 5) are significantly increasing in aggregate Δr , while the log average listing price is decreasing (Column 3). Controlling for both county and year fixed effects, only the effect on log number of active listings remains statistically significant at the 10 percent level (Column 2), suggesting that a 1 p.p. decrease in aggregate Δr reduces the number of listings by around 5%. The effects are consistent with mortgage lock-in reducing housing market liquidity in the form of fewer houses being listed for sale. There is limited evidence that mortgage lock-in is mitigated by house prices fully adjusting and offsetting changes in mortgage rates.

6 Conclusion

This paper provides causal evidence of the effect of mortgage lock-in on moving and labor reallocation. We document three main findings. First, household moving rates decline as mortgage rate deltas decrease, or as households incur a greater financial cost when re-mortgaging. We estimate that a 1 p.p. decline in Δr leads to a 0.68 p.p. decrease in the probability of moving. This effect is economically meaningful and implies that projected rate increases until 2033 will reduce moving by 25%. Second, we show that this effect is nonlinear: once Δr is high enough so that the benefit of refinancing exceeds its cost, moving probabilities become unrelated to Δr . Third, we find that low Δr attenuates household responsiveness to moving shocks in the form of higher-wage employment opportunities. Using a shift-share instrument for MSA-level wage growth, we show that the responsiveness of within-MSA moving rates to wage growth is half as large for households who are more locked in (below-median aggregate Δr) than for those who are less locked in.

The findings highlight unintended consequences of monetary tightening with long-term fixed-rate mortgages, stressing the importance of alternative mortgage market policies. In most countries other than the US, mortgage contracts have some degree of assumability (allowing

¹⁷ Accessible via <https://www.realtor.com/research/data/>.

buyers to assume an existing mortgage on the same property), or portability (allowing borrowers to transfer their mortgage to a new property), such that households can move without having to prepay their current loan (Lea, 2010). In the US, “due-on-sale” clauses typically mandate that the balance of the mortgage loan is due and payable upon sale of the property (Quigley, 1987). For assumability to alleviate widespread distortionary effects, these policies would likely need to be available to a broad range of households as a household’s moving decision would depend on the mortgage associated with the next house being assumable, which the household likely has limited control over.¹⁸ And even with improvements in assumability and portability, our findings suggest that costs associated with assuming and porting could still generate mortgage lock-in effects.

The predominant mortgage contract in the US, the 30-year fixed-rate mortgage, provides households with insurance against interest rate increases, but can cause prolonged periods of mortgage lock-in when mortgage rates rise, emphasizing the role of mortgage market design (Campbell, 2012; Piskorski and Seru, 2018). This also highlights the unique mortgage composition of the US, with average interest rate fixation length in most other countries not exceeding 10 years (Badarinza et al., 2016; Liu, 2022). Moreover, a reduction in labor reallocation may affect productivity and inflationary pressures in the medium term, which is relevant for monetary policy and labor market policies.

¹⁸Mortgages insured by the FHA (and VA and USDA) are assumable, but only a subset of households is eligible for FHA-insured loans (see the FHA Handbook 4000.1).

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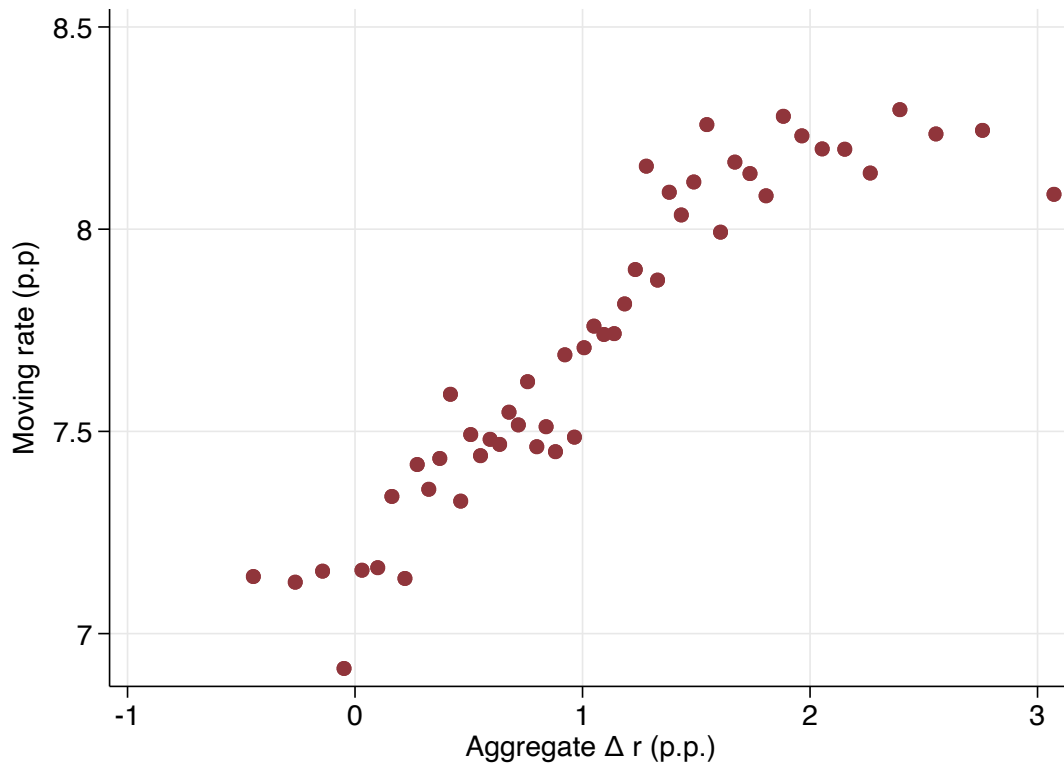
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Figure 1: Average 30-Year Fixed-Rate Mortgage Rates



