Regional Heterogeneity and Monetary Policy*

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Abstract

We argue that the time-varying regional distribution of housing equity influences the aggregate consequences of monetary policy through its effects on mortgage refinancing. Using detailed loan-level data, we show that regional differences in housing equity affect refinancing and spending responses to interest rate cuts but that these effects vary over time with changes in the regional distribution of house price growth and unemployment. We then build a heterogeneous household model of refinancing and use it to explore the aggregate implications for monetary policy arising from our regional evidence. We find that the 2008 equity distribution made spending in depressed regions less responsive to interest rate cuts, thus dampening aggregate stimulus and increasing regional consumption inequality, whereas the opposite occurred in some earlier recessions. Taken together, our results strongly suggest that monetary policy makers should track the regional distribution of equity over time.

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1 Introduction

Collateralized borrowing in the housing market can potentially play an important role in the monetary transmission mechanism, as interest rate cuts encourage mortgage refinancing and home equity extraction to fund current consumption.[1] Since housing markets are locally segmented, regional house price shocks are a critical determinant of home equity and the strength of this *refinancing channel* of monetary policy. In this paper, we argue that the regional distribution of housing equity, which varies substantially across different recessions, plays a crucial role in determining whether monetary stimulus flows to the locations which need it most. Furthermore, we argue that regional differences in the effects of monetary policy do not wash out in the aggregate and so lead to aggregate monetary policy effects that also vary across time with the distribution of housing equity.

Our analysis is motivated by striking differences in the regional distribution of house price growth over time. During the Great Recession, house price declines left many households in the US and Europe with little home equity. Within these monetary unions, house price declines varied substantially across space and were largest in regions where economic activity also declined most (e.g., Nevada or Spain). In contrast, US house prices grew throughout the 2001 recession, with little spatial variation. Variation in home equity then affects the strength of the refinancing channel of monetary policy for two reasons: First, lenders generally require require a minimum level of equity in order to allow borrowers to refinance, even if they are not extracting equity. Second, the level of equity potentially extracted during refinancing clearly depends on the existing level of equity in the house prior to refinancing.

Our paper argues in three steps that regional equity variation has important policy implications. First, we use detailed microdata to show that monetary policy during the Great Recession mostly stimulated those regions with the smallest increases in unemployment and the smallest declines in house prices. In contrast, during the 2001 recession, when regional house price growth and unemployment were largely uncorrelated, refinancing activity was stronger in high-unemployment regions. Second, we build a heterogeneous household model of refinancing and use it to derive the aggregate implications of monetary policy from this regional evidence. Our model implies that interest rate cuts in 2008 indeed had the smallest effects on depressed regions. More importantly, the regional distribution of housing equity in 2008 substantially dampened the aggregate consequences of monetary policy. We then show that under alternative distributions of house prices, such as those in the 2001 recession, interest rate cuts can both better stimulate aggregate consumption and reduce (rather than amplify) regional consumption inequality. Since the distribution of equity both varies across time and changes the consequences of monetary policy, we conclude that it is important for policy makers to track this variation. But what can be done to amplify the effectiveness of monetary policy if regional conditions in the future again mirror those in 2008? In the final part of the paper, we explore a variety of simple mortgage market interventions and macroprudential policies in our model and show they can help to strengthen the refinancing channel of monetary policy under these conditions.

In more detail, the first part of our paper provides empirical evidence about the effects of regional heterogeneity in housing equity on the refinancing channel of monetary policy. We begin this empirical analysis by studying the regional response to interest rate declines immediately following the first

[1] See e.g. https://www.federalreserve.gov/boarddocs/hh/2004/february/testimony.htm and https://www.newyorkfed.org/newsevents/speeches/2012/dud120106.html for recent policy discussion of this channel.

round of the Federal Reserve's large-scale asset purchase program—commonly known as quantitative easing (QE1). QE1 provides a unique opportunity to study the refinancing channel and its interaction with the distribution of housing equity in the economy because of both its magnitude—30-year fixed-rate mortgage rates fell by around 1% in the month after announcement—and the large variation in regional housing market conditions at the time of the announcement.

Using various loan-level data sources, we document three facts about the regional response to QE1. First, there was a boom in household mortgage refinancing right after the QE1 announcement. Second, refinancing activity and the amount of equity extracted increased more in metropolitan statistical areas (MSAs) that had lower unemployment and where homeowners had more housing equity on the eve of QE1. Specifically, very little refinancing occurred in places like Las Vegas and Phoenix, where most homeowners were underwater at the time QE1 was implemented. Third, MSAs with the most refinancing right after QE1 also experienced the largest resulting increase in consumption, as measured by car purchases. Moreover, individual households that refinanced increased their spending sharply, an increase that is even larger for households that removed equity by cashing out when refinancing.

These equity effects on refinancing are robust to a variety of alternative controls for other characteristics that vary across regions. They are also economically meaningful. The increase in refinancing in response to QE1 more than doubles when moving from the bottom quartile to the top quartile of MSAs by home equity. The additional equity extracted in these high equity MSAs adds up to roughly 10% of the differential change in total spending between the high and low equity MSAs during the recession and is comparable to total unemployment benefits paid out in low equity MSAs in 2009. Our estimates also imply that QE1 led to almost 250,000 additional car purchases in these high equity MSAs. Overall, these facts show that the refinancing channel was weakest during the Great Recession in regions with the worst housing and labor market conditions so that monetary policy through this channel stimulated most the locations which needed it least.

Our second set of empirical results moves beyond QE1 to provide evidence that the consequences of monetary policy vary over time. We begin by showing that there was large variation in the distribution of regional house price growth, and therefore regional home equity, in the US across different recessions over the last forty years. It is more difficult to measure local refinancing activity in historical data, but we are able to do so for the 2001 recession. Importantly, this recession was characterized by very different house price patterns than in 2008: aggregate house prices grew throughout the 2001 recession, there was little variation in house price growth across regions and what variation there was had little correlation with unemployment. We show that overall refinancing propensities were much higher during the 2001 recession than during the 2008 recession despite similar declines in interest rates. These recessions also exhibit different relationships between unemployment and refinancing: propensities increased less in high-unemployment MSAs during the Great Recession, whereas the opposite was true in the 2001 recession. This time-series finding complements the evidence from our QE1 event-study that regional refinancing responses depend crucially on regional economic conditions.

Next, we ask: what does this regional evidence imply for the aggregate consequences of monetary policy? Answering this question without a theoretical model is challenging. First, many features of the regional equity distribution move over time. With only a small number of recessions, it is essentially impossible to determine directly from the data which particular features of this distribution determine the strength of the refinancing channel of monetary policy. Second, echoing ideas in Beraja, Hurst, and

Ospina (2016), making inferences about aggregates from regional evidence requires accounting for the offsetting effects of refinancing activity on the behavior of lenders in the economy, which cannot be directly measured in our data. Analyzing these issues thus requires a formal model in order to conduct counterfactuals that cannot be computed in our micro-data alone.

Hence, in the second part of the paper we build an equilibrium, incomplete-markets, heterogenous agents model with both mortgage borrowers and lenders. The key model features are that mortgage borrowers face both idiosyncratic and regional income and house price risk and can refinance their mortgage and extract housing equity by paying a fixed cost. This then implies refinancing decisions which follow threshold rules around some inaction region as in Arrow, Harris, and Marschak (1951), Barro (1972), and Sheshinski and Weiss (1977). While the model includes many quantitatively realistic features and is rich enough to capture key aspects of the data shown in the first part of the paper, the non-linear relationship between equity and refinancing driven by these endogenous threshold rules yields very simple intuition and clarifies why the transmission from interest rate cuts to spending through the refinancing channel depends crucially on the distribution of housing equity.

Households must satisfy a collateral requirement to refinance, so when interest rates fall, those with substantial equity can reduce their interest rate while also extracting equity whereas those currently underwater would need to put up additional cash. Hence, when interest rates fall, many households with positive equity refinance and further increase consumption by extracting equity, whereas almost no households with negative equity do. This leads to consumption responses to interest rate cuts that are highly convex in equity because households that are mildly underwater exhibit the same zero response as those substantially underwater, whereas households with substantial positive equity exhibit much stronger consumption changes than those with mildly positive equity. This convexity then implies that changing the distribution of equity affects the economy's response to rate declines.

Our first quantitative results focus on the consequences of interest rate cuts in a benchmark economy that matches the joint distribution of housing equity and income observed in 2008. We pick the baseline parameters in our model to match the cross-region effects of QE1 documented in the first part of the paper and then compute the aggregate effects of this policy. We find that a decline in interest rates of the magnitude observed after QE1 modestly raises aggregate spending. This implies that the spending offset coming from lenders in equilibrium is not one-for-one. This is because our model features an important role for cash-out activity in determining spending. Households accumulate equity over time and periodically pay a refinancing cost to access this equity. Furthermore, since borrowers are more liquidity constrained than lenders, equity extraction increases spending on net. When interest rates decline, refinancing and equity extraction are accelerated and aggregate spending rises. However, under 2008 economic conditions, this aggregate spending effect is quantitatively small. As in our empirical analysis, we also find that monetary stimulus mainly flows to regions that are doing relatively well and thus amplifies regional inequality.

In contrast, when we simulate the response to the same change in interest rates under economic conditions in 2001, we find very different effects: monetary policy generates much larger aggregate spending responses, and it actually mildly reduces regional inequality. We show these conclusions depend importantly on the fact that in 2001, aggregate house price growth is positive, its spatial variance is low and house price growth is essentially uncorrelated with local economic conditions.

After arguing that the equity distribution in 2008 hampered monetary policy's ability to stimulate the economy through the refinancing channel, we show that various policies can complement interest rate cuts to increase monetary policy's power. In particular, we show that both targeted debt reduction and relaxation of collateral constraints for refinancing can amplify the stimulative effects of monetary policy and also reduce the trade-off with inequality. Policies along these lines were implemented during the Great Recession through the Home Affordable Modification and Refinance Programs (HAMP and HARP), and our results show that such mortgage market interventions can interact importantly with monetary policy. In addition, we explore the role of macroprudential policy and show that time-varying countercyclical leverage requirements have the potential to both dampen the depth of house-price-induced recessions and strengthen the stimulative effects of monetary policy.

Finally, we show that our model implications continue to hold under many alternative assumptions. In these model extensions we account for the presence of adjustable-rate mortgages, calibrated to match the observed regional share in the data; allow for the fact that in this recession large busts were preceded by large booms; allow for cash-out and non-cash-out refinancing; extend our baseline environment with unanticipated one-time interest rate shocks to environments with stochastic, transitory rate changes; show that our results are insensitive to assumptions about short-long interest rate spreads; show robustness to alternative income processes that alter the importance of consumption smoothing motives; and explore alternative assumptions on the lender side of the economy about the share of mortgage debt ultimately held by domestic consumers.

Central banks typically have no mandate to reduce spatial inequality or eliminate regional business cycles, and we are not arguing that monetary policy is the correct instrument to do so. However, monetary policy should care about aggregates, and our results highlight that the aggregate impact of monetary policy depends importantly on the regional distribution of housing equity. Furthermore, even if central banks focus only on aggregate stabilization, their actions will nevertheless have consequences which vary across space. Such regional effects may in turn be important for the design of national fiscal policy, which is often the policy instrument of choice for stabilizing regional business cycles.[2] State and other local authorities also have an obvious interest in forecasting the local consequences of monetary policy. Thus, even if central banks themselves only use regional information to more precisely estimate aggregate effects of their actions, there are still many additional reasons to understand the local implications of monetary policy.

Our analysis focuses on the distribution of equity and inequality across regions rather than across households within regions for several reasons. First, as already noted, house price movements have a very large regional component so that changes in the individual distribution of equity in our data are primarily driven by movements in MSA-level house prices. This is relevant because data on regional house price movements is more readily available at high frequencies than is data on individual equity, which makes regional distributions more practical as inputs for policy making. Second, inequality within regions is largely determined by income and wealth heterogeneity rather than by the refinancing channel of monetary policy. Third, the regional dimension is relevant because labor markets and housing markets are geographically segmented, which induces a joint distribution of equity and income that is very different than at the individual level. For example, within a region, richer households could be buying more expensive houses. But for understanding the time-varying consequences of monetary policy for consumption inequality through the refinancing channel, it matters not

[2] For example, Beraja (2017) quantifies how the US federal tax-and-transfer system helps in stabilizing regional shocks.

that average income and house prices at the individual level are highly positively correlated. Instead, it matters that this correlation changes over time, and this occurs mainly at the regional level because of geographic segmentation. Finally, we have limited information on covariates such as income and unemployment at the individual level but have much richer data for regions.

While we focus on the role of the distribution of equity across US regions for the refinancing channel of monetary policy, we believe our results apply more broadly. Variation in the distribution of other types of collateral can potentially generate many of the same implications for monetary policy. For example, industry-level shocks may change the distribution of collateral across firms and affect the response of investment to monetary policy. Our conclusions also extend beyond the US. The last decade has given rise to persistent variation in economic activity across countries within Europe, and this activity has been strongly correlated with national house price growth. While institutional features of mortgage markets differ across countries, our results suggest that the distribution of house price growth in Europe may have produced similar challenges for monetary policy during this time period.

2 Related Literature

Our work is related to much existing research. First, a vast New Keynesian literature emphasizes intertemporal substitution as the main reason why interest rate changes affect household spending.[3] We also emphasize spending responses to interest rate changes, but depart from the standard New Keynesian assumption of frictionless household capital markets with one-period borrowing. In reality, the bulk of household borrowing occurs through the mortgage market, which features collateral requirements and long-term fixed nominal payments that can only be refinanced at some cost. Together, these features give rise to what we call the "refinancing channel" of monetary policy.

Importantly, the strength of this channel depends on the distribution of housing equity in the economy, which exhibits substantial time variation in the data. This means that policy makers must pay attention to this distribution when determining the rate necessary to achieve a given level of stimulus. We thus contribute a new channel to the growing literature arguing that the economy exhibits time-varying responses to aggregate shocks, which depend on the microeconomic distribution of agents in the economy.[4] Most closely related is Berger et al. (2015) who argue that changes in the distribution of household leverage during the housing boom contributed to the large decline in spending when house prices subsequently crashed. Interestingly, we show here that these same leverage patterns then hampered monetary policy's ability to stimulate the economy in response.

We are not the first to study monetary policy transmission through the mortgage market. For example, on the theoretical side, Rubio (2011), Garriga, Kydland, and Sustek (2013) and Greenwald (2016) also study this channel. However, they assume a representative borrower and generally abstract from the costs of refinancing, in contrast to our environment, which accounts for heterogeneity, incomplete markets, and fixed costs of refinancing. This means that their models have no role for the distribution of housing equity across borrowers, which is the focus of our paper. Our focus on realistic modeling of household borrowing and how it interacts with heterogeneity in the economy parallels many of the themes in Auclert (2015), who argues that the covariance of the marginal propensity to consume with

[3] See Woodford (2003) and Galí (2009) for canonical expositions.

[4] See, e.g. Caballero and Engel (1999), Vavra (2014), Berger and Vavra (2015), and Winberry (2016).

interest rate exposure across agents matters for aggregate consumption responses to rate changes. His analysis abstracts from refinancing. We show that refinancing frictions lead to an important role for the time-varying distribution of housing equity.

Wong (2016) uses a model closer to our own, which includes borrower heterogeneity and costly refinancing but in partial equilibrium, and she focuses on how aging affects monetary policy transmission. Since the age distribution changes slowly across time, age effects are more relevant for cross-country comparisons and long-run trends than for shorter-run changes in the refinancing channel of monetary policy. Guren, Krishnamurthy, and McQuade (2017) and Hedlund et al. (2017) build general equilibrium models with heterogeneity to study how monetary policy interacts with alternative mortgage designs and housing market liquidity, respectively.

On the empirical front, Fuster and Willen (2010) measure effects of QE1 on the primary US mortgage market. They emphasize differential effects on borrowers with different creditworthiness, while we emphasize regional disparities.[5] Chen, Michaux, and Roussanov (2013) explore the link between macroeconomic uncertainty and cash-out refinancing while Bhutta and Keys (2016) show that low interest rates increase the likelihood and magnitude of home equity extraction. Calza, Monacelli, and Stracca (2013) document the importance of variation in mortgage structure across countries for monetary policy. Di Maggio et al. (2017) study the effects of ARM resets on durable consumption, following work by Fuster and Willen (2016) and Tracy and Wright (2016) that studies their effects on mortgage defaults. In subsequent work Di Maggio, Kermani, and Palmer (2016) study the response of refinancing to quantitative easing and replicate our facts at the state-level, but their focus is on the time-varying composition of Fed asset purchases and their differential effects on conforming and non-conforming loans. Agarwal et al. (2015) use data from the Home Affordable Refinancing Program (HARP) to show that refinancing spurs spending and that this channel was strengthened by the program's reduction of collateral frictions. Fratantoni and Schuh (2003) use a heterogeneous-agent VAR with regional heterogeneity in housing markets to study time variation in monetary policy passthrough. Our empirical patterns in the QE1 episode are similar to those documented by Caplin, Freeman, and Tracy (1997) for the 1990 recession based on mortgage data from a single bank. We use more representative data over a longer time period and present a model that allows us to analyze aggregate implications and counterfactuals implied by the regional equity distribution. Our results show that the refinancing channel of monetary policy varies substantially across different recessions.

Finally, a large literature studies a "credit channel" of monetary policy, where changes in collateral values amplify output responses to rate changes.[6] This channel is complementary but distinct from ours, as it arises from monetary policy changing collateral values which, in turn, affect economic activity. In contrast, we take the distribution of collateral at a point in time as given and show that it affects the transmission from interest rates to spending. We think both channels are important and exploring their interactions is an interesting area for future work.

[5] There is a growing literature specifically studying the effects of QE, but focused primarily on financial market reactions; see, for instance, Gagnon et al. (2011); Hancock and Passmore (2011); Krishnamurthy and Vissing-Jorgensen (2011, 2013); Stroebel and Taylor (2012). Chen, Cúrdia, and Ferrero (2012) study the effects of QE through the lens of a DSGE model.

[6] For example, Iacoviello (2005) shows that adding collateral constraints on housing to a financial accelerator model like that in Bernanke, Gertler, and Gilchrist (1999) amplifies the effects of rate changes. See also the related literature on the "balance-sheet" channel of monetary policy, e.g., Gertler and Karadi (2011).

3 Data

We briefly describe our primary mortgage-related data here. The Online Appendix provides additional details as well as discussion of other data used in our analysis.

Our main local refinancing measures come from Equifax's Credit Risk Insight Servicing McDash (CRISM) data set. This data set merges McDash mortgage servicing records (from Black Knight Financial Services) with credit bureau data (from Equifax) and is available beginning in 2005. The structure of the data set makes it possible to link multiple loans by the same borrower together, something that is not possible with mortgage servicing data alone. This allows us to measure refinancing activity much more accurately than what can be achieved with previous data. Since we know both the outstanding amount of the old loan (as well as any second liens) and the new loan, we can measure the dollar amount of equity removed (or "cashed out") from the home during refinancing. CRISM covers roughly two-thirds of the US mortgage market during the period we study.

We also use CRISM data to measure borrowers' home equity. We define home equity as one minus the household's combined loan-to-value (CLTV) ratio, which we estimate for each household by adding balances of first mortgages and any second liens and dividing by estimated property values. We estimate property values using appraisal values at loan origination, which we then update using location-specific house price indices from CoreLogic.[7] Our preferred summary statistic for local equity conditions is the equity of the median borrower in a location.[8] This statistic $E^{med}_{j,t}$ varies across MSAs j and time t. We particularly emphasize $E^{med}_{j,Nov2008}$: median equity in November 2008, just prior to QE1.

We supplement our analysis of refinancing activity using data from the Home Mortgage Disclosure Act (HMDA). For each application, HMDA data reports a variety of loan characteristics including loan purpose (purchase or refinance) and property location. HMDA data has broader coverage than CRISM data and covers a longer time period, which allows us to extend our analysis to the 2001 recession. However, it does not contain information on outstanding loans, which is necessary for measuring both the equity distribution and equity removed during the refinancing process. In the Online Appendix, we show that regional refinancing patterns after QE1 are nearly identical in HMDA and CRISM data.

4 The Refinancing Channel Across Regions: Evidence from QE1

This section documents several facts relating regional heterogeneity in housing equity to the refinancing channel. We use an event-study of the interest rate decline following QE1 to show:

1. Mortgage originations increased substantially after QE1, mostly driven by households refinancing existing mortgages rather than by an increase in new purchases.

2. Refinancing activity and equity extraction were higher in MSAs where homeowners had more equity (which were also locations where unemployment was lower) prior to QE1.

[7] We use zip code indices if available, and MSA-level indices if not. Additional details are provided in the Data Appendix.

[8] We compute medians weighting borrowers by outstanding mortgage balances. Repeating our analysis using the fraction of borrowers with CLTV above 0.8 or above 1 yields very similar results. This is not surprising since Appendix Figure A-1 shows that $E^{med}_{j,t}$ strongly correlates with the fraction of borrowers above these thresholds.

3. Car purchases increased the most after QE1 for individuals who removed equity when refinancing and in MSAs with the largest refinancing response.

4.1 Aggregate Trends in Mortgage Activity Around QE1

Figure 1: Mortgage Refinancing Activity in the US over 2000-2012

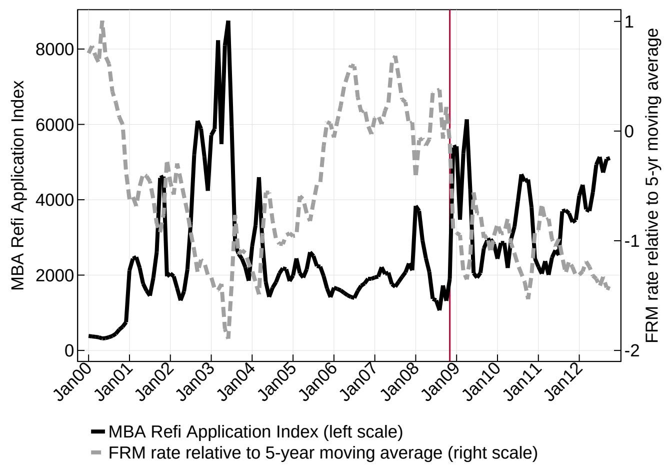


Figure shows monthly average of Mortgage Bankers Association (MBA) Refinancing Index (seasonally adjusted; March 1990=100) and the 30-year fixed-rate mortgage rate (relative to 5-year moving average), also from MBA.

Figure 1 shows the monthly Mortgage Bankers Association Refinance Index from 2000 to 2012 (solid line) as well as the difference between the average 30-year fixed-rate mortgage (FRM) rate in month t and the average of the 30-year mortgage rate over the prior five years (dashed line). Negative values mean mortgage rates in a given month are low relative to previous years, giving many borrowers an incentive to refinance. Several points stand out in Figure 1. First, there is a strong negative relationship between refinancing and mortgage rates: the correlation between the two series is -0.77. Second, mortgage rates fell and refinancing activity expanded sharply when QE1 was announced in November 2008, marked as a vertical line in the figure. We focus on QE1 because it was largely unexpected and led to such a sharp drop in mortgage rates, and because our CRISM data begins in 2005. However, the refinancing channel of monetary policy can potentially operate whenever monetary policy moves mortgage rates. While the refinancing boom after QE1 was larger than at any time since mid-2003, it was stronger still in 2001-2003 when falling rates were coupled with broad-based house price appreciation in most locations. Thus, we will often contrast the effects of the refinancing channel in 2008-2009 with the effects in 2001-2003. Finally, Appendix Figure A-2 shows that similar patterns hold in HMDA data and that the increase in mortgage originations after QE1 was almost entirely refinancing rather than new purchase mortgages. For this reason, we focus our analysis in this paper on refinancing.

4.2 Regional Variation in Equity Distributions Prior to QE1

Throughout the paper, we use metropolitan statistical areas (MSAs) as our measure of "regions".[9] We begin by showing that equity distributions evolved very differently across MSAs between 2007 and 2008. Figure 2 shows the distribution of household housing equity in two different time periods for five MSAs: Chicago, Las Vegas, Miami, Philadelphia, and Seattle. These are examples of MSAs that had house price declines from 2007 to 2008 that were large (Miami and Las Vegas), medium (Chicago), and small (Philadelphia and Seattle).[10] Panel (a) shows the housing equity distribution for these MSAs in January 2007, just prior to the nationwide house price decline. For all five MSAs, housing equity distributions are quite similar. As noted above, we often summarize the distribution in each MSA at a point in time using median equity $E^{med}_{j,t}$. In January 2007, the median household in most of these MSAs had housing equity worth between 30 and 40 percent of its house value. The median household in Las Vegas had equity that was roughly 23 percent of its house value, as house prices in Las Vegas starting falling prior to 2007. Very few households in any MSA had negative equity as of January 2007.

Figure 2: Distributions of Borrowers' Equity in their Homes across 5 MSAs

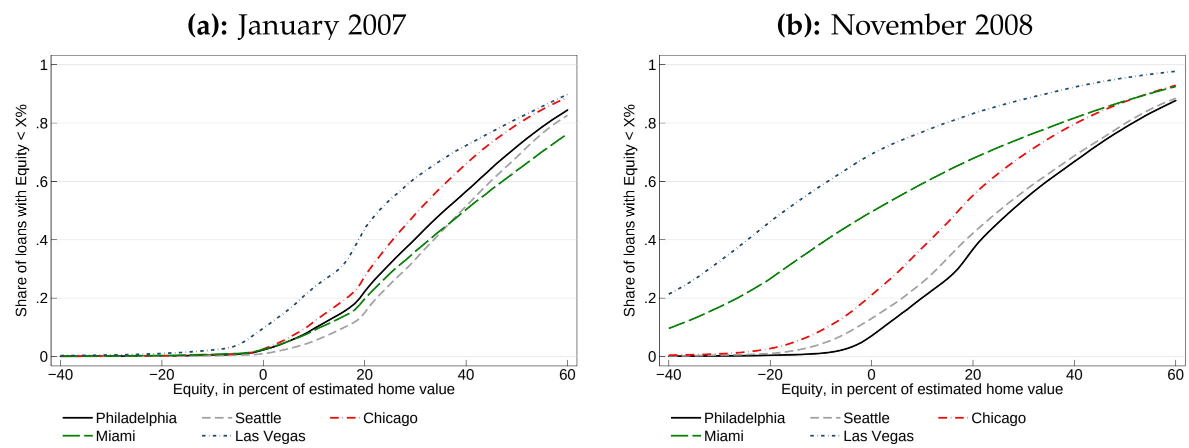


Figure shows the cumulative distribution of borrower equity in five illustrative MSAs in January 2007 and November 2008. Equity is measured for each household using CRISM data as the estimated current house value minus total current mortgage debt, divided by estimated current house value (i.e., equity $= 1-$CLTV). Distributions are weighted by mortgage balance.

