ESSAYS ON MACROECONOMICS AND HOUSING

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The Great Recession of 2007-2009 and the preceding mortgage foreclosure crisis brought renewed attention to the links between the housing and mortgage markets and the macroeconomy in the United States. This dissertation presents three essays on macroeconomics and housing. Using a variety of methodological techniques, I focus in particular on the relationship between housing finance and household consumption.

The first chapter in my dissertation assesses the aggregate and distributional consequences of policies that seek to reduce mortgage default by limiting a borrower's debt payment-to-income ratio. I document empirically that highly creditworthy borrowers appear constrained by the current institutional debt payment-to-income ratio limit. I propose a heterogeneous-agent life-cycle model with a competitive mortgage market, endogenous default on mortgages, and mortgage contract choice consistent with the empirical findings. In the calibrated model, I show that, relative to the current uniformly applied debt payment-to-income ratio cap, a new policy that combines a more strict limit with a costly option to relax the limit lowers default and improves aggregate welfare. The new policy is not Pareto improving, however, and the largest welfare gains accrue to households who have relatively high net worth but low current incomes.

The second chapter uses household-level survey data to estimate the extent to which homeownership functions as a source of consumption insur-

ance against income risk. I document empirically that homeowners experience smaller declines in nondurable consumption during periods of low earnings compared to renters and that, conditional on having low initial liquid wealth, owners use home equity extraction to smooth consumption. These novel stylized facts are consistent with the theory that home equity is a valuable but costly form of consumption insurance. They can additionally be used to discipline the calibration of a general class of incomplete-markets life-cycle models with costly illiquid asset adjustment.

The third chapter leverages methods from the structural vector autoregression literature in macroeconomics to study the transmission of monetary policy shocks to the U.S. residential mortgage market. I find that, in response to contractionary monetary policy shocks, the mortgage interest rate increases, mortgage originations decrease, and the mortgage repayment rate declines as well. I also find that the pass-through of monetary policy shocks to the mortgage market was stronger during the Great Moderation. These results provide aggregate evidence in favor of the mortgage market as an important transmission channel for monetary policy.

BIOGRAPHICAL SKETCH

Malin Hu is a Ph.D. candidate in the Department of Economics at Cornell University, working under the supervision of Christopher Huckfeldt, Kristoffer Nimark, and Karel Mertens. She is an applied macroeconomist who uses quantitative heterogeneous-agent models disciplined by micro-level data to examine questions of policy relevance. Her current research interests lie in household consumption, consumer finance, and the housing and mortgage markets. More broadly, she is interested in the distributional consequences of macroeconomic policy and the implication of household heterogeneity for macroeconomic aggregates.

She received a B.S.F.S. in International Political Economy, *magna cum laude*, from Georgetown University in 2011 and a M.A. in Economics from Cornell University in 2017. She expects to receive her Ph.D. in Economics from Cornell University in May 2019. In August 2019, she will join Vanderbilt University as an Assistant Professor in Economics.

To Dorothy, who helped me find the yellow brick road.

也许没有过去的苦，就没有今天的甜。

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Carson Schneider, Praise Oh, Amanda Kleintop, Katherine Luer, Omar Noureldin, Steven Glinert, Christopher Griffin, Fabian Gunzinger, and George Berry: your Skype chats, text messages, cat pictures, sushi lunches, novella-length emails, and rambles through the Met have sustained me in times good and bad. It says a lot about our respective friendships that, although you are all scattered throughout the country (or beyond) and we may pass through long silences, we inevitably reach the other side to find that not much has changed.

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I reserve my final lines for Gregory Marecki. You brought birdsong to my world. I love you.

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CHAPTER 1

MACROECONOMIC EFFECTS OF HOUSEHOLD LEVERAGE REGULATIONS AFTER THE CRISIS

1.1 Introduction

The sharp increase in mortgage defaults observed during the Great Recession was closely linked to borrowers who had mortgage payments that were large relative to their incomes. Policymakers have identified loose underwriting standards in the residential mortgage market as a contributing factor to the foreclosure crisis and since sought to tighten them. In doing so, regulators confront a trade-off between lowering the risk of mortgage default on one hand and preserving opportunities for homeownership on the other. Policies aimed at mitigating default may curtail access to credit for some households, preventing some homeowners from accessing the equity stored in their homes or deterring some marginal agents from becoming owners at all. Although the aggregate effects of these policies are important, their distributional implications are relevant as well. This paper explores the heterogeneity in welfare changes that result from reforms to household leverage regulations.

Because a high debt payment-to-income (DTI) ratio has been identified as a proxy for greater default risk, policymakers have generally agreed that a limit on borrowers' DTI ratios could reduce the likelihood of a future foreclosure crisis by ensuring that borrowers are better able to repay their loans.[1] There has been less consensus, however, regarding the precise design of these caps on DTI

[1]E.g., the Consumer Financial Protection Bureau (2013): "All things being equal, consumers carrying loans with higher DTI ratios will be less able to absorb any such [negative] shocks and are more likely to default."

ratios. The current institutional limit of 45 percent, in place since 2009, applies uniformly to all borrowers. In contrast, a new regulation from the Dodd-Frank Act combines a more strict DTI limit of 43 percent with a costly option to obtain a loan with a DTI ratio above the limit. This new regulation is due to take effect for the vast majority of the U.S. residential mortgage market in 2021. It is not clear *a priori* which approach is more beneficial from the perspective of household welfare. Furthermore, while some of the effects of the current regulation can be assessed empirically, evaluating the potential outcomes of a future regulation requires a structural model capable of comparing specific DTI limit policies against one another.

My paper studies the aggregate and distributional effects of limits on borrowers' debt payment-to-income ratios. Using loan-level data, I document empirically the effect of the current DTI limit on mortgage originations. I propose a heterogeneous-agent life-cycle model with a competitive mortgage market, endogenous default on mortgage debt, and a discrete choice between mortgage contracts. Using a calibrated version of the model, my main finding is that, relative to the current uniformly applied DTI limit, the new policy that combines a more strict constraint with a costly option to relax the constraint reduces default and increases aggregate welfare. Homeowners with low cash on hand benefit most from the new Dodd-Frank policy. This is not necessarily an obvious result. Because the Dodd-Frank regulations both tighten the DTI limit and impose higher costs on loans with DTI ratios exceeding that limit, one might expect such a policy to decrease welfare relative to the looser limit presently in effect. However, my model suggests that, for this subset of households, the welfare benefits of the newly introduced opt-out provision outweigh those losses because they have a low probability of default. Thus, these households can choose the costly option to relax the limit with only a negligible increase in the mortgage interest rate they receive in equilibrium.

In my empirical analysis, I present three findings regarding the effect of the current institutional DTI limit of 45 percent on mortgage originations. First, I illustrate that, after this policy was introduced, the share of mortgage loans above the limit has declined dramatically while, simultaneously, a growing fraction of borrowers have found themselves close to or at the limit. Second, I show that, following this policy change, the small fraction of borrowers who are able to obtain to the right of the limit are, relative to those exactly on the limit, more creditworthy, obtain loans with lower loan-to-value ratios, and receive a lower interest rate on their mortgages. This second finding is consistent with a story in which policies limiting the DTI ratio are accompanied by a selection of more high-quality borrowers into loans with higher DTI ratios. Third, I document that it is not only risky borrowers who are found on the 45-percent limit: a significant fraction of them have high enough credit scores that their likelihood of default is close to zero. This last finding tentatively suggests that the one-size-fits-all approach of the current DTI regulation may unnecessarily constrain the decisions of very safe borrowers. Given that borrowers above the limit experience significantly different mortgage market outcomes, even after conditioning on observable characteristics, this finding also suggests that a policy that could permit these highly creditworthy households to obtain less constrained loans may yield improvements in welfare.

In order to conduct policy counterfactuals, I develop a heterogeneous-agent life-cycle model with three key ingredients: a competitive mortgage market so that loans are priced in equilibrium, the option for households to default endogenously on their outstanding debt, and a discrete choice between mortgage contracts that captures the relevant institutional details of the new DTI limit from the Dodd-Frank Act. The mortgage contract choice is the most novel feature of the model and is general enough to nest different regulations on household leverage, including the current DTI limit. This makes the model especially powerful for policy evaluation. The goal of the calibration is to ensure the model is consistent with the U.S. residential mortgage market under the current DTI limit regulation. I calibrate parameters so that moments from the stationary distribution of households over states in the model match those from U.S. aggregate, cross-sectional, and loan-level data.

After validating the quantitative fit of the calibrated model, I use it to analyze aggregate and distributional consequences of the current and new DTI limits. I implement the new Dodd-Frank regulation in the calibrated model by lowering the maximum DTI ratio from 45 to 43 percent and giving households the choice between two mortgage contracts, one in which the loan size is subject to the DTI constraint and one in which it is not. I then solve for the stationary distribution of the model under the new policy. My main quantitative exercise, then, is to compare the stationary distributions under the current and new DTI ratio regulations with respect to outcomes like default, homeownership, and welfare. I also consider a counterfactual in which no DTI limit exists.

I present three sets of results from my quantitative exercises. First, a DTI constraint reduces the aggregate default rate while lowering the homeownership rate as well. These declines are driven by borrower selection. In the absence of a DTI limit, low-income and low-net worth households obtain high-DTI loans in equilibrium. After the introduction of a DTI limit, these borrowers reduce their leverage along the intensive and extensive margins, and their exit from the mortgage market accounts for the decline in both foreclosure and homeownership. Second, I show that the costly option to relax the DTI limit introduced under the new Dodd-Frank regulation is primarily exercised by households who have relatively high net worth but low current incomes. These agents value the option to borrow more while also being sufficiently creditworthy to obtain these costlier mortgages in equilibrium. This is reflected in the fact that, relative to a setting without a DTI limit, the Dodd-Frank policy generates a more pronounced association between higher DTI ratios and lower interest rates and loan-to-value ratios. This feature of the model is consistent with my earlier empirical results. Finally, I show that, relative to the current DTI limit, the new DTI regulation delivers both a reduction in the default rate and an increase in aggregate welfare. The caveat is that welfare gains are unequally distributed across households and some are, in fact, strictly worse off under the new reform. The distribution of welfare changes is closely correlated with homeownership: welfare losses generally accrue to young renters, while older homeowners are better off. Welfare gains are particularly high for liquidity-constrained owners who value the costly opt-out under the new DTI regulation for consumption smoothing purposes and have a sufficiently low probability of default to exercise it in equilibrium. The largest welfare losses are concentrated among marginal homeowners who find the new policy's 43-percent DTI limit too constraining and instead choose to rent.

The remainder of the paper proceeds as follows. I connect my paper to the relevant literature in Section 1.2 and discuss institutional details of DTI limits in Section 1.3. I present my empirical findings regarding the effects of the current DTI limit on mortgage originations in Section 1.4. I develop the theoretical model in Section 1.5, then discuss calibration and model fit in Section 1.6. My quantitative analyses of DTI limits follows in Section 1.7. Section 1.8 concludes and discusses avenues for further research.

1.2 Related literature

The Great Recession and the mortgage foreclosure crisis that precipitated it have renewed interest in the role of the housing and mortgage markets in the U.S. macroeconomy.[2] On the theoretical side, my paper builds on the growing body of macroeconomic research that incorporates uninsurable idiosyncratic income risk, a life-cycle savings motive, illiquid housing wealth, and borrowing constraints in models of the U.S. housing and mortgage markets.[3] With its inclusion of long-term secured debt that carries the option to default, my paper also speaks to a related consumer finance literature that uses equilibrium models to study bankruptcy and foreclosure in stationary environments.[4] A distinguishing characteristic of my model is its inclusion of a borrower's mortgage choice problem, which is relatively understudied in the theoretical literature. Corbae and Quintin (2015) develop a model in which borrowers choose between low- or high-down payment fixed-rate mortgages subject to a debt payment-to-income constraint at origination and priced by risk-neutral financial intermediaries. For

[2]Both Davis and Van Nieuwerburgh (2014) and Piazzesi and Schneider (2016) provide useful overviews of recent advances in macroeconomic research on housing and mortgage markets.

[3]See, for instance, Beraja et al. (2019), Berger et al. (2017), Chatterjee and Eyigungor (2015), Chen, Michaux and Roussanov (2013), Corbae and Quintin (2015), Garriga and Hedlund (2017), Gorea and Midrigan (2018), Guren, Krishnamurty and McQuade (2018), Kaplan and Violante (2014), Kaplan, Mitman and Violante (2017), and Wong (2019). Guren et al. (2018) lay out the "new canonical model" of housing and consumption.

[4]See Campbell and Cocco (2015), Chatterjee et al. (2007), and Mitman (2016). Some of the papers mentioned in the previous footnote incorporate mortgage foreclosure into their analyses of the U.S. housing market.

reasons of tractability, their model places strong restrictions on the choices available to agents, as well as the demographic structure of the economy.[5] An earlier paper by Chambers, Garriga and Schlagenhauf (2009) focuses on the implications of mortgage choice in a general equilibrium setting by allowing owners to select between a fixed-rate mortgage and an alternative debt contract. The authors abstract from mortgage default, though, which is central to the objectives of the leverage regulations I study. My main theoretical contribution, then, is to combine a richly specified quantitative model of household consumption and savings behavior with a nontrivial discrete choice between mortgage contracts.

My paper also contributes to an ongoing discussion about the *ex ante* regulations of the residential mortgage market that were enacted in the aftermath of the financial crisis. DeFusco, Johnson and Mondragon (2017) empirically study the effect of the 43-percent DTI limit in the Dodd-Frank regulations on the jumbo loan market, where the policy has already taken effect.[6] The empirical analysis of my paper focuses instead on a DTI limit found in the GSE underwriting requirements and its effects on the conforming segment of the U.S. residential mortgage market, which accounts for roughly three-quarters of all mortgage origination activity. Greenwald (2018) augments a saver-spender New Keynesian model with a DTI constraint and prepayable long-term mortgage debt in order to study the influence of the structure of mortgage finance on the transmission of macroeconomic shocks and to evaluate the Dodd-Frank DTI limit as a tool for macroprudential policy. I complement this existing research on the Dodd-Frank mortgage regulations by using a nonlinear model that is

[5] For instance, only middle-aged agents can own houses, and mortgage refinancing and prepayment—a decision that is central to the predictions of my model—are ruled out by assumption.

[6] A jumbo loan is a mortgage with an outstanding balance at origination that exceeds the conventional conforming loan limits set forward by the underwriting requirements of Fannie Mae and Freddie Mac.

suitable for analyzing mortgage default and household welfare.

1.3 Institutional background

My paper takes as given leverage regulations that policymakers have adopted in practice. To that end, I consider two separate regulations that have placed constraints on a borrower's debt payment-to-income ratio. Currently, the residential mortgage market is characterized by a requirement that conforming mortgage loans be originated with a DTI ratio of 45 percent or less. This requirement is found in the underwriting standards of Freddie Mac and has been in place since 2009. Meanwhile, a new DTI ratio requirement found in the Dodd-Frank Act proposes a maximum DTI ratio of 43 percent at origination while giving borrowers a costly option to relax the limit. This new policy will take effect in 2021 for conforming mortgages, i.e., the segment of the mortgage market already affected by the current 45-percent limit. The timing of these two regulations is important to the analysis that follows: I will use the 45-percent limit as a baseline against which to evaluate the new Dodd-Frank rules.