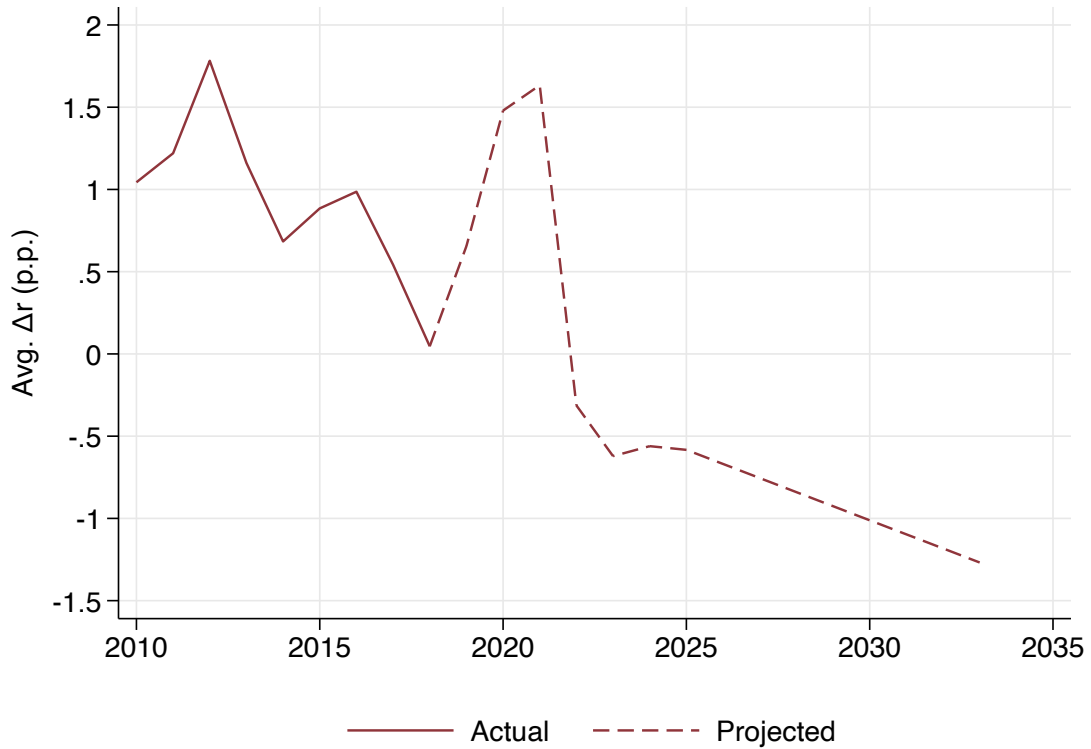
This figure shows average monthly 30-year fixed-rate mortgage rates from the Federal Reserve Bank of St. Louis.

Figure 2: Moving Rates and Aggregate Mortgage Rate Deltas



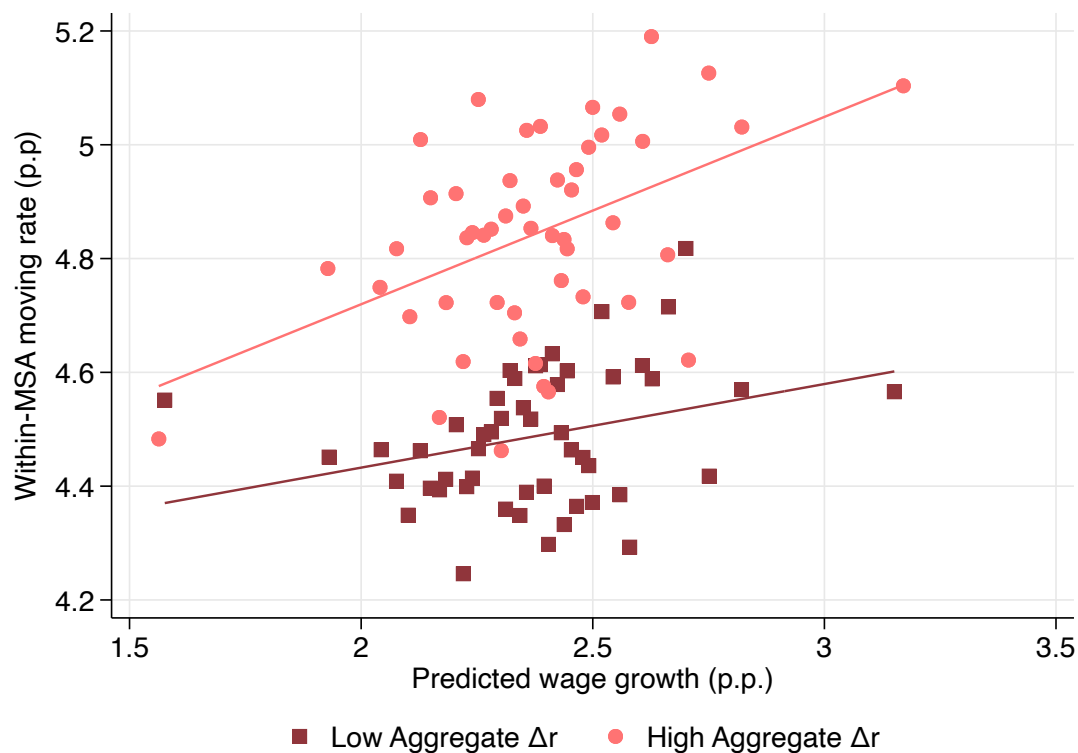
This figure shows a binned scatter plot of the relationship between individual-level moving rates and aggregate mortgage rate deltas. Variables are residualized from controls. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, a zip code house price index, and county \times year fixed effects.