Panel (b) of Figure 2 shows that by November 2008, when QE was announced, there was large variation in equity distributions across MSAs. Between early 2007 and late 2008, the equity distribution in places like Las Vegas and Miami shifted dramatically relative to places like Philadelphia and Seattle. The median household in Las Vegas had negative equity of roughly 17 percent of their house value, and the median household in Miami had zero equity. Conversely, the median households in Philadelphia and Seattle still had home equity that was roughly 25 to 30 percent of their house value. The equity of the median household correlates strongly with other measures of the equity distribution (see e.g. Appendix Figure A-1). For example, roughly 50 percent of households in Miami and 70 percent of households in Las Vegas had negative housing equity in November 2008, while only 6 to 10 percent

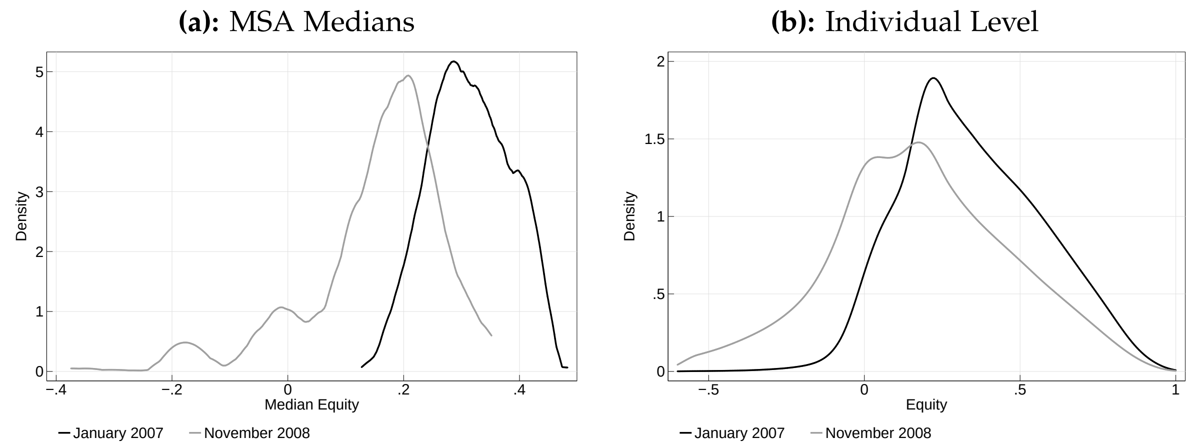
[9] While our analysis could in principle be done using zip codes, this would reduce sample sizes and covariate availability substantially. In addition, regressing zip code-level annual house price changes from 2000-2010 on MSA-level changes gives an R^2 of 0.89, so local house price changes in our period of study are mostly driven by the common MSA component.

[10] Appendix Table A-1 shows descriptive statistics for all 381 MSAs in our analysis.

had negative equity in Philadelphia and Seattle.

Panel (a) of Figure 3 shows the distribution of $E^{med}_{j,t}$ across all 381 MSAs (weighted by MSA population) in January 2007 and November 2008 to highlight that the regional heterogeneity in Figure 2 is representative. On average, equity declined sharply between early 2007 and late 2008 but these declines were not uniform across MSAs. Thus, the distribution of $E^{med}_{j,t}$ shifted sharply left and fanned out over this period. Panel (b) shows that patterns are similar for the distribution of individual equity rather than $E^{med}_{j,t}$ to illustrate that focusing on median equity is not essential for our conclusions.[11]

Figure 3: Distributions of Borrowers' Equity in their Homes — MSA Medians and Individual Level



Panel (a) shows kernel density of $E^{med}_{j,t}$ across 381 MSAs in January 2007 and November 2008; MSAs are weighted by their 2008 population. Panel (b) shows kernel density of individual borrower equity in January 2007 and November 2008; borrowers are weighted by loan amount.

Appendix Figure A-3 shows the relationship between equity, unemployment changes, and house price growth from January 2007 to November 2008.[12] Over this period, differential house price declines across MSAs were the main driver of differences in $E^{med}_{j,t}$. On average, a 10 percent decrease in house prices from January 2007 to November 2008 is associated with an 8.3 percentage point lower $E^{med}_{j,Nov2008}$. We cannot measure local equity before 2005, but this relationship between house price growth and equity allows us to use regional variation in house price growth as a proxy for regional variation in housing equity in earlier periods. Additionally, Appendix Figure A-3 documents that MSAs with the largest increases in local unemployment rates also had the lowest $E^{med}_{j,Nov2008}$. This is unsurprising since the literature has shown that house price declines were associated with weakening labor markets during this period (e.g., Charles, Hurst, and Notowidigdo, 2013; Mian and Sufi, 2014), but it is important for interpreting the inequality effects of monetary policy, since we will now show that refinancing activity responded least to QE1 in the locations with the least home equity.

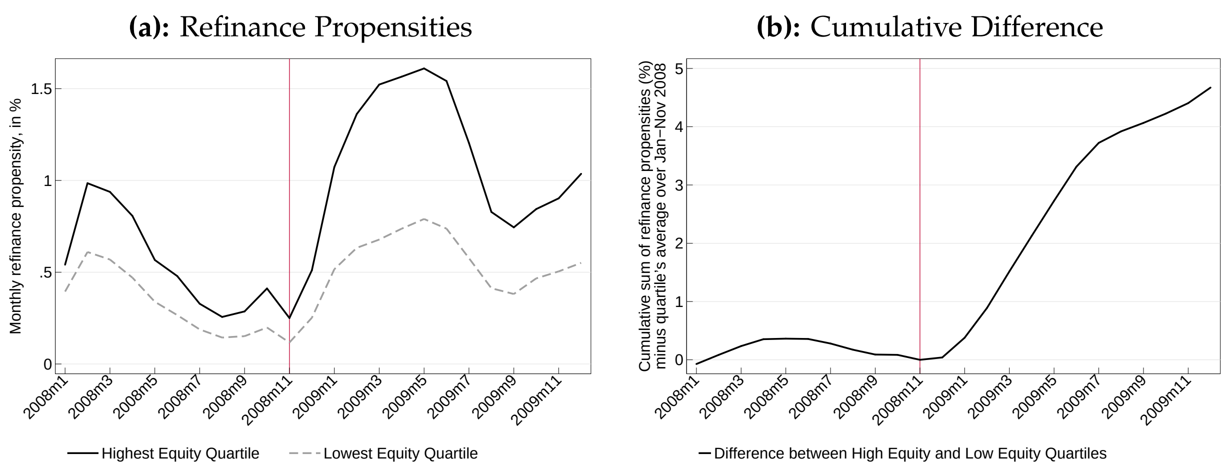
[11] Individual equity is more disperse than median equity at the MSA level because individual variation has life-cycle and other idiosyncratic components that are large relative to cross-region variation, and are less interesting for our analysis since they do not move at business cycle frequencies.

[12] Appendix Table A-2 shows correlations of $E^{med}_{j,Nov2008}$ with many other characteristics of the mortgage stock across MSAs.

4.3 Regional Variation in Mortgage Activity Around QE1

We now show that in the months after QE1 was announced, refinancing activity was much higher in regions with more home equity and lower unemployment. To facilitate the exposition of our results, we divide all MSAs into quartiles based on $E^{med}_{j,Nov2008}$.[13] Figure 4 shows refinancing activity over time for MSAs in the top and bottom quartiles of $E^{med}_{j,Nov2008}$. The bottom quartile of $E^{med}_{j,Nov2008}$ includes MSAs like Las Vegas where the median mortgage borrower was underwater. The top $E^{med}_{j,Nov2008}$ quartile includes MSAs like Seattle where most borrowers had sufficient equity to refinance.

Figure 4: Mortgage Refinance Activity 2008-2009 in Top and Bottom Quartile of MSAs Defined by Median Borrower Equity in November 2008



Panel (a) shows monthly refinance propensities in CRISM, defined as the dollar amount of refinance mortgage originations divided by outstanding mortgage amounts in the prior month. Calculations are done over MSA quartile groups for the highest and lowest $E^{med}_{Nov2008}$ quartiles. Panel (b) shows the cumulative difference between the two groups, after subtracting each group's average refinancing propensity from January to November 2008. Vertical lines show the month of the QE1 announcement (November 2008).

Panel (a) shows monthly refinancing propensities from January 2008 through December 2009. Refinancing propensities are higher throughout in the high equity quartile, but they evolve similarly between high and low equity MSAs up to November 2008. After QE1, refinancing activity jumped—but it jumped much more in the high equity MSAs relative to the low equity MSAs.[14]

Panel (b) shows the cumulative difference between the two groups, after subtracting each group's average refinancing propensity from January to November 2008 to remove the initial level difference. Prior to QE1, the cumulative difference is essentially flat at zero, reflecting the parallel pre-trend in panel (a). After QE1, a sharp difference emerges, eventually leading to a cumulative refinancing propensity about 5 percentage points larger in the high equity MSA group than in the low equity MSA group. This is a substantial difference, since the cumulative refinancing propensity in the low equity group is only 7 percent over the entire year 2009.

[13] Quartiles are population-weighted using 2008 numbers from the Census. This ensures that there are the same number of people within each quartile. Appendix A.1 lists the specific MSAs within each of the $E^{med}_{j,Nov2008}$ quartiles.

[14] The jump happens in January/February (rather than December) because CRISM measures originations, not applications, and there is a delay of 1-3 months between when a mortgage application is initially made and when the actual mortgage origination takes place. In Appendix Figure A-4, we use HMDA data with exact application dates to show that applications jumped immediately after the announcement of QE1, and more so in high equity MSAs.

While Figure 4 shows a clear difference in refinancing responses to QE1 in high and low equity MSAs, one might be concerned that this difference is driven by other factors that vary across these MSAs. We thus complement these figures with difference-in-difference style regressions which allow us to control for additional local factors and assess statistical significance. Specifically, we estimate:

$$Refi_{j,t} = \alpha_j + \alpha_t + \beta(E^{med}_{j,Nov2008} \times postQE) + \Gamma(X_{j,Nov2008} \times postQE) + \varepsilon_{j,t}, \tag{1}$$

where $Refi_{j,t}$ is the monthly refinancing propensity in each MSA over the six months prior to QE1 and the six months after QE1, α_j and α_t are MSA and time fixed effects, and $postQE$ is an indicator variable that equals one for the six months after QE1. We use February 2009 as the start of the post-QE-announcement period given the lag between mortgage applications and originations discussed above. $X_{j,Nov2008}$ is a vector of potential local controls, including changes in the unemployment rate between January 2007 and November 2008, loan characteristics (e.g., average FICO score, mortgage balances, ARM share, GSE share) in November 2008 and demographics (e.g. education and age). To conserve space, we show results in Appendix Table A-3, but some takeaways are worth noting. First, β is always positive and highly statistically significant even when including a variety of additional controls, thus reinforcing conclusions from Figure 4. Importantly, all controls are interacted with $postQE$ so that the responsiveness of refinancing to interest rates can vary with these observable characteristics, and all regressions include MSA fixed effects which absorb any permanent differences in refinancing across MSAs due to unobservables. Adding the average FICO score of mortgage borrowers (interacted with $postQE$) to the regression reduces the coefficient on equity by almost half, but average FICO scores are themselves affected by local equity (since underwater borrowers are more likely to default); therefore, we view the fact that equity remains strongly significant as underscoring its importance in explaining differences in refinancing. The same is true for the last column in the table, where we add all additional controls at once. A linear combination of these variables is very highly correlated with median equity (see the last column of Table A-2); nevertheless, equity remains individually significant.

One might also be concerned that our results could reflect relatively tighter credit supply in low equity locations in the period after QE was announced. However, consistent with the results in Hurst et al. (2016), Appendix Figure A-5 shows that there is little spatial variation in mortgage rates across MSAs, and that rates fell as much in low-equity locations as in high-equity locations after QE1. This suggests that lower refinancing rates in low equity locations are not driven by borrowers facing higher borrowing costs. This likely reflects the fact that during this time period, the mortgage market consists almost entirely of loans whose default risk is insured by GSEs, which do not vary their pricing with regional default risk (again see Hurst et al., 2016).[15]

While we focus on effects of CLTV constraints on refinancing, borrowers must also satisfy payment-to-income (PTI) constraints to refinance. During the QE1 episode, house price declines are highly correlated with increases in unemployment, so it is possible our results might be driven by PTI rather than CLTV constraints. Although it is indeed the case that conditional on local housing equity levels, MSAs with larger increases in unemployment saw moderately smaller increases in refinancing, equity effects remain independently very large. Controlling directly for income also has little effect on our

[15] In addition, in unreported results based on the HMDA data we find no evidence that rejection rates for refinancing applications evolved differentially in low equity MSAs after QE1.

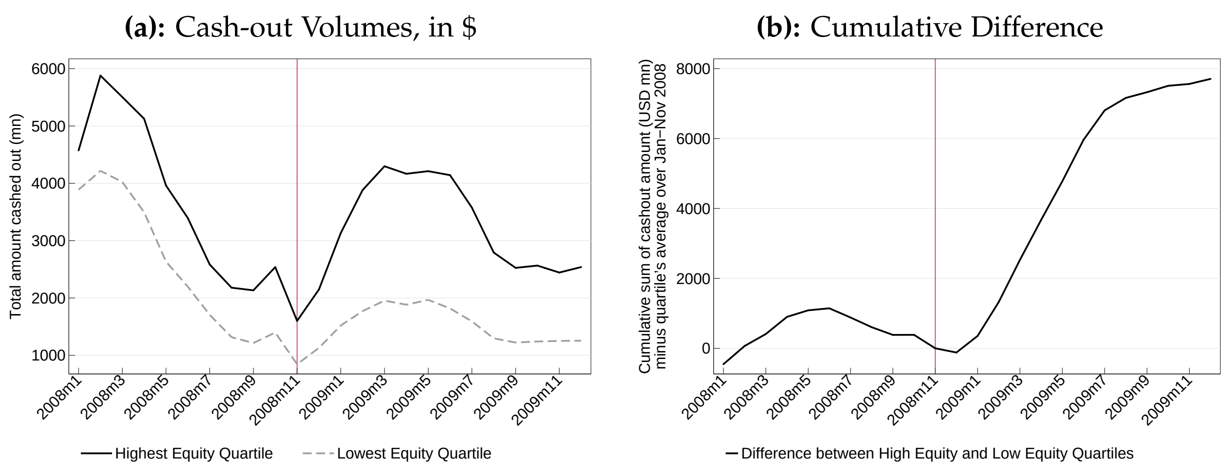
coefficient of interest. In addition, in Appendix Figure A-6, we show that the distribution of PTI for newly originated loans in 2009 is very similar in high and low equity MSAs and exhibits no bunching around institutional constraints, in contrast to striking bunching and spatial variation in the distribution of CLTVs for these same loans. This strongly suggests that our results are primarily driven by spatial variation in equity rather than by spatial variation in PTI constraints.

Collectively, the results from Figure 4 and Table A-3 show there were large regional differences in refinancing activity in response to QE1. Regions with the largest house price declines and thus the least equity were the least responsive to QE1 in terms of subsequent mortgage refinancing activity.

4.4 Regional Variation in Equity Extraction and Spending Around QE1

To what extent do these spatial differences in refinancing activity lead to differences in spending? Unfortunately, local spending data is extremely limited, but we provide evidence on this front in two ways. First, we explore the extent to which households removed equity from their home when refinancing. Prior research has shown that households typically spend a large amount of such "cash-outs" on current consumption and home improvements.[16] Second, we use R.L. Polk data on new car purchases at the MSA level as one measure of local spending, as in Mian, Rao, and Sufi (2013).

Figure 5: Cash-Out Refinancing in Top and Bottom Quartile of MSAs by Median Borrower Equity in November 2008



Panel (a) shows total cash extracted during refinancing in the top and bottom MSA quartiles by $E^{med}_{j,Nov2008}$. Panel (b) shows the cumulative difference between the two groups, after subtracting each group's average cash-out amounts from January to November 2008. Vertical lines show the month of the QE1 announcement (November 2008).

Figure 5 shows the amount of equity removed during refinancing for the top and bottom quartile MSAs by $E^{med}_{j,Nov2008}$. Panel (a) shows dollar amounts per month, while panel (b) shows the cumulative difference between the two groups, after subtracting each group's average cash-out amounts from January to November 2008.[17] The total amount of equity removed during the refinancing process sums over households who removed no equity, those who put equity into their home, and those who

[16]See Brady, Canner, and Maki (2000), Canner, Dynan, and Passmore (2002), Hurst and Stafford (2004) and Bhutta and Keys (2016).

[17]Since CRISM data does not cover the whole mortgage market, we scale up dollar amounts in CRISM for this figure; see Appendix A.2.3 for details.

extracted equity. On net, borrowers remove equity during the refinancing process in both high and low equity locations. At all points in time there is more equity removal in high equity locations, but trends evolve similarly prior to the QE1 announcement. After QE1, equity removal increases substantially in the high $E^{med}_{j,Nov2008}$ locations relative to the low $E^{med}_{j,Nov2008}$ locations.

Summing across all MSAs in the top equity quartile, about $23.7 billion of equity was cashed out during refinancing in the six months after QE1 (January-June). Conversely, for the MSAs in the bottom equity quartile, only $10.9 billion of equity was cashed out. However, some of this $12.8 billion difference reflects the continuation of differential extraction levels prior to QE1. Panel (b) shows the cumulative difference in cash-out amounts over 2009 between the two MSA groups—after subtracting each group's pre-QE averages—amounted to around $8 billion.[18]

Is an $8 billion difference in equity extraction across regions caused by QE1 a large number? Since this number comes from a cross-region calculation, which differences out any aggregate effects, it *should not* be interpreted as the effect of QE1 on aggregate equity extraction or compared to the overall size of the recession. In the second half of the paper we use a model to infer aggregate effects from our cross-region evidence, but for now it is more relevant to compare $8 billion cash-out difference to differences in the size of the recession across regions. Using BEA data we find that $8 billion is around 10% of the cross-region change in spending from 2008 to 2009.[19] This effect is both large and similar in size to effects in our model below. It is also useful to compare these numbers to various other stabilization programs. Unemployment benefit payments in 2009 totaled roughly $16 billion in the lowest equity MSAs, so $8 billion is similar in magnitude but our results show it is differentially flowing to the regions with the lowest instead of highest unemployment rates.[20] Dividing $8 billion by the number of households in the highest equity quartile implies that QE1 increased potential spending per household in those locations by roughly $280. This is similar in size to tax stimulus payments received by households in the recession, and so suggests that QE1 had cross-region effects similar to sending an extra tax rebate only to locations which were already doing relatively well.[21]

Appendix Table A-4 shows results from a regression similar to equation (1) above but with monthly equity removed (relative to outstanding balance) as the dependent variable. We refer to this variable as the cash-out fraction. Echoing the results in Figure 5, we find a positive relationship between $E^{med}_{j,Nov2008}$ and the cash-out fraction after QE1 that is highly significant and robust to a variety of additional controls. We also show that high equity places extract more equity even after conditioning on the frequency of refinancing. That is, the patterns in Figure 5 are not driven purely by the differential refinancing propensities shown in Figure 4. To show this, we add monthly refinancing propensities

[18]Our equity extraction measure does not include HELOC draws. Unlike cash-out refis, HELOC balances can be adjusted without closing costs, and interest rates are usually variable. This mutes incentives to respond to long-term rate declines. Nevertheless, our $8 billion could be overstated if high equity MSAs extract equity by refinancing while low equity MSAs do so through HELOCs. However, using quarterly FRBNY consumer credit panel data, HELOC balances grew more in high equity than low equity MSAs over 2008-2009, and differentially increased in high equity locations by roughly $4 billion after QE1. So including HELOCs would increase the differential QE effects on equity extraction to roughly $12 billion.

[19]Total GDP in low equity MSAs fell by $113.5 billion more than total GDP in high equity MSAs between 2008 and 2009. Scaling these differences by the aggregate share of consumption in GDP of 68% delivers .104=8/(.68*113.5).

[20]Unemployment benefit payments are only reported at the state-level by the Department of Labor, but we apportion state-level benefits payments to individual MSAs using each MSA's share of total state unemployment. This calculation implies the lowest equity MSAs received $16.3 billion in unemployment benefits payments in 2009 and $9.6 billion in 2008.

[21]Equity extraction is an increase in borrowing rather than a transfer, but these can be interpreted similarly under either Ricardian equivalence or in the presence of binding liquidity constraints. Repeating calculations for MSAs in the top half of the equity distribution rather than top quartile delivers $12.3 billion in differential equity extraction, or $216 per household.

over the same period as a separate explanatory variable in our regression. We find that both the coefficient on $E^{med}_{j,Nov2008} \times$ postQE and on the monthly refinancing propensity are positive and strongly significant. Hence, low $E^{med}_{j,Nov2008}$ MSAs both refinanced less and removed less equity, conditional on refinancing. This is intuitive, since these places indeed have less equity to remove when refinancing.

Figure 6: New Auto Sales in Top and Bottom Quartile of MSAs Defined by Median Borrower Equity in November 2008

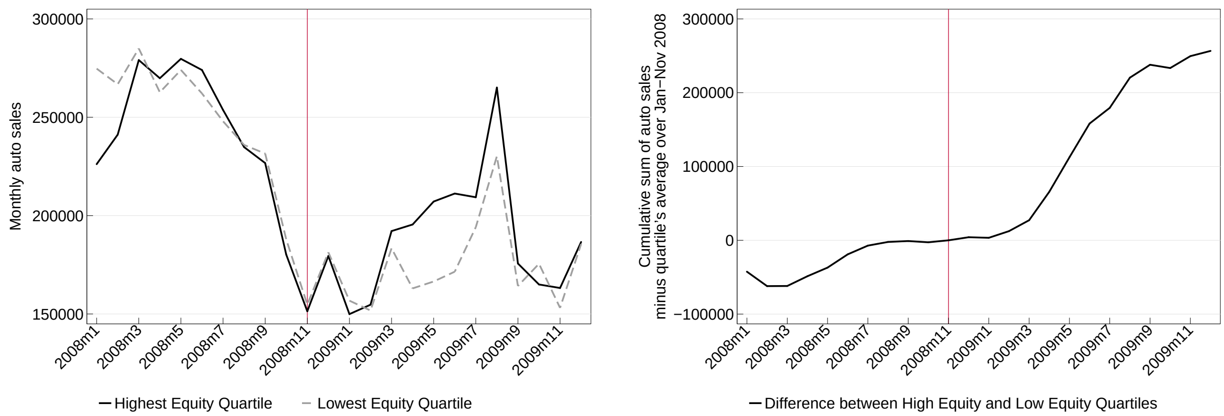


Figure shows the total volume of new car purchases in the top and bottom MSA quartiles by $E^{med}_{j,Nov2008}$ using R.L. Polk data. Panel (a) shows total monthly car purchase volumes, summed over MSAs in each quartile. Panel (b) shows cumulative differences between the two groups, after subtracting from each group's series the group's average car purchases from January to November 2008. MSA groups are the same as in Figure 4. The vertical line shows the month of QE1 announcement.

Since prior research has shown tight links between equity removal and spending, these results suggest that locations with different $E^{med}_{j,Nov2008}$ had different spending responses to QE1. We now show this is indeed the case using auto sales data from Polk. Panel (a) of Figure 6 shows total monthly auto sales in the top and bottom $E^{med}_{j,Nov2008}$ groups. A few things stand out. First, the trend in auto sales was very similar in the high and low equity quartiles prior to QE1. In both groups, new auto sales fell rapidly throughout 2008. Second, these trends remained parallel through February 2009. This is not surprising since refinancing applications that took place in December 2008 would not result in new mortgage originations until January or February 2009. Third, and most important, after February 2009, auto sales diverge sharply between the two equity groups. On average, sales increased by 31 percent in March-May 2009 relative to November 2008 in the high equity MSAs while they only increased 15 percent in the low equity MSAs. This difference is highly economically and statistically significant, and the timing lines up perfectly with expected spending responses to QE1.[22] Panel (b) shows that cumulative differences between the groups through 2009 amount to 250,000 cars, or roughly 1.5 months of sales. It is also worth noting that these differences all occur prior to the start of the Cash-for-Clunkers program in July 2009 and so are not driven by this program.[23]

[22]Appendix Table A-5 shows MSA-level regressions, similar to equation (1), but using the log of monthly new car sales as our dependent variable. β is positive and statistically significant across a variety of specifications with various controls. Furthermore, to directly test the link between refinancing, equity extraction, and auto sales, we add both refinancing and cash-out propensities as independent variables and find they are both correlated with stronger auto sales over this period.