1.3.1 Freddie Mac's underwriting standards

Freddie Mac is one of the two large government-sponsored enterprises (GSEs) that purchase newly originated mortgage loans from lenders in the primary market and package them into mortgage-backed securities that are then sold to investors on the secondary market. Freddie Mac's stated purchase is to "provide liquidity, stability, and affordability to the U.S. housing market" by promoting the flow of capital to primary mortgage lenders.[7] For the purposes of this paper, it is critical to note that the GSEs are only permitted to purchase mortgage loans—termed conforming loans—that meet certain guidelines. Although the GSEs do not lend to households directly, they have an outsize influence on the residential mortgage market by creating incentives for primary lenders to originate loans that conform to their underwriting standards. This influence has been particularly pronounced since the financial crisis. Since entering federal conservatorship in September 2008, the GSEs have jointly purchased or guaranteed around 75 percent of mortgage originations.[8]

In March 2009, Freddie Mac revised its underwriting standards to include a 45-percent maximum debt payment-to-income ratio for all manually underwritten mortgages.[9] Although their underwriting requirements had previously contained guidance regarding the borrower's debt payment-to-income ratio, this was the first time an outright cap was placed on it.[10] In their selling guide, Freddie Mac provides some extenuating circumstances that a lender may use to justify a higher DTI ratio: the borrower having sufficient liquid assets to constitute an ability to repay the mortgage regardless of income; a down payment on the purchase of a property of at least 25 percent; or a strong credit score (i.e., a FICO score of 740 or higher) in conjunction with the lender's assurance that "the

[7] See http://www.freddiemac.com/about/.

[8] This represents $100 billion per month in new mortgage lending. See http://www.fhfa.gov/AboutUs/Reports/ReportDocuments/20120221_StrategicPlanConservatorships_508.pdf.

[9] See http://www.freddiemac.com/singlefamily/guide/bulletins/pdf/bll112408.pdf. Manual underwriting is the process by which a lender assesses various components of the loan application in accordance with underwriting requirements and risk evaluation guidelines published in the Freddie Mac Seller/Servicer Guide. Alternatively, a lender can use Freddie Mac's proprietary automated underwriting system, Loan Product Advisor.

[10] Freddie Mac's selling guidelines have long required additional justification from a lender when originating a mortgage with a DTI ratio greater than 36 percent, but it will be seen in Section 1.4.2 that this requirement is little more than a formality and does not have any binding effect on loans purchased by Freddie Mac.

borrower's credit reputation is excellent."[11] As a result, a small fraction of mortgage loans purchased or guaranteed by Freddie Mac since the implementation of this policy still has a DTI ratio exceeding 45 percent.

1.3.2 The Dodd-Frank Wall Street and Consumer Protection Act

Signed into law in 2010, the Dodd-Frank Wall Street and Consumer Protection Act was intended to address some of the systemic risks that contributed to the Great Recession, including loose underwriting standards by some mortgage lenders. These were the focus of one particular provision of the Dodd-Frank Act, the ability-to-repay rule.[12] The ability-to-repay rule states:

> "...no creditor may make a residential mortgage loan unless the creditor makes a reasonable and good faith determination based on verified and documented information that, at the time the loan is consummated, the consumer has a reasonable ability to repay the loan."

The ability-to-repay rule itself does not explicitly ban certain loan features. If, however, a residential mortgage loan meets certain standards, it will be presumed to be in accordance with the Dodd-Frank ability-to-repay rule. In other words, meeting those standards is a sufficient way for a mortgage lender to comply with the rule; such a loan is, in the parlance of this legislation, called a

[11] See Section 5401.2 of the Freddie Mac Single-Family Seller/Servicer Guide, which can be accessed here: http://www.freddiemac.com/singlefamily/pdf/guide.pdf.

[12] The full text of the Dodd-Frank Act can be found at https://www.congress.gov/bill/111th-congress/house-bill/4173/text. The regulations that are the subject of this paper can be found in Sections 1411 and 1422 of Title XIV.

qualified mortgage. The Dodd-Frank Act delegated authority to finalize these regulations to the newly created Consumer Financial Protection Bureau (CFPB). The CFPB announced the final rule in January 2013, and it officially came into effect for the jumbo loan market in January 2014.[13]

The final rule applies to any consumer credit transaction secured by a dwelling.[14] First, it lays out the conditions that a loan must meet in order to be considered a qualified mortgage: (1) a ban on certain loan features deemed too risky, (2) a cap on points and fees due at origination, and (3) a maximum back-end DTI ratio of 43 percent.[15] Additionally, the final rule clarifies the nature of the legal protection given to a lender that originates a qualified mortgage. Qualified mortgages are granted safe harbor—that is, they are "conclusively presumed" to comply with the ability-to-repay rule, and a borrower who has difficulty repaying a qualified mortgage does not have legal standing to sue the lender. By contrast, if a borrower has trouble repaying a non-qualified mortgage and can successfully demonstrate in court that the mortgage violated the ability-to-repay rule, the lender would be liable for up to three years of interest payments and loan fees that the consumer has already paid, as well as legal fees incurred by the consumer. The final rule thus creates a regulatory incentive for lenders to originate mortgages that satisfy the qualified mortgage criteria.[16] I

[13]The full text of the final rule can be found at https://www.federalregister.gov/documents/2013/01/30/2013-00736/ability-to-repay-and-qualified-mortgage-standards-under-the-truth-in-lending-act-regulation-z.

[14]This excludes open-ended credit lines, timeshare plans, reverse mortgages, and temporary loans.

[15]Prohibited loan features under the rule include negative amortization, interest-only payments, balloon payments, and loan terms exceeding 30 years. A back-end DTI ratio includes in the numerator all of the borrower's debt service costs, which could also include payments on credit card debt, student loans, etc. Since a mortgage payment is by far the largest and more prevalent debt service expenditure incurred by U.S. households, I abstract from other types of liabilities in this paper.

[16]The CFPB writes, "Treating a qualified mortgage as a safe harbor provides greater legal certainty for creditors and secondary market participants than a rebuttable presumption of compliance. Increased legal certainty may benefit consumers if as a result creditors encouraged to

interpret the higher legal cost associated with default on a mortgage originated with a debt payment-to-income ratio above the 43-percent limit as a costly option for borrowers to relax the limit.

Notably, the final rule granted a transitional period during which mortgages that are eligible for sale to or guarantee by a GSE will still be considered a qualified mortgage if they satisfy the first two qualified mortgage requirements, thereby making these loans exempt from the 43-percent DTI limit. The GSE exemption will last until January 2021 or when the GSEs are removed from federal conservatorship, whichever occurs earliest. The residential mortgage market has therefore yet to see the full effect of the Dodd-Frank regulations.

Policymakers and relevant market participants have disagreed on the overall effect and desirability of the Dodd-Frank ability-to-repay rule. The Mortgage Bankers Association has argued that the potential legal liability associated with loans that do not satisfy the qualified mortgage criteria may lead lenders to charge their borrowers higher interest rates, even if they represent relatively low credit risk, or leave that part of the mortgage market altogether. In a similar vein, the American Bankers Association has advocated for the elimination of the 43-percent DTI standard altogether, calling it "arbitrary" and "inflexible."[17] The CFPB has countered by arguing that approximately 70 percent of mortgages originated between 1997 and 2003 would have satisfied the Dodd-Frank criteria, implying that the latter would have limited scope.[18]

For simplicity, I will refer to qualified mortgages as low-DTI loans when discussing the Dodd-Frank mortgage regulations for the remainder of the paper

make loans that satisfy the qualified mortgage criteria."

[17]See https://www.mba.org/issues/residential-issues/Dodd-Frank-improvements and https://www.aba.com/Advocacy/Documents/Mortgage-Reforms.PDF, respectively.

[18]See Moskins (2014).

because the debt payment-to-income ratio of the borrower at origination satisfies the 43-percent limit. Conversely, a high-DTI loan will be a mortgage that carries a DTI ratio greater than 43 percent. The option to obtain a high-DTI loan under the Dodd-Frank policy is costly in the sense that a lender who originates such a loan incurs a greater foreclosure cost in the event the borrower defaults on it.

1.4 Effects of the current DTI limit on mortgage originations

The introduction of an explicit 45-percent cap on the borrower's debt payment-to-income ratio in Freddie Mac's underwriting requirements provides a setting in which to empirically assess the effects of a DTI limit on the allocation of credit in a large segment of the residential mortgage market. I use the Freddie Mac Single Family Loan-Level Dataset to establish three facts about this policy. The first fact echoes a finding already documented by Greenwald (2018), while the remaining two are new to the literature.

I begin by demonstrating that the current 45-percent limit is binding for a nontrivial fraction of newly originated mortgages. Next, I show that borrowers on the constraint have lower credit scores, higher loan-to-value ratios, and higher mortgage interest rates relative to borrowers to the right of the limit. This suggests that borrowers exactly at the DTI limit tend to be riskier. Finally, I demonstrate that, despite this, a subset of borrowers with a DTI ratio of exactly 45 percent have high enough credit scores to constitute minimal default risk. This last result is consistent with a story in which the current institutional DTI limit constrains at least some highly creditworthy households.

1.4.1 Data description

The Freddie Mac Single Family Loan-Level Dataset contains quarterly loan-level origination data on fully-amortizing 15-, 20-, and 30-year fixed-rate mortgages with full documentation that were purchased or guaranteed by Freddie Mac from 1999 to 2016. I limit my analysis to loans with 30-year terms that are collateralized by owner-occupied housing and have non-missing data on the DTI ratio, FICO score, interest rate, and loan-to-value (LTV) ratio.[19] This leaves approximately 18 million loans in my sample. I provide summary statistics in Section A.1 of the appendix.

1.4.2 Changes in the distribution of DTI ratios

My first empirical finding is that the 45-percent DTI limit introduced by Freddie Mac in 2009 is binding, at least for a subset of borrowers. Figure 1.1 plots the annual distribution of debt payment-to-income ratios at origination for the years 2005 through 2016. It is clear that the distribution of DTI ratios has changed markedly during this period, even as the distribution of loan-to-value ratios has remained relatively stable.[20] Prior to the introduction of the DTI limit in 2009, the DTI ratio distribution does not display an indication of a binding constraint at any level. Afterwards, the share of originations with a DTI ratio greater than 45 percent has shrunk while that of loans with a DTI ratio just below the limit has increased. These observations indicate that, as an underwriting requirement, the DTI limit has exercised greater influence on mortgage originations

[19]The FICO score is the borrower's credit score, named after the company—Fair, Isaac, and Company—that first introduced it. The loan-to-value ratio is the original mortgage loan amount divided by the mortgage property's appraised value.

[20]I plot the distribution of LTV ratios over this time in Section A.2 of the appendix.

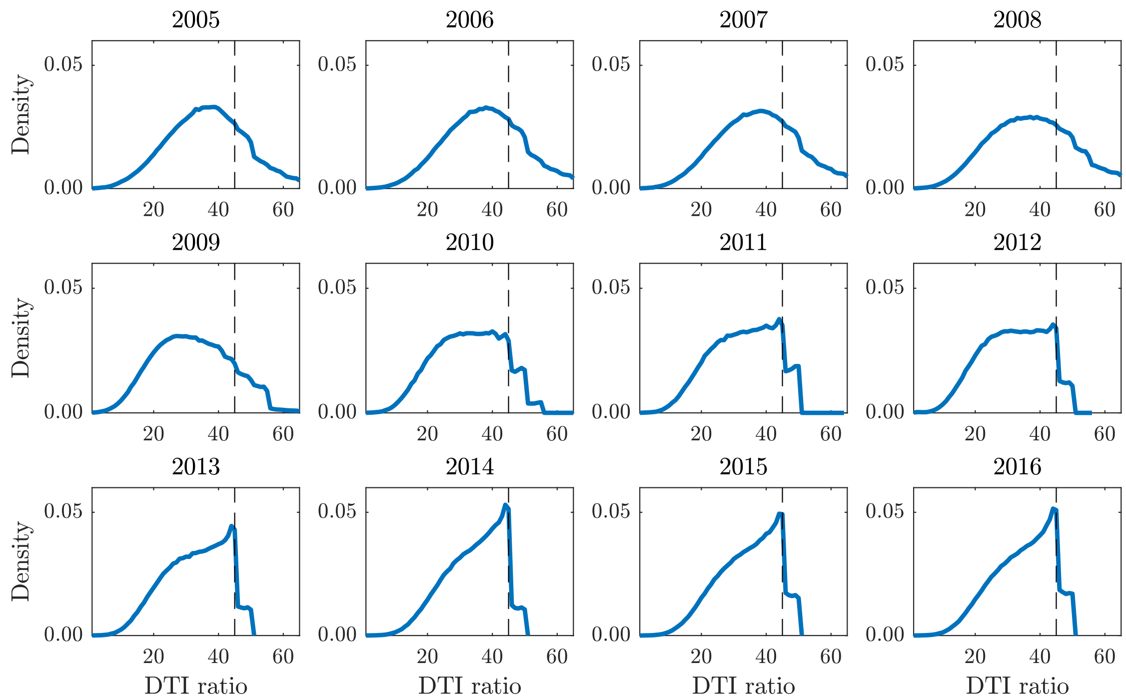

Figure 1.1

Distribution of DTI ratios at origination of mortgage loans purchased or guaranteed by Freddie Mac. Mortgages are grouped into 1-percentage point bins. The dashed black vertical line corresponds to the 45-percent DTI limit for manually underwritten loans. Source: Mac Single Family Loan-Level Dataset, 2005-2016.

during the post-crisis years in a way that it previously had not.

Figure 1.2 provides another way to visualize the bunching of loans to the left of the limit and the reduction of loans above the limit. It plots on an annual basis the share of mortgage originations that have a DTI ratio greater than 43 percent, between 43 and 45 percent, or above 45 percent. As of 2016, just under 20 percent of originations had a DTI ratio above 43 percent, the limit prescribed in the Dodd-Frank Act's mortgage regulations. Of these, slightly more than half have a DTI ratio between 43 and 45 percent, which is to say that they satisfy Freddie Mac's underwriting requirements but not the new Dodd-Frank DTI limit. This suggests that, once the exemption of conforming loans from the latter expires, a good fraction of mortgages could be subject to increased legal liability, potentially altering the allocation of credit in meaningful ways.

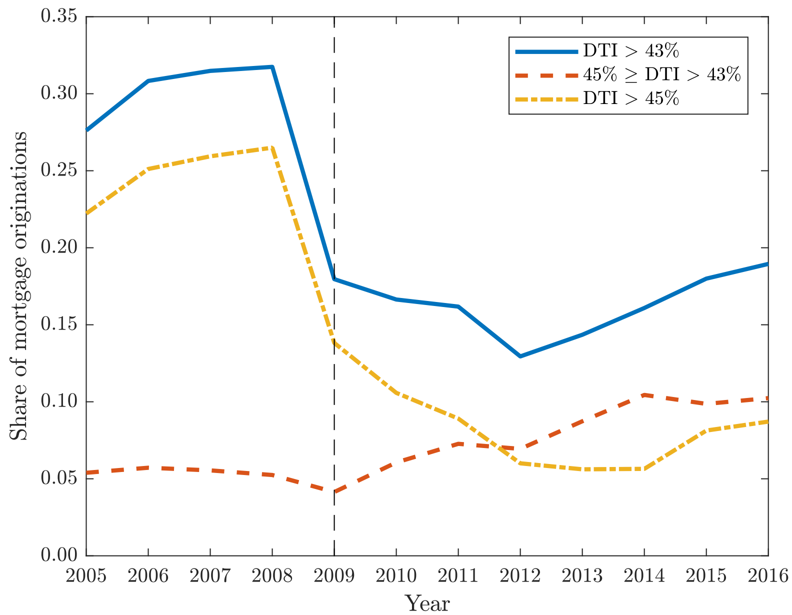

Figure 1.2

Shares of loans with a DTI ratio above 43 percent, between 43 and 45 percent, and above 45 percent, among mortgage loans purchased or guaranteed by Freddie Mac. The dashed black vertical line corresponds to the year in which the 45-percent DTI limit was introduced. Source: Mac Single Family Loan-Level Dataset, 2005-2016.