Figure 3: Actual and Projected Average Mortgage Deltas



This figure shows actual and projected average mortgage differentials. We project the distribution of mortgage deltas using the 2018 mortgage rate distribution and aggregate 30-year fixed-rate mortgage rates (2018-2023) and projected mortgage rates (2024, 2025 and 2033). Projected mortgage rates are computed using 10-year treasury rates 1-, 2-, and 10-years forward, and assuming a constant mortgage rate spread between 30-year fixed rate mortgage rates relative to 10-year treasury spot rates.

Figure 4: Moving Rates and Wage Growth by Degree of Mortgage Rate Lock-In



This figure shows a binned scatter plot of the relationship between within-MSA moving rates and MSA-level wage growth. Variables are residualized from controls. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, a zip code house price index, and county and year fixed effects. High and low aggregate Δr refer to borrowers who are above or below the sample median aggregate Δr , respectively.

Table 1: Summary Statistics

	Mean	Med.	St. Dev.
Moving Rate (p.p)	7.47	0.00	26.28
Within-MSA Moving Rate (p.p)	4.53	0.00	20.80
Refinancing Rate (p.p)	6.12	0.00	23.96
Δr (p.p.)	1.04	0.77	1.97
Aggregate Δr (p.p.)	1.07	1.03	1.06
Mortgage Rate (p.p.)	5.10	4.86	2.00
Average 30-Year Fixed Mortgage Rate (p.p.)	4.06	3.99	0.35
Mortgage Balance (\$1,000)	205.48	151.85	213.97
Mortgage Payment (\$1,000)	1.66	1.30	3.13
Remaining Mortgage Term (years)	21.02	24.00	8.00
Vantage Score	745.93	770.00	85.21
Income (\$1,000)	69.87	61.00	33.26
Debt-to-Income Ratio (p.p)	23.57	22.00	12.05
Credit Card Utilization (p.p)	26.71	14.00	29.86
Female (p.p.)	48.62	0.00	49.98
Age (years)	49.52	49.00	12.94
Observations	3,924,788		

Notes: This table shows descriptive statistics for our sample between 2010 and 2017. Credit outcomes and demographics are from the Gies Consumer and small business Credit Panel. Average 30-year fixed mortgage rates are from the Federal Reserve Bank of St. Louis.

Table 2: The Effect of Mortgage Rate Deltas on Moving Rates

Dependent Variable:	$\mathbb{I}[Moved]$	Δr	$\mathbb{I}[Moved]$
	OLS	FS	IV
	(1)	(2)	(3)
Δr	0.18*** (0.02)		0.68*** (0.07)
Aggregate Δr		0.53*** (0.01)	
Zipcode FE	Yes	Yes	Yes
County \times Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
F-Stat		1,910.76	
Observations	3,924,792	3,924,792	3,924,792

Notes: Column 1 reports OLS estimates of Equation (29). Column 2 reports estimates of the first-stage Equation (28). Column 3 reports two-stage least squares estimates of Equation (29). Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: The Effect of Wage Growth on Moving Rates by Degree of Lock-In

Dependent Variable: Aggregate Δr Group:	$\mathbb{I}[Moved]$					
	Low			High		
	OLS (1)	FS (2)	IV (3)	OLS (4)	FS (5)	IV (6)
Wage Growth	0.01 (0.02)		0.51* (0.29)	0.01 (0.01)		1.20*** (0.43)
Wage Growth IV		0.64*** (0.14)			0.69*** (0.16)	
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
F-Stat		20.64			18.82	
P-value of (3) = (6)						0.13
Observations	1,898,764	1,898,764	1,898,764	1,895,616	1,895,616	1,895,616

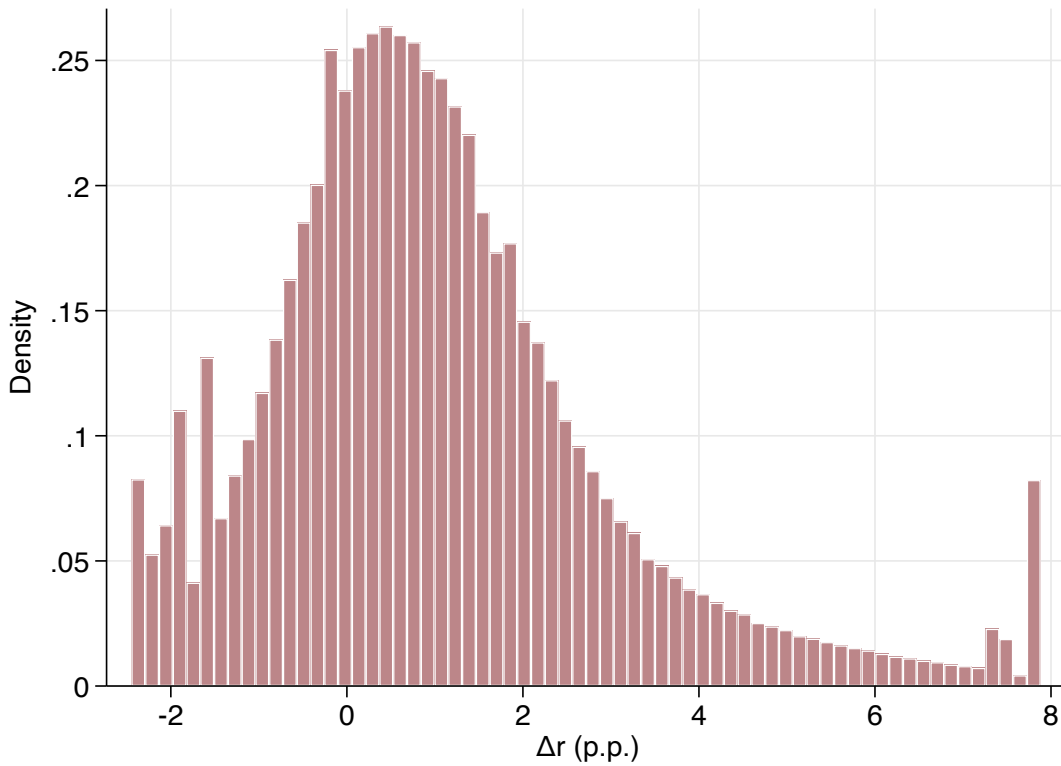
Notes: Columns 1 and 3 report OLS estimates of the relationship between moving rates and MSA-level wage growth. Columns 2 and 4 report first-stage estimates of the Bartik wage growth IV. Columns 3 and 6 report two-stage least squares estimates of Equation (30). High and low aggregate Δr refer to borrowers who are above or below the sample median aggregate Δr , respectively. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Internet Appendix for “Mortgage Lock-In, Mobility, and Labor Reallocation”