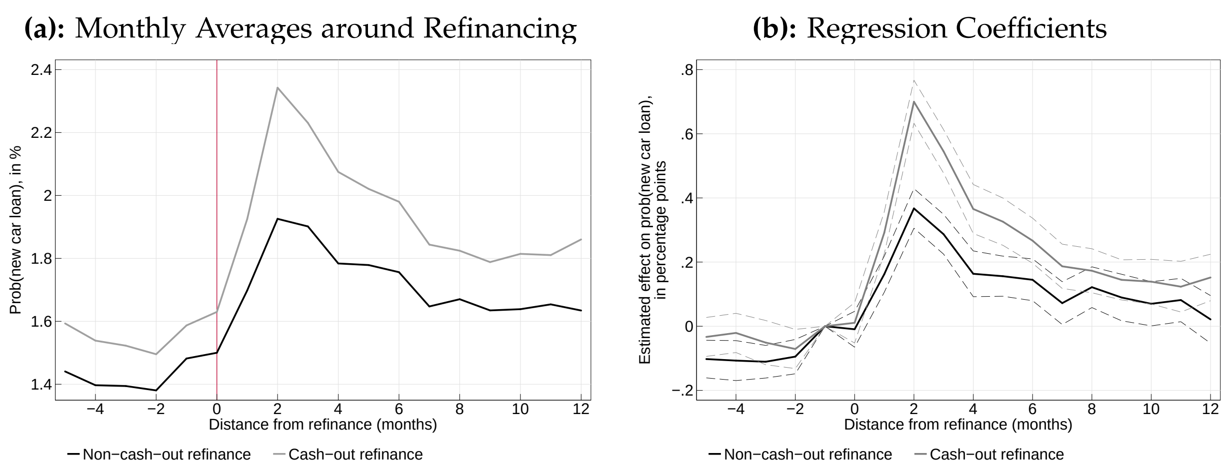
[23]The start of the program can be seen as a large spike in panel (a). Although irrelevant for our regressions with MSA fixed effects, clunker shares are actually mildly negative correlated with median equity which should imply *larger* responses to

4.4.1 Household-level Analysis of Spending after Refinancing

Of course, high and low equity MSAs differ in many ways, so that observed differences in spending following QE1 could be due to factors other than mortgage refinancing and equity withdrawal. Our spending regressions include both MSA fixed effects and long-run MSA trends to control for many differences across MSAs, so any alternative explanation would need to interact at high frequencies with our QE1 event study. However, channels aside from refinancing might satisfy this requirement. For instance, mortgages defaults were higher in low $E^{med}_{j,2008}$ MSAs, which would lower credit scores and make it more difficult to benefit from lower interest rates on car loans.

To provide direct evidence that spending effects indeed arise from refinancing, we move to CRISM data at the household level (rather than the MSA level) and study spending responses of borrowers who refinanced at some point in 2009. The credit record component of the data includes information on each borrower's monthly auto loan balances, and we follow the literature (e.g. Agarwal et al., 2015; Di Maggio, Kermani, and Palmer, 2016) in using large balance increases from one month to the next as a proxy for a car purchase.[24] We then conduct an "event study" where we look at borrowers' propensity to purchase a car in the months around refinancing. Given our earlier analysis, we are particularly interested in how spending responses differ between cash-out and non-cash-out refinances.[25]

Figure 7: Borrower-Level Evidence on Response of Car Purchase Propensity to Refinancing



Panel (a) shows average fractions of refinancing borrowers who obtain a new car loan in each month surrounding a mortgage refinancing (in month 0), distinguishing between cash-out and non-cash-out refinancing. We identify a borrower as obtaining a new car loan in month t if their car loan balance increases by \$2,000 or more between month $t-1$ and month t. Panel (b) shows coefficients on month indicators (relative to the refinancing month, with -1 as the omitted month) from a regression of the new car loan indicator on calendar-month-by-MSA fixed effects as well as months-from-refinancing indicators interacted with whether the refinancing involves cash-out. Dashed lines are 95 percent confidence intervals based on robust standard errors clustered at the MSA level. Results are based on a 50 percent sample of borrowers in CRISM who refinance in 2009.

Panel (a) of Figure 7 simply shows average car purchase propensities for borrowers in the months

cash-for-clunkers in low equity regions. (A one standard deviation increase in median equity is associated with a decrease in clunker shares by one-fifth of a standard deviation.) This correlation, together with the fact that the program pulled forward many purchases from the future, may explain why spending differences with equity disappear after July 2009.

[24] Following Agarwal et al. (2015) we use a \$2,000 threshold, but using higher cutoffs makes little difference.

[25] We call a refinancing a cash-out if, after subtracting 2 percent from the new loan to cover closing costs, the new mortgage is at least \$5,000 above the old mortgage(s). This is close to the binary indicator used by GSEs, and conclusions are not sensitive to altering the cutoff. According to this metric, 44 percent of refinances in our 2009 sample were cash-outs.

before and after completing a cash-out or non-cash-out refinance. Supporting the view that refinancing spurs spending, purchase propensities spike for both groups following the refinance, and more so for borrowers who remove equity during the process. Panel (b) shows monthly coefficients (and 95 percent confidence intervals) from a regression of the car purchase indicator on calendar-month-by-MSA fixed effects, as well as indicators of the distance in months to the time of the refinance, with month -1 as the omitted month.[26] The results show a strong increase in car purchase propensities in the months following refinancing, with a peak after two months that is almost twice as large for cash-out as for non-cash-out refinances. Effects remain positive for several months after the refinancing, and there is little pre-trend prior to refinancing. While this link from refinancing to car spending is not necessarily causal (we do not have exogenous variation in refinancing propensity at the individual level), it nevertheless supports the view that refinancing in the wake of QE1 did stimulate consumer spending, and more so if the borrower also removed equity in the process.

The results in this section suggest that QE1 raised aggregate spending by borrowers (in part by inducing them to remove equity) but that regional spending responses differed with equity at the onset of QE1. Collectively, our results show that the "refinancing channel" of monetary policy interacts with the regional distribution of housing equity and that the 2008 distribution reduced the effectiveness of monetary policy by preventing it from stimulating places which needed it most.

5 The Time-Varying Refinancing Channel in the US

In this section, we first show that there is substantial time-variation in the regional distribution of house price growth and its correlation with unemployment changes. We then focus on the 2001 recession, which exhibits house price patterns most distinct from 2008. We show that this recession also has very different refinancing patterns. Together these results provide evidence that the time-varying regional equity distribution produces time-varying effects of monetary policy through the refinancing channel.

Since CRISM data begins in 2005, we cannot construct the housing equity data necessary to simply replicate our prior analysis in earlier recessions. However, as noted in Section 4.2, house price changes and housing equity are strongly correlated in this recession. Motivated by this relationship, we now show that the regional distribution of house price growth varies substantially across time. Panel (a) of Figure 8 shows average real house price growth across states in CoreLogic data from 1976-2013.[27]

While the large house price declines in the Great Recession stand out, there is substantial variation across time. During the 2001 recession, real house prices were growing rather than falling, and house price declines in the previous three recessions were mild. Panel (b) plots the standard deviation of house price growth across states in each year. Clearly, spatial variation in house price growth was unusually high in the late 80s and in the Great Recession and unusually low during the 2001 recession.

Finally, panel (c) explores relationships between state-level unemployment and house price growth, a moment that will be particularly important for determining monetary policy implications for regional inequality. In particular, we run a regression of one-year house price growth on state-level one-year changes in unemployment (in percentage points) interacted with annual dummies for each year from

[26] One can alternatively implement this regression with borrower and month fixed effects, and results are very similar.

[27] State-level house prices are deflated using the CPI-U and are population weighted. We concentrate on the state-level rather than MSA-level distribution of house price growth, since MSA-level labor market data is only available starting in 1990, but patterns at the MSA (and zip code) level are similar for the mean and standard deviation.

Figure 8: Changes in Distribution of House Price Changes Across Time

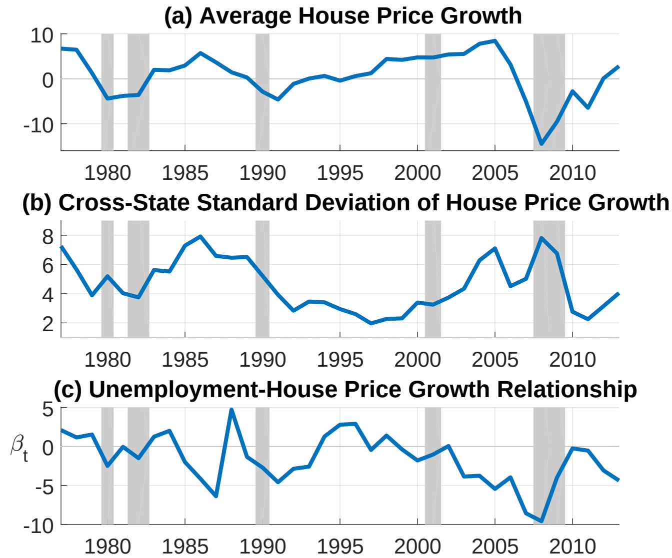


Figure shows time-series of the mean and standard deviation of state-level annual house price growth and of the cross-state relationship between house price growth and unemployment rate changes. Calculations are population weighted by state.

1976-2013 and including year and MSA fixed effects so that the results are not driven by slow moving state-level trends or aggregate unemployment changes or house price growth:

$$\Delta \log HP_{i,t} = \alpha + \beta_t \Delta UR_{i,t} + \gamma_t + \zeta_i + \epsilon_{i,t} \tag{2}$$

β_t then measures the comovement between house prices and unemployment in the cross-section each year. Panel (c) shows that in the Great Recession, unemployment and house price growth were unusually negatively correlated. Again, these patterns vary across time. In the 2001 and 80s recessions there was basically no relationship between unemployment and house price growth.

In the following section we build a theoretical model consistent with these time-series patterns and show they imply important time-varying consequences of monetary policy. Supporting these conclusions, Figure 9 illustrates that the pass-through of monetary policy through the mortgage market was much stronger in the 2001 recession than in the 2008 recession and that regional effects were also very different. Panel (a) shows the times-series of monthly refinancing propensities in HMDA for the lowest and highest unemployment quartile MSAs during the 2008 recession.[28] MSAs are sorted into quartiles based on the total increase in unemployment from November 2007 to October 2009; the top (bottom) quartile experienced unemployment increases of 6.3 percent or more (3.8 percent or less) over this period.[29] Given the high correlation between unemployment changes and house price changes, the unemployment results in panel (a) are very similar to those shown for equity quartiles in Figure 4.

Panel (b) shows time-series patterns for monthly refinancing by unemployment quartiles during the 2001 recession. The sorting is again done by total increases in unemployment over this period; for the top (bottom) quartile the unemployment rate increased by 2.5 percent or more (1.6 percent or less). The

[28]Since CRISM data starts in 2005 we must use HMDA data for this analysis.

[29]These periods match turning points in the overall seasonally adjusted US civilian unemployment rate. In the earlier episode, national unemployment increased from a low of 3.9 percent in December 2000 to a high of 6.3 percent in June 2003. In the latter episode, unemployment increased from 4.7 percent in November 2007 to 10.0 percent in October 2009.

Figure 9: Refinancing Propensities for High and Low Unemployment Change Quartiles, 2008 Recession and 2001 Recession

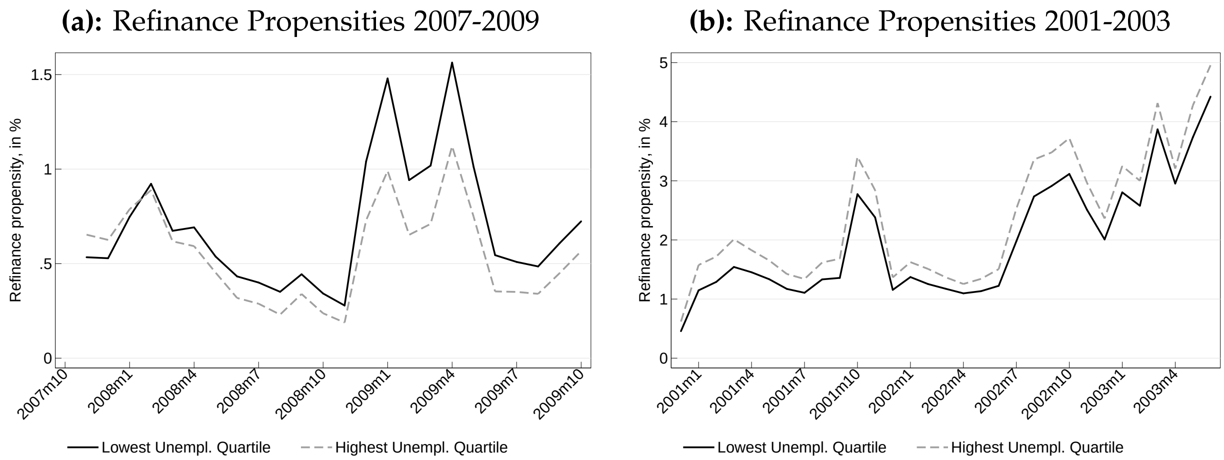


Figure shows monthly refinancing propensities for the top and bottom quartiles of MSAs by unemployment changes. Specifically, for each MSA we compute the change in unemployment between November 2007 and October 2009 (panel a) and December 2000 to June 2003 (panel b). Each MSA is placed into quartiles based on this measure. The quartiles are defined such that there is equal population in each quartile. Refinancing propensities are computed using HMDA data on origination volumes (by month of the loan application) divided by the total number of mortgages in MSA quartiles from the American Community Survey in 2008 (panel a) or 2000 (panel b).

results are very different from those shown in panel (a): during the entire period, refinancing volumes were higher in the MSAs with more rapidly rising unemployment.[30] Overall refinancing propensities were also dramatically higher in this earlier episode, when house prices were growing rather than shrinking (especially between mid-2002 and mid-2003). While there was no single monetary policy "event" during this period, as the federal funds rate instead declined gradually, it is evident from Figure 1 that overall mortgage rate declines relative to recent levels were similar in 2001-2003 and 2007-2009. The fact that the incentive to refinance in terms of lower mortgage rates was similar during both recessions but refinancing activity was much higher in 2001-2003 is consistent with the fact that household equity was much higher during this period.

6 A Model of Regional Heterogeneity and Monetary Policy

In this section, we move to a theoretical analysis of the interaction between monetary policy and regional heterogeneity that can be used to interpret our cross-region empirical results. Our goal is to clarify how the regional equity distribution affects transmission from interest rate cuts to both local and aggregate spending through the refinancing channel. The equity distribution is time-varying, and we argue that this leads to certain situations where expansive monetary policy provides the least stimulus to the places that need it most and thus faces a trade-off between stimulating aggregate spending and

[30] Chen, Michaux, and Roussanov (2013) similarly find that over 1993-2009, refinancing activity was relatively higher in states with worse economic conditions (after controlling for aggregate conditions or including quarter fixed effects). Avery et al. (2011) compare refinance propensities in 2003 and 2010 based on credit records and note the much lower propensities in the latter year; while these data do not allow one to measure borrower equity, state-level differences in propensities are consistent with lack of equity being an important impediment to refinancing in 2010.

increasing regional consumption inequality. Our model includes many realistic features of mortgage markets, including equilibrium effects between borrowers and lenders but is intentionally stylized in many other dimensions, as the goal is to transparently illustrate how the refinancing channel of monetary policy interacts with the regional distribution of equity. Embedding our framework into a richer DSGE structure might produce more realistic numerical results but would complicate the analysis in a way that obscures the interaction between interest rates and local equity. More importantly, as discussed in Section 8.5, complicating the analysis in this way would only amplify our conclusions.

The starting point is a standard consumption-savings model with income shocks and borrowing constraints as in Huggett (1993). To this standard framework, we add housing and mortgages. Houses are subject to stochastic regional house price shocks, and agents can borrow against the value of their homes using fixed-rate mortgages that can be refinanced by paying a fixed cost. We account for equilibrium interactions between borrowers and lenders by assuming that mortgage payments are received by lenders in the economy who potentially adjust consumption when borrowers refinance.

6.1 Model Description

Environment. The economy is populated by a continuum of infinitely-lived households, indexed by i and located in region $j = 1, 2, ..., J$, and a representative lender.

Idiosyncratic Earnings. In each period t, household's nominal earnings are given by y_t^{ij}, which follows a random walk with drift,

$$log(y_t^{ij}) = \mu_y^j + log(y_{t-1}^{ij}) + \varepsilon_t^{ij}$$

with region-specific income drift μ_y^j and mean zero income shock ε_t^{ij}, which is i.i.d. over time but possibly correlated both across and within regions.

Assets and Liabilities. Households have access to a risk-free nominal asset a_t^{ij} paying nominal interest rate r_t, with a no-borrowing constraint $a_t^{ij} \geq 0$. They are endowed with one unit of housing with nominal price q_t^j, which can be used as collateral for mortgage borrowing. House prices follow a random walk with drift,

$$log(q_t^j) = \mu_q^j + log(q_{t-1}^j) + \nu_t^j$$

where μ_q^j is region-specific trend house price growth and ν_t^j is a mean zero individual house price shock that is i.i.d. over time but is perfectly correlated within a region.

We assume that both earnings and house prices are random walks for two reasons. The first is computational: it allows us to reduce the state space, as we show in Appendix A.3. The second is because it simplifies aggregation: households can be collected into regions and aggregated in a straightforward manner without adding additional state variables because aggregate, regional, and idiosyncratic household shocks enter symmetrically in the problem.

Since our empirical evidence focuses on refinancing for non-moving households, we assume for simplicity that agents cannot buy or sell houses and that mortgage debt is of infinite maturity. Nominal mortgage debt requires a constant mortgage payment $r_{\tau_0}^m m_{\tau_0}^{ij}$ every period, which is determined at the moment of debt issuance τ_0. However, households can refinance their mortgage at any time $\tau > \tau_0$

by paying a fixed monetary cost $F^{ij}_\tau q^j_\tau$.[31] We assume that F^{ij}_t is an i.i.d. stochastic process that is uncorrelated with house prices or income in order to generate heterogeneity in refinancing decisions conditional on other household states and thus better fit the data, but our conclusions are similar if this randomness is eliminated.

When refinancing, households lock in the current nominal interest rate r^m_τ and future mortgage payments $r^m_\tau m^{ij}_\tau$. Furthermore, we assume that when refinancing, households always borrow up to the maximum amount allowed by the loan-to-value requirement γ. This simplifies the household decision problem and computations in our benchmark model, but we show in Section 8.2 that relaxing this assumption has little effect on our conclusions. This implies that the new mortgage balance is $m^{ij}_\tau = \gamma q^j_\tau$ and that cashed-out equity is $m^{ij}_\tau - m^{ij}_{\tau_0}$. These borrowing constraints capture the primary features of fixed-rate mortgages with options to refinance common in the US. Finally, we assume nominal interest rates $\{r_t, r^m_t\}$ follow an exogenous Markov process, which we discuss in the calibration.

Household Problem. For notational clarity, we drop agent and region indices ij when describing the household problem. We start by describing how households' sequential budget constraints at time t depend on refinancing decisions and then formally state the household problem and value function.

In a period where the household does not refinance, the sequential budget constraint is

$$p_t c_t + a_{t+1} \leq a_t(1 + r_t) + y_t - \gamma r^m_{\tau_0} q_{\tau_0}$$

where c_t is period t real consumption and p_t is the price level. In a period where the household refinances, the sequential budget constraint is

$$p_t c_t + a_{t+1} \leq a_t(1 + r_t) + y_t - \gamma r^m_t q_t + \gamma(q_t - q_{\tau_0}) - F_t q_t$$

In order to state the household problem recursively, we first express all variables relative to house prices. In particular, define $\tilde{x}_t = \frac{q_{\tau_0}}{q_t}$ as the inverse of household accumulated equity and $\{\tilde{a}_t, \tilde{y}_t, \tilde{p}_t\}$ as real assets, real earnings, and real consumption good prices in terms of house prices. Furthermore, in order to bound the value function and ensure real variables have a well-defined stationary distribution, we exogenously bound $\tilde{y}$ between $[\underline{y}, \bar{y}]$, and assume earnings and house prices grow on average at identical rates (i.e., $\mu_y = \mu_q$). Finally, as with nominal interest rates, we assume $\tilde{p}_t$ follows an exogenous Markov process which is possibly correlated with local house prices and earnings but grows on average at rate π.

Then, the value function of a household with assets $\tilde{a}$, earnings $\tilde{y}$, accumulated equity $\tilde{x}$, mortgage rate and balance $\{r^m_0, \gamma\tilde{x}\}$, and facing prices $\tilde{p}$, current nominal mortgage rate r^m, nominal interest rate r, and fixed cost F can be written recursively as,

$$V(\tilde{a}, \tilde{y}, \tilde{x}, r^m_0, r^m, r, F, \tilde{p}) = \max\{V^{norefi}(\tilde{a}, \tilde{y}, \tilde{x}, r^m_0, r^m, r, F, \tilde{p}), V^{refi}(\tilde{a}, \tilde{y}, \tilde{x}, r^m, r, F, \tilde{p})\}$$

$$V^{norefi}(\tilde{a}, \tilde{y}, \tilde{x}, r^m_0, r^m, r, F, \tilde{p}) = \max_{\{\hat{a}', c\}} u(c) + \beta \mathbb{E}[V(\hat{a}' \frac{\tilde{x}'}{\tilde{x}}, \tilde{y}', \tilde{x}', r^m_0, r^{m'}, r', F', \tilde{p}'))|(\tilde{y}, \tilde{x}, r^m, r, F, \tilde{p})]$$

$$s.t. \quad \tilde{p}c + \hat{a}' \leq \tilde{a}(1 + r) + \tilde{y} - \gamma r^m_0 \tilde{x}$$

[31] We assume the fixed cost is proportional to current house prices so that these costs remain relevant in the presence of house price growth and because this is necessary to make the household value function homogeneous in house prices.

$$
\begin{aligned}
&\hat{a}' \geq 0, c \geq 0 \\
&log(\tilde{x}') = -\mu_q + log(\tilde{x}) - \nu \\
&log(\tilde{y}') = \mu_y - \mu_q + log(\tilde{y}) + \varepsilon - \nu
\end{aligned}
$$

$$
\begin{aligned}
V^{refi}(\tilde{a}, \tilde{y}, \tilde{x}, r^m, r, F, \tilde{p}) &= \max_{\{\hat{a}', c\}} u(c) + \beta \mathbb{E}[V(\hat{a}' \frac{\tilde{x}'}{\tilde{x}}, \tilde{y}', \frac{\tilde{x}'}{\tilde{x}}, r^m, r^{m'}, r', F', \tilde{p}'))|(\tilde{y}, \tilde{x}, r^m, r, F, \tilde{p})] \\
s.t. \quad & \tilde{p}c + \hat{a}' \leq \tilde{a}(1+r) + \tilde{y} - \gamma r^m + \gamma(1 - \tilde{x}) - F \\
& \hat{a}' \geq 0, c \geq 0 \\
& log(\tilde{x}') = -\mu_q + log(\tilde{x}) - \nu \\
& log(\tilde{y}') = \mu_y - \mu_q + log(\tilde{y}) + \varepsilon - \nu
\end{aligned}
$$

Inspecting this problem, we can see the household's incentives to refinance. When the current interest rate r^m is below the rate when the household last refinanced r^m_0, the household can secure a permanently lower mortgage payment, even if house prices are unchanged. When the current house price is above the price when the household last refinanced, the household can refinance to cash-out accumulated equity $\frac{1}{\tilde{x}_t}$ even if rates have not changed, but then faces greater future mortgage payments. Furthermore, when $\mu_q > 0$, households accumulate equity, on average, when not refinancing. Once enough time has passed to acquire substantial equity, it is optimal to refinance and cash out this equity. This logic is typical of fixed adjustment cost models, where inaction is optimal until the state changes enough to justify paying the fixed cost. These models are often stylized enough that the state-space is one-dimensional with optimal policies characterized by a single adjustment "threshold." This is not true in our setup since we have a richer state-space, with a state (assets $\tilde{a}_t$) evolving endogenously when not refinancing. Numerical solutions nevertheless yield refinancing decisions characterized by threshold equity levels, which depend on assets, income, fixed costs, and interest rates.

Finally, in order to characterize policy functions numerically, it is helpful to eliminate a state variable. By assuming that households period utility function is $u(c_t) = \frac{c_t^{1-\sigma}}{1-\sigma}$ with $\sigma \geq 1$ and $\tilde{p}$ is a random walk with a drift, we show in Appendix A.3 that we can eliminate $\tilde{p}$ as a state variable because the value function is homogenous of degree $\sigma - 1$ in $\tilde{p}$. We denote this transformed value function $J(\tilde{a}, \tilde{y}, \tilde{x}, r^m_0, r^m, r, F)$. Appendix A.3 also provides a detailed description of our computational procedure. In practice, because we wish to compute aggregate consumption as well as its cross-regional variance, we need $\tilde{p}$ to have a well-defined stationary distribution. As such, we assume that consumption good prices are proportional to local house prices, implying that $\tilde{p}$ grows at a constant rate $\pi - \mu_q$ and $\tilde{c}$ can be interpreted as real consumption.[32]

Mortgage Lenders. We introduce mortgage lenders because we are interested in computing aggregate consumption responses to changes in interest rates. If we ignored lenders when computing aggregate consumption, we would potentially miss important offsetting equilibrium effects. For example, when borrowers refinance after a decline in interest rates, the dividends accruing to lenders decrease, which should reduce their consumption (see Greenwald, 2016).

