State Dependent Effects of Monetary Policy: The Refinancing Channel

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Online Appendix

A County Data Description

In this section, we describe our data sources and the construction of the county-level demographic variables used in our analysis.

For each county, we obtain the median age and the share of the population with a college degree from the Census, the unemployment rate and share of employment in manufacturing from the Bureau of Labor Statistics, and per-capita income from the Bureau of Economic Analysis.

We measure lender competitiveness using the Hirschman-Herfindahl Index computed across mortgage lenders within the county.[1] This measure is also used in Scharfstein and Sunderam (2016). The index is constructed using data from HMDA (the Home Mortgage Disclosure Act).

We consider two measures of home values. Our first measure is the average home price accumulation over the life of the mortgage. We compute real house prices using the consumer price index. We then compute the log difference between the current home price and the value of the house at origination.

The median sale price of homes comes from two sources. We have monthly house-price data from the Global Financial Data Real Estate database from 1975 to present. The home prices are based on information from Freddie Mac and Fannie Mae. For house prices prior to 1975, we use regional data from the U.S. Bureau of the Census and U.S. Department of Housing and Urban Development. The two different data series have very similar trends in the overlapping post-1975 period.

[1]We thank David Berger for sharing these data with us.

Table 1: Average Rate Gap and County Characteristics

Time FE	Yes	Yes	No	No	No	No	No	No	No	No
County FE	Yes	No	Yes	No	No	No	No	No	No	No
R-squared	0.738	0.5432	0.1866	0.0546	0.0257	0.0119	0.0042	0.0004	0.0001	0.0001
Variables:	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(XIV)	(X)
Unemployment rate				0.0818***						
				(0.010)						
Per capita income					-0.3566***					
					(0.020)					
Share colleged educated						-0.5863***				
						(0.050)				
Home equity accumulation							-0.5117***			
							(0.060)			
Median age								0.0909*		
								(0.040)		
Manufacturing share									0.0003	
									(0.000)	
Share male										0.2296
										(0.410)

We use individual data on home equity to compute the average level of home equity. For each loan, we compute home equity (price minus the balance). We then winsorize the top and bottom 1 percent of the home equity values to abstract from outliers. Finally, we take an average across all loans within the county, weighted by loan balance.

B Average Rate Gaps and County Characteristics

In this section, we show how the average rate gap varies over time and across counties. We also show how the average rate gap correlates with observable county-level characteristics (unemployment rate, per capita income, share of college educated, home equity accumulation, median age, manufacturing share, and share of males in the population). The table below reports the estimated coefficient from regressing the average rate gap on the observable characteristic. Standard errors are given in parenthesis.

C Robustness

C.1 Alternative moments

This section reports estimates of the state dependent effects of monetary policy using three alternative moments of the distribution of potential savings: the present value of potential savings, the fraction of loans with positive savings, and the spread of the existing mortgage rate relative to the threshold interest rate proposed by Agarwal, Laibson and Driscoll (2013). We find that the effects of a change in mortgage rates is state dependent, varying with the values of these alternative moments of the distribution.

First, we consider an alternative measure of the potential savings from refinancing based on the present value of savings from pursuing the following simple refinancing strategy: the existing loan is refinanced with a FICO-specific 30-year fixed-rate mortgage and the new loan is repaid over the remaining life of the mortgage being refinanced. To simplify the notation, we suppress the dependence of the interest rate on FICO score and region.

Consider a 30-year mortgage with a fixed interest rate r^{old} that was originated at $T-30$ and matures at time T. The loan is repaid with fixed payments which we denote by Payment^{old}. These payments are given by:

$$\text{Balance}_{T-30} = \sum_{k=1}^{30} \frac{\text{Payment}^{old}}{(1+r^{old})^k}.$$

If the person refinances at the beginning of time t, before the mortgage payment is due, the balance owned on the old loan is given by the present value of the remaining payments:

$$\text{Balance}_t = \sum_{k=t}^{T} \frac{\text{Payment}^{old}}{(1+r^{old})^{(k-t)}}.$$