Julia Fonseca Lu Liu

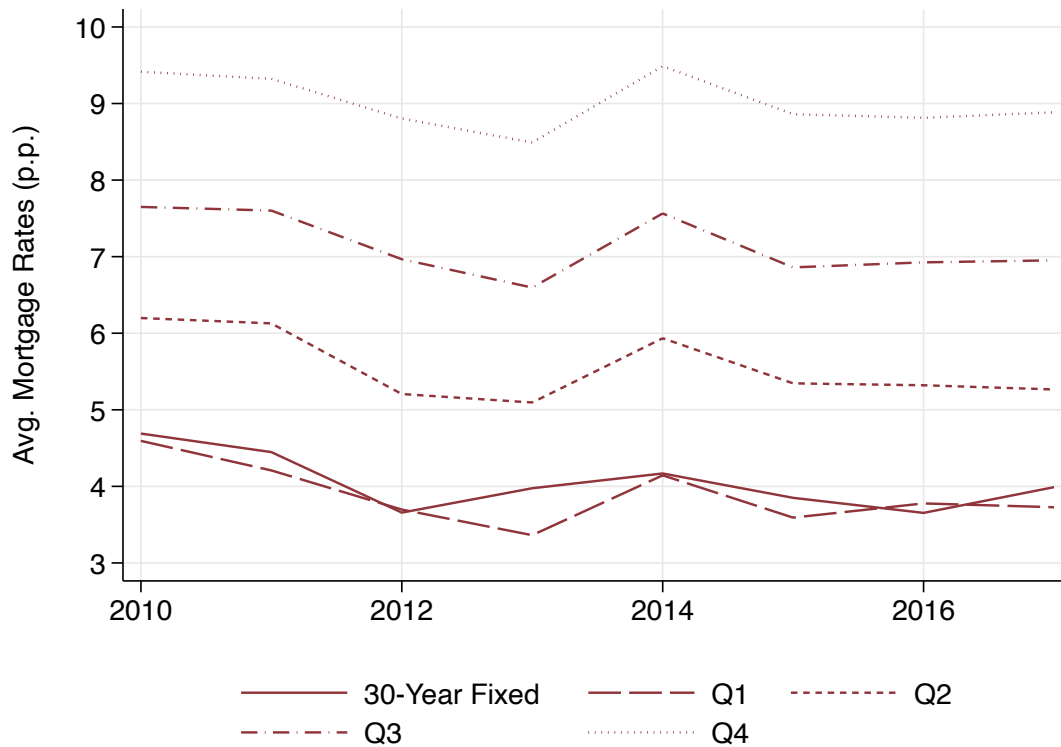
A Additional Figures and Tables

Appendix Figure A1: Histogram of Mortgage Rate Deltas



This figure shows a histogram of household-specific mortgage rate deltas (Δr), measured as the difference between the mortgage rate that the household locked in at the time of mortgage origination and the current average 30-year fixed mortgage rate.

Appendix Figure A2: Average Mortgage Rates by Quartile



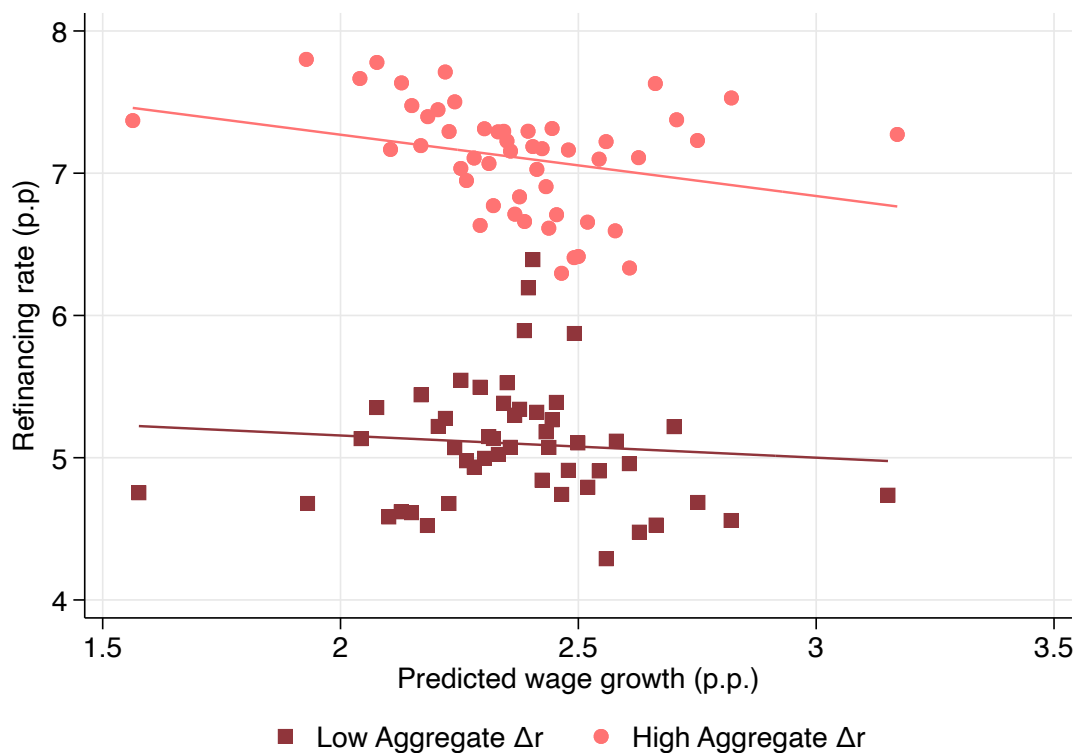
This figure shows average mortgage rates by quartile of the mortgage rate distribution, as well as the average 30-year fixed rate. When computing average mortgage rates for a given year, we restrict attention to mortgages originated that year with a 30-year term and a balance below the conforming loan limit.