However, a large fraction of mortgage debt is ultimately held by foreign lenders, and we do not

[32] While we make this assumption mainly for simplicity and convenience, Stroebel and Vavra (2016) show that local retail prices indeed respond strongly to changes in local house prices. As an alternative, we have also performed all our computations by exogenously bounding $\tilde{p}$ and our quantitative results are almost identical.

want to count changes in their consumption as offsets against the consumption of domestic borrowers. Thus, we assume that mortgage debt is paid into a mutual fund and that share θ of this fund is held by a representative US lender while share $1-\theta$ is held by foreign lenders (e.g., Chinese investors). This means that the representative lender ultimately holds a fixed fraction θ of outstanding mortgage debt. For simplicity, we assume the representative lender is a permanent income consumer and receives certain dividend payments d from the mutual fund (a consequence of a law of large numbers for households). Given a law of motion for dividends $d' = \tilde{G}(.)$, the lender's value function is:[33]

$$
\begin{aligned}
V_R(a_R, d, r) &= \max_{c_R, a'_R} u(c_R) + \beta_R V(a'_R, d', r') \\
s.t. \quad c_R + a'_R &\leq a_R(1+r)e^{-\pi} + \theta d \\
c_R &\geq 0
\end{aligned}
$$

Recursive Equilibrium Definition. A Recursive Equilibrium is an initial distribution S for $\{\tilde{a}, \tilde{y}, \tilde{x}, r_0^m, F\}$ across households i in regions j; initial lender assets a_R^0; a law of motion for d', r^m and r; value functions $J(\tilde{a}, \tilde{y}, \tilde{x}, r_0^m, r^m, r, F), V_R(a_R, d, r)$; and policy functions $\left[\hat{a}', \tilde{c}, \tilde{x}, \mathbb{I}^{refi}\right](\tilde{a}, \tilde{y}, \tilde{x}, r_0^m, r^m, r, F)$ and $[a'_R, c_R]\,(a_R, d)$ such that

1. The policy functions solve households' and lender's problems.
2. For all realizations of $\{\tilde{y}_t(i,j), \tilde{x}_t(i,j), F_t(i,j), r_t^m, r_t\}_{t=0}^{\infty}$ across households and regions (i,j), the law of motion for dividends $G(S, r^m, r)$ implied by the policy functions is equal to the perceived law of motion by lenders $\tilde{G}(.)$ and satisfies

$$
d_t = \int \left[(1 - \mathbb{I}_t^{refi}(i,j))\gamma r_{0,t}^m(i,j)\tilde{x}_t(i,j) + \mathbb{I}_t^{refi}(i,j)\left(\gamma r_t^m + F_t(i,j) - \gamma(1 - \tilde{x}_t(i,j))\right)\right] didj
$$

This equilibrium definition does not impose market clearing on the asset and consumption market because we take interest rates, goods and house prices, and income as exogenously determined. However, we assume the mortgage market clears by introducing the representative lender.[34] Finally, a region in this economy is defined as a collection of households that experience common shocks to house prices and income. Aggregates are simply obtained by adding up all regions.

6.2 Calibration Strategy

The model is annual and most parameters are standard. As is common in the risk-sharing literature, we set $\sigma = 2$ to generate an intertemporal elasticity of substitution of $1/2$. We assume a constant nominal risk-free rate $r = 0.03$, inflation rate of $\pi = .02$ and set $\beta = 0.95$. For simplicity, we set $\beta_R = \frac{1}{1+r}e^{-\pi}$ so that lenders perfectly smooth consumption. For our baseline results, we assume the nominal mortgage rate is constant at $r^m = 0.06$ and then show the response to a one-time, unanticipated permanent decline to $r^m = 0.05$, which roughly matches 30-year fixed rates before and after QE1.

[33] The law of motion is determined in equilibrium as a function of the refinancing decisions of all households. Since we do not endogenize interest rates, this is straightforward since we can calculate the present value response of dividends to a decline in interest rates entirely from the borrower side and then separately calculate lender consumption responses.

[34] One can interpret this as a partial equilibrium or as a small open economy with a fixed exchange rate, where interest rates and prices are determined internationally.

This specification illustrates effects transparently in the simplest possible environment and facilitates numerical calculations, since it eliminates r^m expectations from the value function. In Section 8 we instead assume that r^m follows an AR process and show that this delivers very similar quantitative conclusions. We set $\gamma = 0.8$, so that new mortgages require 20 percent equity and $\theta = 0.5$ to account for the substantial fraction of US mortgage debt held abroad, either directly (about 20 percent in 2008 Flow of Funds data) or indirectly through ownership of other institutions (such as banks) that hold mortgage debt. We show robustness to this assumption in Section 8.

Following Kaplan and Violante (2010), income shocks are normally distributed with standard deviation of 0.1 to match earnings changes in PSID data. This is the total standard deviation of household income, but some portion of income is common to households in a region. The standard deviation of this common component is set to 0.025, to match our regional data.[35] As described above, trend income and house price growth are assumed identical. We calibrate house prices to match the annual growth rate and standard deviation of nominal MSA house price changes from 1990-2014 in CoreLogic data of 0.025 and 0.065. We assume that in the stochastic steady-state, shocks to house prices and income are independent. This independence *on average* is assumed when households make their policy decisions, but one of the primary questions we explore in our model is how particular realizations of shocks affect the consequences of monetary policy. During the Great Recession, house prices fell substantially on average but there were substantial differences across regions, which were highly correlated with income changes. Since our empirical evidence is drawn from this period, we calibrate the remaining parameters of the model to match the distribution of house prices and income in 2008 and the refinancing responses across regions following QE1. We call this calibration our *baseline* economy.

More specifically, to construct our baseline economy, we initialize the model from the stochastic steady-state, but in period t, we hit the economy with the aggregate house price decline of 12.5% observed in 2008. Households are also hit with an additional regional house price shock which can take the value -12.5%, 0%, +12.5% so that 1/3 of regions experience a total house price decline of 25%, 1/3 experience a decline of 12.5% and 1/3 experience no decline. The 25% decline is picked to match the house price decline for the lowest housing equity quartile in our empirical analysis, while the 0% change matches that in the highest housing equity quartile. This means regions in our model can be mapped directly to those in our empirical analysis. Similarly, we calibrate regions so they differ by -2SD, 0 and +2SD of the regional income shock. If these income shocks were uncorrelated with house prices our simulated economy would have 9 regions, representing the 3x3 combinations of house price and income shocks. However, we instead assume regional house price and income shocks are perfectly correlated in our baseline model to match the very high correlation in the Great Recession. This means our baseline economy effectively has three regions: relatively high house price and income, middle house price and income and low house price and income.

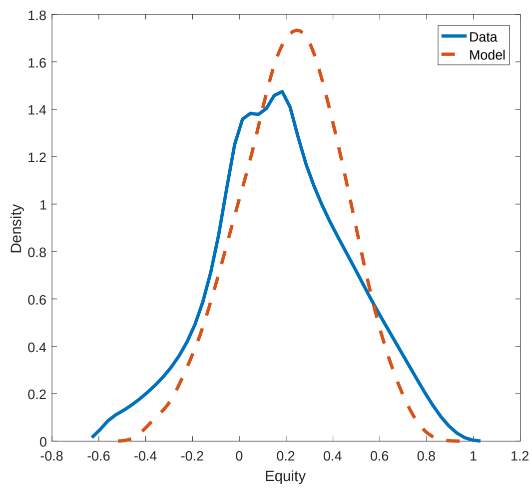
Finally, the fixed cost process is calibrated to match the regional responses to mortgage rate reductions under QE1. In particular, we assume that each household draws an i.i.d. fixed cost each period that can take on either a high or a low value and pick the levels of the high and low fixed costs and their relative probabilities to target a monthly refinancing rate just prior to QE1 of 0.0025, an increase in the refinancing rate of 0.0025 in the lowest house price region, an increase of 0.0075 in the middle

[35] Under the random walk assumption, idiosyncratic and regional income shocks enter identically in the value function and so total income is the only state. Regional income shares affect regional but not aggregate impulse responses.

house price region, and an increase of 0.011 in the highest house price region.

We calibrate to the 2008 period rather than the stochastic steady-state for several reasons. First, this is the period for which we have strong empirical evidence on the distribution of house price changes, income and refinancing responses from our QE1 event study. Second, our loan level data starts in 2005. It is unclear that any year over the housing boom-bust represents a "normal" steady-state period. Furthermore, by design, monetary stimulus is correlated with recessions and so any empirical evidence on the effects of interest rate reductions is going to come from periods with negative aggregate conditions. That is, any empirical measure of refinancing elasticities to interest rate reductions will always be primarily identified from recession periods; therefore, we explicitly target this elasticity during such a period in the model. Finally, we focus on the elasticity of refinancing to interest rate reductions across regions rather than aggregate changes in refinancing since aggregate relationships may be contaminated by other confounding unmodeled aggregate shocks.

Figure 10: 2008 Household Equity Distribution: Model vs. Data



This figure compares the household level density of equity in 2008 with no reduction in interest rates to the empirical distribution just prior to QE1 in November 2008.

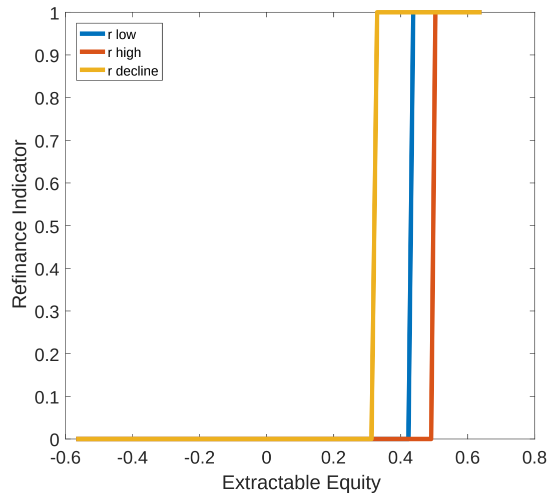
Figure 10 shows that although not directly targeted by our calibration, the household level distribution of equity in the 2008 calibration of the model is a good fit to the empirical distribution shown in Figure 3. While it would be desirable to also compare model and data relationships between home equity, financial assets and consumption at either the household or regional level, unfortunately, the empirical data necessary to make these comparisons does not exist. Nevertheless, we view the model fit in Figure 10 as well as the fact shown below that the model reproduces cross-region refinancing patterns before and after QE1 as a reassuring check on its quantitative usefulness.

6.3 Theoretical Results in the 2008 Baseline Economy

Figure 11 shows the threshold property for refinancing decisions in a stationary environment with permanently high or low mortgage rates for a household with median income and assets, as well as in a non-stationary environment right after a permanent mortgage rate decline.[36] The refinancing equity threshold is lower when mortgage rates are permanently low than when they are permanently

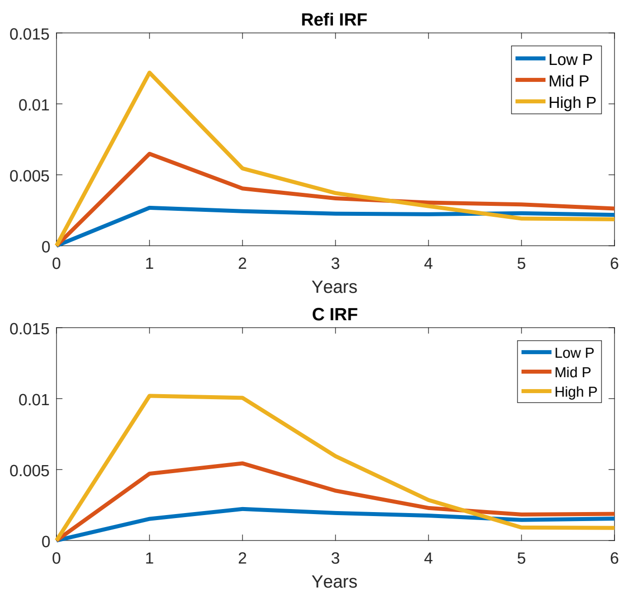
[36] Since households cannot sell housing, extractable equity is all equity above the fraction $1-\gamma$ required when refinancing.

Figure 11: Refinance Decision Follows a Threshold Policy



high, leading to more frequent refinancing. More importantly, right after a mortgage rate decline, households refinance at even lower levels of equity. Intuitively, refinancing is more frequent in an economy with low mortgage rates because the cost of borrowing—future mortgage payments—is lower while the benefit—equity cash-out net of fixed costs—is independent of mortgage rates.[37]

Figure 12: Response to Interest Decline by Region

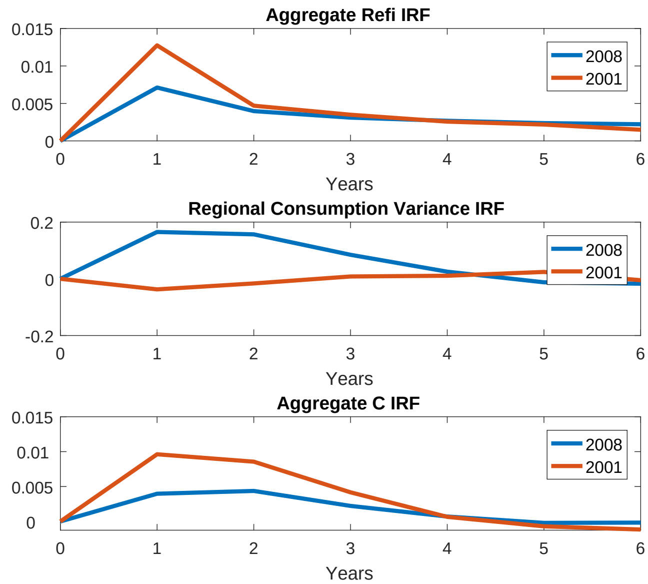


For the baseline 2008 calibration, the refinancing impulse response function (IRF) shows the change in the monthly fraction of households refinancing in response to a one percentage point reduction in mortgage rates. The consumption (C) IRF shows the change in log consumption in response to the same one percentage point reduction in mortgage rates.

Figure 12 shows the impulse response of each region to a decline in mortgage rates from 0.06 to 0.05 in the baseline economy which matches economic conditions in 2008. The top panel shows the change in the fraction of loans refinancing at a monthly rate. By construction, this matches the changes

[37] Appendix Figure A-8 shows how the refinancing threshold changes with assets and earnings. The threshold is generally increasing in each. Intuitively, the marginal utility of an extra unit of resources coming from equity extraction is higher when current assets or earnings are lower, making households want to refinance more often at lower equity levels.

Figure 13: Aggregate Stimulus vs. Regional Inequality in 2008 and 2001



Impulse response functions show the change in the monthly fraction of households refinancing, log aggregate consumption and log consumption variance across regions in response to a one percentage point reduction in mortgage rates. See text for the description of the baseline economy calibrated to match November 2008 as well as the model specification for the 2001 recession.

in Figure 4, since the model is calibrated to hit these numbers. Just as in the data, regions with high equity are more likely to refinance in response to the decline in rates. The bottom panel shows that real consumption also responds more in high equity regions. While we do not have broad consumption data at the regional level, this is consistent with empirical patterns for auto spending in Figure 6.

We next compute aggregate consumption and the variance of log consumption across regions. The blue lines in Figure 13 show responses to the decline in mortgage rates in our 2008 baseline economy and give our first important theoretical result: a reduction in interest rates increases aggregate consumption but also increases the variance of consumption across regions. This increase in variance occurs because consumption increases most in regions with high house prices. Since house prices and income are correlated in this economy, these regions already have the highest income and consumption before the interest rate declines. Thus, while monetary policy increases overall consumption, it does so mainly by stimulating consumption in locations that are already doing relatively well.

This trade-off between aggregate stimulus and inequality is strongly suggested by our empirical results showing a strong correlation between house prices, income, refinancing and auto spending around QE, but the model addresses the concern that 1) our empirical results measure only cross-region effects on borrowers and not offsetting aggregate effects from lenders and 2) we do not have comprehensive empirical measures of regional consumption. Despite these potential concerns, our model nevertheless implies that under economic conditions in 2008, rate declines modestly increased aggregate consumption but that these benefits flowed most strongly to regions doing relatively well. There are two reasons that declines in lender consumption do not fully offset aggregate borrower effects. First, some mortgage debt is owned by foreign lenders. Second, although the MPC out of monthly payment changes is 1 for both borrowers and lenders since the rate change is permanent, the presence of cash-out refinancing leads to new spending, on net. This is because borrowers consume a large fraction of extracted equity on impact while lenders smooth consumption of the income they receive from future repayment of that borrowing, as shown in Appendix Figure A-9.

6.4 Counterfactual Analysis

That our model reproduces the behavior of the economy just before and after QE1 gives us confidence in using it for more ambitious counterfactual analysis. We now show that the theoretical effects of monetary policy are highly non-linear with respect to the regional distribution of housing equity. This means that accounting for the time-variation in this distribution that we showed in Section 5 is crucial for correctly predicting the aggregate and cross-region consequences of monetary policy.

6.4.1 2008 vs. 2001 Economic Conditions

Figure 13 compares the impulse response function of aggregate refinancing activity, aggregate consumption and regional consumption inequality to an interest rate shock in the 2008 baseline model to that which would occur if regional house price patterns in 2008 had instead looked like those in 2001. Under the 2001 model distribution of shocks, house prices are constant for the lowest one-third of regions, rise by 5% for the middle third, rise by 10% for the highest third of regions, and regional house prices and income are uncorrelated.

As seen in Figure 13, changing the equity distribution dramatically changes the consequences of monetary policy: in 2001, the same decline in interest rates raises aggregate consumption by 2.5 times as much as in 2008 (middle panel).[38] This means QE1 would have had much larger stimulative effects if enacted under the equity distribution in 2001 as opposed to 2008. There are two reasons for the larger consumption response: First, as shown in the top panel, the aggregate refinancing response to the rate decline is nearly twice as large in 2001 because fewer borrowers are underwater.[39] Second, households that refinance have more equity to extract in 2001, which contributes to an additional consumption boost. Interestingly, as seen in the middle panel of the figure, inequality across regions falls mildly when rates fall in 2001 so that there is not always a trade-off between stimulus and regional inequality.

To understand why the 2008 distribution of equity makes consumption respond less to monetary policy than in 2001, it is useful to first explain why interest rate reductions lead to increased consumption. Figure 14 shows the distribution of extractable equity in our baseline 2008 calibration (in dotted green) and in 2001 (in dashed purple) as well as the fraction of households adjusting for a given level of equity when the interest rate is permanently 0.06 (in red), permanently 0.05 (in blue), and in the period when it declines from 0.06 to 0.05 (in yellow).[40] This is the analogue to Figure 11 but averaging over the endogenous joint distribution of assets and income for each value of extractable equity. Consistent with the threshold policy in Figure 11, households are more likely to refinance when equity is large. Since $r^m > r$, households always consume some fraction of their equity when refinancing.[41] This means that consumption increases if more households refinance.

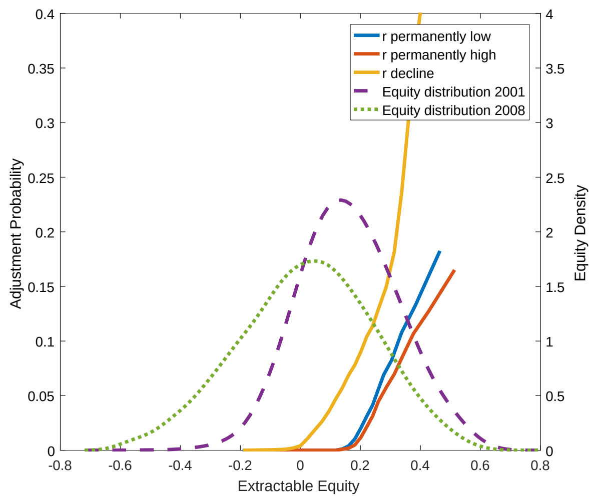
[38] Specifically, consumption rises by 0.37% in the first year in 2008 vs. 0.92% in 2001. The consumption of borrowers rises by 0.56% in 2008 and 1.15% in 2001, so lender offsets are similar in both years.

[39] Interest rate declines cause a 1.27 percentage point increase in 2001 and a 0.71 percentage point increase in 2008.

[40] Note that here we plot extractable equity while Figure 10 plots actual equity which adds back $1 - \gamma = 0.2$.

[41] On average this MPC is 0.5 so that half of extracted equity is consumed on impact. Unsurprisingly, this number is higher for households with low liquid assets and smaller for those with high liquid assets.

Figure 14: Distribution of Equity and Refinancing Probability: 2008 Calibration vs 2001



Note: This figure shows the simulated distribution of equity and the fraction of households refinancing under two different equity distributions.

When interest rates decline, households lower their refinancing threshold substantially, as shown by the yellow line. This is because some households that would not choose to extract equity today if their interest rate was already low choose to extract equity sooner so that they can obtain the new lower rate. Thus, when interest rates decline, there is a burst of (cash-out) refinancing and an increase in consumption. This extra refinancing arises from the mass of households between the red line and the yellow line, since households to the right of the red line will refinance even if interest rates do not decline, and households to the left of the yellow line will not refinance even if rates do decline.[42] It is not the fraction of households that want to refinance and extract equity that matters for the strength of the interest rate impulse response, it is the change in this fraction that is the relevant object for assessing the consequences of interest rate declines.[43] In 2008, the distribution of equity shifts left and fans out relative to 2001. On net, this leaves many fewer households in the region where refinancing decisions are triggered by the rate decline and so reduces refinancing impulse responses. This then leads to smaller aggregate consumption responses.

6.4.2 Housing Equity Statistics and the Consequences of Monetary Policy

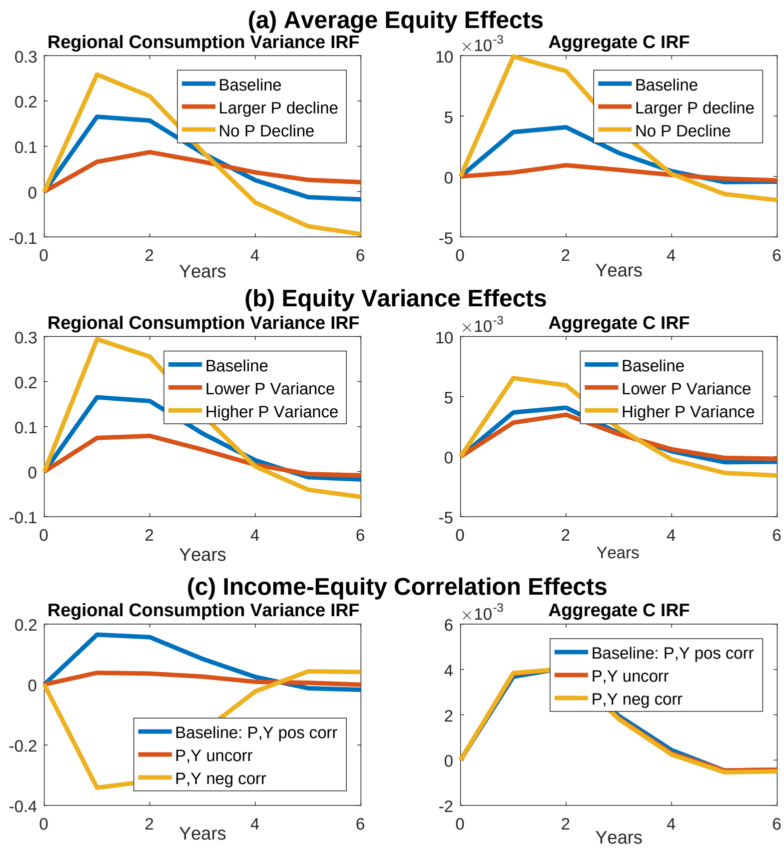
The distribution of equity in 2008 in the model is different in three ways from 2001. What are the independent roles of changes in the level of equity, the regional variance of equity, and the correlation between regional income and regional equity for aggregate responses in 2008? Furthermore, why does a change in interest rates in 2008 increase regional inequality much more than in 2001? We now show the role of each of these components of the distribution of equity in shaping aggregate consumption and regional inequality responses to interest rate declines.

Panel (a) of Figure 15 shows the effect of changing the mean of the equity distribution at the time of

[42] The change in the fraction of households refinancing with equity x is given by the vertical difference between the red and yellow lines, so the total change in refinancing is given by this difference integrated over the distribution of equity.

[43] That is, only those households whose decision to refinance is triggered by the rate decline contribute to the extensive margin and interest rate impulse response. For example, in a world where there was no cost to refinancing all households refinance every period and a rate decline does not increase refinancing.

Figure 15: Effects of Changing Equity Distribution



Impulse response functions show the change in log aggregate consumption and in log consumption variance across regions in response to a one percentage point reduction in mortgage rates. The baseline economy includes a 12.5% aggregate house price decline. In panel a, the "larger P decline" calibration features a 25% decline in house prices. The variance of equity and its correlation with income are fixed at the 2008 calibration across all simulations. In panel b, the high variance calibration doubles the difference between high and low house price regions, while the low variance calibration halves it. All economies feature the same baseline decline in house prices and correlation with income. In the bottom panel, the baseline calibration has income and house prices positively correlated across regions. In the other two calibrations they are uncorrelated or negatively correlated. All simulations feature the same baseline decline in house prices and variance across regions.

a decline in interest rates. As the level of house prices rises, both inequality and aggregate consumption respond more to the same decline in interest rates. Aggregate consumption responses increase with house prices, since more households are pushed into the part of the equity distribution where refinancing decisions respond to rate changes, and households also have more equity to consume conditional on refinancing. Regional inequality responds more to rate declines when house prices rise because refinancing decisions and resulting consumption responses are highly convex in equity. In regions with negative equity, few households refinance and consumption responses are always near zero. This is true whether households are deeply underwater or only mildly underwater. In contrast, the consumption response to interest rates increases rapidly with equity as equity rises. This means that shifting the distribution of the equity to the right has no effect on consumption responses for those on the left side of the distribution, while it increases them substantially for those on the right side of the distribution. Since initial levels of equity and income are positively correlated in our 2008 baseline, an increase in average equity increases the response of regional inequality to rate declines.

Panel (b) of Figure 15 shows the effects of changing the variance of equity across regions. An increase in the variance of equity amplifies both the response of consumption inequality and aggregate consumption to rate declines. The intuition is almost identical to that for the effects of mean shifts and again follows immediately from Figure 14. Moving households with low equity to even lower equity has no effect on consumption responses to monetary policy, since these households do not refinance anyway. In contrast, additional equity amplifies the consumption response of those households on the right side of the distribution with substantial equity.

Finally, Panel (c) of Figure 15 shows the effects of changing the correlation between income and equity. If income and equity are uncorrelated, then interest rate declines have almost no effect on regional inequality and when income and equity are negatively correlated, declines in interest rates substantially reduce regional inequality. In contrast, the correlation between income and equity has almost no effect on aggregate consumption impulse responses. The intuition for inequality effects is straightforward: Consumption *levels* are higher in high income than in low income regions. Consumption *responses* to interest rate changes are higher in high equity than in low equity locations. When income and equity are correlated, this means that interest rate declines exacerbate the initial consumption inequality. If income and house prices are instead uncorrelated, as in the stochastic steady-state or our 2001 calibration, then changes in consumption when interest rates fall are largely uncorrelated with initial levels of consumption, and if they are negatively correlated then inequality is reduced.