1.4.3 Changes in loan and borrower characteristics around the DTI limit

My second empirical finding demonstrates that, after the implementation of the 45-percent cap on the DTI ratio, loans with a DTI ratio above 45 percent are associated with more creditworthy and less leveraged borrowers relative to loans precisely at the limit. The panels of Figure 1.3 plot the detrended interest rate, LTV ratio, and borrower's credit score before and after the the change in Freddie Mac's underwriting standards in the first quarter of 2009.[21] These three

[21]The credit score reported in the dataset is the credit score used to originate the mortgage, so it does not reflect any changes in the borrower's likelihood of default as a result of receiving a

mortgage.

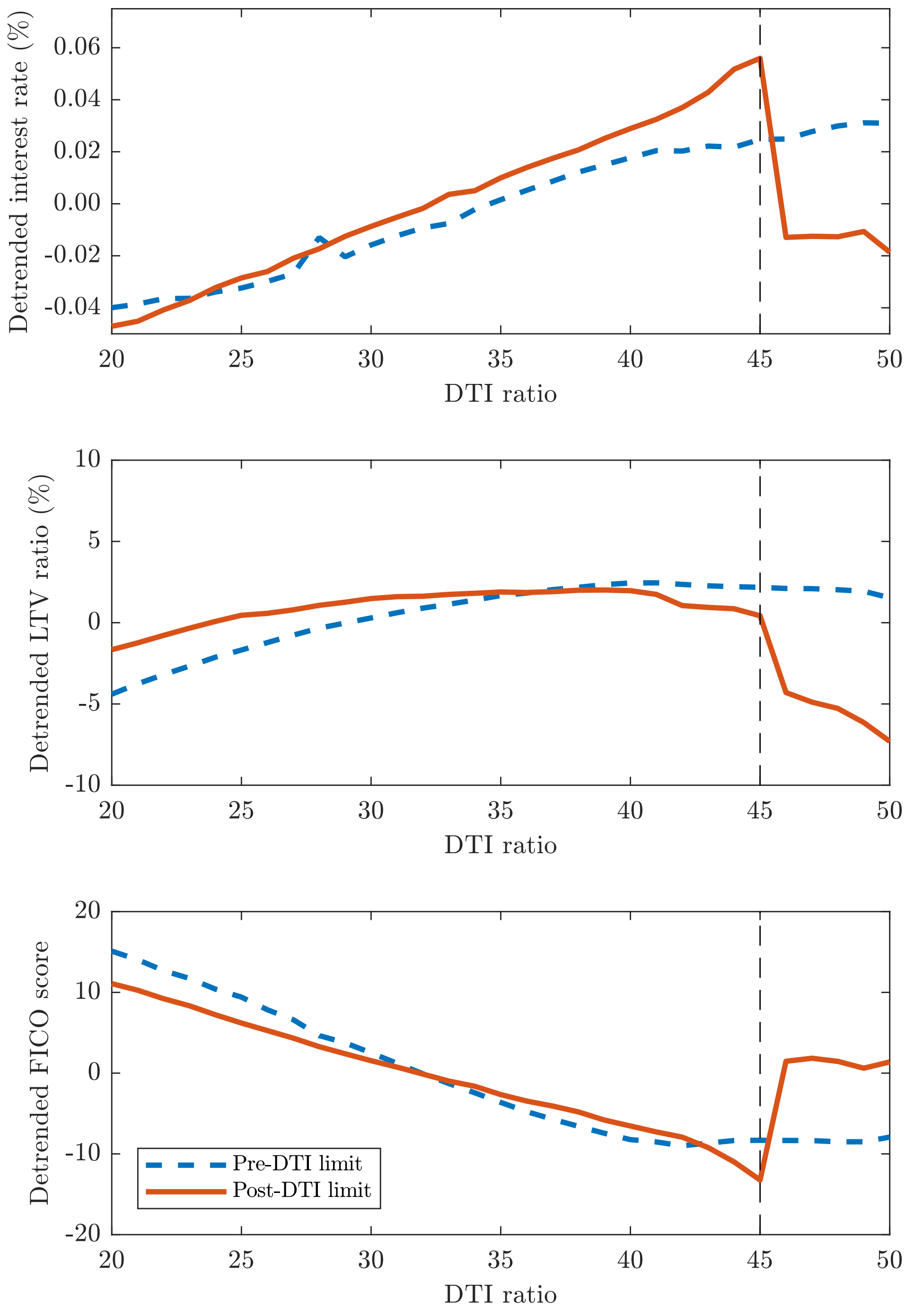

Figure 1.3

Detrended mortgage interest rate, LTV ratio, and credit scores around Freddie Mac's 45-percent DTI limit. Detrending is accomplished by regressing the dependent variable in question on a vector of quarter dummy variables and calculating the mean residual from that regression for each 1-percentage point DTI bin for pre-2009Q1 (dashed blue line) and post-2009Q1 (solid red line) observations. The dashed black vertical line corresponds to the 45-percent DTI limit. Source: Freddie Mac Single Family Loan-Level Dataset.

loan characteristics exhibit no visible differences on either side of the 45-percent DTI limit prior to the policy change. There are, furthermore, clear and nearly monotonic relationships between the DTI ratio and the three loan characteristics. The interest rate and LTV ratio are increasing in the DTI ratio on the loan, while the FICO score is decreasing in the DTI ratio. During this period, loans with a DTI ratio above 45 percent carry above-average interest rates and LTV ratios and below-average credit scores.

After Freddie Mac added the DTI limit to their underwriting requirements, though, significant differences in these three loan characteristics emerge around the 45-percent DTI threshold. Loans with a DTI ratio just above the threshold have an interest rate that is almost 8 basis points lower than those at the threshold. Their average LTV ratio is also around 7 percentage points lower. The difference in credit scores mirrors that in interest rates: high-DTI loans are held by borrowers with a FICO score that is around 20 points higher than loans with DTI ratios exactly at the limit following the policy change. Notably, compared to high-DTI loans that were originated prior to the policy change, high-DTI loans originated afterwards are now associated with below-average interest rates, below-average LTV ratios, and above-average FICO scores. This stark reversal suggests a shift in borrower composition occurred after the introduction of the DTI limit.

To control for variables that may affect loan and borrower characteristics, I use a difference-in-differences design in the spirit of DeFusco, Johnson and Mondragon (2017) to estimate the change in the characteristics of a high-DTI loan, relative to a low-DTI loan, after the 45-percent DTI limit is added to Freddie Mac's underwriting requirements. The specification I use is

$$y_{it} = \alpha + \beta_1 HighDTI_i + \beta_2 (HighDTI_i \times Policy_t) + \gamma_t + X_i'\delta + \varepsilon_{it}, \tag{1.1}$$

where y_{it} is a particular loan characteristic of loan i originated in quarter t, α is the constant term, γ_t is a vector of quarter dummy variables, X_i is a vector of other loan-specific characteristics, and ε_{it} is an error term clustered at the state level.[22] $HighDTI_i$ is an indicator variable that takes a value of 1 if the DTI ratio of loan i exceeds 45 percent. $Policy_t$ is an indicator variable that takes a value of 1 if the quarter of origination is 2009Q1 or later.[23] The coefficient of interest is β_2, which is the differential change in the dependent variable for high-DTI loans relative to low-DTI loans following the introduction of the 45-percent DTI limit. When estimating the regression, I restrict my sample to loans with a DTI ratio in a symmetric window around 45-percent that were originated between 2006 and 2014.

Estimated values for the coefficients β_1 and β_2 in Equation (1.1) are presented in Table 1.1. The patterns I document regarding the interest rate, LTV ratio, and credit score in Figure 1.3 survive after controlling for other loan characteristics and are statistically significant at the 1 percent level, though the magnitudes in the differences of these characteristics between low- and high-DTI loans are somewhat smaller. Relative to low-DTI loans, the interest rate of high-DTI loans declines by 3.3 basis points, the LTV ratio declines by 4.8 percentage points, and the FICO score increases by 6.5 points after the Freddie Mac DTI limit is implemented.[24]

[22] X_i includes dummy variables for the state in which the property is located, the purpose of the loan (i.e., if it is a refinance or purchase loan), and the type of property.

[23] It is not necessary to include $Policy_t$ as a regressor because it is absorbed by the time dummy variables.

[24] As a robustness check, I use a more flexible specification that allows the effect of the DTI limit to vary with the DTI ratio in order to demonstrate that these results are not being driven

	(1) Interest rate	(2) LTV ratio	(3) FICO score
DTI > 45%	0.005***	0.007	-1.768***
	(0.000)	(0.900)	(0.000)
DTI > 45% × Policy	-0.033***	-4.786***	6.456***
	(0.000)	(0.000)	(0.000)
Observations	1,861,384	1,861,384	1,861,384

p-level in parentheses.
Robust standard errors are clustered at the state level.
* p < 0.10, ** p < 0.05, *** p < 0.01.

Table 1.1

Effect of the 45-percent DTI limit on high-DTI loans relative to low-DTI loans. The two rows correspond to estimated values for the coefficients β_1 and β_2 from the difference-in-differences specification in Equation (1.1) with the interest rate, LTV ratio, and FICO score serving as the dependent variable in turn. Source: Freddie Mac Single Family Loan-Level Dataset.

1.4.4 The creditworthiness of borrowers at the DTI limit

My third empirical finding shows that borrowers with high credit scores can still be found at the 45-percent DTI limit. As discussed in Section 1.3.1, one condition under which Freddie Mac can make an exception to the 45-percent DTI ratio requirement is if the borrower has a credit score of at least 740 and the lender provides assurance of the borrower's excellent credit reputation.[25] Although the credit score is only one factor considered by mortgage lenders when underwriting a loan and having a strong credit score is not a sufficient

merely by the DTI ratio being above the limit but, rather, a change precisely *at* the 45-percent cutoff. Details can be found in Section A.3 of the appendix.

[25]According to Experian, one of the three large credit-reporting agencies, a credit score between 740 and 799 indicates "very good" credit. The 740 credit score is also a relevant cutoff for primary mortgage lenders who sell to Freddie Mac. Each loan sold to Freddie Mac is charged a delivery fee ("credit fee in price") that depends on the credit score and LTV ratio of the borrower. Holding the LTV ratio constant, delivery fees are decreasing in the credit score, and a credit score of at least 740 represents the top tier of creditworthiness. See https://www.experian.com/blogs/ask-experian/infographic-what-are-the-different-scoring-ranges/ and http://www.freddiemac.com/singlefamily/pdf/ex19.pdf, respectively.

condition for obtaining a loan with a DTI ratio greater than 45 percent, it does provide a rough proxy for borrower quality.

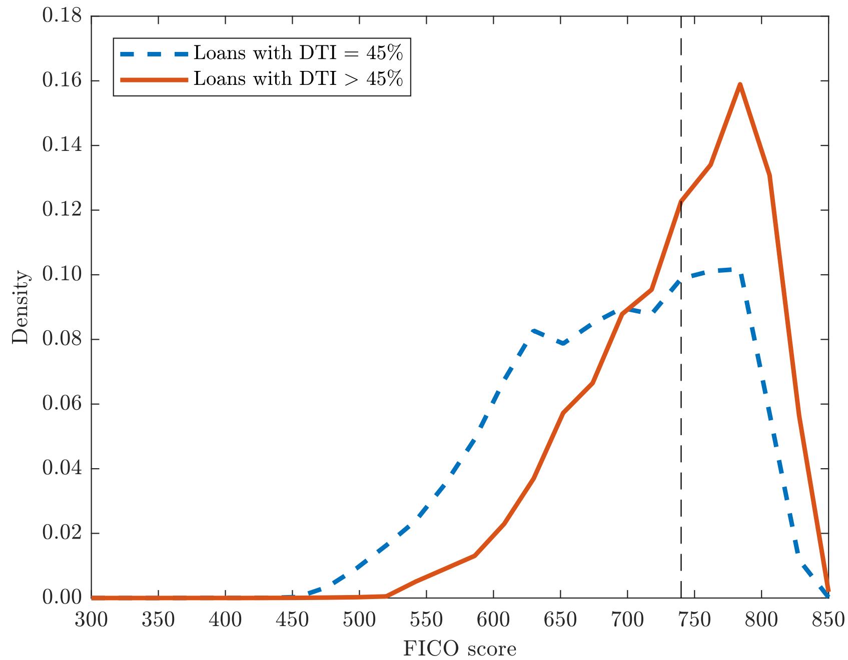

Figure 1.4

Distribution of credit scores for borrowers at the 45-percent DTI limit (dashed blue line) versus borrowers with DTI ratios above the limit (solid red line) among mortgages originated after the DTI limit was introduced. The dashed black vertical line corresponds to the threshold credit score of 740, which is the point at which Freddie Mac may consider purchasing a loan with a DTI ratio above the limit. Source: Freddie Mac Single Family Loan-Level Dataset.

Figure 1.4 plots the distribution of credit scores associated with mortgage loans originated in 2009Q1 or later (i.e., after the policy was implemented) that have a DTI ratio of exactly 45 percent versus a DTI ratio greater than 45 percent. Consistent with my previous results in Section 1.4.3, while it is true that borrowers at the limit are on average less creditworthy, a subset of them have a credit score of at least 740, which means that they are creditworthy enough—at least in this one observable dimension—to be eligible for loan with a DTI ratio above the limit. A credit score of 740 is also significant because it is associated with the borrower having a negligible risk of default. Because I cannot observe the mortgage loans that borrowers at the limit would have optimally chosen in its absence, the data are insufficient for determining if households are in reality constrained by the DTI requirement. Nevertheless, the fact there exist high-credit score borrowers with a DTI ratio of exactly 45 percent does raise the possibility that some of them could be of good enough quality to obtain a high-DTI ratio but do not. This may be due to the somewhat idiosyncratic nature of the discretion that mortgage lenders exercise when they choose to originate a loan with a DTI ratio above the GSE limit.

Why should it matter that objectively creditworthy households are at the DTI limit? As shown in Section 1.4.3, the mere act of being above the 45-percent DTI limit is associated with real differences in mortgage market outcomes. It is particularly of note that, even after conditioning on the credit score of a borrower, loans to the right of the limit are associated with a lower cost of borrowing. Taken together, these findings suggest that, relative to the current approach, it may be beneficial to have a more flexible DTI limit that would permit these highly creditworthy borrowers to be less constrained in this dimension. A more formal evaluation of this claim, however—along with an evaluation of how the precise design of DTI limits affects aggregate and distributional outcomes—requires a structural model.

1.5 A heterogeneous-agent life-cycle model with endogenous default and mortgage contract choice

In this section, I develop a model capable of comparing two approaches to DTI limits that have been adopted by policymakers in practice. On one hand, the current policy applies a 45-percent maximum DTI ratio uniformly to all borrowers. On the other hand, a new policy from the Dodd-Frank Act that is slated to take effect in 2021 implements a more strict DTI limit of 43 percent while giving borrowers a costly option to relax that limit. Because this policy has yet to be implemented for a large segment of the U.S. residential mortgage market, a model is needed to forecast its potential aggregate and distributional consequences.

1.5.1 Model environment

The model features a constant population of overlapping generations of households who maximize expected discounted lifetime utility. Households split their lives between working and retirement. Each period, they receive an age-specific endowment income that, during their working years, is subject to uninsurable idiosyncratic risk. They derive utility from nondurable consumption and housing services and can save in both a liquid asset and illiquid housing wealth. Housing services can be obtained through a rental market or by purchasing a home, which yields a service flow every period. Owners can borrow using illiquid mortgage debt and have the option to default.

The model also features a continuum of competitive, risk-neutral, infinitely lived financial intermediaries that maximize expected discounted profit. I assume that financial intermediaries can observe the household's current state, i.e., they can perfectly screen their borrowers. Intermediaries store households' liquid savings at the risk-free rate and supply mortgage debt demanded by borrowers at an interest rate pinned down by the requirement that, in equilibrium, a lender breaks even on a loan-by-loan basis.