Appendix Figure A3: Event Study



This figure shows estimates and 95% confidence intervals of Equation (31) for borrowers with aggregate mortgage delta greater or equal to 2 p.p. in 2010. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, a zip code house price index, and zip code fixed effects. Standard errors are double clustered at the county and origination-month-year level.

Appendix Figure A4: Placebo Check: Refinancing Rates and Wage Growth



This figure shows a binned scatter plot of the relationship between refinancing rates and MSA-level wage growth. Variables are residualized from controls. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, a zip code house price index, and county and year fixed effects. High and low aggregate Δr refer to borrowers who are above or below the sample median aggregate Δr , respectively.

Appendix Table A1: The Effect of Wage Growth on Moving Rates by Degree of Lock-In
Excluding Borrowers Past the Kink

Dependent Variable:	$\mathbb{I}[Moved]$					
	Low			High		
Aggregate Δr Group:	OLS	FS	IV	OLS	FS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Wage Growth	0.01 (0.02)		0.51* (0.29)	0.03* (0.02)		1.53** (0.61)
Wage Growth IV		0.63*** (0.14)			0.63*** (0.17)	
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
F-Stat		20.10			14.38	
P-value of (3) = (6)						0.08
Observations	1,898,764	1,898,764	1,898,764	1,107,551	1,107,551	1,107,551

Notes: Columns 1 and 3 report OLS estimates of the relationship between moving rates and MSA-level wage growth. Columns 2 and 4 report first-stage estimates of the Bartik wage growth IV. Columns 3 and 6 report two-stage least squares estimates of Equation (30). High and low aggregate Δr refer to borrowers who are above or below the sample median aggregate Δr , respectively. We exclude from the high aggregate Δr group those borrowers with aggregate $\Delta r > 2\%$, which approximately corresponds to the kink point in the relationship between aggregate Δr and moving rates. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table A2: Robustness to Controlling for Timing

Dependent Variable:	$\mathbb{I}[Moved]$				
	(1)	(2)	(3)	(4)	(5)
Δr	0.68*** (0.07)	1.99*** (0.15)	2.00*** (0.49)	2.84*** (0.69)	2.08*** (0.67)
Zipcode FE	Yes	Yes	Yes	Yes	Yes
County \times Year FE	Yes	Yes	Yes	Yes	Yes
Origination Year FE	No	Yes	No	No	No
Origination Half-Year FE	No	No	Yes	No	No
Origination Quarter-Year FE	No	No	No	Yes	Yes
Last Refi FE	No	No	No	No	Yes
Controls	Yes	Yes	Yes	Yes	Yes
F-Stat	1,910.76	319.51	74.60	105.64	105.77
Observations	3,924,792	3,924,792	3,924,792	3,924,792	3,924,792

Notes: This table reports two-stage least squares estimates of Equation (29) with additional fixed effects, indicated in the bottom rows. F-stat refers to the first stage F-statistic. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table A3: Placebo Check: The Effect of Wage Growth on Refinancing Rates

Dependent Variable:	$\mathbb{I}[Refinanced]$					
	Low			High		
Aggregate Δr Group:	OLS	FS	IV	OLS	FS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Wage Growth	0.08** (0.04)		-0.45 (0.48)	0.09*** (0.03)		-1.59*** (0.56)
Wage Growth IV		0.64*** (0.14)			0.69*** (0.16)	
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
F-Stat		20.64			18.82	
P-value of (3) = (6)						0.12
Observations	1,898,764	1,898,764	1,898,764	1,895,616	1,895,616	1,895,616

Notes: Columns 1 and 3 report OLS estimates of the relationship between refinancing rates and MSA-level wage growth. Columns 2 and 4 report first-stage estimates of the Bartik wage growth IV. Columns 3 and 6 report two-stage least squares estimates of Equation (30) with refinancing as the dependent variable. High and low aggregate Δr refer to borrowers who are above or below the sample median aggregate Δr , respectively. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table A4: Robustness to Present Value of Mortgage Payments

Dependent Variable:	$\mathbb{I}[Moved]$					
	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Δ PVM	0.01*** (0.00)	0.01*** (0.00)	0.01*** (0.00)	0.04*** (0.00)	0.06*** (0.01)	0.06*** (0.01)
Zipcode FE	Yes	Yes	Yes	Yes	Yes	Yes
County \times Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Origination Quarter-Year FE	No	Yes	Yes	No	Yes	Yes
Last Refi FE	No	No	Yes	No	No	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
F-Stat				420.07	75.65	75.76
Observations	3,847,503	3,847,503	3,847,503	3,847,503	3,847,503	3,847,503