The intuition for the lack of aggregate effects is slightly more subtle and reflects two offsetting forces. Overall, consumption growth is largest for regions with high house price growth and low income, since they have more equity and are also more liquidity constrained. However, low income regions also have lower initial consumption levels than high income regions. This means that the change in consumption *levels* for high equity high income regions is similar to that of high equity low income regions, so that changing the proportion of such regions by altering the correlation between income and house prices has a negligible effect on aggregate consumption responses.

Of course, as shown in Figure 14, the interaction between refinancing and the equity distribution is highly non-linear, so the effects of changing any one moment of the equity distribution will always depend on the initial distribution of equity. For example, effects of a given aggregate house price shock on monetary policy will depend on both the initial mean and variance of equity, since both features of the initial distribution will determine how the mean shift interacts with non-linear refinancing decisions. The above analysis shows the effects of particular changes under the 2008 initial distribution, but the policy function in Figure 14 implies the equity distribution will matter much more generally.

We now illustrate this concretely by showing that shifts in the mean of the equity distribution have effects on monetary policy that depend on the variance of the distribution. Let $IRF_{f_0(\mu,\sigma)} = \frac{\Delta C}{\Delta r^m}$ be the response on impact (in the first year) of consumption to a 1% decline in interest rates given an initial equity distribution f_0 with mean μ and standard deviation σ. Then let $\Delta IRF_{f_0(\mu,\sigma)} = \frac{IRF_{f_0(\mu+10,\sigma)} - IRF_{f_0(\mu,\sigma)}}{IRF_{f_0(\mu,\sigma)}}$. $\Delta IRF_{f_0(\mu,\sigma)}$ measures how a 10 percentage point increase in the mean of the equity distribution affects the impulse response of consumption to interest rates. Figure 16 plots $\Delta IRF_{f_0(\mu,\sigma)}$ as we change the cross-region standard deviation of equity σ. The leftmost point in the figure sets $f_0(\mu,\sigma)$ equal to the stochastic steady-state distribution, and then we steadily increase the cross-region standard deviation of equity. In the stochastic steady-state with $\sigma = 2.5\%$, a 10% increase in house prices increases the aggregate consumption response to a 1% rate decline by almost 60%. However, when σ is higher, this same mean increase in house prices has a smaller effect on the response of consumption to a

Figure 16: Effect of σ on $\Delta IRF_{f_0(\mu,\sigma)}$

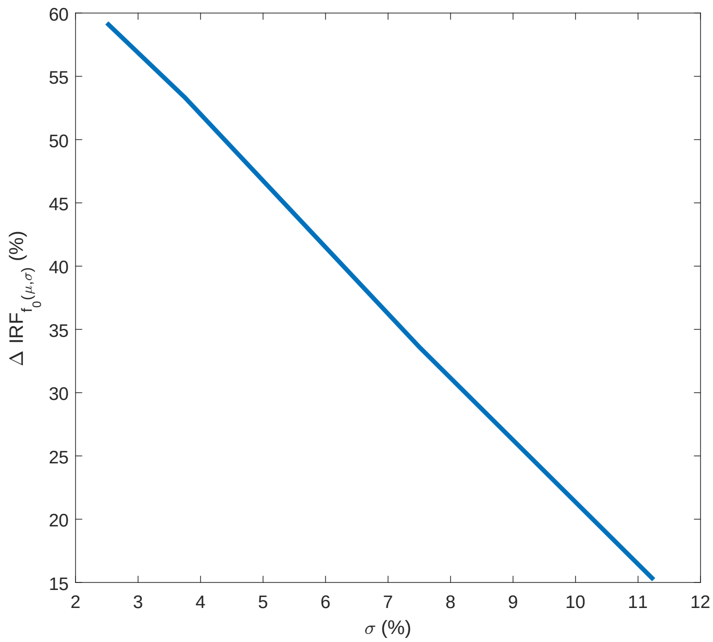


Figure shows how much a 10% increase in equity changes the aggregate consumption response to a 1% decrease in r^m, for different values of the cross-region standard deviation of equity.

rate drop.[44] This is because when the variance of equity is large, more households are either deeply underwater or have so much equity that they will extract it even without a decrease in rates. A rightward shift in the equity distribution then has relatively modest effects, since it does not induce deeply underwater households to refinance, and makes households with substantial equity even less sensitive to monetary policy.

These results demonstrate that the effects of shocks to average equity for monetary policy cannot be determined without tracking the equity distribution. A corollary of this result is that understanding the refinancing channel of monetary policy requires a full accounting of the distribution of equity and so cannot be analyzed in frameworks which abstract from heterogeneity.

7 Interaction with Fiscal and Macroprudential Policies

The analysis thus far argues that monetary policy in 2008 provided the least stimulus to regions which needed it most and that this dampened its aggregate effects. We now show that various complementary policies can potentially boost the effectiveness of monetary policy in such situations. In particular, we study mortgage modification policies, which capture elements of policies implemented in the Great Recession, as well as macroprudential policies that alter LTV caps in response to economic conditions.

We explore two mortgage modification policies: "debt forgiveness" and "relaxed refinancing requirements." We intentionally implement these policies in a stylized fashion in order to starkly illustrate their interactions with monetary policy, but the first policy captures elements of the mortgage

[44] In other words, in the stochastic steady-state $\frac{\partial IRF_{f_0(\mu,\sigma)}}{\partial \mu} > 0$ but $\frac{\partial^2 IRF_{f_0(\mu,\sigma)}}{\partial \mu \partial \sigma} < 0$.

write-downs available to some borrowers under HAMP, while the second is more similar to the HARP program.[45] We model debt forgiveness by assuming that a portion of mortgage debt for any household that is underwater in 2008 is forgiven. In particular, all households with an LTV greater than γ have their loans adjusted so that LTV=γ.[46] Under the relaxed refinancing requirements policy, we allow underwater households to refinance rates without meeting the LTV requirement. To reflect the fact that these policies also explicitly eliminated appraisal and other fees associated with refinancing, we assume that underwater households can refinance without paying the fixed cost under both policies.

Panel (a) of Figure 17 shows the response to these modification programs, holding interest rates constant. That is, it shows the effects of the programs alone with no simultaneous monetary policy change. The debt reduction program increases total consumption in the economy as it redistributes resources from unconstrained lenders to more constrained borrowers.[47] It also reduces regional inequality, since debt forgiveness is available only to underwater households. In contrast, relaxing refinancing requirements has no effect when interest rates are held constant because underwater households have no reason to refinance, even if it is costless, when rates are constant. Thus, this policy has no effect in the model unless accompanied by a reduction in mortgage rates.

Panel (b) of Figure 17 shows the response to *simultaneously* lowering rates and implementing mortgage modification. That is, it shows the combined effects of these policies. For comparison, we also show the baseline economy with a rate decline but no mortgage modification. Relative to the baseline, the combined policies lead to larger increases in spending and smaller increases in inequality.

Since impulse responses in panel (b) of Figure 17 are computed relative to an economy without either mortgage modification or monetary policy, they tell us the combined effects of these policies. In contrast, panel (c) isolates impacts of monetary policy from direct effects of mortgage modification. In particular, we compute consumption statistics with both rate declines and mortgage modification relative to an economy with mortgage modification but no rate decline. Clearly, the presence of either modification program increases the effectiveness of monetary policy and reduces its inequality effects. Interestingly, from the perspective of monetary policy, these two mortgage modification programs work nearly identically. Both policies increase the sensitivity of underwater households to changes in rates and so amplify the response of spending to interest rate declines. The fact that debt forgiveness has larger effects than relaxed refinancing requirements in panel (b) arises because this policy has direct effects on the economy independently of rate changes, while the relaxed refinancing requirements policies work only through their interaction with interest rates. Since debt forgiveness has both direct effects as well as interaction effects with monetary policy, the combined effects are ultimately larger. However, implications for the efficacy of monetary policy are nearly identical.

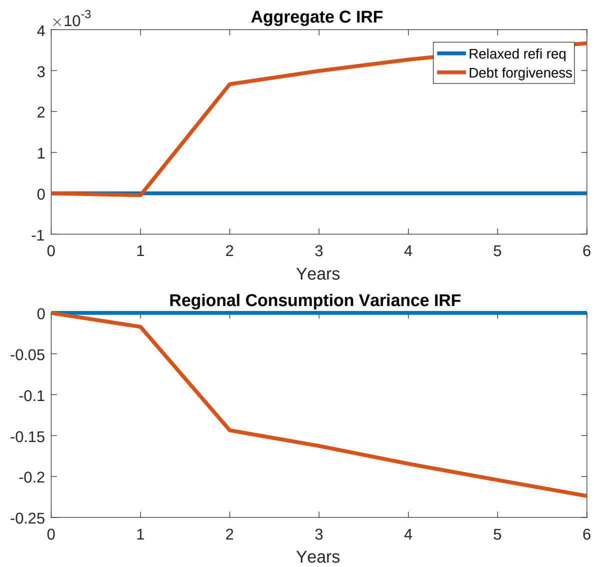
[45] Existing research has shown that institutional features such as servicer participation and market power matter for the consequences of these policies as actually implemented (Agarwal et al., 2015, 2016). Also, especially with modification programs, which in practice usually focus on delinquent borrowers, moral hazard is an important concern that we do not consider. We are not evaluating the specifics of program implementations in the Great Recession or the detailed institutional design of any such programs. We are instead interested in the broad ways in which such programs, independently implemented by the fiscal authority, might affect the consequences of monetary policy.

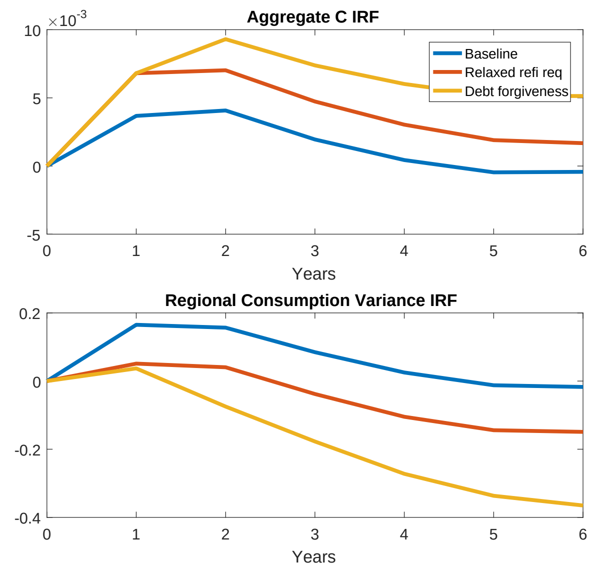
[46] We account for the negative effect of this policy on lenders, although in reality, lenders would likely be compensated by the government, which in turn would raise taxes. But these taxes would likely be borne disproportionately by the richer lenders. Even with lump-sum taxes from all households, borrowers with forgiven debt would receive a net transfer.

[47] These effects are negligible on impact but grow with time. This is consistent with conclusions in Ganong and Noel (2017) that debt forgiveness has little effect on consumption if, as in our experiment, households still have no equity after forgiveness.

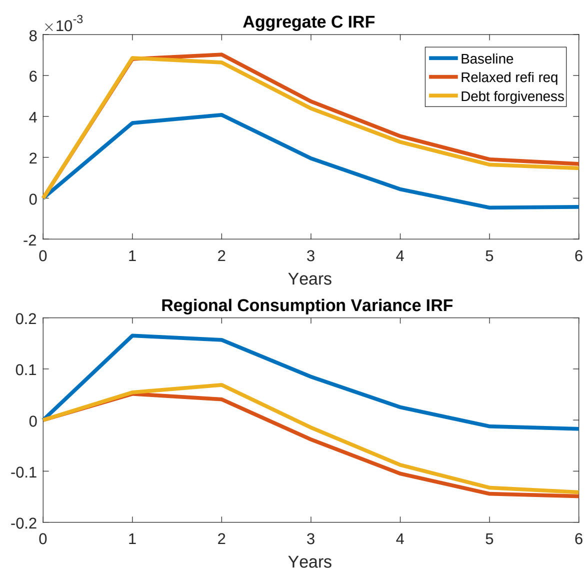
Figure 17: Mortgage Modification Effects

(a): Response to Mortgage Modification w/ Constant r^m **(b):** Response to Mortgage Modification + r^m Decline





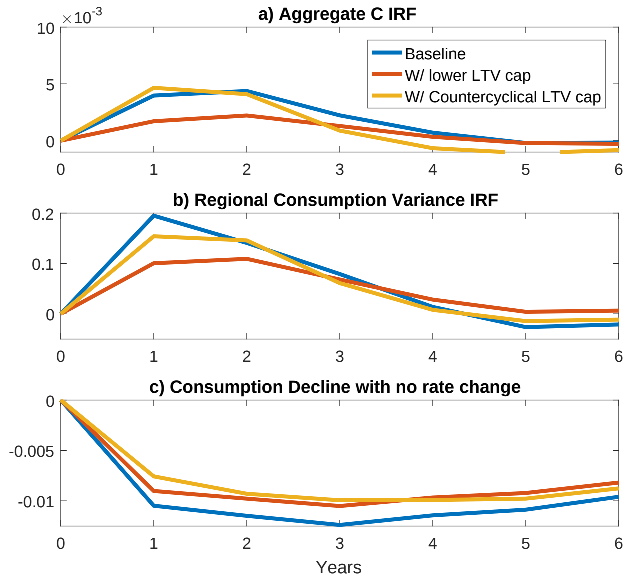
(c): Response to r^m Decline, Taking Mortgage Modification Programs as Given



Panel (a) of this figure shows the effects of the debt reduction and relaxed refinancing requirement policies described in the text when interest rates are held fixed. Panel (b) shows the effects of simultaneously reducing rates and implementing the modification policies. Panel (c) shows the change in output and inequality from reducing interest rates and implementing mortgage modification relative to an economy that implements mortgage modification but has no decline in rates.

In our final policy exercise, we explore how a simple form of macroprudential policy can interact with the refinancing channel of monetary policy. In particular, we consider two forms of risk regulation. In the first experiment, we simply lower the LTV cap, γ, from 0.8 to 0.7. In the second experiment, we implement a countercyclical LTV cap that is set to 0.7 during normal times but then rises to 0.9 during the Great Recession. That is, the central bank limits risk during good times but then relaxes constraints and increases liquidity in response to bad shocks.[48]

Figure 18: Effects of Countercyclical LTV Cap



Panel (a) shows consumption effects of reducing rates in the Great Recession in the baseline economy with a 0.8 LTV compared to an economy with a permanently lower LTV cap of 0.7 and to an economy that has an LTV cap of 0.7 prior to the Great Recession which is then raised to 0.9 for one year. Panel (b) shows effects of monetary policy on inequality in the same three scenarios. Panel (c) shows the depth of the recession *without* any interest rate decline under the three LTV policies.

The red line compared to the blue line in Figure 18 shows effects of a permanently tighter LTV cap. The first two panels show this reduces both the aggregate stimulus power and the increase in regional inequality generated by rate cuts. This is unsurprising, as tighter borrowing constraints just reduce the general importance of the refinancing channel. The more interesting results are shown in yellow, when the LTV cap is lowered ex-ante but then increased ex-post, after large declines in aggregate house prices. This policy leaves the stimulative power of monetary policy unchanged but reduces its effects on inequality relative to the baseline (yellow vs. blue), and also reduces the depth of the recession, as increased borrowing capacity dampens spending declines. In this sense, the countercyclical LTV cap dominates either of the other policies: it reduces the depth of the recession even with no additional monetary policy action, but it also relaxes LTV requirements when and where they bind most, which reduces the trade-off between stimulus and inequality.

Thus, even though the regional distribution of shocks in 2008 substantially hampered monetary policy transmission, there is at least some scope for mitigating these effects under such conditions. Policies that help underwater households refinance can interact importantly with interest rate changes

[48]In the results shown here, we assume that this increase in the LTV cap during the Great Recession is completely unanticipated and lasts for a single year. We have solved a version of the model where households are aware of the countercyclical LTV policy ex-ante and recessions that trigger this LTV change occur with some small but non-zero probability and it delivered nearly identical results; therefore, we present results for the simpler environment.

to amplify effects of monetary policy. Similarly, well-designed macroprudential policy has scope to reduce risk in the economy while maintaining the strength of monetary policy when it is needed most.

8 Robustness and Model Extensions

In this section, we consider many model extensions and show that time-variation in the consequences of monetary policy continues to hold. This is because our conclusions are crucially driven by two simple and robust model features, which also hold in the data: 1) Underwater households cannot refinance without putting new cash into the house, which makes policy functions very non-linear in equity. 2) The regional distribution of equity changes across time. Time-varying refinancing responses to rate changes arise immediately from the interaction of these two features. Since this non-linearity is highly robust across models (and indeed in any reasonable model, underwater households should not be able to refinance and tap into home equity), it is unsurprising that our conclusions are equally robust. Our discussion is intentionally brief but additional details are provided in Appendix A.3.

8.1 Accounting for Additional Heterogeneity

8.1.1 ARM Shares

Our baseline analysis assumes that all mortgages have fixed rates. In reality, a substantial fraction of households have adjustable-rate mortgages (ARMs) whose rates reset even if households do not refinance. The presence of ARMs has some potential to change the refinancing channel of monetary policy. On the one hand, with ARMs, payments decrease when rates decline even if households do not refinance. To the extent that borrowers have higher MPCs than lenders, this should amplify the spending response to monetary policy (e.g., Auclert, 2015). On the other hand, the presence of ARMs reduces the interaction between cash-out decisions and interest rate declines since households do not need to accelerate equity extraction to take advantage of lower rates today. This makes cash-out-based spending less responsive to monetary policy.

Accounting for ARMs also potentially matters for regional inequality, since panel (a) of Appendix Figure A-10 shows that ARM shares of outstanding loans in November 2008 were higher in MSAs with lower equity. This is because ARM shares increased more strongly during the boom years in areas with larger price increases, which subsequently experienced larger busts. Since ARMs were more prevalent in low equity regions, it is possible more mortgages experienced rate declines in these regions despite our previous evidence that fixed-rate mortgages were less likely to adjust.

The importance of ARM offsets depends crucially on what fraction of ARM borrowers actually saw rate resets after QE1. There are many reasons why not all ARM borrowers benefit from rate declines: (i) Most ARMs are "hybrids" with initial fixed-rate periods of 3, 5, 7 or 10 years. (ii) ARMs typically have "rate floors," which are often set at the initial interest rate of the loan. (iii) The length of the ARM fixed-rate period often coincides with the length of an interest-only (IO) period during which the borrower only pays interest but does not amortize principal. When the IO period ends, required payments jump up, which can more than offset simultaneous rate decreases. Panel (b) of Appendix Figure A-10 shows the share of ARMs that experience significant rate reductions of 1 percentage point or more from November 2008 – June 2009 against $E^{med}_{j,Nov2008}$.[49] Clearly, differences across MSAs in rate resets are muted relative to differences in ARM shares in (a). Overall, the variation in ARM resets with $E^{med}_{j,Nov2008}$ is less than half that of FRM refinancing propensities.[50] Thus, declines in effective rates were still larger in MSAs with higher equity after accounting for ARMs.

To explore the role of ARMs for our theoretical results, we solve a model in which some households borrow using FRMs while others use ARMs. ARMs in the model adjust every period to the current mortgage rate, and we calibrate the share of ARMs across regions to match the variation in panel (a) of Appendix Figure A-10. In light of the above discussion, this substantially overstates the actual regional variation in ARM resets in response to QE1, and so is a very conservative upper bound on the extent to which ARMs change our conclusions. Panel (a) of Appendix Figure A-11 shows that even under this conservative calibration, ARMs have a negligible effect on our conclusions. This is because even in low equity regions, FRM shares are large, and overall spending responses to interest rate declines are dominated by cash-out effects. Low house price regions have more ARM but less FRM rate resets. On net, the FRM effect dominates so that there are more rate reductions in high equity regions. Moreover, in low equity regions there is no cash-out activity since there is no equity to remove, while in high equity regions there is a significant cash-out and spending response to rate declines.[51]

Panel (b) of Appendix Figure A-11 separately decomposes the role of ARM and FRM borrowers in determining aggregate time-series variation in spending responses to rate declines. Clearly, time-variation is much larger for FRM borrowers than ARM borrowers, and aggregate spending patterns are much closer to those of FRM borrowers since they are a larger share of the economy. However, the spending response of ARM borrowers still declines by 20% in 2008 relative to 2001. It is also interesting to note that in 2001, FRM borrowers respond more to rate declines than ARM borrowers, in contrast to typical intuition that more flexible mortgages amplify responses to monetary policy. This is because when FRM borrowers actively refinance, they also extract equity and thus front-load their increase in spending, while passive rate resets under ARMs do not result in equity extraction.

8.1.2 Preceding Booms

Does the boom-bust nature of the Great Recession where regions with the largest house price declines previously had the largest house price booms change our implications for regional inequality? In panel (c) of Appendix Figure A-11 we repeat our baseline exercise but in a model where the house price bust is preceded by a boom to show that our conclusions are unchanged.

8.2 Endogenous Cash-out

In our baseline model, we abstract from the distinction between cash-out and non-cash-out refinancing by assuming households always extract all available equity when refinancing. We make this assumption largely for tractability, but we now show it makes little difference for our conclusions. In particular,

[49] We also require that the recorded required monthly payment not increase over the same period (which may indicate that the loan's IO period expired).

[50] The regression line in panel (b) has a slope of -0.059 (s.e. $=$ 0.009). Meanwhile, regressing the 6-month refinancing propensity (from January-June 2009) on $E^{med}_{j,Nov2008}$ yields a coefficient of +0.147 (s.e. $=$ 0.028).

[51] Since this result is driven by variation in equity, it is consistent with results in Di Maggio et al. (2017) that after *conditioning* on equity, greater ARM shares are associated with larger spending responses to rate changes.

panel (a) of Appendix Figure A-12 shows that results are very similar in a model where households can choose between a cash-out refi, modeled as before, and a pure rate refi, in which they lower their rate but do not cash-out any equity. Allowing households to choose between cash-out and non-cash-out refi makes little difference because households in high equity locations typically extract equity when refinancing anyway, and households in low equity locations on average have little equity to extract, so that the distinction between a cash-out and a rate refi is less relevant.[52]

8.3 Interest Rate Process

In our baseline, we assume mortgage rates are constant across time and show responses to one-time unanticipated declines in these rates. In response to QE1, mortgage rates declined and remained low for an extended period of time. This one-time shock illustrates the mechanism in the simplest environment and increases the computational tractability of the model, which allows some of the robustness exercises in this section. However, panel (b) of Appendix Figure A-12 shows results when r^m instead follows an AR process, with persistence of 0.89 and standard deviation of 0.0055 to match 30-year mortgage rates from 1990-2015. Since the results with this interest rate process are similar, we use the simpler one-time shock as our baseline. Our baseline model also assumes that monetary policy lowers the long-term mortgage rate r^m but not the short-term rate r. This describes the behavior of rates during QE1 since short-term rates were at the zero lower bound. However, conventional monetary policy would typically result in both rates falling. Panel (c) of Appendix Figure A-12 shows that results are similar when we lower both r and r^m to maintain a constant spread.

8.4 Income Process

The solution to the equity extraction problem balances transaction costs against the desire to extract housing equity. Since our baseline model includes only permanent income shocks, desired equity extraction is largely determined by past and current house price shocks and interest rate behavior rather than by a desire to smooth transitory income shocks. Introducing persistent but not permanent income shocks would substantially complicate the model solution, but it is straightforward to introduce completely transitory income shocks and thus a role for equity extraction in smoothing income shocks. Panel (d) of Appendix Figure A-12 shows that results are very similar in this model.[53]

8.5 General Equilibrium Effects

In our baseline, 50 percent of mortgage payments ultimately go to non-US consumers. A large share of mortgage debt is held by commercial banks, which are owned in part by foreign shareholders, so measuring the foreign share of mortgage holders is difficult. In Appendix Figure A-13, we explore two extreme assumptions for mortgage debt holdings. This also allows us to assess the importance of equilibrium lender forces for our results. As the foreign share of lenders declines, equilibrium effects

[52] In this model, the overall cash-out share of refinancing when mortgage rates decline is 65 percent as compared to roughly 50 percent in the data just after QE1. However, our model does not allow households to access equity by selling housing, so it is not surprising that cash-out refinancing is a little larger share in the model.

[53] The standard deviation of these temporary shocks is set to 0.05 to match various estimates from earnings data.

grow in importance and aggregate consumption responds less to rate reductions. However, short-run effects remain positive even in the unrealistic case where all mortgage payments go to domestic households. Thus, none of our conclusions about short-run stimulus-inequality trade-offs are altered. This is because cash-out refinancing is an important part of stimulus effects. Since we assume lenders are equally distributed geographically, their behavior is irrelevant for cross-region results.

We treat income and house prices as exogenous, as it simplifies the analysis substantially and allows us to provide more transparent intuition for our main mechanism. However, endogenizing income and house prices in a more fully fledged DSGE framework should amplify our conclusions. We find that refinancing activity and consumption responses to interest rates are stronger in well-off regions. If some portion of spending is on non-tradable goods and if greater mortgage borrowing drives up house prices, then income and house prices will rise more in initially well-off locations, amplifying initial inequality. Similarly, endogenizing aggregate income and house prices will amplify aggregate time variation if greater aggregate spending generates greater aggregate income, as in New Keynesian models. In fact, in the representative agent model of Greenwald (2016), endogenizing house prices indeed amplifies the feedback from equity shocks to monetary stimulus.[54]

We also take aggregate inflation as exogenous. If inflation rises when interest rates fall, this introduces a nominal debt revalution effect which transfers resources from lenders to borrowers. Such interactions are previously explored extensively in Auclert (2015).