The key feature of the model is the inclusion of a choice between mortgage contracts. The choice of contract affects the tightness of the DTI constraint in the household's problem and the financial intermediary's cash flow in the event that a borrower defaults on their loan. Both are necessary in order to capture the fact that the new Dodd-Frank DTI limit both directly limits the size of mortgages and shapes the incentives of lenders to offer one type of contract versus another. Furthermore, the contract choice problem is flexible enough to nest different sets of leverage regulations, including the current uniformly applied DTI limit, by adjusting relevant parameter values and placing appropriate restrictions on the household's choice set.

Preferences and endowments

A household maximizes expected discounted lifetime utility, defined as

$$\max \ \mathbb{E}\left\{\sum_{j=1}^{T}\left[\beta^{j-1}u\left(c_j, s_j\right)\right] + \beta^{T}\nu\left(W_T\right)\right\},$$

where j indexes the household's age, β is the subjective discount factor, and $u(\cdot)$ is the flow utility function satisfying standard Inada conditions. The flow utility function takes the form

$$u(c, s) = \frac{1}{1-\sigma}\left(c^{\alpha}s^{1-\alpha}\right)^{1-\sigma},$$

where c is nondurable consumption and s is housing services. σ is the coefficient of relative risk aversion and α is the preference weight on nondurable consumption. Households have a bequest motive so that, in the terminal period of life T, they receive utility from end-of-life wealth W_T according to the function

$$\nu(W_T) = B\frac{W_T^{1-\sigma}}{1-\sigma},$$

where B controls the strength of the bequest motive. The bequest motive is needed to ensure that, consistent with the data, households reach the end of their lives with positive net worth.

A household supplies labor inelastically from age 1 until they retire at age T_R. The log income received by a household of age j is

$$\log y_j(z) = \begin{cases} \chi_j + z & \text{if } 1 \le j < T_R \\ \Phi\left(y_{T_R-1}(z)\right) & \text{if } T_R \le j \le T. \end{cases} \tag{1.2}$$

While working, log income is the sum of a deterministic component indexed by age χ_j and an idiosyncratic component z. The idiosyncratic component of income follows the first-order Markov process

$$z' = \rho z + \varepsilon', \ \varepsilon' \overset{i.i.d.}{\sim} \mathcal{N}\left(0, \sigma_\varepsilon^2\right).$$

Following Guvenen and Smith (2014), households in retirement receive a constant pension income that is a function $\Phi(\cdot)$ of the income received in the last year of their working life $y_{T_R-1}(z)$.

Asset technology

All households can save in a liquid asset a. The liquid asset takes the form of deposits held by financial intermediaries that earn a rate of return each period. Financial intermediaries have access to international capital markets where the risk-free rate r is determined by the net supply of safe financial assets. A zero-profit condition on deposits implies that the household will also earn the risk-free rate on their deposits. A household's position in the liquid asset is subject to a no-borrowing constraint.

Households obtain housing services either through the rental market or the owner-occupied housing market. The supply of rented housing services is perfectly elastic so that a household can rent s units of housing services at a rate R per unit each period. I assume that $s \leq h_{small}$, i.e., that a renter cannot obtain more housing services than those implied by the smallest possible house size. This assumption captures the fact that, in reality, rental properties lack many of the amenities that owner-occupied properties possess.[26] Adjusting the stock of rented housing services between time periods is costless.

The supply of owner-occupied housing is also perfectly elastic. A household can purchase housing stock h at a price normalized to 1, and, so long as the household remains an owner, the housing stock yields a one-to-one flow of housing services (i.e., $s = h$) every period. Adjustment of the housing stock incurs a transaction cost κ_h, and I assume that households may only own one house at any given time. As in Chatterjee and Eyigungor (2015), owner-occupied housing is subject to an i.i.d depreciation shock δ_h each period whereby

$$\delta_h = \begin{cases} \delta > 0 & \text{with probability } \zeta \\ 0 & \text{with probability } 1 - \zeta. \end{cases} \tag{1.3}$$

An owner hit by the depreciation shock thereby incurs a maintenance cost of $\delta_h h$. By definition, an owner is a household with $h > 0$, while a renter is a household with $h = 0$.

Owners can use their housing wealth as collateral for mortgage debt m, which is modeled after the fixed-rate, long-term mortgage contracts commonly used in the United States. Mortgage loans are supplied by infinitely lived risk-

[26] In the stationary equilibrium of the model, this constraint does not bind due to the selection of low-income, low-wealth households into renting.

neutral financial intermediaries so that the interest rate on a newly originated loan is determined in equilibrium and is a function of the household's state. This interest rate remains fixed for the duration of the loan. The outstanding balance on a new loan is fully amortized over the remaining life of the borrower.[27] When an owner obtains a new loan, they incur a transaction cost of κ_m. A borrower may only hold one mortgage loan at a time. Note that loan prepayment—making a loan payment in excess of the minimum required payment—is permitted and does not incur a transaction cost.[28]

The size of a new loan is subject to two constraints at origination. The first is a loan-to-value constraint,

$$m \leq \theta h,$$

which states that the face value of the loan m cannot exceed a fraction θ of the value of the home h. The second is a debt payment-to-income constraint,

$$\pi_{min,j}(m, r_m) \leq \lambda(q)\, y_j(z),$$

where $\pi_{min,j}(m, r_m)$ is the minimum mortgage payment defined by the standard amortization formula,

$$\pi_{min,j}(m, r_m) = \frac{(1 + r_m)^{T-(j-1)}}{(1 + r_m)^{T-(j-1)} - 1} r_m m. \tag{1.4}$$

This DTI constraint states that the minimum mortgage payment on a loan—which is a function of the borrower's age j, the loan size m, and the interest rate on the loan r_m—cannot exceed a fraction $\lambda(q)$ of the borrower's contemporaneous income. The tightness of the DTI constraint is the first instance in which the

[27]A fully amortized fixed-rate loan is fully paid off by the end of its term and one in which the minimum loan payment due each period is constant.

[28]In the United States, prepayment penalties are relatively rare. Indeed, the Dodd-Frank Act banned most prepayment penalties except on certain high-priced loans.

borrower's choice of mortgage contract appears. It is a function of the contract type q in the following manner:

$$\lambda(q) = \begin{cases} \lambda & \text{if } q = L \\ \\ \infty & \text{if } q = H. \end{cases} \tag{1.5}$$

Households who choose a low-DTI loan ($q = L$) must select a loan size that satisfies the institutional cap on the debt payment-to-income ratio, which is set by the parameter λ. Households who choose a high-DTI loan ($q = H$) can select a loan size that is not bound by this limit.

Conditional on the choice of contract, a mortgage originated to a household of age j specifies a face value m', interest rate r'_m, and maturity $T - j$ such that the household receives m' in the period of origination and promises to make a sequence of payments $\left\{\pi_j(m', r'_m)\right\}_{j+1}^{T}$ so that the balance on the loan equals zero after the household makes their final payment.[29] The law of motion on the balance of an outstanding loan is

$$m' = (1 + r_m)\, m - \pi_j(m, r_m), \tag{1.6}$$

where the mortgage payment is subject to the constraint

$$\pi_j(m, r_m) \geq \pi_{min,j}(m, r_m).$$

A mortgage loan is terminated prior to maturity if the borrower prepays it in its entirety, refinances an existing mortgage, or sells their house. In this case, the intermediary receives the outstanding balance on the loan plus interest,

$$(1 + r_m)\, m.$$

[29]I follow other papers in this literature, such as Kaplan, Mitman and Violante (2017) and Wong (2019), in amortizing mortgages over the remaining life of the household. This convention is consistent with the observed negative correlation between age and loan duration and ensures that I do not have to track loan maturity as an additional state variable in the model.

A borrower can also default on their mortgage, which sets their outstanding debt to zero at the cost of surrendering the underlying collateral to the intermediary, which is the value of the home net of depreciation.[30] The intermediary recovers the collateral less foreclosure costs,

$$(1-\delta_h)\,h-\gamma\,(q)\,,$$

where these foreclosure costs will depend on the type of contract upon which the household is defaulting in the following manner:

$$\gamma\,(q)=\begin{cases}\gamma_L & \text{if } q=L\\ \\ \gamma_H & \text{if } q=H.\end{cases} \tag{1.7}$$

A critical restriction I place on the parameterization of the foreclosure costs is that, from the lender's perspective, default on a high-DTI loan is more costly than default on a low-DTI loan, i.e., $\gamma_H > \gamma_L$. This reflects the greater legal liability assigned by the Dodd-Frank legislation to mortgages with DTI ratios above the statutory limit.

1.5.2 Household's optimization problem

The household's optimization problem can be written in recursive form. The current state of an age-j household is summarized by the vector $\omega \equiv (a, h, \delta_h, m, q, r_m, z)$. An age-$j$ household has the value function

$$V_j\,(\omega)=\max\left\{V_j^R\,(\omega)\,,V_j^M\,(\omega)\,,V_j^P\,(\omega)\,,V_j^D\,(\omega)\right\}, \tag{1.8}$$

where the value functions inside the maximum operator correspond to the discrete choices available to a household in the current period. V_j^R is the value of

[30]This is the sale value of the house and is equal to what an owner would have received from liquidating their home.

renting, V_j^M is the value of owning and obtaining a new mortgage loan, V_j^P is the value of owning and making a payment on an existing loan, and V_j^D is the value of defaulting on outstanding debt.

The timing of the model in each period is as follows. At the beginning of the period, a household of working age receives their depreciation and income shocks; a retired household only receives a depreciation shock. A household makes a decision over the discrete choices available to them by solving the associated optimization problems and selecting the choice that yields the highest expected lifetime utility.

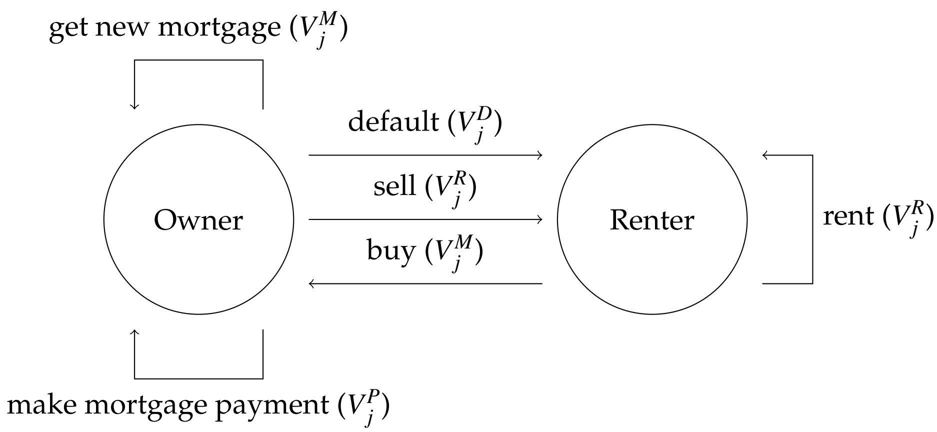

Figure 1.5

Discrete choices in the household's problem.

The set of feasible discrete choices depends on whether the household is an existing renter or owner and is summarized in Figure 1.5. If the household is an existing renter, they either continue as a renter (V_j^R) or purchase a house (V_j^M). If the household is an existing owner, they can remain an owner either by making a payment on an existing mortgage loan (V_j^P) or by obtaining a new mortgage loan, which can occur if the owner refinances the loan or adjusts their housing stock (V_j^M). An existing owner can transition to renting by selling their house (V_j^R) or defaulting on outstanding debt, if any (V_j^D). Consumption occurs at the end of the period.

If a household chooses to rent, they choose nondurable consumption, rented housing services, and liquid savings to solve

$$
\begin{aligned}
& V_j^R(\omega) = \max_{c,s,a'} \; u(c,s) + \beta \mathbb{E}_{\delta_h', z'|z} \max\left\{V_{j+1}^R(\omega'), V_{j+1}^M(\omega')\right\} \\
& \qquad \text{s.t.} \\
& c + Rs + a' \leq y_j(z) + (1+r)a + (1-\delta_h)h - (1+r_m)m - \mathbb{1}_{h \neq 0}\kappa_h \qquad (1.9) \\
& a' \geq 0 \\
& \omega' = (a', 0, \delta_h', 0, 0, 0, z').
\end{aligned}
$$

The right-hand side of the flow budget constraint defines the household's cash on hand, which includes current income; liquid wealth; and, if the household is transitioning from owning to renting, the sale value of the house net of depreciation, repayment of any outstanding mortgage debt, and the housing adjustment cost. The flow budget constraint accommodates the case of existing renters who continue to rent, as well as homeowners who sell their home and transition to renting. The continuation value reflects the fact that a household who rents today can continue renting or become a homeowner in the next period.

If a household chooses to own and obtain a new mortgage, they choose nondurable consumption, liquid savings, housing wealth, mortgage debt, and type of mortgage contract to solve

$$
\begin{aligned}
V_j^M(\omega) = & \max_{c,a',h',m',q' \in \{L,H\}} u(c,h') + \beta \mathbb{E}_{\delta_h',z'|z} V_{j+1}(\omega') \\
& \quad \text{s.t.} \\
& c + a' + h' \leq y_j(z) + (1+r)a + (1-\delta_h)h - (1+r_m)m + m' - \mathbb{1}_{h' \neq h}\kappa_h - \kappa_m \\
& m' \leq \theta h' \\
& \pi_{min,j}\left(m', r'_{m,j}(\omega)\right) \leq \lambda(q') y_j(z) \\
& a' \geq 0 \\
& \omega' = \left(a', h', \delta_h', m', q', r'_{m,j}(\omega), z'\right).
\end{aligned}
\tag{1.10}
$$

This optimization problem is central to the model. It both presents households with the broadest menu of choices and captures the interaction of borrowers with the mortgage market. The size of the new loan is subject to constraints on the LTV and DTI ratios, where, as described by Equation (1.5), the choice of a high-DTI loan ($q' = H$) relaxes the DTI constraint completely and the choice of a low-DTI loan ($q' = L$) requires the DTI ratio to be less than the parameter λ:

$$
\lambda(q') = \begin{cases} \lambda & \text{if } q' = L \\ \infty & \text{if } q' = H. \end{cases}
$$

Crucially, when a household chooses to obtain a new mortgage, the interest rate they receive on the new loan, $r'_{m,j}(\omega)$, is a function of the household's idiosyncratic state and fixed for the remaining duration of the loan. Similarly, the borrower's choice of mortgage contract type q' is also carried forward into tomorrow's state. The flow budget constraint accommodates renters who transition to homeownership, existing owners who sell their old house and purchase a new one, and owners who leave their housing stock unchanged but refinance their existing mortgage.

If a household chooses to own and continue with an existing mortgage loan, they choose nondurable consumption, liquid savings, and a mortgage payment to solve

$$
\begin{aligned}
V_j^P(\omega) &= \max_{c,a',m'} u(c,h) + \beta \mathbb{E}_{\delta_h',z'|z} V_{j+1}(\omega') \\
&\quad \text{s.t.} \\
&c + \delta_h h + a' \leq y_j(z) + (1+r)a - (1+r_m)m + m' \\
&m' \leq (1+r_m)m - \pi_{min,j}(m, r_m) \\
&a' \geq 0 \\
&\omega' = (a', h, \delta_h', m', q, r_m, z').
\end{aligned}
\tag{1.11}
$$

The inequality in the law of motion for mortgage debt gives borrowers the option to prepay their mortgage, if desired, without incurring any penalty. The household's state in the next period ω' accounts for the fact that the household continues with their predetermined housing stock, type of mortgage contract, and mortgage interest rate.