Notes: This table reports two-stage least squares estimates of Equation (29) with Δ PVM as the independent variable. F-stat refers to the first stage F-statistic. Controls include mortgage balance, mortgage payment, the fraction of the mortgage that has been paid off, credit score, age, age squared, gender, and a zip code house price index. Standard errors are double clustered at the county and origination-month-year level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Appendix Table A5: County-Level Mortgage Rate Delta and Housing Market Outcomes

Dependent Variable:	Log(No. of Listings)		Log(Listing Price)		Log(Days on Market)	
	(1)	(2)	(3)	(4)	(5)	(6)
Aggregate Δr	0.14*** (0.01)	0.05* (0.03)	-0.07*** (0.01)	-0.00 (0.03)	0.05*** (0.01)	0.02 (0.03)
County FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	No	Yes	No	Yes	No	Yes
Observations	6,056	6,056	6,058	6,058	6,058	6,058

Notes: Columns 1 and 2 report results for the log number of listings. Columns 3 and 4 report results for the log average listing price. Columns 5 and 6 report results for the median number of days on the market. Robust standard errors are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

B Model Calibration and Simulation

We calibrate the model in described in Section 2 to match stylized features of the data, and to obtain predictions for household moving behavior that we can map to our empirical findings. The parameters used for the model calibration are shown in Table B6. Note that the simulation primarily captures relative moving patterns with respect to Δr , and does not target the moving rate *level* across households.

In addition, we introduce a drift term c to the interest rate process, to match the Δr distribution in the data, which has more mass in the positive domain given a history of decreasing rates.

$$r_2 = c + r_1 + \epsilon, \text{ where } \epsilon \sim \text{i.i.d. } \mathcal{N}(0, \sigma_\epsilon). \quad (32)$$

Panel 1 shows the calibration of mortgage rates, which broadly match the distribution of Δr , and the median loan balance in the data. Since mortgage rates have been declining over most of the sample period, the interest rate shock is shifted by c to match the mass of Δr that is in the positive domain, but the simulation could be done to cover any given range of Δr . Panel 2 shows that the standard deviation of the moving shock σ_η is 0.05, while the starting level of income Y_1 is 100,000 USD. To allow for additional dimensions of household heterogeneity, we further assume heterogeneity in refinancing (k^r) and moving cost (k^m), which are i.i.d normally distributed with mean and standard deviation μ_{k^r}, σ_{k^r} and μ_{k^m}, σ_{k^m} , respectively, shown in Panel 3.¹⁹ For the moving cost parameters, we do not have underlying information on the true distribution of moving cost in the data. We set the mean to 10,000 USD and the standard deviation to 5,000 USD to capture, together with the magnitude of the moving shock, that only a small fraction of households would want to move in a given period, in line with the data. The calibration of these magnitudes largely governs the level probability of moving across households, which we are not targeting. We further set the mean of the refinancing cost to 2,000 USD, and the standard deviation to 500 USD, which (together with the loan size) determine the point from which the relationship between moving rates and Δr flattens.

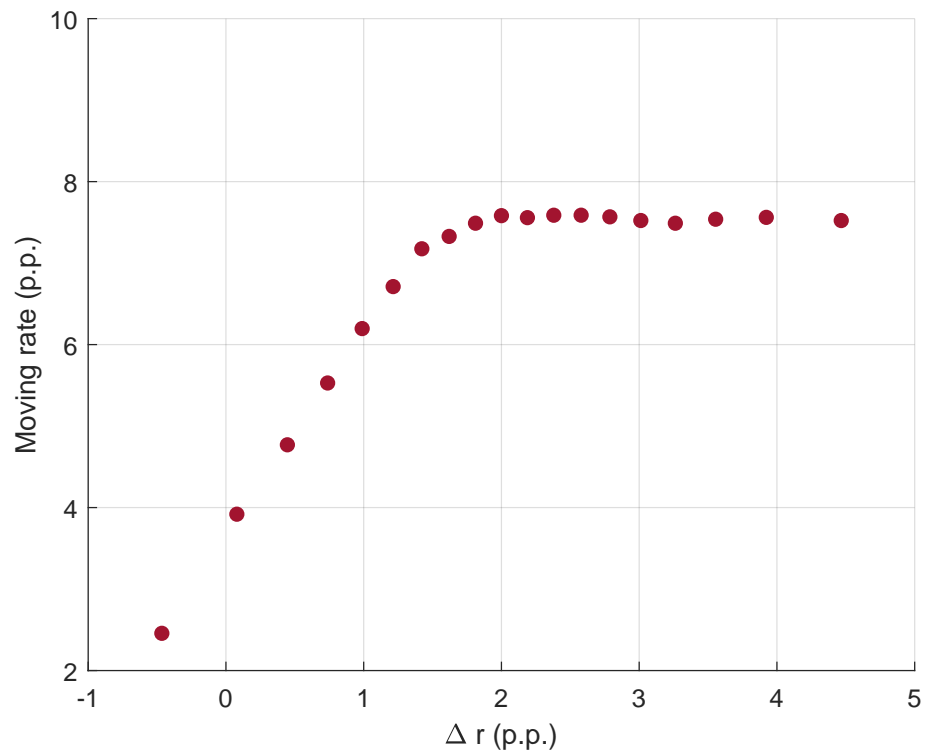
¹⁹We truncate the cost distributions such that all costs are weakly positive. An alternative would be to assume a log-normal distribution which does not materially affect results.