Finally, we take both r and r^m as given and do not impose liquid asset market clearing. However, when r^m falls, liquid savings rise mildly. If we imposed asset market clearing, this would lead to a small decline in r and increase consumption through standard intertemporal substitution channels. Furthermore, these asset responses increases with the strength of the refinancing response to r^m. Thus, imposing asset market clearing would complicate the model but amplify our effects.

8.6 Housing Adjustment and Default

We do not allow households to buy/sell housing or default on mortgages. Allowing households to move to extract equity would complicate the setup but would produce similar non-linear interactions between equity and consumption. Introducing a construction sector and endogenous housing should also amplify our results. When households have more equity, there is more scope to purchase larger houses and increased housing demand will 1) drive up house prices and amplify initial equity differences and 2) drive up construction, amplifying initial income differences. Introducing an option to default and move to rental housing should similarly amplify cross-region effects. Only underwater households face default risk. When rates fall, mildly underwater households may put cash into their homes to refinance, lower payments and avoid default but this is infeasible for deeply underwater households. Thus, rate declines should have little effect on default in the hardest hit locations.

9 Conclusions

The Great Recession led to a prolonged period of monetary stimulus throughout much of the developed world. These policies are typically studied through the lens of representative agent New

[54]We thank Dan Greenwald for computing these results.

Keynesian models, which emphasize the importance of intertemporal substitution. In this paper, we explore a complementary channel of monetary transmission through collateralized lending and show that understanding this channel requires moving beyond a representative borrower. Non-linear interactions between collateral constraints, refinancing and spending mean that the distribution of housing equity plays a crucial role in the economy's response to interest rate declines.

Using an equilibrium, heterogeneous household model of mortgage borrowing, we argue that the regional distribution of housing equity during the Great Recession substantially dampened the refinancing channel of monetary policy. Furthermore, large variation in house price growth that was strongly correlated with local economic activity meant that monetary stimulus largely flowed to the locations which needed it least. These theoretical conclusions rest importantly on the distribution of equity, which is assumed away in typical representative agent analyses: under alternative distributions of housing equity, such as that observed in 2001, monetary policy is much more powerful and can potentially moderate regional business cycles.

We provide evidence of these collateral effects using novel household-level data that include comprehensive information on mortgage debt and refinancing. We show that after QE1, there was an aggregate increase in refinancing but that there was little response in the hardest hit regions, where many households were underwater. The empirical distribution of house price growth was quite different during the 2001 recession: aggregate house price growth was positive throughout the recession, and regional house price growth was uncorrelated with local unemployment. Consistent with our theoretical predictions, there was much more refinancing activity during the 2001 easing cycle than during the Great Recession, and refinancing was actually more common in regions with high unemployment. Thus, the data confirm that time-varying heterogeneity in the distribution of collateral is important for understanding the consequences of monetary policy across time.

Our data come from the US mortgage market, so our analysis focuses on regional house price shocks since they are the dominant source of shocks to home equity. Changes in the distribution of other types of collateral will generate many of the same implications for monetary policy, but the relevant sources of shocks and heterogeneity may differ. For example, sectoral shocks may play an important role in influencing the distribution of collateral across firms and influence the response of investment to monetary policy through similar mechanisms. Variation across time in economic activity and its correlation with housing equity and other forms of collateral is also not unique to the US. Europe has experienced persistent cross-country differences in economic growth that are highly correlated with house price movements. While the prominence of fixed-rate mortgages and other institutional features of mortgage contracts differs between the US and Europe and across countries within Europe, Section 8.1.1 shows that our conclusions are not particularly sensitive to variation in fixed-rate shares. We leave a more thorough analysis of the effects of the collateral distribution in these alternative contexts to future work, but our analysis suggests that central banks are likely to face trade-offs which vary importantly with the distribution of collateral. Since this distribution varies across time, tracking its evolution is crucial for accurately assessing the effects of policy at any point in time (see Fuster, Guttman-Kenney, and Haughwout, 2016, for an effort along those lines).

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Online Appendix

A.1 MSA Groups Used in Figures 4, 5, and 6

Note: For large MSAs that are subdivided into Metropolitan Divisions, we use the latter (throughout the paper).

MSAs in the quartile with lowest E^{med} in November 2008:

Akron, OH; Anderson, IN; Bakersfield, CA; Bangor, ME; Battle Creek, MI; Bay City, MI; Bradenton-Sarasota-Venice, FL; Canton-Massillon, OH; Cape Coral-Fort Myers, FL; Carson City, NV; Cleveland-Elyria-Mentor, OH; Dalton, GA; Danville, IL; Dayton, OH; Deltona-Daytona Beach-Ormond Beach, FL; Detroit-Livonia-Dearborn, MI; El Centro, CA; Elizabethtown, KY; Elkhart-Goshen, IN; Fairbanks, AK; Flint, MI; Fort Lauderdale-Pompano Beach-Deerfield Beach, FL; Fort Walton Beach-Crestview-Destin, FL; Fort Wayne, IN; Fresno, CA; Grand Rapids-Wyoming, MI; Greeley, CO; Hagerstown-Martinsburg, MD-WV; Hanford-Corcoran, CA; Holland-Grand Haven, MI; Indianapolis-Carmel, IN; Jackson, MI; Jacksonville, FL; Kalamazoo-Portage, MI; Kankakee-Bradley, IL; Lake Havasu City-Kingman, AZ; Lakeland-Winter Haven, FL; Lansing-East Lansing, MI; Las Vegas-Paradise, NV; Madera-Chowchilla, CA; Mansfield, OH; Memphis, TN-MS-AR; Merced, CA; Miami-Miami Beach-Kendall, FL; Modesto, CA; Monroe, MI; Muskegon-Norton Shores, MI; Napa, CA; Naples-Marco Island, FL; Niles-Benton Harbor, MI; Oakland-Fremont-Hayward, CA; Ocala, FL; Orlando-Kissimmee, FL; Oxnard-Thousand Oaks-Ventura, CA; Palm Bay-Melbourne-Titusville, FL; Palm Coast, FL; Panama City-Lynn Haven-Panama City Beach, FL; Pensacola-Ferry Pass-Brent, FL; Phoenix-Mesa-Scottsdale, AZ; Port St. Lucie, FL; Providence-New Bedford-Fall River, RI-MA; Punta Gorda, FL; Redding, CA; Reno-Sparks, NV; Riverside-San Bernardino-Ontario, CA; Sacramento–Arden-Arcade–Roseville, CA; Saginaw-Saginaw Township North, MI; Salinas, CA; San Diego-Carlsbad-San Marcos, CA; Santa Rosa-Petaluma, CA; Sebastian-Vero Beach, FL; Springfield, OH; St. George, UT; Stockton, CA; Sumter, SC; Tampa-St. Petersburg-Clearwater, FL; Terre Haute, IN; Toledo, OH; Vallejo-Fairfield, CA; Visalia-Porterville, CA; Warren-Troy-Farmington Hills, MI; Weirton-Steubenville, WV-OH; West Palm Beach-Boca Raton-Boynton Beach, FL; Wheeling, WV-OH; Winchester, VA-WV; Worcester, MA; Youngstown-Warren-Boardman, OH-PA; Yuba City, CA; Yuma, AZ.

MSAs in the quartile with highest E^{med} in November 2008:

Albany-Schenectady-Troy, NY; Alexandria, LA; Anderson, SC; Asheville, NC; Athens-Clarke County, GA; Austin-Round Rock, TX; Baltimore-Towson, MD; Barnstable Town, MA; Baton Rouge, LA; Beaumont-Port Arthur, TX; Bellingham, WA; Bethesda-Frederick-Rockville, MD; Billings, MT; Binghamton, NY; Bismarck, ND; Blacksburg-Christiansburg-Radford, VA; Boulder, CO; Bridgeport-Stamford-Norwalk, CT; Buffalo-Niagara Falls, NY; Burlington-South Burlington, VT; Cambridge-Newton-Framingham, MA; Cedar Rapids, IA; Charleston, WV; Charlottesville, VA; Cleveland, TN; College Station-Bryan, TX; Corvallis, OR; Cumberland, MD-WV; Dubuque, IA; Duluth, MN-WI; Durham-Chapel Hill, NC; Edison-New Brunswick, NJ; Elmira, NY; Eugene-Springfield, OR; Fargo, ND-MN; Florence, SC; Fort Smith, AR-OK; Glens Falls, NY; Grand Forks, ND-MN; Grand Junction, CO; Great Falls, MT; Greenville-Mauldin-Easley, SC; Harrisburg-Carlisle, PA; Harrisonburg, VA; Hartford-West Hartford-East Hartford, CT; Honolulu, HI; Hot Springs, AR; Houma-Bayou Cane-Thibodaux, LA; Huntsville, AL; Iowa City, IA; Johnson City, TN; Kingsport-Bristol-Bristol, TN-VA; Lafayette, LA; Lake Charles, LA; Lancaster, PA; Lawrence, KS; Lebanon, PA; Longview, WA; Lynchburg, VA; Midland, TX; Missoula, MT; Mobile, AL; Mount Vernon-Anacortes, WA; Nassau-Suffolk, NY; New Orleans-Metairie-Kenner, LA; New York-White Plains-Wayne, NY-NJ; Ocean City, NJ; Philadelphia, PA; Pittsburgh, PA; Pittsfield, MA; Portland-Vancouver-Beaverton, OR-WA; Raleigh-Cary, NC; Reading, PA; Roanoke, VA; Salem, OR; San Angelo, TX; San Francisco-San Mateo-Redwood City, CA; San Jose-Sunnyvale-Santa Clara, CA; Seattle-Bellevue-Everett, WA; Sioux City, IA-NE-SD; Sioux Falls, SD; Spokane, WA; State College, PA; Trenton-Ewing, NJ; Tulsa, OK; Victoria, TX; Wenatchee-East Wenatchee, WA; Williamsport, PA; Wilmington, NC; Yakima, WA; York-Hanover, PA.

A.2 Additional Data Description

A.2.1 CRISM

We start with a 50% sample of all McDash (also known as LPS) mortgages linked to Equifax credit records that were outstanding for at least one month between January 2007 and December 2010. The CRISM data set provides the linked Equifax credit records for each McDash mortgage for the lifetime of the loan, including an additional 6 months before origination and after termination. This link is done directly by Equifax. Credit records provide a consumer's total outstanding debt amounts in different categories (first-lien mortgages, second-lien mortgages, home equity lines of credit [HELOCs], auto loans, etc.). Additionally, in any month, Equifax provides the origination date, amount, and remaining principal balance of the two largest (in balance terms) first mortgages, closed-end seconds, and HELOCs outstanding for a given consumer.

We convert these records into a loan-level panel with each loan's type, origination month, origination amount, termination month, and remaining principal balance for all months that the loan is outstanding. We restrict our sample to those consumers who start our sample with two or fewer loans in each category and never have more than three of any of these types of loans outstanding.[1] This amounts to about 96% of the population of Equifax borrower IDs, and these IDs cover about 90% of the loans in McDash. In creating this loan-level data set, we assume that the month in which the loan stops appearing in Equifax is the month that it was terminated.

The variables that McDash provides are already in the form of a loan-level panel and include: origination date, origination amount, remaining principal balance, termination date, termination type, lien type, interest type, property zip code, and purpose type. We match these to our Equifax panel. We consider an Equifax loan/McDash loan pairing a match if the origination date of the Equifax loan is within 1 month and the origination amount is within $10,000 of the McDash loan. If more than one loan is matched, we use the origination amount, date, termination date, zip code, and termination balance as tiebreakers. We are able to match more than 93% of McDash loans using these restrictions, with more than 80% matching the origination information perfectly (up to $1 in balances due to rounding).

We use the set of Equifax/McDash matched loans as our universe in our analysis. Owing to the restrictions above, this amounts to about 82% of the McDash universe. We also verify that we are correctly measuring the termination date and termination balance using the Equifax records by checking these variables against their McDash counterparts for the matched loans.

Over our period of interest (2008-9), our sample contains about 15 million mortgages per month; per MSA-month, we have on average 39,200 mortgages. One way to assess the coverage of our sample is to compare the outstanding mortgage balances by MSA to those in the FRBNY Consumer Credit Panel (CCP). The balances in our sample correspond on average to 29% of those in the CCP (with little variation over time), with a cross-sectional standard deviation across MSAs of 5% (the 25th percentile is at 26%, the 75th percentile at 32%). Since we start with a 50% random sample from CRISM and apply some filters as explained above, this means that CRISM covers over 60% of outstanding mortgages over this period.

A.2.2 Measuring Refinancing Propensities

Our goal is to measure the proportion of outstanding loans in an MSA that were refinanced in a given month. For the denominator, we start with all outstanding first liens (where lien type is measured using the McDash variable) in our Equifax/McDash matched universe, but exclude in each month loans that terminate in the next month because they were transferred to another servicer or terminate

[1] This restriction allows us to infer the origination month, origination balance, and balance of the third largest loan of any loan type even though this information does not appear explicitly in Equifax, where if the third largest loan is also the newest loan, we assume its origination month to be the first month it appears in Equifax. We also drop loans that do not have complete consecutive Equifax records.

for unknown reasons (since we will be looking at the proportion of loans that are voluntarily paid off and refinanced).

We count a loan as being refinanced if: (1) its McDash termination type is a "voluntary payoff," and (2) for that consumer, there is another loan that is opened around the time of the first loan's termination on the same property (i.e. the new loan is a refinance, rather than a new purchase loan). More specifically, the most clear indicator that the new loan was a refinance is if the loan has a matching McDash loan (about 70%), and that McDash loan is marked as a refinance loan (in McDash's purpose type variable). On the other hand, the loan is clearly a new purchase loan if the purpose type is marked as such. However, about 25% of McDash loans have purpose type "Unknown" or "Other," and about 30% of the new loans are not matched in McDash (they only appear in Equifax, since McDash does not cover the entire market) and thus have no purpose type attached.

We thus use the following rules to identify refinances. We start by looking for any loan in the Equifax data set that has an open date within 4 months of the McDash loan's termination date. We find at least one such loan for about 81% of the voluntary terminations in 2008 and 2009. We classify these new loans as a refinance if either:

- The loan also appears in McDash and is tagged as a refinance in the purpose-type variable (61% of the McDash-matched loans).
- The loan also appears in McDash and is tagged as an "Unknown" or "Other" purpose type, and has the same property zip code as the original loan.
- The loan appears only in Equifax but the borrower's Equifax address does not change in the 6 months following the termination of the original loan.

This allows us to compute our measure of interest, the balance-weighted refinance propensity, as (balance outstanding in t-1 of loans that were refinanced in month t) / (balance outstanding in McDash in month t-1 that does not terminate for unknown reason in month t).

As a check, we calculate the refinance propensities separately for the three different cases above (McDash, known purpose; McDash, unknown purpose; Equifax), and find that these refinance propensities are very similar.

A.2.3 Measuring Cash-outs

To measure cash-out refinancings, we need to both identify refinances and how the balance of the new loan compares to the outstanding balace of the loan(s) paid off in the process.

We begin with Equifax/McDash first liens (again using the McDash lien type variable), and keep only those loans that have a McDash purpose type of refinance or unknown/other. Our algorithm to identify whether our new loan is a refinance is similar to the algorithm above. This time, we look for a loan (or loans) in Equifax that terminate(s) around the time when the new loan is originated and check that this loan looks like it was refinanced. We use McDash refinances rather than outstanding loans as our point of reference for these statistics so that we can better represent all refinances, rather than introducing potential bias through only seeing refinances of McDash loans.

Specifically, we call any loan in the Equifax data set that terminates between -1 and 4 months from our new loan's close date a "linked" loan, including first mortgages as well as closed-end seconds and HELOCs, and we call the new loan a refinance if:

- The loan is a known refinance in McDash. (For 86% of these, we find a linked loan in either McDash or Equifax. For the remaining 14%, we would consider these refinances where there was no previous loan on the property.)
- The loan has an "Unknown" or "Other" purpose type in McDash and a linked loan in McDash that has a matching property zip code.

- The loan has an "Unknown" or "Other" purpose type in McDash and a linked loan that appears only in Equifax, but the consumer's Equifax address does not change in the 6 months after the new loan was opened.

If there is more than one linked loan that is a first mortgage in Equifax, we link only the loan that is closest in balance to the origination amount of the new mortgage. We also allow to be linked only those Equifax loans that exist in the Equifax data for at least three months to prevent the refinanced loan balance from being counted in the old balance of the loan.

For each of these cases, we can then calculate the cash-out amount as the difference between the origination amount on the refinance loan and the balance of the linked loan(s) at termination. In order to capture the correct origination amount on the refinance loan, we want to ensure that we are also including any "piggyback" second liens that are opened with the refinance loan that we find in McDash. Thus, we look for any loan in the Equifax record linked to our refinance loan that has an Equifax open date within three months of our refinance loan and an origination balance of less than 25% of our loan's origination balance if labeled a first mortgage and less than 125% of the refinance loan's origination balance if labeled a HELOC or CES, and add the balance of these piggyback seconds to the refi origination amount when calculating cash-out amounts.[2] To eliminate outliers, we also drop cash-out and "cash-in" amounts that are greater than $1,000,000. These amount to dropping less than 0.05% of the refinance loans.

At the MSA level, this allows us to calculate the amount cashed out relative to the total outstanding balance in month t-1. To estimate total dollar amounts cashed out, we scale up the amount cashed out by the ratio of total housing debt outstanding in an MSA according to the FRBNY Consumer Credit Panel (CCP) relative to the total outstanding balance in our CRISM sample. (The CCP amounts are available as end-of-quarter snapshots, so we interpolate between them to get a monthly series.)

In Figure A-7, we compare the total estimated quarterly cash-out amounts to those estimated on prime conventional loans by Freddie Mac.[3] The figure shows that the two series co-move closely and also show similar levels. The higher level in CRISM is expected, since the Freddie Mac series does not include subprime/Alt-A as well as FHA and VA loans.

A.2.4 Measuring CLTVs/Equity

We start with all matched first-lien McDash loans. For a given month, we take the corresponding Equifax record and assign all outstanding second liens to the outstanding first liens in Equifax using the rule that each second lien is assigned to the largest first lien (in balance terms) that was opened on or before the second lien's opening date. We then add the assigned second lien balance(s) to the McDash balance of our original loan as our measure of secured debt on a property, which is the numerator of CLTV. For the denominator, the estimated updated property value, we start from the appraisal amount of the property at the time of the McDash loan origination and update it based on the local home price index from CoreLogic (using the zip-code-level index if available, and the MSA-level index if not).

Equity is simply defined as $1 - CLTV$. When taking medians within an MSA (our measure $E^{med}_{j,t}$), we weight individual observations by their current outstanding first-lien loan balance (from McDash).

A.2.5 HMDA

For robustness, in Figure A-4 we use a different measure of refinancing activity based on data made available as part of the Home Mortgage Disclosure Act (HMDA), which requires mortgage lenders

[2]We impose these upper bounds because we want to avoid picking up other first lien mortgages (to purchase another property) the borrower might originate at the same time.

[3]To make the two comparable, we multiply our CRISM total by 1/0.9175, where 0.9175 is the share of mortgage balances in CRISM that is in MSAs (as opposed to micropolitan statistical areas or rural areas) as of November 2008.

to report information on mortgage applications and originations. The HMDA data are generally perceived to be the most comprehensive and representative source of information on mortgage applications and originations, with market coverage estimated to be around 90%.[4] For each application, HMDA reports the geographic location of the property, the desired loan amount, the loan purpose (purchase or refinance), and whether the loan application led to an origination, was rejected by the lender, or was withdrawn by the borrower.[5] While the public-use HMDA data contain only calendar year indicators, the private-use version of the data set (available to users within the Federal Reserve System) also contains the exact application date and the exact action date. The action date is the date on which the loan is originated, the application is rejected, or the application is withdrawn. These exact dates make the data suitable for high frequency event studies (see, for example, Fuster and Willen, 2010). In all our analysis using HMDA data, we retain only applications that led to originations (action code = 1), and always use the application date (rather than the action date). We drop multifamily properties and mortgages with an origination amount >$3 million (about 0.015% of loans).

While the HMDA data are ideal for measuring the flow volume of mortgage origination activity across locations, it has two prominent limitations. First, for refinance loans, the HMDA data do not include any information on the loan that is paid off. As a result, we cannot use the HMDA data to estimate the extent to which households are removing cash from their mortgage during the refinancing process—a limitation we overcome with the CRISM data we focus on in the main paper. Second, the HMDA data do not include any information on the loans after they are originated. Thus, HMDA is not informative about how many outstanding mortgages there are in an MSA. The stock of outstanding mortgages is necessary to measure a refinancing propensity.

To obtain an estimate of the number of outstanding mortgages in each MSA, we supplement HMDA with data from the 2008 American Community Survey (ACS), which reports the number of outstanding mortgages (but not their amount) and the number of households for fine geographic areas. Since the ACS samples only a fraction of the population, we scale up the number of households based on Census information on the overall number of households in the US in 2008. We use the same scaling factor for the number of mortgages in each location. By combining the ACS data with the HMDA data, we can compute the number of loan originations per number of outstanding mortgages for each location within the U.S.

The measures of MSA-level refinancing propensities in late 2008/early 2009 are highly correlated between the HMDA data and the CRISM data, once we account for the lag in CRISM relative to HMDA. The population-weighted cross-sectional correlation between the HMDA refinance propensity in December 2008 and the CRISM refinance propensity in January (February) 2009 is 0.87 (0.88). Pooling the second half of 2008 and the first half of 2009, the correlation between HMDA and CRISM propensities is 0.84 for the one-month-forward and 0.78 for the two-month-forward CRISM propensities.

A.2.6 Other Data

We now briefly describe some additional data used in our analysis. We measure unemployment rates for each MSA using data from the BLS's Local Area Unemployment Statistics. Our measure of labor income is based on the Individual Income Tax ZIP Code Data made available by the Internal Revenue Service. We first cumulate wage and salary incomes at the MSA level and then divide by the number of tax returns. We exclude tax returns from the top income category (>$200,000) since those households can play a dominant role in driving average income changes; however, they are likely not the ones for which payment-to-income constraints (which we want to proxy for) are most relevant. Including those households, using adjusted gross income instead of wage and salary income, using the growth over 2007-2008 instead of 2008-2009, or using the income level instead of the growth rate does not change any of our conclusions in the regression tables below.

[4] See, for instance Dell'Ariccia, Igan, and Laeven (2012).

[5] There are actually three designated loan types within the HMDA data: origination, refinancing, and home improvement. We combine the home improvement loans with the refinancing ones in our work below.

Our MSA-level demographic controls come from the ACS. We combine the 2007 and 2008 data to ensure the sample sizes are large enough to minimize measurement error. We measure each MSA's age composition, education composition, the percentage of homeowners, and the percentage of households with a mortgage. We restrict the ACS data to those individuals between the ages of 21 and 75 (inclusive) that were not living in group quarters (e.g., dorms, prisons, or medical facilities).

A.3 Model Proofs and Description of Numerical Solution

We provide here the proof of the homogeneity of the value function as well as a description of our computational procedure.

To show the homogeneity property, we proceed by guess and verify. The value functions for refinancing and not refinancing are

$$\begin{aligned}
V^{norefi}(\tilde{a},\tilde{y},\tilde{x},r_0^m,r^m,r,F,1)\tilde{p}^{\sigma-1} &= \max_{\{\hat{a}'\}} \frac{\left(\tilde{a}(1+r)+\tilde{y}-\gamma r_0^m\tilde{x}-\hat{a}'\right)^{1-\sigma}}{1-\sigma}\tilde{p}^{\sigma-1} \\
&+\beta\mathbb{E}[V(\hat{a}'\frac{\tilde{x}'}{\tilde{x}},\tilde{y}',\tilde{x}',r_0^m,r^{m'},r',F',1)(\tilde{p}')^{\sigma-1}|\tilde{y},\tilde{x},r^m,r,F,1] \\
V^{refi}(\tilde{a},\tilde{y},\tilde{x},r^m,r,F,1)\tilde{p}^{\sigma-1} &= \max_{\{\hat{a}'\}} \frac{\left(\tilde{a}(1+r)+\tilde{y}-\gamma r^m+\gamma(\tilde{x}-1)-F-\hat{a}'\right)^{1-\sigma}}{1-\sigma}\tilde{p}^{\sigma-1} \\
&+\beta\mathbb{E}[V(\hat{a}'\frac{\tilde{x}'}{\tilde{x}},\tilde{y}',\frac{\tilde{x}'}{\tilde{x}},r^m,r^{m'},r',F',1)(\tilde{p}')^{\sigma-1}|\tilde{y},\tilde{x},r^m,r,F,1]
\end{aligned}$$

Then we can eliminate $\tilde{p}$ as a state variable to obtain the transformed value function,

$$\begin{aligned}
J(\tilde{a},\tilde{y},\tilde{x},r_0^m,r^m,r,F) &= \max\{J^{norefi}(\tilde{a},\tilde{y},\tilde{x},r_0^m,r^m,r,F),J^{refi}(\tilde{a},\tilde{y},\tilde{x},r^m,r,F)\} \\
J^{norefi}(\tilde{a},\tilde{y},\tilde{x},r_0^m,r^m,r,F) &= \max_{\{\hat{a}'\}} \frac{\left(\tilde{a}(1+r)+\tilde{y}-\gamma r_0^m\tilde{x}-\hat{a}'\right)^{1-\sigma}}{1-\sigma} \\
&+\beta e^{(1-\sigma)(\mu_q-\pi)}\mathbb{E}\left[J(\hat{a}'\frac{\tilde{x}'}{\tilde{x}},\tilde{y}',\tilde{x}',r_0^m,r^{m'},r',F')|\tilde{y},\tilde{x},r^m,r,F\right] \\
J^{refi}(\tilde{a},\tilde{y},\tilde{x},r^m,r,F) &= \max_{\{\hat{a}'\}} \frac{\left(\tilde{a}(1+r)+\tilde{y}-\gamma r^m+\gamma(\tilde{x}-1)-F-\hat{a}'\right)^{1-\sigma}}{1-\sigma} \\
&+\beta e^{(1-\sigma)(\mu_q-\pi)}\mathbb{E}\left[J(\hat{a}'\frac{\tilde{x}'}{\tilde{x}},\tilde{y}',\frac{\tilde{x}'}{\tilde{x}},r^m,r^{m'},r',F')|\tilde{y},\tilde{x},r^m,r,F\right]
\end{aligned}$$

In order to solve the transformed value function, we discretize $\log\tilde{x}$ using 60 grid points evenly spaced with width μ_q between 0.45 and -1.025, 64 grid points for $\tilde{a}$ between 0 and 1, with more grid points near the lower asset values to account for the concavity of the value function, and 46 grid points for $\tilde{y}$ evenly spaced in logs between -0.5 and 0.5. The stochastic shock can take on 3 values: -1SD, 0, and +1SD with probabilities computed using the Tauchen algorithm. Households assume that interest rates will remain constant in the future, and the model is solved with both $r^m = 0.06$ and $r^m = 0.05$. The short-term interest rate r is permanently set to 0.03. The model is then solved using value function iteration. Finally, the model is simulated using 50,000 households and 9 regions. Households are initialized at median income and no assets in a middle income, middle house price region and 300 years of the model are discarded as an initial burn-in. Using a longer burn-in period or changing initial conditions prior to the burn-in period leaves results unchanged.