If an existing borrower exercises the option to default, they choose consumption, rented housing services, and liquid savings to solve

$$
\begin{aligned}
V_j^D(\omega) &= \max_{c,s,a'} u(c,s) - \xi + \beta \mathbb{E}_{\delta_h',z'|z} \left[\varphi V_{j+1}^M(\omega') + (1-\varphi) V_{j+1}^R(\omega') \right] \\
&\quad \text{s.t.} \\
&c + Rs + a' \leq y_j(z) + (1+r)a \\
&a' \geq 0 \\
&\omega' = (a', 0, \delta_h', 0, 0, 0, z').
\end{aligned}
\tag{1.12}
$$

A household who defaults discharges all outstanding mortgage debt and loses their house, freeing them from the obligation of making a mortgage payment and covering depreciation costs due in the current period. At the same time, they incur a flow utility loss ξ and are excluded from the owner-occupied housing and mortgage markets for a stochastic period of time. The household begins the next period with zero outstanding mortgage debt and zero housing wealth and regains access to the owner-occupied housing and mortgage markets with exogenous probability φ. I assume that all households who choose to default solve this optimization problem regardless of the type of mortgage contract they hold.

In the last period of life, the household must repay any outstanding mortgage debt and is prohibited from further borrowing. This imposes the restriction $m' = 0$ on the problem in Equation (1.10), but the optimization problems that an age-T household solves are otherwise unaltered. End-of-life wealth is

$$W_T = (1 + r)\, a' + h'.$$

1.5.3 Financial intermediary's optimization problem

Mortgage contracts are issued by financial intermediaries. Intermediaries are risk neutral, infinitely lived, and perfectly competitive. They discount the future at the rate $r+\phi$, where ϕ is a parameter that captures mortgage servicing costs.[31] I assume that financial intermediaries can perfectly observe a household's current state and decision rules. Competition ensures that each mortgage is priced so that the face value of the loan equals the expected present value of its future cash flows.

The present value of the existing mortgage held by an age-j household can

[31]These are direct costs associated with servicing a loan, i.e., payment collection, quality assurance, or corporate overhead. See https://www.mba.org/publications/insights/archive/mba-insights-archive/2018/mba-chart-of-the-week-average-servicing-costs-per-loan.

be written as

$$\Pi_j(\omega) = \begin{cases} (1+r_m)\,m & \text{if repay} \\ (1-\delta_h)\,h - \gamma(q) & \text{if default} \\ (1+r_m)\,m - m'_j(\omega) + \frac{1}{1+r+\phi}\mathbb{E}_{\delta'_h,z'|z}\Pi_{j+1}(\omega') & \text{otherwise,} \end{cases} \tag{1.13}$$

where $\omega' = \left(a'_j(\omega), h'_j(\omega), \delta'_h, m'_j(\omega), q'_j(\omega), r'_{m,j}(\omega), z'\right)$. This equation summarizes the three possible actions that a household with an existing loan can take. If the borrower repays the loan in full, then the intermediary receives the remaining balance on the loan plus interest. If the borrower defaults on the mortgage, then the intermediary recovers the depreciated value of the underlying collateral less foreclosure costs.[32] Recall from Equation (1.7) that the foreclosure costs are a function of the predetermined type of contract on which the household defaults such that

$$\gamma(q) = \begin{cases} \gamma_L & \text{if } q = L \\ \gamma_H & \text{if } q = H, \end{cases}$$

where $\gamma_L < \gamma_H$ by assumption. Finally, a borrower can continue with a loan by making a mortgage payment. The intermediary then receives the payment and the continuation value of the loan.

In the last period of life, a borrower either repays or defaults on all outstanding debt. This requirement pins down the present value of a mortgage held by age-T household so that

$$\Pi_T(\omega) = (1+r_m)\,m$$

in the case of repayment and

$$\Pi_T(\omega) = (1-\delta_h)\,h - \gamma(q)$$

[32]Pennington-Cross (2006) and Campbell, Giglio and Pathak (2011) find the property values of foreclosed houses tend to be lower than those of non-foreclosed properties.

in the case of default. These terminal conditions make it possible to compute $\Pi_j(\omega)$ for $j \in \{1, 2, \ldots, T-1\}$ using backward induction.

Free entry among financial intermediaries implies that, on a loan-by-loan basis, the face value of a newly originated loan equals the expected present value of future cash flows so that the lender earns zero profit:

$$m'_j(\omega) = \frac{1}{1 + r + \phi} \mathbb{E}_{\delta'_h, z'|z} \Pi_{j+1}(\omega'). \tag{1.14}$$

Thus, conditional on the household's current idiosyncratic state, the financial intermediary will offer an interest rate $r'_{m,j}(\omega)$ such that Equation (1.14) is satisfied.

1.5.4 Equilibrium definition

I solve for the stationary recursive equilibrium of the model. To establish notation, I define the state space W as Cartesian product $A \times H \times D \times M \times Q \times R_M \times Z$, and let the σ-algebra Σ_W be defined as $B_A \otimes B_H \otimes B_M \otimes B_{R_M} \otimes P(D) \otimes P(Z)$, where B_A, B_H, B_M, B_Q, and B_{R_M} are the Borel σ-algebras on A, H, M, Q, and R_M, respectively, and $P(D)$ and $P(Z)$ are the power sets of D and Z, respectively. Let $\Omega = \mathcal{A} \times \mathcal{H} \times \mathcal{M} \times \mathcal{Q} \times \mathcal{R}_\mathcal{M}$ be the typical subset of Σ_W.

For a given parameterization of the model and a distribution of age-1 households μ_1, a stationary recursive equilibrium consists of

1. household value functions $\left\{V_j^R(\omega), V_j^M(\omega), V_j^P(\omega), V_j^D(\omega)\right\}$ and policy functions $\left\{c_j(\omega), s_j(\omega), a'_j(\omega), h'_j(\omega), m'_j(\omega), q'_j(\omega)\right\}$;
2. a mortgage interest rate schedule $r'_{m,j}(\omega)$; and

3. a stationary measure $\Lambda_j^*(\Omega)$;

such that,

1. given $r'_{m,j}(\omega)$, household value and policy functions solve the optimization problems in Equations (1.8), (1.9), (1.10), (1.11), and (1.12);
2. given the household's policy and value functions, $r'_{m,j}(\omega)$ is such that financial intermediaries' zero-profit condition in Equation (1.14) is satisfied; and
3. the invariant probability measure satisfies

$$\Lambda_{j+1}^*(\Omega) = \int_{\Omega} Q_j(\omega, \Omega) \left[\Lambda_j^*(d\omega) + \mu_1(d\omega)\right] \tag{1.15}$$

for all $\Omega \in \Sigma_W$ and where the transition function $Q_j(\omega, \Omega)$ is defined as

$$Q_j(\omega, \Omega) = \mathbb{1}_{a'_j(\omega)\in\mathcal{A},\, h'_j(\omega)\in\mathcal{H},\, m'_j(\omega)\in\mathcal{M},\, q'_j(\omega)\in\mathcal{Q},\, r'_{m,j}(\omega)\in\mathcal{R}_{\mathcal{M}}} \sum_{\delta'_h} \sum_{z'} \pi(\delta'_h)\, \pi(z'|z). \tag{1.16}$$

I solve the model numerically using backwards induction and provide a detailed outline of the solution algorithm in Section A.5 of the appendix.

1.6 Calibration

Before I can use the model to evaluate the aggregate and distributional consequences of DTI limits and forecast the potential effects of new Dodd-Frank DTI policy, I must ensure that the parameterized model is a reasonable environment for those quantitative exercises. To that end, the goal of the calibration is to have the stationary distribution of households over states reproduce key features of aggregate, household-level, and loan-level data after the Great Recession—including some of the empirical results from Section 1.4—assuming that the current 45-percent DTI limit is in place. Specifically, I employ a measure of the bunching at the existing DTI limit as a target in the calibration procedure, then verify that the calibrated model is consistent with the documented patterns of loan selection.

The current policy is implemented in the model by setting the maximum DTI ratio on a low-DTI loan λ to 45 percent and restricting all borrowers to low-DTI loans (i.e., $q' = L$ for all households in all states). I abstract from the existence of loans with DTI ratios greater than 45 percent in the model implementation of the Freddie Mac policy because the process by which those loans exist in reality appears to be largely driven by lender discretion that lies outside of the usual underwriting standards. The most important feature from the Freddie Mac data that I require my model to replicate is the measure of households at or near the DTI limit, since that is the subset of the population likely to be most affected by the introduction of the new Dodd-Frank regulation.

I calibrate a subset of parameters externally, and the remainder are calibrated internally to match moments in the data. I assess the fit of the model by comparing life-cycle profiles of household wealth accumulation and the distribution of loan characteristics in the data to those generated by the model.

1.6.1 Externally calibrated parameters

Table 1.2 summarizes the externally calibrated parameters and their sources. These values are either based on direct empirical evidence or taken from the existing literature.

	Description	Value	Source
μ_1	Distribution of age-1 households		SCF (2016)
$\left\{\chi_j\right\}_{j=1}^{T}$	Age-specific income		PSID (1999-2015)
λ	Maximum DTI ratio on low-DTI loan	0.45	Freddie Mac
φ	Exclusion from mortgage market	0.14	Equifax
r	Risk-free rate	0.017	FRED
ρ	Persistence of income shock	0.91	Floden and Lindé (2001)
σ	Risk aversion	2	Standard in literature
σ_ϵ	Standard deviation of income shock	0.21	Floden and Lindé (2001)
T	Number of model periods	59	U.S. life expectancy
T_R	Retirement age	44	Normal retirement age
θ	Maximum LTV ratio	0.85	Greenwald (2018)

Table 1.2

Externally calibrated parameters.

Preferences and endowments

One period in the model corresponds to one year. Households enter the model at age 22, retire at age 65, and die at age 80, implying $T = 59$ and $T_R = 44$. As is standard in the macroeconomics literature, the coefficient of relative risk aversion σ is equal to 2.

Following Floden and Lindé (2001), I set the persistence of the idiosyncratic income process ρ to 0.91 and its standard deviation σ_ε to 0.21. As in Kaplan and Violante (2014), I use data from the 1999-2015 waves of the Panel Study of Income Dynamics to estimate the deterministic component of income $\left\{\chi_j\right\}_{j=1}^{T}$ by regressing log annual household labor income on a quartic polynomial in age for a sample of households whose heads are between ages 22 and 64. Pension income received in retirement is modeled after Guvenen and Smith (2014).[33]

[33] Section A.4 in the appendix contains further details on the parameterization of the deterministic component of income and pension income.

Asset technology

I set the risk-free rate r equal to the 1-year Treasury constant maturity rate less the annual rate of CPI inflation and average the difference over the years 1971-2016. This results in a value of 1.27 percent. The probability that a household who has defaulted on their mortgage can regain access to the mortgage market in the next period, φ, is 0.143. This implies a mean duration of exclusion from borrowing of 7 years and corresponds to the length of time that a foreclosure flag remains on a consumer's credit report.[34] Since I calibrate the stationary distribution of the model under the assumption that the current 45-percent DTI limit is already in effect, I set the maximum DTI ratio on a low-DTI loan λ to 0.45. I set the maximum LTV ratio θ to 0.85 in line with Greenwald (2018).

Distribution of age-1 households

I divide the measure of age-1 households μ_1 across idiosyncratic income states in accordance with the invariant distribution of z. I stratify a sample of households with heads between the ages of 22 and 27 in the 2016 Survey of Consumer Finances (SCF) into N_z groups according to their labor income, where N_z is the number of discretized income states used in the numerical solution of the model.[35] Within each income group, I compute the homeownership rate, the fraction of homeowners with mortgages, mean liquid assets, and mean home equity. I initialize the cross-sectional distribution of age-1 households in the model to match these means.

[34] See https://www.equifax.com/personal/understanding-credit/.

[35] I set $N_z = 5$ when solving the model numerically.

1.6.2 Internally calibrated parameters

A set of 11 parameters in the model are selected jointly to minimize the weighted distance between a vector of moments from the stationary distribution of households over states in the model and their empirical counterparts. I define the calibration loss function as

$$\sum_{i=1}^{10} \text{weight}_i \left(\frac{\text{model}_i - \text{data}_i}{1 + |\text{data}_i|} \right)^2 . \tag{1.17}$$

The three moments that receive relatively more weight in the calibration loss function are the foreclosure rate (0.7 percent), the homeownership rate (62 percent), and the fraction of newly originated loans with DTI ratios between 43 and 45 percent (10 percent). The first two moments are relevant policy objectives, and the third captures the bunching observed in the distribution of DTI ratios at origination on loans purchased by Freddie Mac. Of the remaining seven targets, six are cross-sectional moments regarding household wealth portfolios that I compute from the 2016 SCF. I exclude households whose net worth is above the 95th percentile because the SCF is designed to over-sample relatively wealthy families for whom home equity is a less important form of savings.[36] The final moment is the depreciation rate for housing.

Table 1.3 provides a list of the 11 internally calibrated parameters plus the two foreclosure cost parameters, the moments targeted in the estimation, and

[36]The SCF over-samples families that are likely to be relatively wealthy in order to increase representation of the upper tail of the wealth distribution and to make possible analyses of less widely held asset classes—e.g., direct holdings of government bonds—that would otherwise require a prohibitively large sample size. These families correspond to the "list sample" since they are selected using specially edited individual tax returns provided by the Internal Revenue Service. In the 2004 SCF, the list sample accounts for only 15 percent of observations in the bottom 95 percent of the wealth distribution but 88 percent of observations in the top 5 percent. See https://www.federalreserve.gov/econresdata/scf/files/scf2001list.sampleredesign9.pdf for more information on the survey design of the SCF.

	Description	Value	Target	Data	Model
α	Nondurable cons. weight	0.898	Aggregate housing stock	2.73	2.13
B	Bequest weight	5.803	Share retired owners w/ debt	0.37	0.33
β	Discount factor	0.905	Aggregate net worth	2.27	2.24
δ	Depreciation shock	0.481	Foreclosure rate (%)	0.70	0.62
h_{small}	Smallest house size	9.284	Aggregate liquid wealth	0.64	0.65
κ_h	Housing adj. cost	0.287	Share loans w/ DTI $\in (43, 45]$	0.10	0.09
κ_m	Mortgage adj. cost	0.093	Share owners w/ debt	0.63	0.61
ϕ	Mortgage servicing cost	0.022	Mean mortgage int. rate (%)	4.17	4.06
R	Housing rental rate	0.916	Homeownership rate	0.62	0.57
ξ	Utility loss from default	1.486	Mean LTV ratio	0.39	0.26
ζ	Depreciation shock prob.	0.056	Mean depreciation rate (%)	2.27	2.27
γ_L	Low-DTI loan default cost	0.287	Set to housing adj. cost κ_h		
γ_H	High-DTI loan default cost	2.138	CFPB analysis from *Federal Register*		

Table 1.3

Parameters chosen to match moments in the data. The values for aggregate housing stock, net worth, and liquid wealth are relative to mean household income in the stationary distribution.

the value of their model equivalents.[37] Although the parameters governing the foreclosure costs, γ_L and γ_H, are not directly involved in computing the calibration loss function, I place restrictions on their values that depend on the internally calibrated parameters and therefore include them in this table. I discuss the parameterization of the foreclosure costs later in this section.

Preferences and endowments

The weight on nondurable consumption α is calibrated to 0.898, and the discount factor β is calibrated to 0.905.[38] Both are similar to values found in the literature. The parameter governing the strength of the bequest motive, B, is set to 5.803. Too small a value of B leads retired agents to obtain new mortgages near the end of life and leads to a large spike in the default rate at age T. The

[37]Section A.4 details how the targeted moments were calculated.

[38]Compared to models with a representative agent, a lower discount factor is typically needed in incomplete-markets models in order to offset the precautionary savings motive. For instance, Berger et al. (2017) arrive at a calibrated value of 0.9175 for the discount factor in their model, and Corbae and Quintin (2015) have a discount factor of 0.876.

flow utility loss from default ξ is set to 1.486.

Asset technology

The smallest size house available for purchase, h_{small}, is set to 9.284, which is about 3.7 times larger than average household income in the model. Given the general rule of thumb that the price of a home should not exceed 2.5 to 3 times one's annual income, this is a plausible estimate. h_{small} is important in determining the fraction of borrowers who are near the 45-percent DTI limit. A large enough minimum house size is needed to push borrowers towards a loan size with a sufficiently large mortgage payment. If h_{small} is too large, though, marginal homeowners choose to rent instead, resulting in a more creditworthy pool of borrowers who are more likely to choose loan sizes with low DTI ratios and thereby reducing the fraction of borrowers near the limit.