The balance of the new mortgage is the same as that of the old mortgage. The new mortgage payment is computed assuming that the mortgage is paid off over a 30-year period:

$$\text{Balance}_t = \sum_{k=1}^{30} \frac{\text{Payment}^{new}}{(1+r^{new})^k}.$$

The present value of savings associated with this refinancing strategy is:

$$\text{Savings}_t = \left[\sum_{k=t}^{T} \frac{\text{Payment}^{old} - \text{Payment}^{new}}{(1+r^{new})^{(k-t)}}\right] - \frac{\text{Balance}_T}{(1+r^{new})^{T-t}}, \tag{1}$$

where Balance_T is the balance of the refinanced mortgage at time T. We can rewrite equation (1) as:

$$\text{Balance}_t + \text{Savings}_t = \left[\sum_{k=t}^{T} \frac{\text{Payment}^{old}}{(1+r^{new})^{(k-t)}}\right].$$

This equation shows that if the household chooses its new mortgage so that the new mortgage payment is equal to the old mortgage payment, it can cash out Savings_t. They do so by borrowing $\text{Balance}_t + \text{Savings}_t$, and using Balance_t to pay the old mortgage. With this strategy, the household takes out a mortgage loan that is larger than the existing mortgage loan and receives the difference between the two loans in cash.

We convert our nominal measures of potential savings into real terms using the Consumer Price Index (base year 1999). We construct this measure of savings for every mortgage at time t. We then compute the average level of savings at time t. We denote the average level of savings across mortgages by A_{2t}:

$$A_{2t} = \frac{1}{n_t} \sum_{i=1}^{n_t} \text{Savings}_{it}. \quad (2)$$

The unconditional quarterly mean and standard deviation of the average savings from refinancing are -294 and $2,424$ dollars, respectively.

We now discuss the estimates of regression (2) obtained for the case where A^c_{t-1} is the average of savings from refinancing. Here, both β_1 and β_2 are significant at the one percent level. To interpret these coefficients, suppose that all the independent variables in regression (2) are initially equal to their time-series averages and that average of savings are initially equal to its mean value of $-\$294$. Our estimates in column 2 of Panel A of Table 2 imply that a 25 basis points drop in mortgage rates raises the share of loans refinanced by about 7.2 percent. Now suppose that the drop in mortgage rates happens when the average savings from refinancing is equal to $\$2,130$, which is the mean value of ($-\$294$) plus one standard deviation ($\$2,424$). Then, the refinancing rate rises to 10.4 percent. So, the marginal impact of a one standard-deviation increase in the average savings from refinancing is 2.5 percentage points.

Panels B and C of Table 2 consider two additional alternative moments of refinancing savings: the fraction of loans with positive savings, and the spread of the existing mortgage rate relative to the threshold interest rate proposed by Agarwal, Laibson and Driscoll (2013). We again find that the effects of a change in mortgage rates is state dependent, varying with the values of these alternative moments of the distribution.

C.2 Instrumenting with the 2-year Treasury Yield

This section provides additional estimates of the state dependent effects of monetary policy. In the main text, we instrumented for the response to a change in mortgage rate using high-frequency changes in the Federal Funds futures rate. Here, we show that the results are robust to instrumenting using the high-frequency changes in the 2-year Treasury yield within a 60-minute window around the Fed's announcement. Changes in

Table 2: State dependency of monetary policy and refinancing

Refinancing over the year	**OLS (I)**	**IV (II)**
Panel A		
ΔR(t)	0.045***	0.081***
	(0.005)	(0.017)
ΔR(t) x Average savings	0.021**	0.028**
	(0.004)	(0.009)
Panel B		
ΔR(t)	-0.022	-0.004
	(0.033)	(0.063)
ΔR(t) x Fraction positive rate gap	0.140**	0.183*
	(0.058)	(0.111)
Panel C		
ΔR(t)	0.118***	0.253***
	(0.030)	(0.088)
ΔR(t) x Spread of old rate to ADL	0.069**	0.163*
threshold	(0.028)	(0.089)
County Fixed Effects	Yes	Yes
SPF Controls	Yes	Yes
Additional county controls	Yes	Yes

Notes: Estimates from regression (2). IV is based on futures. Standard errors are in parentheses. 10, 5, and 1 percent significance levels are denoted by *, **, and ***, respectively.