Appendix Table B6: Model Calibration

Parameter	Value	Description
<i>Panel 1: Mortgage Rates</i>		
r_1	4	Initial level of mortgage rate (p.p.)
c	-2	Constant (shift of interest rate shock distribution) (p.p.)
σ_ϵ	1.5	S.d. of interest rate shock (p.p.)
L	150,000	Starting loan balance (USD)
<i>Panel 2: Wages and Moving Shock</i>		
σ_η	0.05	S.d. of moving shock
Y_1	100,000	Starting income level (USD)
<i>Panel 3: Moving and Refinancing Cost</i>		
μ_{κ^m}	10,000	Mean moving cost (USD)
σ_{κ^m}	5,000	S.d. moving cost (USD)
μ_{κ^r}	2,000	Mean refinancing cost (USD)
σ_{κ^r}	500	S.d. refinancing cost (USD)

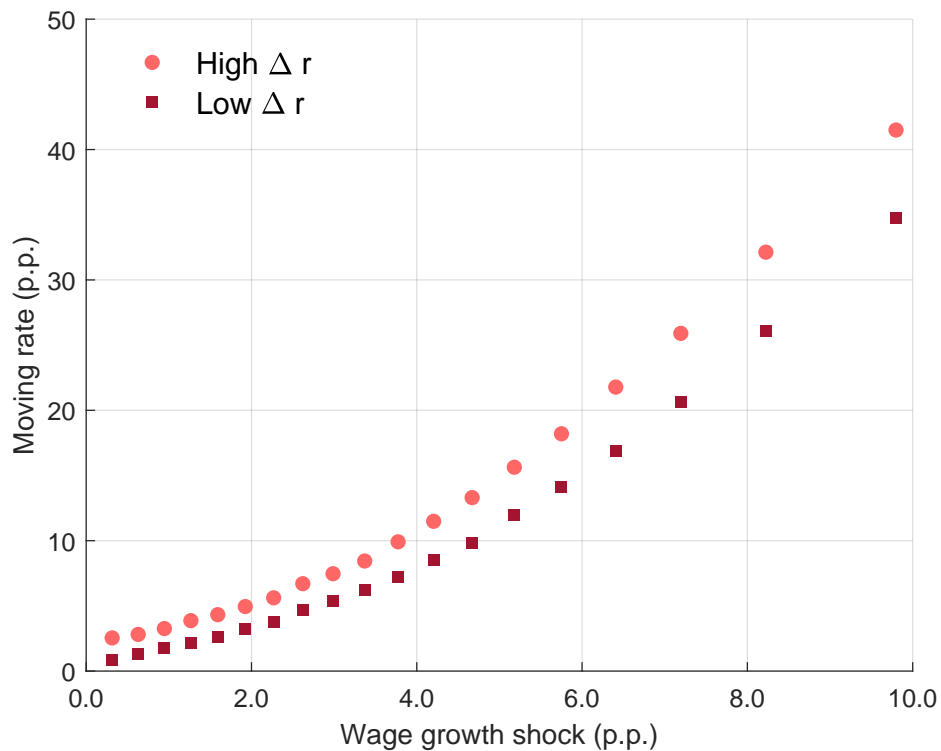
Notes: This table shows the calibration of parameters for the baseline simulation of the model (described in Section 2).

Appendix Figure B5: Simulated Moving Rates and Mortgage Rate Deltas



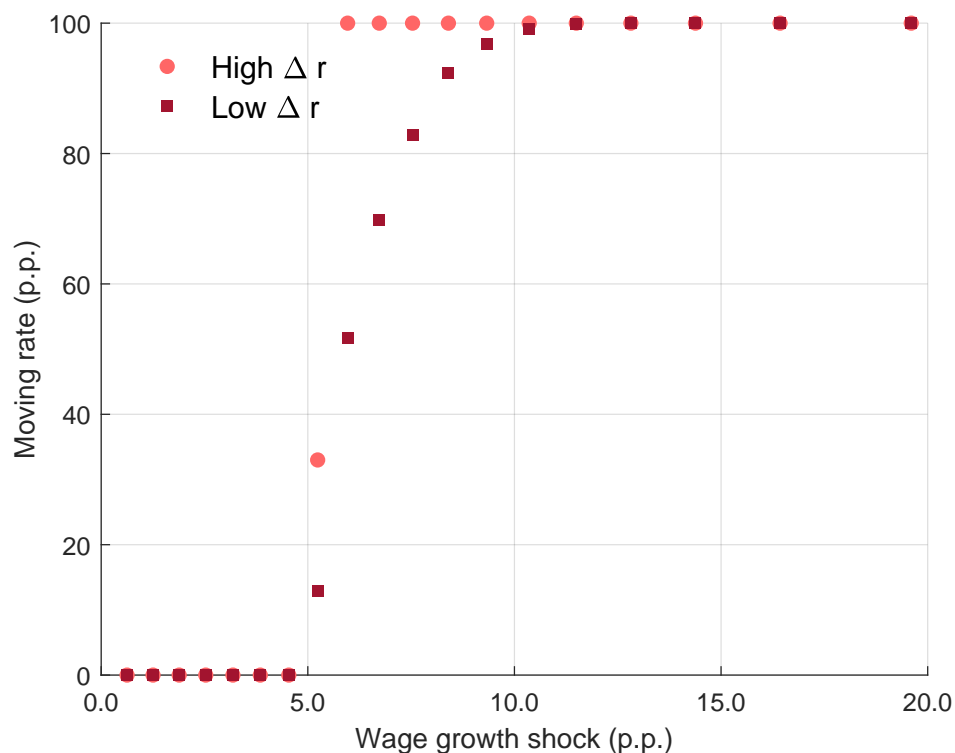
This figure shows an equal-sized binned scatter plot of the relationship between simulated moving rates and mortgage rate deltas.