The housing and mortgage adjustment costs, κ_h and κ_m, are calibrated to 0.287 and 0.093, respectively. Taken together, these values imply that a household who finances the purchase of a new home with a mortgage loan will pay 4.1 percent of the value of the home in transaction costs and that a homeowner who refinances their mortgage must pay a loan origination fee equal to 3.7 percent of average household income.[39] The estimates for the two adjustment costs are broadly in line with previous values found in the literature.[40]

The depreciation shock δ is set to 0.481 and is essential in helping the model

[39]This is assuming that the household buys a house of size h_{small}, which is indeed the most commonly chosen house size in the stationary distribution.

[40]Berger and Vavra (2015) estimate that the fraction of the value of durable goods lost to adjustment costs is 5.3 percent. Gorea and Midrigan (2018) arrive at a calibrated value for the fixed cost of obtaining a new home equity loan that is 2.3 percent of mean per-capita income in their model.

match the observed foreclosure rate of 0.7 percent.[41] Negative equity is a necessary—though not sufficient—condition for default in this class of models. This is the "double-trigger" hypothesis of foreclosure: the default decision requires both negative home equity and some adverse shock to current cash on hand.[42] Since the loan-to-value constraint prevents households from starting their tenure as owners with negative equity and house prices are constant in my model, a sufficiently large depreciation shock is needed to generate borrowers who are underwater on their mortgages. The probability of the depreciation shock ζ is set so that the expected value of the depreciation shock equals 2.27 percent, the depreciation rate of private residential investment estimated by the Bureau of Economic Analysis. Given the calibrated value of δ, this implies that ζ equals 0.056 so that, on average, a household experiences a positive depreciation shock once every 18 years.

The mortgage servicing cost ϕ is set to 0.022. Intuitively, this allows the model to match the average interest rate on the 30-year fixed rate mortgage of 4.17 percent.[43] The rental rate of housing R is set to 0.916, quite a bit higher than the user cost of housing implied by the risk-free rate, housing depreciation rate, and the cost of borrowing. This wedge generates additional incentive for homeownership in the model.

[41]See https://www.attomdata.com/news/heat-maps/2016-year-end-u-s-foreclosure-market-report/.

[42]Note that, for plausible parameterizations of the housing and loan transaction costs, an owner with positive equity in the home will never default as long as they have the option to sell. For a further discussion of this, see Foote, Girardi and Willen (2008).

[43]The mean mortgage interest rate is the interest rate on 30-year fixed-rate mortgages less annual CPI inflation, averaged over 1971-2016. The data used for calculating this are from FRED.

Lender's foreclosure costs

The parameterization of the lender's foreclosure costs, γ_L and γ_H, is critical to the quantitative results of the model. I restrict the cost of default on a low-DTI loan γ_L to equal to the internally calibrated value of the housing adjustment cost κ_h of 0.287. This restriction is motivated by the fact that, in reality, the lender is responsible for selling repossessed properties following foreclosure. It is thus reasonable to assume that, if a household defaults on a mortgage, the intermediary instead bears the costs of selling the underlying collateral.

Because the Dodd-Frank Act creates a new legal liability relative to existing rules for lenders who originate high-DTI loans, I restrict the cost of default on a high-DTI loan γ_H to be greater than the cost of default on a low-DTI loan γ_L. As discussed in Section 1.3, if a borrower with a high-DTI mortgage brings a successful legal claim under the ability-to-repay rule, the lender is liable for up to three years of fees and finance charges, along with the borrower's legal expenses. This stands in contrast to the stronger legal protection given to mortgage loans that satisfy the 43-percent DTI constraint.

To discipline the value of γ_H, I follow a cost-benefit analysis of the Dodd-Frank ability-to-repay rule that the Consumer Financial Protection Bureau (2013) included in its submission of the final rule to the *Federal Register*. Part of this analysis includes an estimate of the resource costs implied by the legal liability assigned to a high-DTI loan. To start, I define a typical mortgage in the stationary distribution of my calibrated model as having an initial balance of 6.16, an interest rate of 4.06 percent, a maturity of 30 years, and an origination fee of 0.093.[44] In line with the CFPB's analysis, I use the midpoint of the

[44] I compute the initial loan balance by multiplying the average LTV ratio at origination in the

three-year window to calculate the interest payments and loan fees that would be owed by a lender. For the typical mortgage in the model, this amounts to 0.46 units of the nondurable consumption good. The CFPB estimates that lenders' and borrowers' legal expenses would sum to $34,500. This is equal to 66 percent of mean household income and translates to 1.68 units of nondurable consumption.[45] In total, the resource loss incurred by a lender due to default on a high-DTI loan, γ_H, is 2.14. This is around 35 percent of the initial loan size and more than 7 times the size of γ_L, the calibrated cost of foreclosure on a low-DTI loan to the lender.

In reality, not every borrower who is unable to repay a mortgage loan will bring a case against the responsible lender, as that decision will depend on, among other factors, whether the borrower lives in a judicial or non-judicial foreclosure state and their willingness and/or ability to obtain legal representation. Substantial evidence nonetheless suggests that mortgage lenders are indeed worried about these regulations.[46] Fuster, Lo and Willen (2017) estimate that, over 2008-2014, the price of intermediation in the mortgage market increased by around 30 basis points per year and that this trend appears to be driven by increased net costs of mortgage servicing and heightened aversion to liability risk among lenders. Kim et al. (2018) document that, after the financial crisis, the GSEs and the U.S. government required loan originators to repurchase mortgages collateralizing GSE securities if one or more of the "representations and warranties" made upon selling the loans to the GSEs was inaccurate. By

stationary distribution, 0.66, by h_{small}. In the stationary distribution, the mean mortgage interest rate at origination is 4.06 percent. The origination fee is equal to κ_m, the calibrated mortgage transaction cost in the model.

[45]Mean household labor income in the 1998 SCF is $52,108 in 2013 CPI-U-RS adjusted dollars. Mean household labor income in the model is 2.53.

[46]The CFPB, for one, concedes that its estimate of litigation costs relies on "very conservative (likely unrealistic) assumptions."

the third quarter of 2015, these lender repurchases amounted to $76.1 billion. They also note that, under the auspices of the False Claims Act, the Department of Justice has litigated cases in which Federal Housing Administration loans were improperly originated and that cumulative settlements under this effort amounted to $6.6 billion. In light of this, the fact that Dodd-Frank creates the potential for increased legal claims against mortgage lenders—even if there is uncertainty about how many will claims will ultimately be brought—should be taken seriously.

1.6.3 Model fit

Overall, the model does a good job of matching the targeted moments. It is able to replicate the foreclosure rate and generates a homeownership rate that is close to what is seen in the data. The model also matches the share of newly originated mortgages that have a DTI ratio between 43 and 45 percent, thereby producing the bunching at the DTI limit documented in Section 1.4.2. The model understates the ratio of aggregate mortgage debt to aggregate housing stock relative to the data (0.26 versus 0.39, respectively) and has difficulty replicating the ratio of the aggregate housing stock to mean income (2.73 in the data versus 2.14 in the model). This may be a result of the fact that house prices in my model are fixed.

I evaluate the fit of the model by assessing its ability to account for non-targeted moments in the data. Figure 1.6 plots life-cycle profiles of wealth accumulation for households from the 2016 SCF and their model counterparts.[47]

[47]When computing these life-cycle profiles, I also exclude households in the top 5 percent of the net worth distribution in order to be consistent with the calibration strategy.

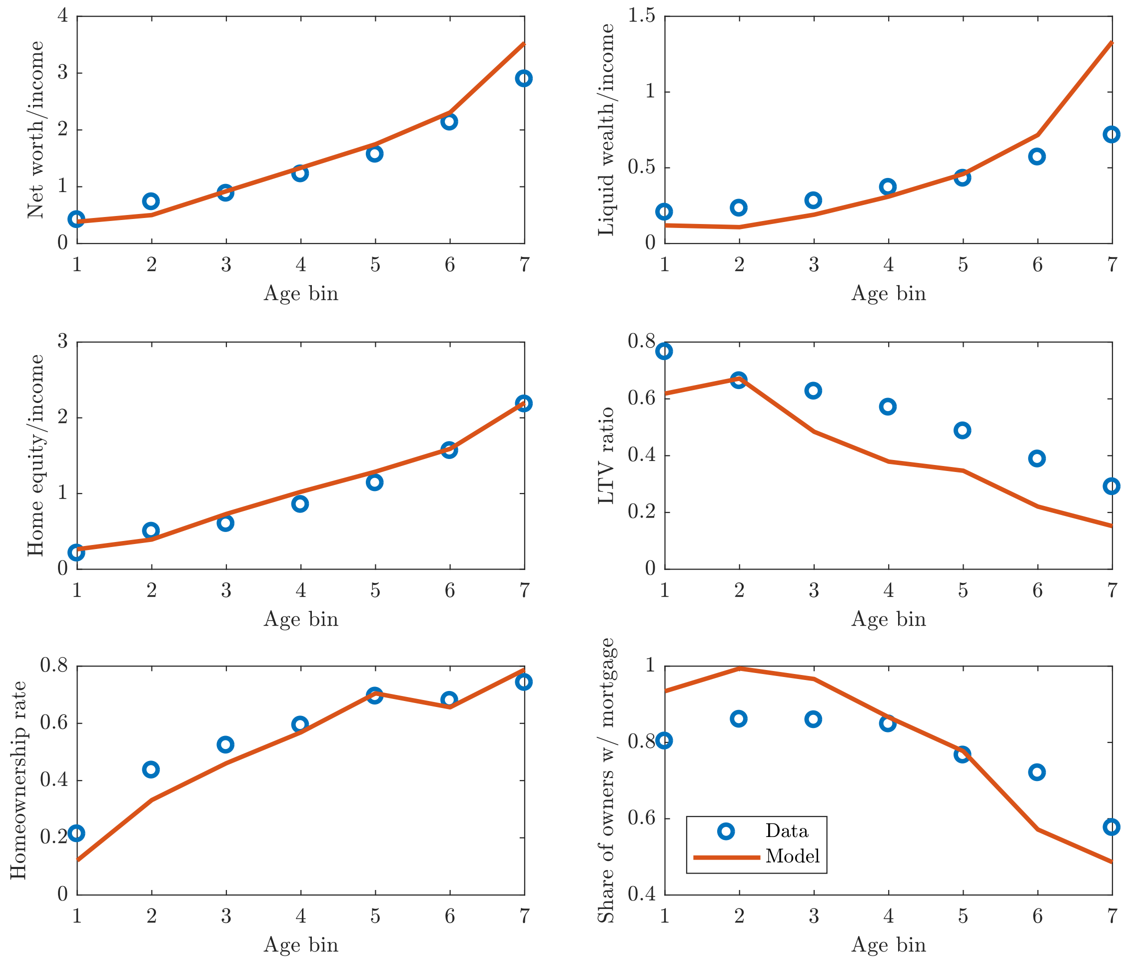

Figure 1.6

Life-cycle wealth accumulation in the data (blue circles) and the model (red line). Model moments are computed from the stationary distribution of households with the Freddie Mac 45-percent DTI limit in place. Age bins: 1 = 22-27, 2 = 28-33, 3 = 34-39, 4 = 40-45, 5 = 46-51, 6 = 52-57, 7 = 58-64. Data source: 2016 Survey of Consumer Finances.

I focus on results from agents' working life (i.e., ages 22-64) since my model's approach to retirement is too parsimonious to adequately capture the sources of risk and financial decisions that confront aging households in actuality.[48] As in the data, the model generates a gradual increase over the life cycle in net worth relative to income. It slightly overstates the net worth of households in the years immediately preceding retirement, a feature that is driven by the over-

[48]Specifically, I am unable to produce the large accumulation of wealth, relative to labor income, observed in the data.

accumulation of liquid assets in anticipation of lower expected income. The over-accumulation of liquid savings is likely due by the fact that the model abstracts from other savings instruments that households use for smoothing consumption during retirement. The model captures well the steady accumulation of home equity over the life cycle, even if households in the model at all ages hold less leveraged positions in their home than in the data. The model reproduces the increase, then gradual flattening out, of the homeownership rate as households age. It also able to replicate the fact that the share of owners with mortgage debt decreases over the life cycle.

	Data	Model
Mean LTV ratio at origination	76.6	66.3
Mean DTI ratio at origination	34.7	18.3
Mean mortgage interest rate at origination	3.90	4.06

Table 1.4

Mean loan characteristics at origination in the data and the model. Model moments are computed from the stationary distribution of households with the Freddie Mac 45-percent DTI limit in place. Data source: Freddie Mac Single Family Loan-Level Dataset.

Next, I compare mortgage originations in the stationary distribution of the model to those in the Freddie Mac Single Family Loan-Level Dataset. To make a consistent comparison with the calibrated model, I compute the empirical moments from mortgage loans that were originated in 2016. As can be seen in Table 1.4, my model predicts that, on average, a newly originated mortgage loan has a LTV ratio of 66 percent, a DTI ratio of 18 percent, and an interest rate of 4.06 percent, compared to 77 percent, 35 percent, and 3.90 percent in the data, respectively.

Figure 1.7 plots model-implied distributions of the LTV ratio, DTI ratio, and the interest rate at origination against their data counterparts. The model-implied distribution of LTV ratios at origination matches well the distribution

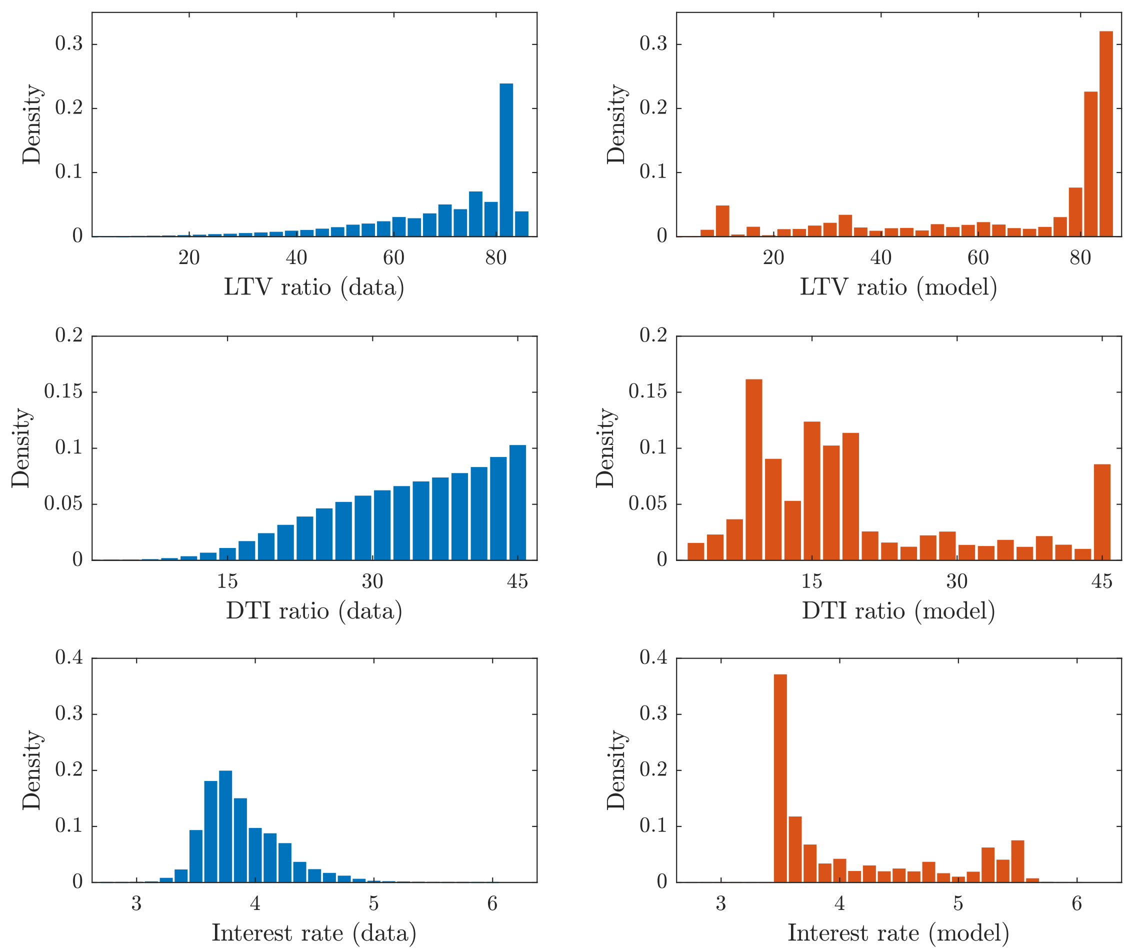

Figure 1.7

Distributions of LTV ratio, DTI ratio, and interest rate at origination in the data (blue bars) and the model with the Freddie Mac 45-percent DTI limit in place (red bars). Data source: Freddie Mac Single Family Loan-Level Dataset.

in the data. By design, the distribution of DTI ratios in the model produces a mass of loans immediately to the left of the 45-percent mark; however, it also generates a counterfactually large share of loans with very low DTI ratios. This is likely a consequence of making a maturity of the loan a function of household age. A borrower who obtains a mortgage very early in their life receives a mortgage whose maturity exceeds what it is seen in reality, where 30-year terms are the norm. *Ceterus paribus*, this mechanically implies a small minimum mortgage payment. Since these are not the borrowers that should be most directly affected by changes in the DTI constraint, though, this feature of the model-implied DTI distribution is less relevant for the policy analysis that follows. Finally, the model generates dispersion in the cost of borrowing and is consistent with the fact that a plurality of borrowers face low mortgage interest rates while a smaller share of borrowers have a higher objective probability of default and consequently receive a higher interest rate.