A number of alternative models are explored in Sections 7 and 8 which involve changes to the baseline computational setup.

In the version of the model with ARMs, we assume that the households with ARMs' current payment moves one-for-one with the current mortgage rate when not refinancing. In particular, the J^{norefi} is identical except that r_0^m is always equal to r^m.

We calibrate the ARM share in bad regions to 30 percent, the ARM share in the middle regions to 20 percent and in the good regions to 10 percent. As described in the text, this is a conservative calibration for assessing the importance of ARMs since it overstates the actual variation in interest rate flexibility across space in 2008 as most ARMs do not have substantive rate resets during the QE episode.

We next explore a version of the model in which the housing bust in 2008 is preceded by a house price boom. Specifically, we assume that in the period before the Great Recession, there is an aggregate house price increase of 10% and a regional shock of $\pm 7.5\%$ that is perfectly negatively correlated with the shock during the bust. This roughly captures house price movements in the last year of the housing boom. We do not recalibrate parameters in this exercise to match the effects of QE1, but they are similar to the baseline.

We then move to a model which partially endogenizes the cash-out decision when refinancing. In particular, we let households choose between two different options when refinancing: 1) Extracting all of their housing equity when refinancing, as in our baseline. 2) Extracting no equity and only resetting the rate. In this model, we now have three value functions: J^{norefi}, $J^{refi\ and\ cash-out}$, $J^{refi\ rate\ only}$. $J^{refi\ and\ cash-out}$ is identical to J^{refi} in the original problem (except with a continuation value that maximizes over three rather than two value functions). When doing a pure rate-refi, the mortgage balance is unchanged but the household pays a fixed cost to change their fixed rate to the current mortgage rate in the economy. This means that $J^{refi\ rate\ only}$ is identical to J^{norefi} except that the rate adjusts to the current mortgage rate and the household must pay the refinancing cost. Note also that this value function is identical to that for the ARM model above, except that the household must pay the fixed cost to obtain the current rate instead of obtaining it for free:

$$J^{refi\ rate\ only}(\tilde{a}, \tilde{y}, \tilde{x}, r^m, r, F) = \max_{\{\hat{a}'\}} \frac{(\tilde{a}(1+r) + \tilde{y} - \gamma r^m \tilde{x} - F - \hat{a}')^{1-\sigma}}{1-\sigma} + \beta e^{(1-\sigma)(\mu_q - \pi)} \mathbb{E}\left[J(\hat{a}' \frac{\tilde{x}'}{\tilde{x}}, \tilde{y}', \tilde{x}', r^m, r^{m'}, r', F') | \tilde{y}, \tilde{x}, r^m, r, F \right]$$

Also note that this model introduces no new parameters, so the calibration strategy is identical to that in the baseline model. Ultimately, few households in the model choose to do rate only-refinancing with no cash-out even when they have this option, because the general equity accumulation and extraction problem still plays a primary role in decisions. A household who is contemplating a rate only refinance today still knows that in the future, they will eventually want to extract equity. Since the fixed cost of refinancing is the same whether they extract equity or not today, it makes sense to extract equity when refinancing to secure the low rate rather than doing a rate refi today and then paying the fixed cost again in the near future to extract equity.

Since we write the above value functions for general interest rate processes, the statement of the problem with stochastic interest rates is identical to that in the baseline model with a one-time unanticipated shock. Computationally, in the baseline model with a one-time shock, we only need to solve the model for two values of r^m to compute impulse responses, and we do not need to calculate expectations over r^m. In the model with stochastic mortgage rates, r^m takes on 5 values with probabilities computed using the Tauchen algorithm, and this state-variable enters expectations in the value function.

A.4 Appendix Tables

Table A-1: Descriptive Statistics. Data on 381 MSAs; statistics are unweighted.

	Mean	SD	p10	p25	p50	p75	p90
Median equity share (E^{med}), Jan 2007	0.293	0.066	0.209	0.243	0.289	0.345	0.383
Median equity share (E^{med}), Nov 2008	0.160	0.110	0.015	0.120	0.190	0.230	0.261
Δ House Price Index, Jan 2007-Nov 2008	-0.111	0.113	-0.286	-0.161	-0.086	-0.033	0.010
Δ Unemployment, Jan 2007-Nov 2008	2.297	1.370	0.700	1.400	2.100	3.000	4.100
Δ Labor Income, 2008-2009	0.003	0.022	-0.022	-0.009	0.003	0.017	0.025
Average mortgage characteristics as of Nov 2008 (based on CRISM):							
FICO score	701.8	17.4	679.4	689.4	701.6	714.9	723.5
Current interest rate (%)	6.23	0.16	6.02	6.13	6.23	6.34	6.43
Loan age (months)	39.3	3.8	34.6	36.6	39.1	41.6	44.8
Share jumbos (based on current balance)	0.046	0.048	0.007	0.014	0.029	0.063	0.115
Average balance of non-jumbo loans (1000s)	130.7	46.2	87.3	100.0	117.3	153.2	181.2
Share adjustable-rate mortgages	0.136	0.098	0.057	0.070	0.098	0.171	0.272
Share GSE securitized	0.615	0.097	0.498	0.572	0.631	0.676	0.721
Share privately securitized	0.158	0.086	0.083	0.103	0.127	0.180	0.262
Local demographics (based on ACS):							
Years of education (shares)							
12	0.147	0.033	0.105	0.124	0.146	0.170	0.192
13-15	0.315	0.042	0.262	0.287	0.316	0.339	0.371
16	0.172	0.048	0.112	0.135	0.168	0.203	0.234
>16	0.266	0.026	0.236	0.250	0.263	0.281	0.300
Age group (shares)							
31-45	0.286	0.026	0.252	0.271	0.285	0.303	0.318
46-40	0.340	0.024	0.311	0.326	0.340	0.356	0.370
>60	0.206	0.038	0.167	0.183	0.202	0.223	0.244
Homeowners (share)	0.779	0.053	0.712	0.751	0.785	0.813	0.839
Mortgage borrowers (share)	0.543	0.065	0.454	0.505	0.552	0.591	0.619

Table shows descriptive statistics for all 381 MSAs in our analysis sample, including the distribution of median equity shares (E^{med}) in January 2007 and November 2008, the distribution of house price and unemployment rate changes (in percent and percentage points, respectively) between January 2007 and November 2008, the distribution of changes in average labor income between 2008 and 2009, distributions of a number of characteristics of the outstanding mortgages in each MSA as of November 2008 (taking balance-weighted averages within each MSA), and local demographic characteristics as of 2008. For years of education and age groups, the base categories (<12 years of education; ages 21-30) are not shown. The share of mortgage borrowers is relative to all households, not just homeowners.

Table A-2: Relationships between Median Equity and Unemployment Increases as well as Various Average Characteristics of Outstanding Mortgages

	(1)	(2)	(3)	(4)	(5)	(6)
Δ Unemployment, Jan 2007-Nov 2008	-0.0597***					-0.00236
	(0.00877)					(0.00434)
Δ Labor Income, 2008-09		3.705***				0.423
		(0.513)				(0.257)
FICO score			0.00404***			0.00528***
			(0.000661)			(0.000627)
Current interest rate (%)				-0.362***		0.347***
				(0.110)		(0.0662)
Loan age (months)				0.00238		-0.000393
				(0.00413)		(0.00142)
Share jumbos (based on current balance)				-0.473**		0.661***
				(0.227)		(0.125)
Average balance (non-jumbo)				-0.0189		0.169***
				(0.0467)		(0.0280)
Share adjustable-rate mortgages					-1.128***	-0.942***
					(0.321)	(0.150)
Share GSE securitized					0.0793	-0.437***
					(0.124)	(0.0643)
Share privately securitized					0.956**	-0.642***
					(0.409)	(0.217)
Constant	0.302***	0.159***	-2.690***	2.365***	0.126	-4.621***
	(0.0208)	(0.0107)	(0.467)	(0.766)	(0.0910)	(0.761)
Demographics	N	N	N	N	N	Y
N	381	381	381	381	381	381
Adj. R^2	0.36	0.31	0.30	0.16	0.17	0.85

Table shows the results of regressions of median equity as of November 2008 ($E^{med}_{j,Nov2008}$) on various other variables observed as of November 2008 (and shown in Table A-1). Sample consists of 381 MSAs. MSAs are weighted by their 2008 population. Robust standard errors in parentheses. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A-3: The Responsiveness of Local Refinancing Activity to Equity and Other Local Characteristics around QE1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$E^{med}_{Nov2008} \times$ postQE	1.711***	1.161***	1.530***	0.920***	1.088***	1.856***	1.694***	0.483***
	(0.232)	(0.258)	(0.288)	(0.237)	(0.115)	(0.233)	(0.186)	(0.184)
$\Delta UR_{Jan07-Nov08} \times$ postQE		-0.0911***						-0.0511***
		(0.0188)						(0.0131)
$\Delta Income_{2008-09} \times$ postQE			2.123*					-1.028
			(1.233)					(0.776)
FICO × postQE				0.0107***				0.00876***
				(0.00101)				(0.00180)
Current int. rate × postQE					-1.688***			-0.812***
					(0.117)			(0.210)
Loan age × postQE					-0.0229***			-0.0326***
					(0.00369)			(0.00521)
Jumbo share × postQE					-1.843***			-1.238***
					(0.293)			(0.409)
Average balance (non-jumbo) × postQE					-0.218***			-0.231***
					(0.0315)			(0.0881)
ARM share × postQE						2.269***		-0.188
						(0.496)		(0.393)
GSE share × postQE						0.954***		-0.305*
						(0.240)		(0.170)
Private sec. share × postQE						-2.112***		0.190
						(0.616)		(0.534)
Demographics × postQE	N	N	N	N	N	N	Y	Y
MSA fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Month fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.87	0.87	0.87	0.88	0.90	0.88	0.89	0.90
Adj. R^2 (within)	0.18	0.22	0.19	0.28	0.35	0.25	0.30	0.38
Observations	4572	4572	4572	4572	4572	4572	4572	4572

Table shows results from regressions of monthly refinancing propensities in 381 MSAs from August 2008 to July 2009, measured in CRISM, on median equity in each MSA interacted with a dummy "postQE" that equals one for the period February–July 2009, and other variables also interacted with postQE. Demographic controls in columns 7 and 8 are location-specific shares of individuals with different years of education: 12,13-15,16,>16 (<12 is omitted), shares of individuals with ages: 31-45,46-60,>61 (21-30 is omitted), homeowner shares and the share of households with mortgages, from the ACS. Each of these demographic controls is interacted with "postQE" to allow for differential responses to rate declines. All regressions also include MSA and month fixed effects. For reference, the average monthly refinancing propensity over August 2008–January 2009 was 0.4 percent, while over February–July 2009 it was 1.2 percent. Descriptive statistics of explanatory variables are provided in Table A-1. MSAs are weighted by their 2008 population. Robust standard errors (clustered by MSA) in parentheses. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A-4: The Responsiveness of Cash-Out Refinancing Activity to Equity and Other Local Characteristics around QE1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$E^{med}_{Nov2008} \times$ postQE	0.167***	0.138***	0.147***	0.103***	0.123***	0.171***	0.157***	0.0458**	0.0626***
	(0.0224)	(0.0266)	(0.0271)	(0.0233)	(0.0177)	(0.0248)	(0.0189)	(0.0207)	(0.0137)
$\Delta UR_{Jan07-Nov08} \times$ postQE		-0.00479***						-0.00414***	
		(0.00176)						(0.00145)	
$\Delta Income_{2008-09} \times$ postQE			0.236**					0.0303	
			(0.117)					(0.0906)	
FICO × postQE				0.000862***				0.000297	
				(0.0000968)				(0.000227)	
Current int. rate × postQE					-0.115***			-0.112***	
					(0.0146)			(0.0231)	
Loan age × postQE					-0.00140***			-0.00219***	
					(0.000434)			(0.000567)	
Jumbo share × postQE					-0.147***			-0.0226	
					(0.0398)			(0.0472)	
Average balance (non-jumbo) × postQE					-0.00633			-0.00454	
					(0.00537)			(0.0123)	
ARM share × postQE						0.00399		-0.230***	
						(0.0493)		(0.0435)	
GSE share × postQE						0.131***		0.0437*	
						(0.0291)		(0.0251)	
Private sec. share × postQE						0.0990		0.266***	
						(0.0663)		(0.0667)	
Refinancing propensity									0.0610***
									(0.00331)
Demographics × postQE	N	N	N	N	N	N	Y	Y	N
MSA fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Month fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R^2	0.80	0.80	0.80	0.81	0.81	0.80	0.80	0.82	0.84
Adj. R^2 (within)	0.12	0.12	0.12	0.15	0.17	0.13	0.14	0.20	0.32
Observations	4572	4572	4572	4572	4572	4572	4572	4572	4572

Table shows results from regressions of monthly equity removed (relative to outstanding balances) in 381 MSAs from August 2008 to July 2009, measured in CRISM, on median equity in each MSA interacted with a dummy "postQE" that equals one for the period February–July 2009, and other variables also interacted with postQE. Demographic controls in columns 7 and 8 are location-specific shares of individuals with different years of education: 12,13-15,16,>16 (<12 is omitted), shares of individuals with ages: 31-45,46-60,>61 (21-30 is omitted), homeowner shares and the share of households with mortgages, from the ACS. Each of these demographic controls is interacted with "postQE" to allow for differential responses to rate declines. All regressions also include MSA and month fixed effects. For reference, the average monthly equity removed over August 2008–January 2009 was 0.09 percent of outstanding balances, while over February–July 2009 it was 0.14 percent of outstanding balances. Descriptive statistics of explanatory variables are provided in Table A-1. MSAs are weighted by their 2008 population. Robust standard errors (clustered by MSA) in parentheses. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A-5: The Responsiveness of New Vehicle Spending around QE1

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$E^{med}_{Nov2008} \times$ postQE	0.389***	0.246**	0.227***						
	(0.0851)	(0.113)	(0.0574)						
$E^{med}_{Nov2008} \times$ time trend (monthly)		0.0103	0.0110***						
		(0.00918)	(0.00316)						
(Refinancing propensity)$_{t-2}$				0.0994***	0.116***			0.0977***	0.112***
				(0.0244)	(0.0206)			(0.0224)	(0.0194)
(Cashout/balance)$_{t-2}$						0.485***	0.369***	0.0250	0.0447
						(0.165)	(0.0923)	(0.107)	(0.0626)
Fixed effects	MSA&month	MSA&month	MSA&month	MSA&month	MSA&month	MSA&month	MSA&month	MSA&month	MSA&month
Adj. R^2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Adj. R^2 (within)	0.04	0.03	0.05	0.04	0.04	0.01	0.01	0.04	0.04
Observations	4572	9144	18288	4572	9144	4572	9144	4572	9144
Date range	200808-200907	200801-200912	200701-201012	200808-200907	200801-200912	200808-200907	200801-200912	200808-200907	200801-200912

Column 1 shows results from regression of monthly log(auto sales) in 381 MSAs on median equity (E^{med}) in each MSA (as of November 2008) interacted with a dummy "postQE" that equals one from February 2009 onward. In columns 2 and 3, the sample period is extended and a monthly trend interacted with $E^{med}_{Nov2008}$ is added. In columns 4 and 5, log(auto sales) is directly regressed on two-months-lagged local refinancing propensities; in columns 6 and 7 the same is repeated for local cash-out amounts (relative to outstanding balance). Columns 8 and 9 add both refinancing measures simultaneously. All regressions also include MSA and month fixed effects. MSAs are weighted by their 2008 population. Robust standard errors (clustered by MSA) in parentheses. Auto sales are from R.L. Polk; refinancing propensities and cash-out fractions are measured in CRISM. Significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

A.5 Appendix Figures

Figure A-1: Median Equity vs. Fraction of Borrowers over CLTV 80 or CLTV 100 Thresholds, as of November 2008.

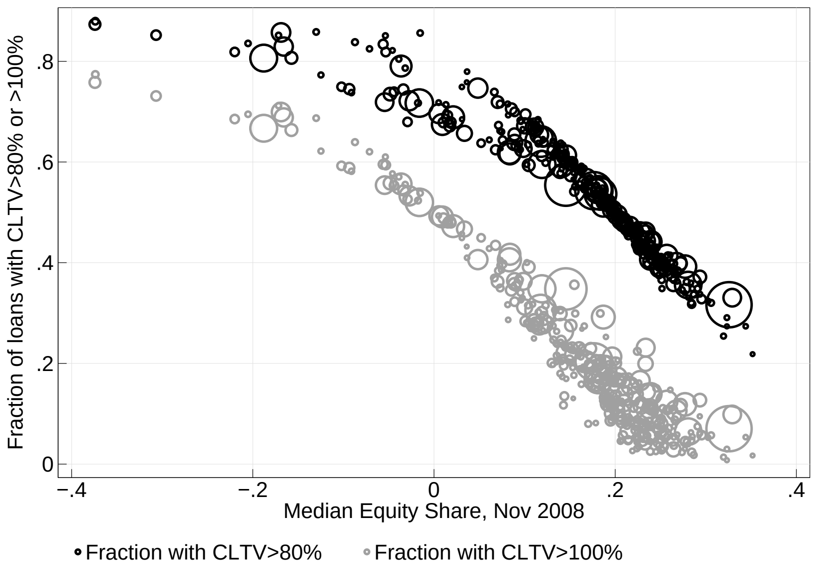


Figure shows the relationship between median equity in an MSA as of November 2008 ($E^{med}_{j,Nov2008}$) and the share of borrowers in the MSA who have an estimated CLTV in the same month higher than 80 percent (black circles) or higher than 100 percent (gray circles). Equity/CLTVs are measured based on CRISM. Each observation is an MSA, with 381 in total (per series). The size of the circle represents the 2008 population of the MSA.

Figure A-2: Mortgage Activity in the US over 2000-2012, Based on HMDA Data

(a): Refinance Mortgage Originations **(b):** Purchase Mortgage Originations

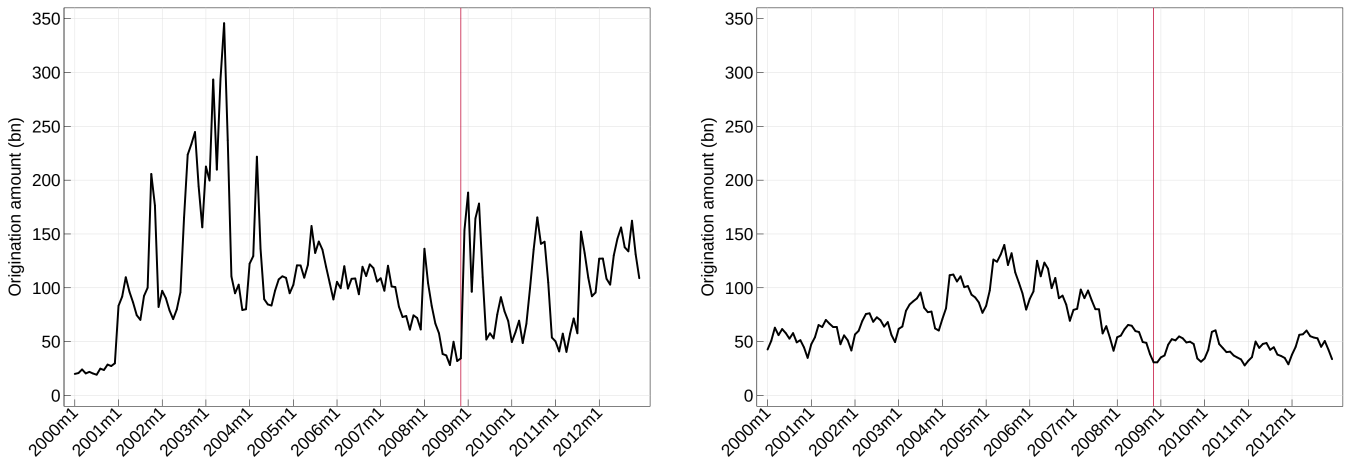
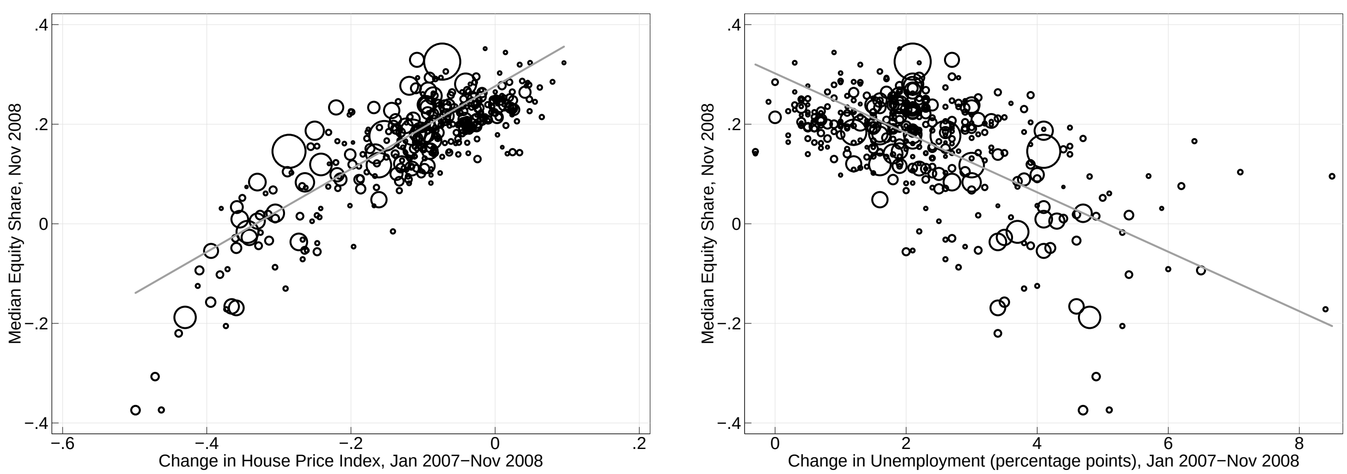


Figure shows mortgage originations on 1-4 unit homes in HMDA, by month in which the borrower applied for the loan. The vertical line indicates the month of the QE1 announcement (November 2008).

Figure A-3: Relationship between Equity and Other Measures of Economic Activity.

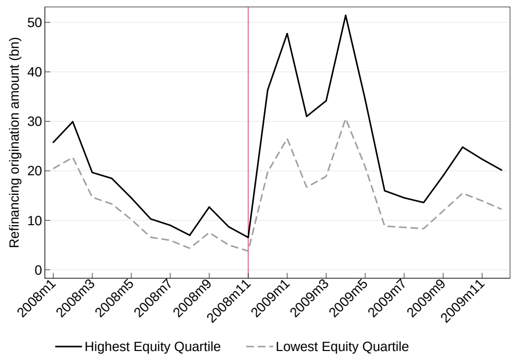
(a): House Price Growth vs. Median Equity **(b):** Unemployment Rate Change vs. Median Equity



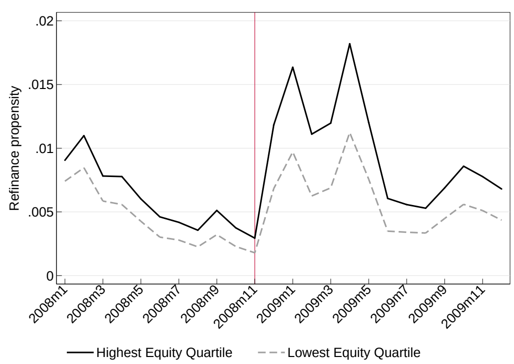
Panel (a) shows MSA house price growth between January 2007 and November 2008 vs. the median borrower's equity (as a share of estimated home value) in the MSA in November 2008. Each observation is an MSA, with 381 in total. The size of the circle represents the 2008 population of the MSA. The figure also shows the simple (population weighted) regression through the scatter plot: a 1 percent decline in house prices is associated with a 0.83 percentage point decrease in median equity (standard error 0.07) with an R-squared of 0.69. Panel (b) shows the change in an MSA's unemployment rate between January 2007 and November 2008 vs. the median borrower's equity (as a share of estimated home value) in the MSA in November 2008. The simple regression line shows that a 1 percentage point increase in the unemployment rate is associated with a 6.0 percentage point decline in median equity (standard error 0.09) with an R-squared of 0.36.