Appendix Figure B6: Simulated Moving Rates and Positive Wage Shocks by Degree of Mortgage Rate Lock-In



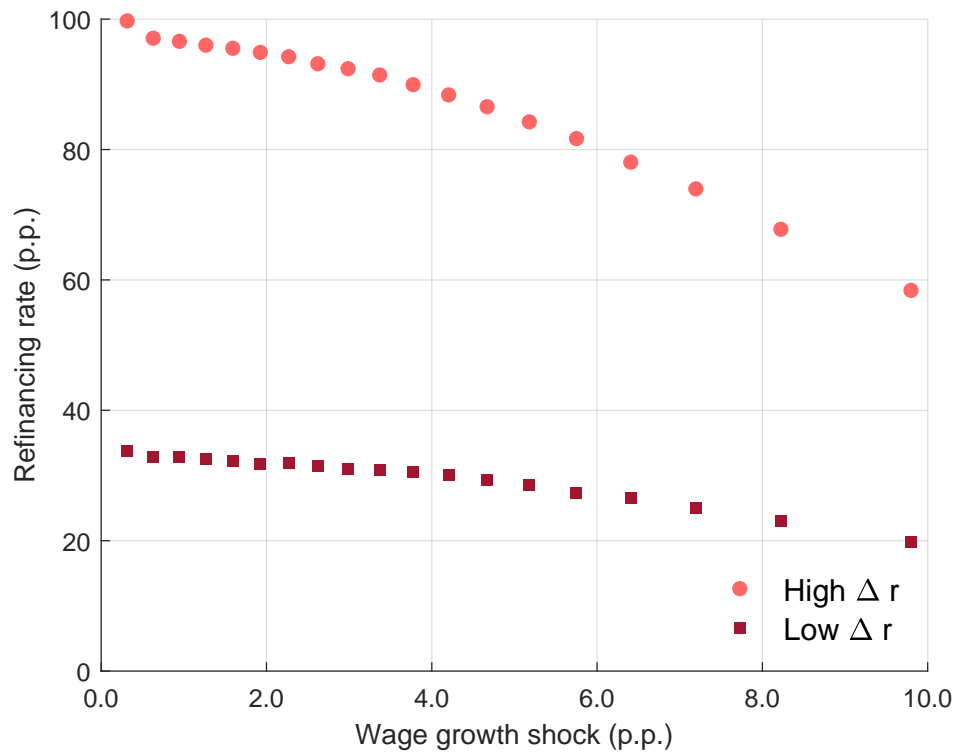
This figure shows an equal-sized binned scatter plot of the relationship between simulated moving rates and positive wage growth shocks (over the range of the wage growth shock $\eta \in [0, 10]\%$), for households with low (below median) and high (above median) mortgage rate deltas.

Appendix Figure B7: Simulated Moving Rates and Positive Wage Shocks by Degree of Mortgage Rate Lock-In (Large Wage Shocks)



This figure shows an equal-sized binned scatter plot of the relationship between simulated moving rates and positive wage growth shocks (over the full range of the wage growth shock in the positive domain), for households with low (below median) and high (above median) mortgage rate deltas. In this simulation, we reduce the mean of the moving cost μ_{κ^m} to 5,000 USD, with no heterogeneity in moving or refinancing cost ($\sigma_{\kappa^r} = 0, \sigma_{\kappa^m} = 0$), and increase the standard deviation of the moving shock σ_η to 0.1, relative to the baseline calibration specified in Table B6.

Appendix Figure B8: Simulated Refinancing Rates and Wage Shocks by Degree of Mortgage Rate Lock-In



This figure shows an equal-sized binned scatter plot of the relationship between simulated refinancing rates and wage growth shocks.

C Present Value of Mortgage Payments

A fully-amortizing mortgage with original term to maturity T_0 (in years), annual mortgage rate r_0 and original loan size L_0 has a constant annual mortgage payment $M(r_0, L_0, T_0)$ of:

$$M(r_0, L_0, T_0) = \frac{r_0}{1 - (1 + r_0)^{-T_0}} \cdot L_0 \quad (33)$$

The discounted present value of all mortgage payments (“PVM”) between today and time T is:

$$PVM = \sum_{t=0}^T \rho^t \cdot M(r_0, L_0, T_0) = (\rho + \rho^1 \dots \rho^T) \cdot M(r_0, L_0, T_0) = \frac{(1 - \rho^T)}{1 - \rho} M(r_0, L_0, T_0), \quad (34)$$

where $\rho = \frac{1}{1+\delta}$ and δ is the discount rate used for discounting. The difference in the net present value of mortgage payments under the locked-in rate r_0 and the current market rate r_t is:

$$\Delta PVM(r_0, r_t) \equiv \frac{(1 - \rho^T)}{1 - \rho} [M(r_0, L_0, T_0) - M(r_t, L_0, T_0)]. \quad (35)$$

To measure $\Delta PVM(r_0, r_t)$ empirically, we start by using our observed measure of payments $M(r_0, L_0, T_0)$, the locked-in interest rate r_0 , and the term T_0 to infer the original loan size L_0 using equation (33). Once we have a measure of L_0 , we use equation (33) to compute the counterfactual loan payment under the current interest rate $M(r_t, L_0, T_0)$, measured as the average 30-year fixed prime rate in year t . With both the observed and the counterfactual payment, we compute $\Delta PVM(r_0, r_t)$ according to equation (35), setting the discount factor ρ to 0.96.

Our instrument for $\Delta PVM(r_0, r_t)$ is analogous to our baseline instrument for mortgage rate deltas and exploits variation coming solely from the timing of mortgage origination. Specifically, we use equation (33) to compute the counterfactual payment under the average 30-year fixed prime rate at the month of origination, $M(r_{p(0)}, L_0, T_0)$. We then define our instrument for $\Delta PVM(r_0, r_t)$ as:

$$\text{Aggregate } \Delta PVM(r_{p(0)}, r_t) \equiv \frac{(1 - \rho^T)}{1 - \rho} [M(r_{p(0)}, L_0, T_0) - M(r_t, L_0, T_0)]. \quad (36)$$