1.7 Quantitative analysis of DTI limits

Having verified that the calibrated model is a good representation of the mortgage market as it currently stands while also capturing important dimensions of the life-cycle consumption and savings behavior of households, I use it to assess the aggregate and distributional consequences of two policies, Freddie Mac's 45-percent DTI limit and Dodd Frank's 43-percent DTI limit with a costly option to relax the limit. To illustrate the effects of these policies, I consider two policy changes. The first is a change from a setting characterized by the absence of a DTI limit—what I refer to as the no-DTI-limit baseline—to Freddie Mac's 45-percent DTI limit. The no-DTI-limit baseline is implemented by restricting borrowers to a high-DTI loan and setting the lender's foreclosure costs to its low value, γ_L, for all loans. This parameterization proxies a pre-crisis regulatory environment in which only the standard LTV constraint applies and mortgages with high DTI ratios are not penalized by greater legal costs. The second is a change from the Freddie Mac policy to the Dodd-Frank policy. I implement the Dodd-Frank regulation in the model by lowering the maximum DTI ratio on a low-DTI loan λ to 43 percent and allowing households to optimally choose between a high- or low-DTI loan. These two sets of comparisons are designed to capture the observed progression of household leverage regulations and to provide the appropriate initial policy against which to benchmark the pending Dodd-Frank regulations.[49] I summarize the mortgage contract parameters for each policy environment in Table 1.5.

	θ	λ	γ
	No DTI limit		
High-DTI loan	0.85	∞	0.29
	Freddie Mac		
Low-DTI loan	0.85	0.45	0.29
	Dodd-Frank		
Low-DTI loan	0.85	0.43	0.29
High-DTI loan	0.85	∞	2.14

Table 1.5

Mortgage contract parameters under the no-DTI-limit baseline, the Freddie Mac policy, and the Dodd-Frank policy. θ is the maximum LTV ratio, λ is the maximum DTI ratio, and γ is the lender's foreclosure cost.

I begin by quantifying the trade-off between mortgage default and homeownership that results from the two policies. I then study the patterns of borrower selection that can explain the aggregate decline in mortgage default. The Freddie Mac policy reduces leverage most among low-income and low-wealth households, and that in turn drives most of the observed decline in the aggregate default rate. Relative to the Freddie Mac DTI limit, the Dodd-Frank policy shapes household decisions in two opposing ways. On one hand, the more strict cap on the DTI ratio further reduces borrowing and foreclosure among the poorest households. On the other hand, wealthier households who have low incomes use the costly high-DTI contract to increase their leverage, thereby raising the default rate among this group. Because default is already extremely uncommon among wealthier households, though, the first channel dominates

[49] I abstract from transition dynamics and assume that the economy unexpectedly jumps from one steady state to another.

the second so that, overall, the aggregate foreclosure rate is lower. Finally, I show that the Dodd-Frank policy improves aggregate welfare relative to the Freddie Mac policy but produces heterogeneous changes in welfare across individual households: welfare gains are strongly correlated with the ability to choose the costly option to relax the DTI limit in equilibrium, as well as with homeownership status.

1.7.1 Aggregate effects of DTI limits

In Table 1.6, I outline the consequences of the Freddie Mac and Dodd-Frank regulations for aggregate outcomes. I find that, in the model, a constraint on a borrower's debt payment-to-income ratio is effective at reducing mortgage foreclosure. Relative to the no-DTI-limit baseline, the Freddie Mac 45-percent DTI limit reduces the foreclosure rate by half from 1.20 percent to 0.62 percent. At the same time, the Freddie Mac policy lowers the homeownership rate from 65 to 57 percent. This is also a substantial decline.[50]

Relative to the Freddie Mac regulations, the Dodd-Frank policy further reduces the default and homeownership rates slightly. The lower foreclosure rate occurs in spite of the fact that, under the Dodd-Frank regulations, the share of high-DTI loans among newly originated mortgages increases substantially, with 20.6 percent of borrowers choosing the costly high-DTI loan option.

[50]To place the decrease in the homeownership rate into perspective, the homeownership rate in the United States reached 69 percent during the peak of the housing boom before falling to 63 percent in 2016.

	No DTI limit	Freddie Mac	Dodd-Frank
Default rate (%)	1.20	0.62	0.52
Homeownership rate (%)	64.7	57.0	56.3
% owners with mortgage	67.8	61.2	62.6
LTV ratio (%)	71.8	66.3	65.7
DTI ratio (%)	51.9	18.3	49.8
Mortgage interest rate (%)	4.28	4.06	3.97
% mortgages with DTI > 43	30.0	8.53	20.6
Aggregate net worth	2.26	2.24	2.20
Aggregate liquid wealth	0.63	0.65	0.64
Aggregate home equity	1.62	1.60	1.56

Table 1.6

Aggregate effects of the Freddie Mac and Dodd-Frank DTI limits, compared to the no-DTI-limit baseline. All moments are computed from the stationary distribution of the model under the different leverage regulations. Aggregate net worth, liquid wealth, and home equity are reported relative to aggregate income.

1.7.2 The importance of borrower selection in lowering default

Next, I study the changes in household behavior that explain the aggregate effects of the two DTI policies and underscore the role of borrower selection in driving those results. In Figure 1.8, I plot the default rate, the homeownership rate, the percent of households who obtain new loans, the LTV ratio at origination, the DTI ratio at origination, and the high-DTI loan share of newly originated loans conditional on household income across the three regulatory environments (i.e., no DTI limit, Freddie Mac, and Dodd-Frank). I do the same in Figure 1.9, where I condition instead on household net worth.

I begin by comparing household decisions under the no-DTI-limit baseline versus Freddie Mac's 45-percent DTI limit and find that the large declines in the aggregate default and homeownership rates are driven by a reduction in leverage among households in the bottom half of the income and wealth distri-

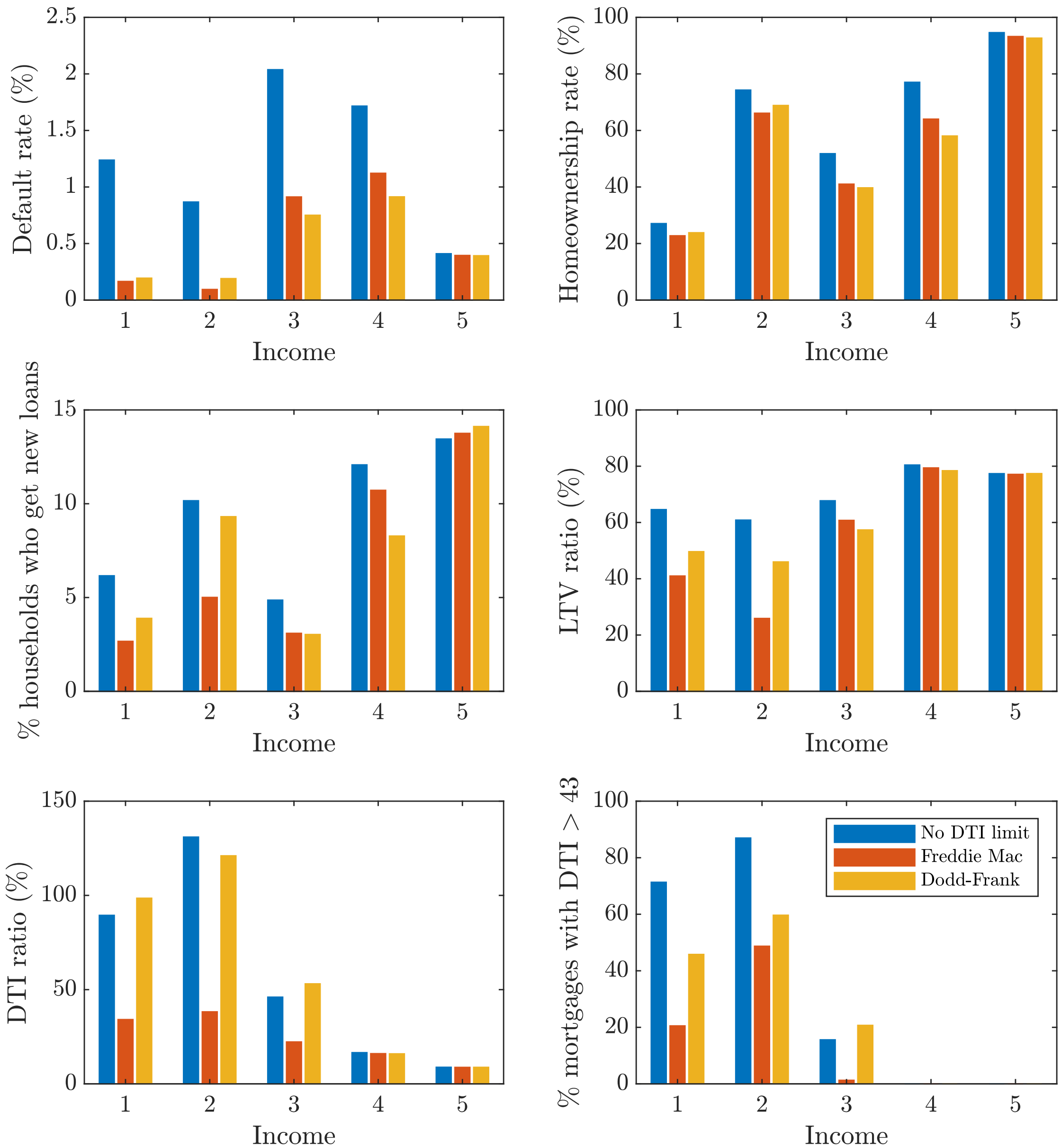

Figure 1.8

Default rate, homeownership rate, share of owners with mortgages, percent of households who obtain a new mortgage, LTV ratio at origination, DTI ratio at origination, and share of mortgage originations with a DTI ratio above 43 percent by income quintile. All moments are computed from the stationary distribution of the model under the different leverage regulations.

butions. As Figure 1.8 demonstrates, borrowers in the bottom 40 percent of the income distribution obtain almost all mortgages that are originated with a DTI ratio greater than 43 percent; the Freddie Mac policy affects these households most. These households respond by reducing borrowing along both the exten-

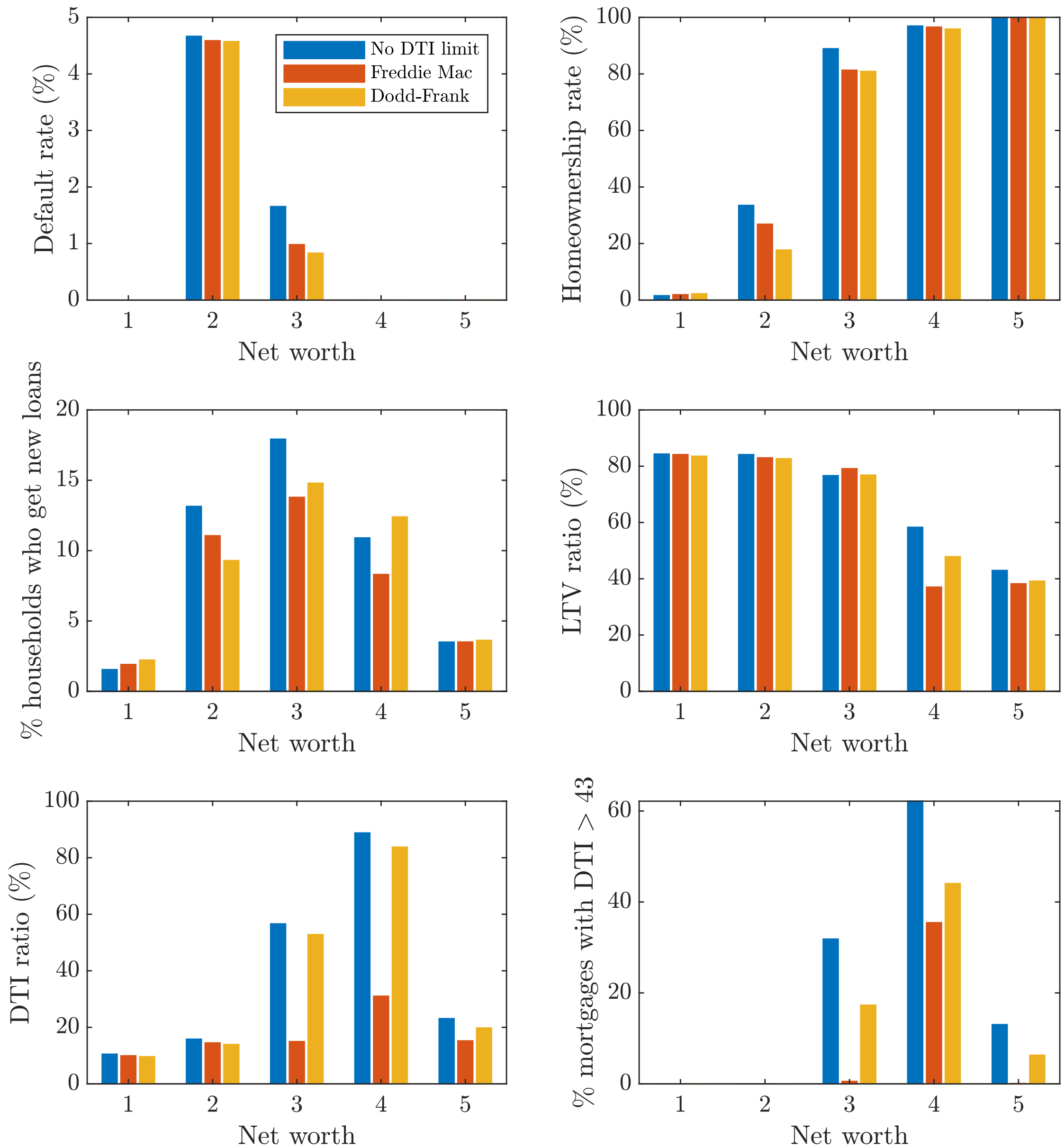

Figure 1.9

Default rate, homeownership rate, share of owners with mortgages, percent of households who obtain a new mortgage, LTV ratio at origination, DTI ratio at origination, and share of mortgage originations with a DTI ratio above 43 percent by net worth quintile. All moments are computed from the stationary distribution of the model under the different leverage regulations.

sive and intensive margins: the share of households in the two lowest income quintiles who still obtain a new loan after the Freddie Mac policy is introduced falls by half, and, conditional on choosing to get a mortgage, poor borrowers choose lower loan-to-value ratios at origination. A similar result can be seen among borrowers who rank in the bottom 40 percent of the wealth distribution, as indicated by Figure 1.9. The intuition for this result is straightforward. The introduction of a DTI limit will be most constraining for households with low contemporaneous income, high demand for mortgage debt, and a high minimum mortgage payment. In the presence of such a limit, many such borrowers will forgo a new loan altogether or, if they continue to choose to borrow, reduce the size of their loans. Since these households have a higher propensity for default, removing them from the borrower population reduces the overall default rate.