Figure A-4: Mortgage Refinance Activity 2008-2009 in Top and Bottom Quartile of MSAs Defined by Median Equity in November 2008, Based on HMDA Data

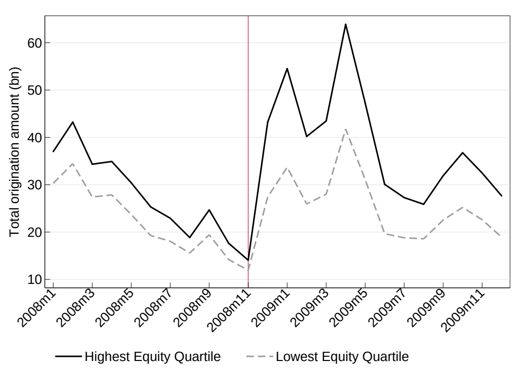
(a): Refinance Origination Volumes



(b): Refinance Propensities



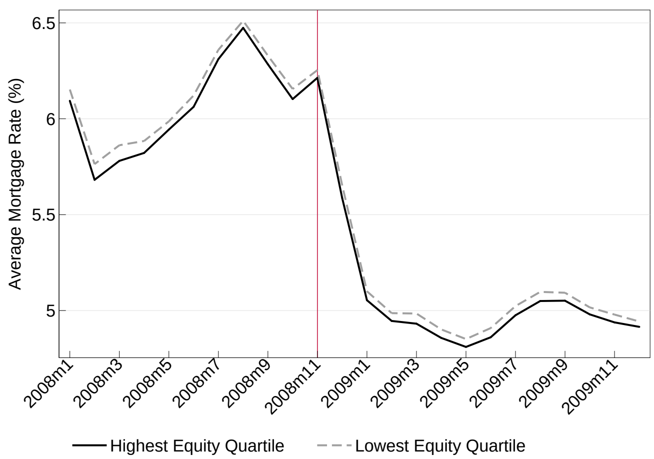
(c): Total Origination Volumes (Refinance and Purchase)



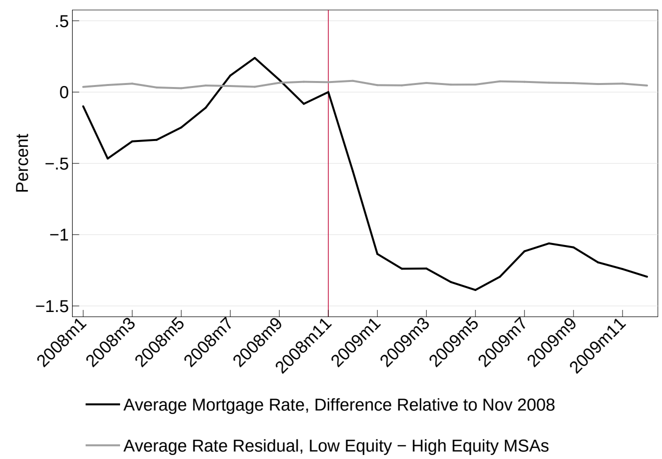
Panel (a) shows total mortgage refinance volume in HMDA by month in which borrower applied for the mortgage, where months are re-defined such that they start on the 25th day of the prior month. Panel (b) shows corresponding refinance propensities, defined as the number of refinance originations in HMDA divided by the total number of mortgages outstanding as measured in the 2008 American Community Survey. Panel (c) shows total mortgage origination volume (purchase and refinance) in HMDA by month in which borrower applied for the mortgage. In all three panels, calculations are done at the level of MSA quartile groups and vertical lines indicate the month of the QE1 announcement (November 2008).

Figure A-5: No Spatial Variation in Mortgage Interest Rates

(a): Raw Interest Rates by Equity Quartile



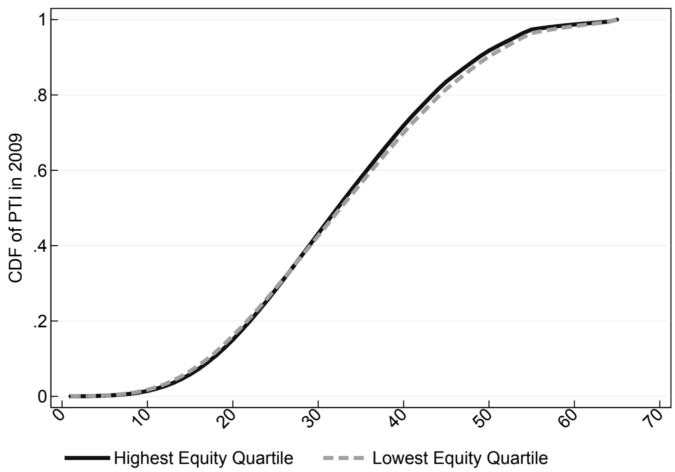
(b): Interest Rate Gaps After Controlling for Observables



Panel (a) shows average interest rate on newly originated non-purchase mortgages in CRISM in the top and bottom MSA quartiles by $E^{med}_{j,Nov2008}$, showing that the evolution of mortgage rates was almost identical across locations. In panel (b), the black line shows the difference in the average interest rate on newly originated mortgages relative to its level in November 2008. The gray line shows the gap between average rate residuals in the top and bottom MSA quartiles by $E^{med}_{j,Nov2008}$. Rate residuals are obtained following Hurst et al. (2016), by regressing each newly originated mortgage's interest rate on quadratic functions of FICO and LTV, and dummies for different loan purposes (purchase, rate refi, cashout refi, unknown), all interacted with month dummies. The gap averages only around 5 basis points over our sample and does not increase after QE1.

Figure A-6: 2009 Distributions of PTI and CLTV for Top and Bottom Quartile of MSAs Defined by Median Borrower Equity in November 2008

(a): PTI (2009)



(b): CLTV (2009)

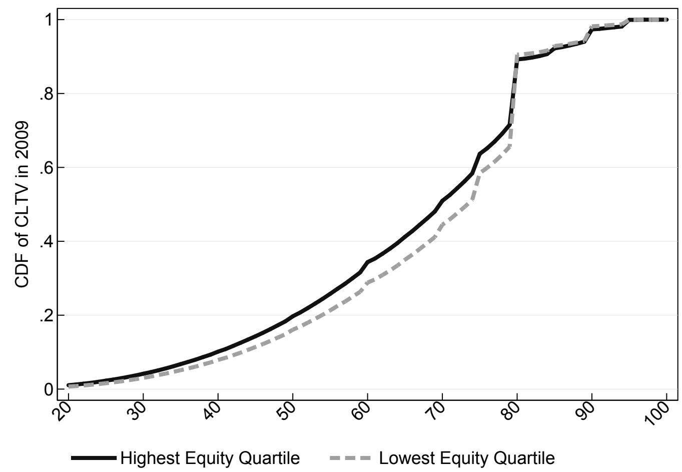


Figure shows the distribution of PTI and CLTV at origination in high and low equity MSA groups for loans originated in 2009 using the pooled sample of loans acquired by Fannie Mae and Freddie Mac in Single Family Loan Performance (SFLP) Data. In total, we observe 1,886,365 originations in the highest equity quartile and 1,514,085 originations in the lowest equity quartile. We set the 48,537 loans with missing PTI equal to 0.65 since SFLP does not report PTI above 0.65, but results are similar when instead excluding these loans. Panel (a) shows that the distribution of PTI exhibits little bunching and is similar in both high and low equity MSAs (computed over the stock of all loans in CRISM). Panel (b) shows that the distribution of CLTV (for the flow of new mortgages in SFLP) exhibits substantial bunching and varies substantially with equity (computed over the stock of mortgages in CRISM).

Figure A-7: Estimated Cash-out Amounts from Freddie Mac vs. in our CRISM data

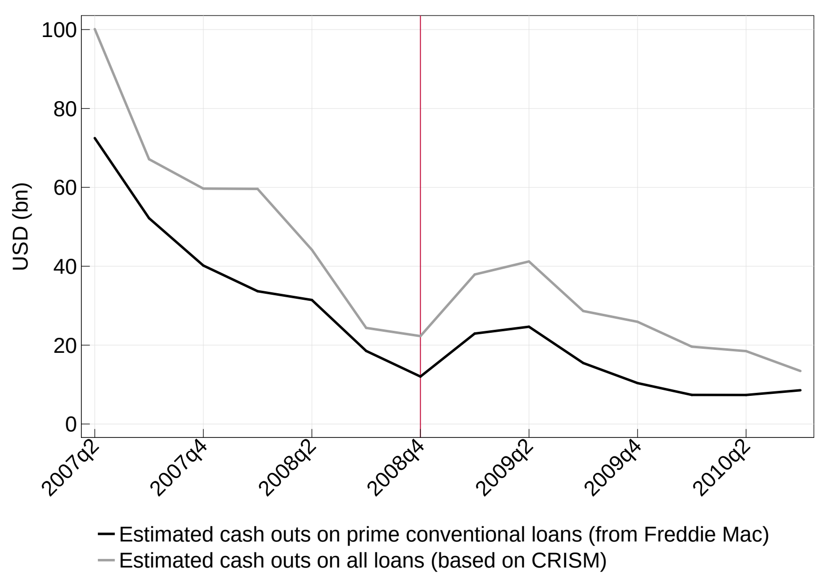


Figure shows estimated quarterly cash-out volumes on prime conventional (non-government) mortgages estimated by Freddie Mac (obtained from `http://www.freddiemac.com/finance/docs/q4_refinance_2014.xls`), as well as those we obtain based on the CRISM data (which also include FHA/VA loans) after scaling up as explained in Section A.2.3.

Figure A-8: Relationship between Refinancing Threshold, Equity and Income

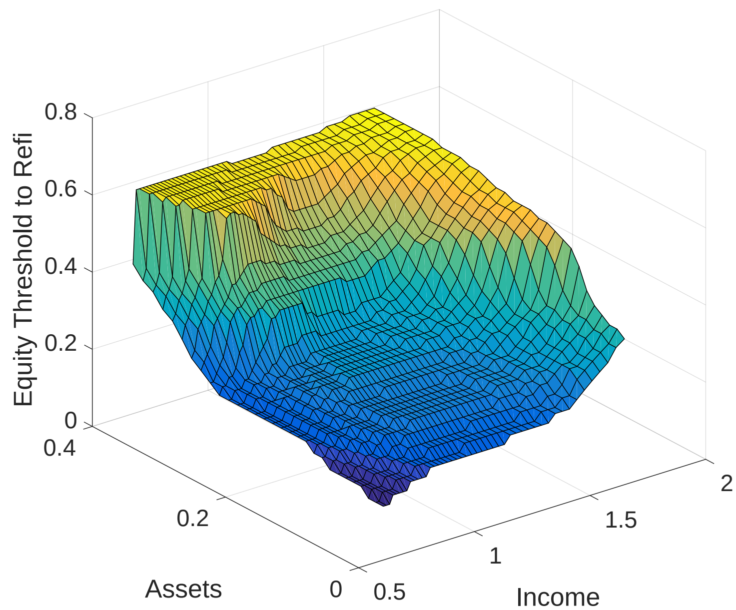


Figure shows refinancing threshold for each asset and income value for low fixed cost.

Figure A-9: Borrower and Lender Contribution to Aggregate Consumption Impulse

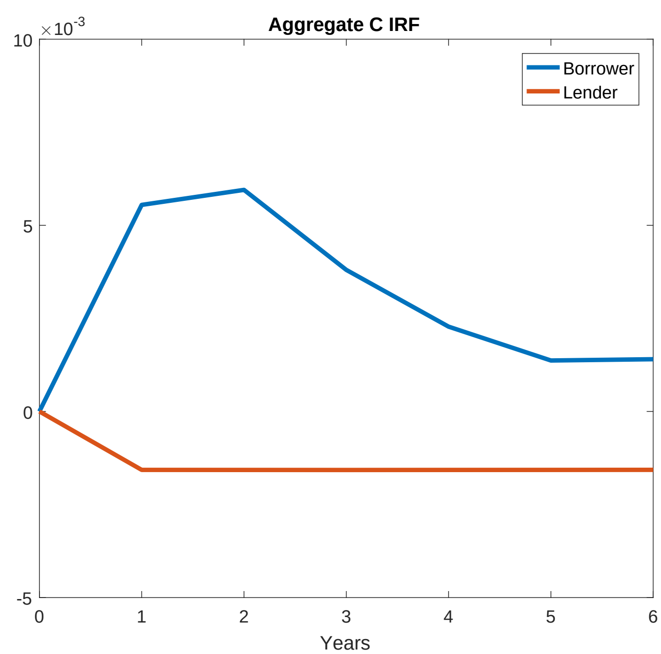


Figure shows the separate contributions of borrowers and lenders to the aggregate consumption impulse response in the 2008 baseline model shown in Figure 13.

Figure A-10: Adjustable-Rate Mortgage Shares pre-QE1 and Payment Reductions over Nov 2008 – June 2009

(a): ARM Shares vs. Median Equity **(b):** Sizeable ARM Payment Reductions vs. Median Equity

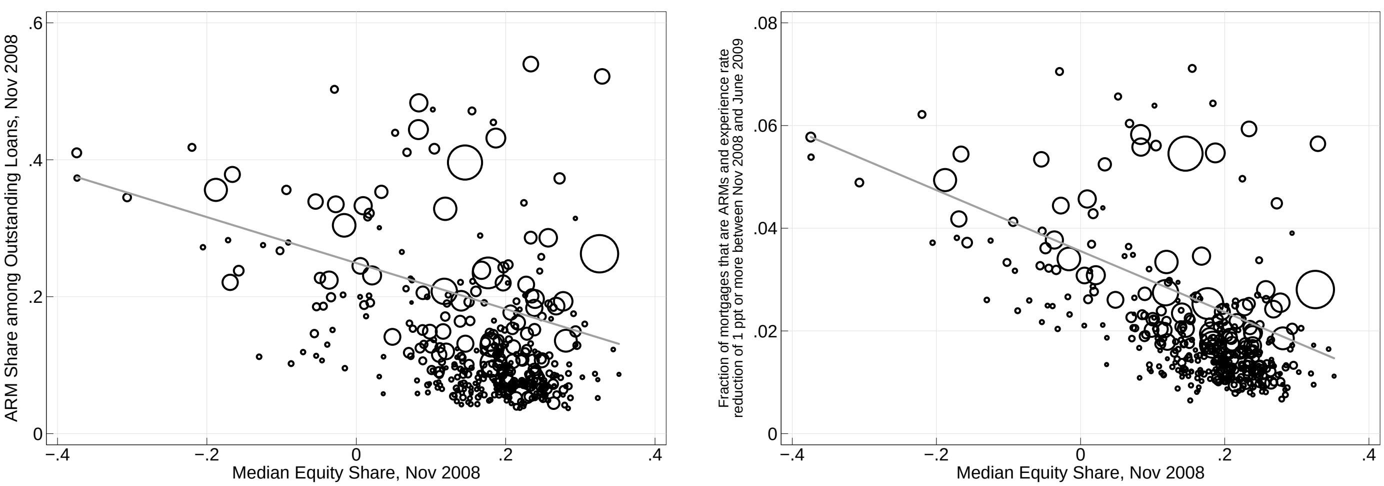
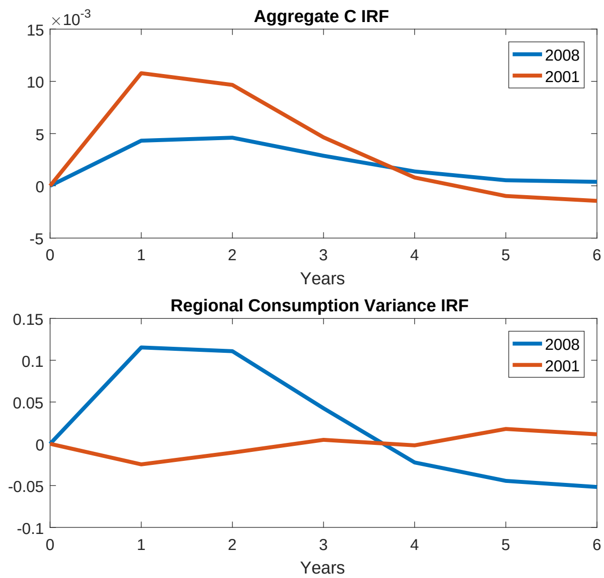


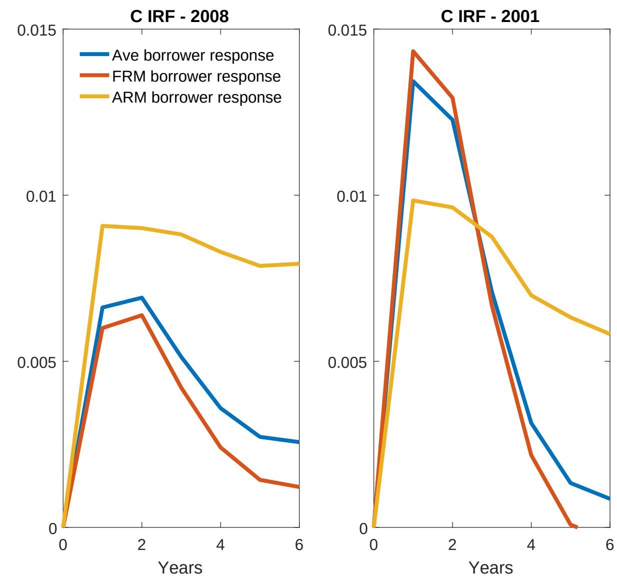
Figure shows scatter plots of the balance-weighted fraction of adjustable-rate mortgages (ARMs) in a given MSA (panel a) or the balance-weighted fraction that are ARMs and experience a rate reduction of 1 percentage point or more over November 2008 – June 2009 (panel b), as measured in the CRISM data, versus the median equity share (E^{med}) within the MSA as of November 2008. The size of the circle represents the 2008 population of the MSA. The gray lines represent simple regression lines fitting the scatter plot (population weighted).

Figure A-11: Accounting for Ex-Ante Heterogeneity

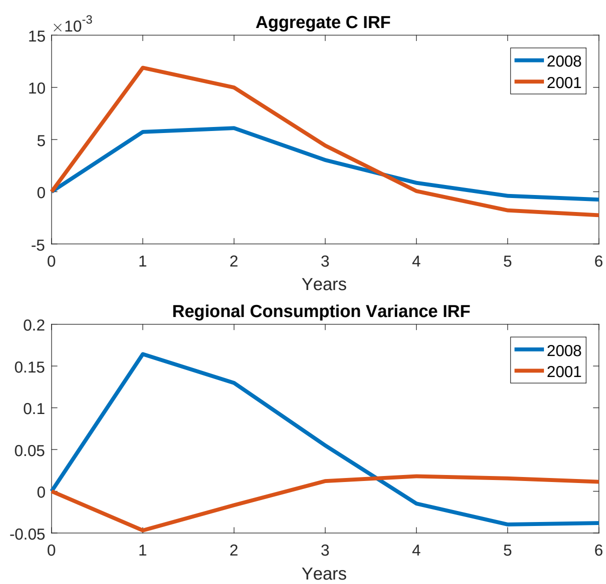
(a): Match ARM-Share



(b): Spending responses of ARM vs. FRM borrowers



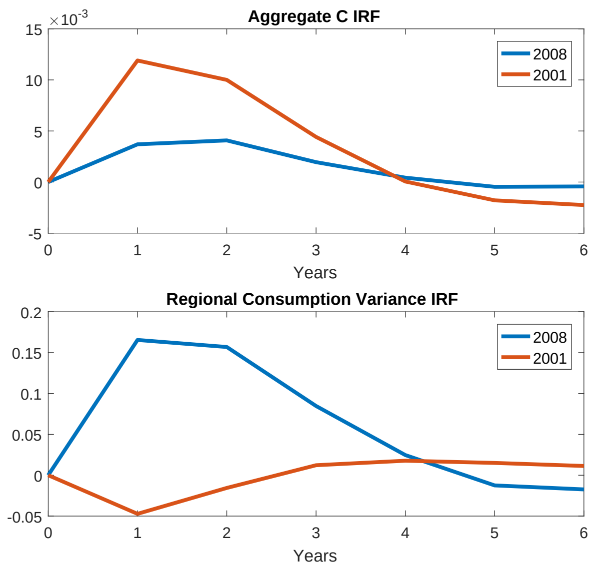
(c): Boom-Bust



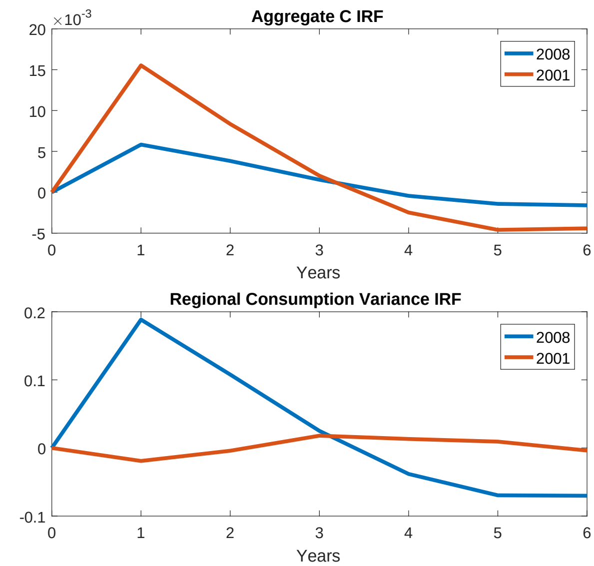
Panel (a) repeats Figure 13 in a model with both FRM and ARMs calibrated to match the regional differences with house prices in the data. Panel (b) shows the average spending response of ARM borrowers, FRM borrowers and their share-weighted averages in 2008 compared to 2001. Note that the share-weighted average borrower average is not identical to the aggregate spending response since it includes no lender responses. Panel (c) repeats Figure 13 in a model where regions with the largest house price declines experience a prior house price boom.

Figure A-12: Robustness Results

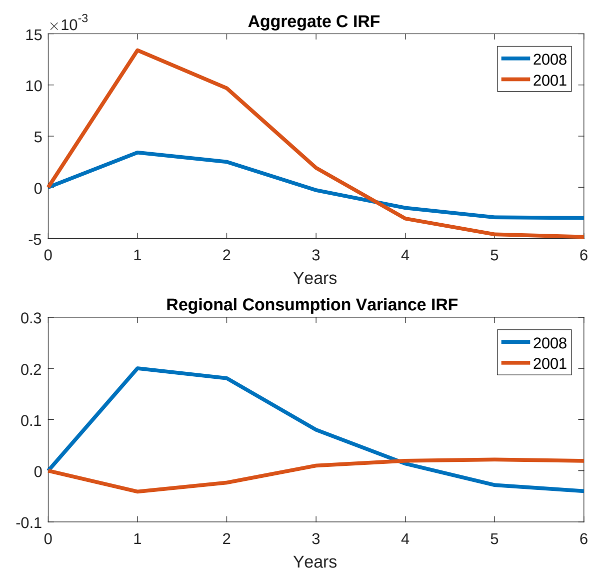
(a): Relaxing Full Cash-out Assumption



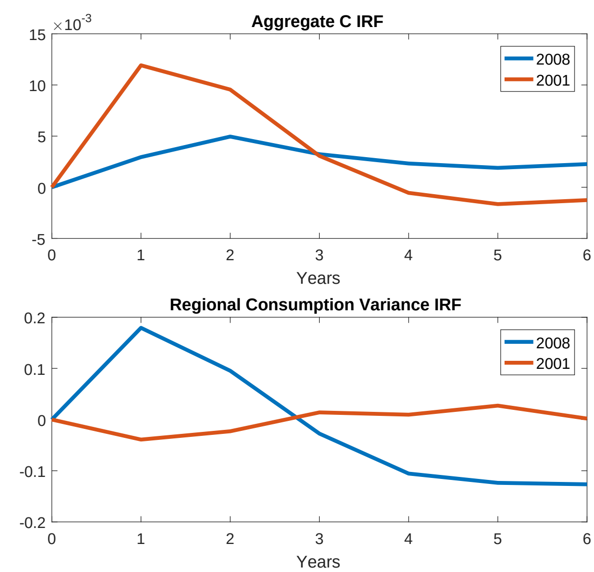
(b): Stochastic Mortgage Rate



(c): Reduce r and r^m

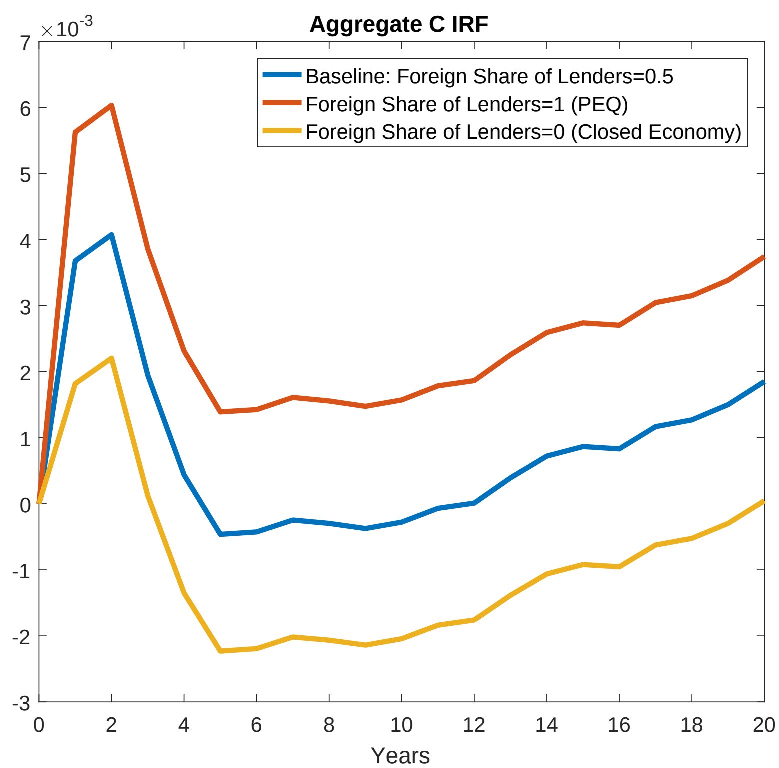


(d): Include temporary income shocks



This figure repeats Figure 13 in several alternative models. In panel (a) households can choose between full cash-out and no cash-out refinancing. In panel b) interest rate movements are stochastic instead of a one-time shock. In panel (c) r and r^m both decline, with a constant spread. In panel (d) households experience i.i.d. transitory income shocks.

Figure A-13: Importance of GE Effects from Lenders' Consumption



This figure shows aggregate consumption IRFs for alternative assumptions on what share of mortgage debt is held by domestic households, whose income will fall when interest rates decline.