Table 3: State dependency of monetary policy and refinancing

	(I)
Panel A: Fraction refi	
ΔR(t)	0.094***
	(0.011)
ΔR(t) x Average rate gap	0.224**
	(0.181)
Panel B: Fraction cash-out refi	
ΔR(t)	0.125***
	(0.015)
ΔR(t) x Average rate gap	0.138***
	(0.022)
Panel C: Change in balance, given cash-out refi	
ΔR(t)	0.280***
	(0.059)
ΔR(t) x Average rate gap	0.253***
	(0.067)
County Fixed Effects	Yes
SPF Controls	Yes
Additional county controls	Yes

Notes: Estimates from regression (2). IV based on changes in the 2-year Treasury yield. Standard errors are in parentheses. *, **, and *** give significance at 10, 5, and 1 percent levels.

the 2-year Treasury yield have been used as measures of monetary shocks by Gertler and Karadi (2015) and Gilchrist et al. (2015). Table 3 reports our estimates of regression specification (2), using the high-frequency changes in the 2-year Treasury yield as an instrument for changes in the mortgage rate. The estimated state dependent effects of monetary policy obtained using this alternative instrument are very similar to those reported in Tables 1 of the main text.

C.3 Additional county-level controls

In this section, we show that our estimates of the state dependent nature of the effects of monetary policy are robust to the inclusion of interactions between county-level controls

Table 4: State dependency of monetary policy and refinancing

	(I)		(II)	
	coefficient	std error	coefficient	std error
ΔR(t) x Average rate gap(t-1)	0.266***	(0.076)	0.562***	(0.181)
ΔR(t) x Average savings(t-1)				
ΔR(t) x Home equity(t-1)			0.605	(0.584)
ΔR(t) x House price change(t-1)			-0.229	(0.171)
ΔR(t) x Unemployment rate(t-1)			-0.030	(0.016)
ΔR(t) x Median age(t-1)			-0.001	(0.003)
ΔR(t) x Manufacturing share(t-1)			0.008*	(0.003)
ΔR(t) x Share college(t-1)			0.155	(0.154)
ΔR(t) x ARM share(t-1)			-0.004	(0.176)
ΔR(t) x Herfindahl index(t-1)			0.023	(0.026)
County Fixed Effects	Yes		Yes	
County interaction controls	No		Yes	

Notes: Estimates from regression (2). For comparison, we report the coefficients from Table 1 in the main text in this table's columns I and II. Column III is the estimated effects when we include the county demographics interacted with the change in mortgage rates. Standard errors are in parentheses. *, **, and *** give significance at 10, 5, and 1 percent levels.

and the change in mortgage rates. These estimates, reported in Table 4 below, are similar to those in Table 1, in the main text. The fact that including interaction terms does not change the estimate elasticities implies that the state dependency that we highlight is distinct from other potential mechanisms explored in the literature. These mechanisms include, for instance, differential responses in refinancing to a decline in mortgage rates due to differences in competitiveness of the local lending market. It is also distinct from state dependency related to variation in the value of home equity across counties.

Table 5: State dependency of monetary policy and refinancing

	(I)
Panel A: Fraction refi	
ΔR(t)	0.041***
	(0.005)
ΔR(t) x Average rate gap	0.096**
	(0.023)
Panel B: Fraction cash-out refi	
ΔR(t)	0.070***
	(0.003)
ΔR(t) x Average rate gap	0.073***
	(0.005)
Panel C: Change in balance, given cash-out refi	
ΔR(t)	0.136***
	(0.015)
ΔR(t) x Average rate gap	0.044*
	(0.030)
County Fixed Effects	Yes
SPF Controls	Yes
Additional county controls	Yes

Notes: The table reports the response to a decline in interest rates. It therefore reports the estimates from regression equation (2), multiplied by -1. Standard errors are in parentheses. *, **, and *** give the significance at the 10, 5, and 1 percent levels.

D OLS results

The table below reports the OLS results corresponding to Table 2 of the main text.

E Model aggregate process

In our model, we assume that the aggregate state variables (log of aggregate income, log of house prices, and log of the real interest rate) evolve according to the vector autoregression process described in Equation (16), Section 6.2:

$$\triangle S_t = B_1 \triangle S_{t-1} + B_2 \triangle \log\left(r_{t-1}\right) a_{t-1} + u_t$$

where B_1 is a 4×4 matrix, B_2 is a 4×1 vector, and u_t is a Gaussian disturbance.

We now provide evidence that the process does well relative to other specifications, in terms of the root-mean-squared error (RMSE). Table 6 below shows that none of the RMSE associated with the alternative specifications is smaller, taking sampling uncertainty into account, than the RMSE associated with specification (16). At the same time, specification (16) does have a statistically significant smaller RMSE than many alternative specifications.

The standard errors are computed as follows. We draw a set of coefficients from the joint distribution of estimated coefficients. We use the set of coefficients to construct one-step-ahead forecasts and compute the RMSE. We repeat these two steps for 100,000 draws of coefficients, and then compute the standard error of the RMSE.

Table 6: Root-mean-squared forecasting errors of regressions

Regression	**RMSE**	**SE**
$\triangle S_t = B_1 \triangle S_{t-1} + B_2 \triangle r_{t-1} a_{t-1} + u_t$	0.233	0.035
$\triangle S_t = B_1 \triangle S_{t-1} + u_t$	0.221	0.004
$\triangle S_t = B_1 \triangle S_{t-1} + B_2 \triangle S_{t-2} + u_t$	0.293	0.008
$\triangle S_t = B_1 \triangle S_{t-1} + B_2 \triangle S_{t-1} a_{t-1} + u_t$	0.294	0.099
$S_t = S_{t-1} + B_1 S_{t-1} A_{t-1} + u_t$	0.258	0.066

F Model computation

To solve the model numerically, we implement the following procedure. First, we reformulate the choice variables to rectangularize the problem and simplify computational issues that arise from the endogenous mortgage constraint. The problem is reformulated in terms of the leverage ratio, defined as

$$q_{jat} = b_{jat} / p_t h_{jat} \geq 0.$$

We solve the budget constraint for consumption and replace consumption in the utility function. The choices variables are therefore $s_{jat}, h_{jat}, 1(\text{rent})_{jat}, 1(\text{adjust})_{jat}, q_{jat}$. We discretize the idiosyncratic income variable y_{jat}. We simulate the quarterly process for the aggregate state vector, S_t, to obtain the annual probability transition matrix for S_t. We discretize S_t using the Rouwenhorst method. There are 32 grid points for S_t and two grid points for y_{jat}. The value functions ($V^{\text{own \& noadjust}}(z_{jat})$, $V^{\text{own \& adjust}}(z_{jat})$ and $V^{\text{rent}}(z_{jat})$) are approximated as multilinear functions in the states, where $z_{jat} = [S_t, y_{jat}, \text{assets}_{jat}]$. There are four endogenous states $\text{assets}_{jat} = \left[s_{jat}, h^o_{jat}, b_{jat}, r_{jat}\right]$. We use 10 knots for b_{jat}, s_{jat}, and h^o_{jat}, and 5 knots for r_{jat}. The knots are spaced more closely together near the constraints for b_{jat} and s_{jat}. The value functions are interpolated between knots.

The model is solved via backward induction from the final period of life. At each age and each case, the optimal policies are computed using a Nelder-Meade algorithm, comparing the value functions for each of the three cases (to rent, to own a home and adjust the mortgage, to own a home and not adjust the mortgage) to generate the overall policy function.

To estimate the regression used in our empirical section with data simulated from the model, we proceed as follows. The model is initialized with the same distribution of wealth and mortgage rates for 1994, obtained from the Survey of Consumer Finances and the Core Logic database. We then feed the actual path for house prices, aggregate income, and interest rates for the period 1994-2007. Each cohort faces the historical path for the state variables, as well as the realized aggregate state variables. Given their individual and aggregate states, they make their consumption, mortgage, housing, and savings decisions. Given the observed decisions and states, we estimate the regression used in our empirical work and compare our model-based estimates with the empirical estimates.