I next compare household decisions under the Freddie Mac policy to those under the Dodd-Frank policy, which lowers the maximum DTI ratio from 45 to 43 percent while providing the costly option to obtain a loan that is not subject to a DTI limit. In Section 1.7.1, I found that, in the aggregate, the Dodd-Frank regulations slightly lowered the foreclosure rate while, at the same time, the fraction of borrowers with high-DTI loans more than doubled. Figures 1.8 and 1.9 clearly illustrate that it is households in the middle of the wealth distribution who have low current incomes that choose the costly high-DTI loan after Dodd-Frank comes into effect. These are akin to the wealthy hand-to-mouth households discussed by Kaplan and Violante (2014). Intuitively, due to their lower cash on hand but high overall net worth, such borrowers have a relatively high demand for mortgage debt for consumption smoothing purposes yet are also low credit risks from the financial intermediary's perspective. In equilibrium, then, these households are able to choose the costly high-DTI contract and many find it optimal to do so. The prevalence of high-DTI loans in the middle of the wealth distribution actually pushes up the default rate among this subset of borrowers. Because their probability of default is already near zero, however, this increase is outweighed by the large decline in foreclosures among the poorest households, many of whom, when faced with the more stringent DTI constraint on a low-DTI mortgage contract under Dodd-Frank, now choose to not obtain a new mortgage.

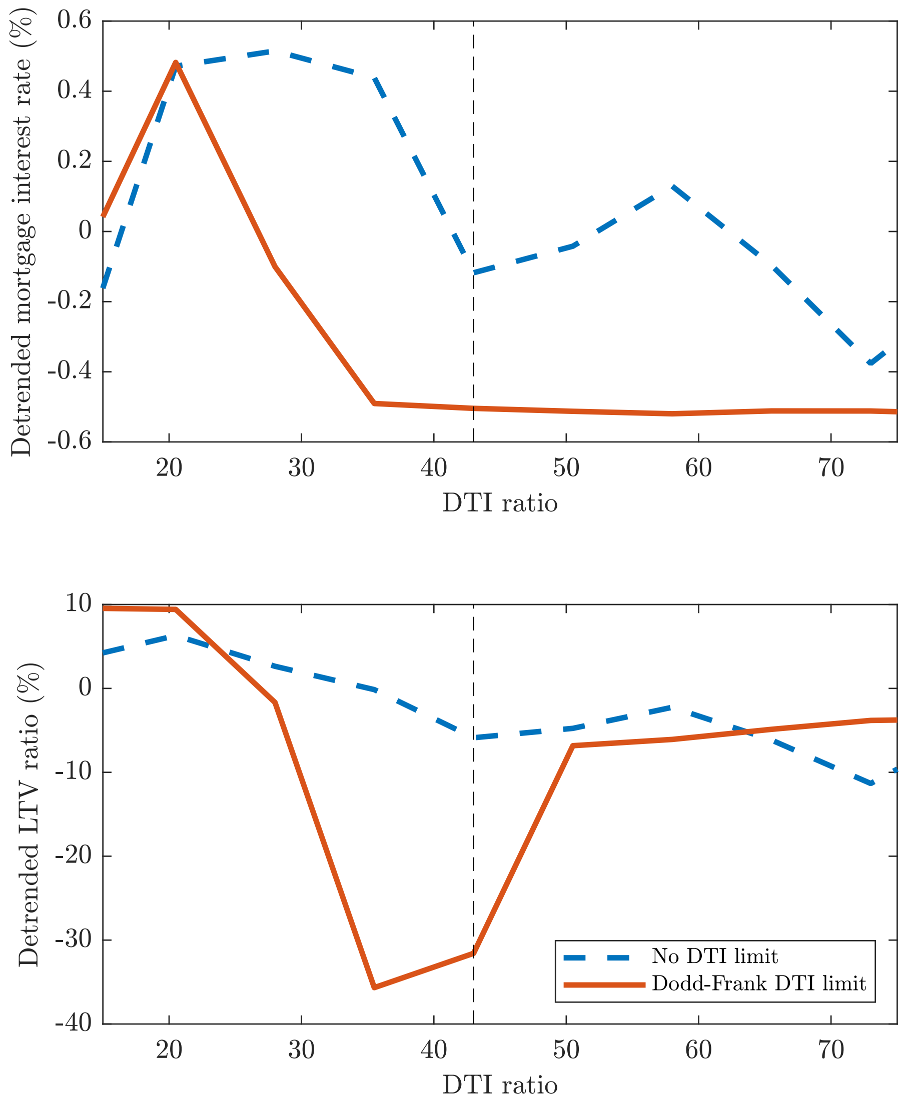

Figure 1.10

Model-implied interest rate and LTV ratio as a function of the the DTI ratio under the no-DTI-limit baseline (dashed blue line) versus the Dodd-Frank DTI limit (solid red line). The dashed black line corresponds to a DTI ratio of 43 percent, which is the maximum DTI ratio on a low-DTI loan under the Dodd-Frank rules.

The selection of borrowers who are in the middle of the wealth distribution but have low cash on hand into high-DTI loans under the Dodd-Frank policy can also be seen in Figure 1.10. These graphs plot the model-implied mortgage interest rates and LTV ratios at origination as a function of the DTI ratio under both the Dodd-Frank policy and the no-DTI-limit baseline.[51] Although the model with the Dodd-Frank policy does not generate any visible discontinuity in either variable at the 43-percent DTI limit, the results are qualitatively consistent with my earlier empirical analysis of the differences in the characteristics of low- and high-DTI loans. Relative to the no-DTI-limit baseline, mortgages with higher DTI ratios have lower interest rates and LTV ratios than mortgages with lower DTI ratios under the Dodd-Frank policy.

1.7.3 The heterogeneous welfare consequences of DTI limits

Finally, I examine the consequences of the Freddie Mac and Dodd-Frank policies for household welfare and highlight the extent to which households are differentially affected by them. Let $V_j(\omega)$ and $\tilde{V}_j(\omega)$ be the value functions under the initial and new policies for an age-j household in state ω, respectively. Then the consumption-equivalent welfare change $\Delta C_j(\omega)$ is the percent by which the nondurable consumption of an age-j household in state ω would have to change to make them indifferent between the two policies:

$$\Delta C_j(\omega) = \left[\left(\frac{\tilde{V}_j(\omega)}{V_j(\omega)}\right)^{\frac{1}{\alpha(1-\sigma)}} - 1\right] \times 100.$$

The average consumption-equivalent welfare change is thus

$$\Delta C = \int \Delta C_j(\omega)\, d\Lambda_j(\omega),$$

[51] Since my model does not feature aggregate uncertainty, detrending is accomplished simply by subtracting from each variable their respective mean in the stationary distribution.

where $\Lambda_j(\omega)$ is the stationary distribution of households under the initial policy.

Although the uniformly applied DTI limit under the Freddie Mac policy results in a substantial decrease in the aggregate default rate and the average cost of borrowing, it lowers welfare relative to the no-DTI-limit setting. The average consumption-equivalent welfare loss across households is 0.92 percent of lifetime consumption, and households are unanimously opposed to the policy. Welfare losses are particularly high for borrowers who, in the absence of a DTI limit, would have chosen to obtain a loan with a DTI ratio greater than 45 percent in their respective states. The consumption-equivalent welfare gain associated with the removal of the limit for these high-DTI borrowers is 2.55 percent, a substantial figure.[52]

	Losers	Winners
% of households	38.3	61.3
Welfare change (%)	-0.15	0.42
Homeownership rate (%)	36.6	69.5
Net worth	0.70	3.13
Liquid wealth	0.14	0.94
Age	34	62

Table 1.7

Model-implied distribution of welfare changes under Dodd-Frank relative to Freddie Mac. Losers are households whose consumption-equivalent welfare change is strictly negative; winners are households whose consumption-equivalent welfare change is at least zero. Net worth and liquid wealth are reported relative to income.

If the economy were to transition immediately from the current Freddie Mac policy to the new Dodd-Frank regulations, which tighten the DTI constraint but provide households with a costly opportunity to circumvent it, households

[52]The large welfare loss for this group of households can be accounted for by the fact that a majority of them—55 percent—find it optimal to switch to renting after the Freddie Mac policy is introduced. Of the remaining 45 percent of high-DTI borrowers who continue to own under the Freddie Mac policy, 37 percent continue with an existing mortgage loan, thereby forgoing the opportunity to refinance their loans, and 8 percent continue to get a new mortgage after the policy change.

would be slightly better off: on average, their welfare increases by 0.20 percent in consumption-equivalent terms. Table 1.7 indicates that households disagree about the desirability of the Dodd-Frank policy. 62 percent of households experience a welfare gain from the Dodd-Frank rules that is, on average, equivalent to 0.42 percent of their lifetime consumption, and the remaining 38 percent see their welfare fall by an average of 0.15 percent. Welfare gains and losses are concentrated among distinct groups in the population. Winners from the reform are older, have higher net worth, and more likely to be homeowners, while losers are younger, have lower net worth, and are also more likely to be renters.

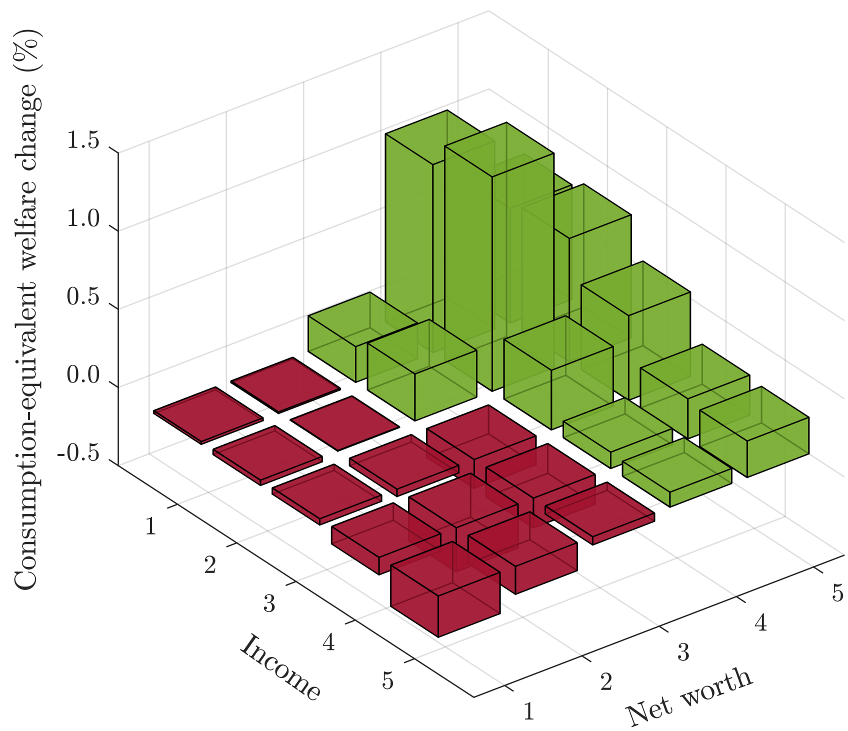

Figure 1.11

Consumption-equivalent welfare changes by income-net worth groups under the new Dodd-Frank DTI limit versus the current Freddie Mac DTI limit. Net worth quintiles are on the x-axis, and income quintiles are on the y-axis. The green and red bars indicate a positive and negative welfare change, respectively.

The predicted pattern of loan selection under the new Dodd-Frank mortgage regulations—that it is households with relatively high net worth but low contemporaneous incomes who exercise the costly option to relax the 43-percent limit—strongly hints that liquidity constrained homeowners benefit most from this reform. Figure 1.11 confirms this intuition by plotting consumption-equivalent welfare changes by both net worth and income quintile. Welfare gains are highest for households who simultaneously fall between the 60th and 80th percentiles of the net worth distribution and the bottom 20 percent of the income distribution. The distribution of welfare changes in the very middle of the net worth distribution is illustrative of the trade-off embodied by the new Dodd-Frank DTI limit. For such households with the lowest incomes, the gain from the ability to relax a borrowing constraint outweighs the corresponding increase in the mortgage interest rate. Households with higher incomes in this middle net worth quintile, though, do not value the option to increase their leverage as much and, in response to both the tighter DTI limit and the additional costliness of a high-DTI loan, may instead optimally demand less mortgage debt.

The distribution of welfare changes also suggests close link between welfare and homeownership. In spite of the illiquidity of home equity as an asset, the option to access mortgage debt is valued as a form of consumption insurance in a setting with incomplete markets.[53] With this in mind, I split the households in the model into four groups based on whether they had chosen to own or rent under the initial policy and whether they continued to own or rent after the new policy is implemented. To provide context, I show the size of these flows between owning and renting in Table 1.8. Of households who had chosen to own in the no-DTI-limit setting, 12 percent of them rent under the Freddie Mac

[53]In an earlier version of their paper, Gorea and Midrigan (2018) demonstrate that households in their model have a smoother consumption than in an otherwise identical one-asset Bewley model for this reason, even though the illiquidity of home equity as an asset produces substantial welfare losses.

policy, while the flow from renting to owning is negligible. When the economy switches from the Freddie Mac policy to the Dodd-Frank policy, the outflow of owners to renters is only half as large, and 6 percent of renters under the Freddie Mac policy now choose to own instead.

	Baseline to Freddie Mac	Freddie Mac to Dodd-Frank
Own to own	87.8	94.1
Own to rent	12.2	5.9
Rent to own	0.9	6.0
Rent to rent	99.1	94.0

Table 1.8

Model-implied flows between homeownership and renting. The first column of numbers compares the no-DTI-limit baseline to the Freddie Mac 45-percent DTI limit, and the second column compares the Freddie Mac policy to the Dodd-Frank 43-percent DTI limit.

I depict the mean consumption-equivalent welfare change across these four groups for the two policy changes in Figure 1.12. Relative to the no-DTI-limit baseline, all four groups experience an average welfare loss after the Freddie Mac policy is introduced.[54] The loss is greatest for households who, in their given state, had initially chosen to own but switch to renting after the policy change. Borrowers with DTI ratios above the Freddie Mac limit of 45 percent constitute the majority of these own-to-rent households. These are precisely the households who exhibit a higher objective probability of default, and their exit from the pool of borrowers after the introduction of a DTI limit accounts for the observed decline in the foreclosure rate.[55] By contrast, only 19 percent of households who own under both the no-DTI-limit baseline and the Freddie

[54]The welfare losses under the Dodd-Frank policy *relative to the baseline* are similar in magnitude.

[55]Own-to-rent switchers who had obtained a new mortgage loan in the baseline received a mortgage interest rate of 4.89 percent. This is 61 basis points greater than the mean mortgage interest rate at origination in the no-DTI-limit stationary distribution and 144 basis points greater than the mortgage interest rate implied by a mortgage interest rate with a default premium of zero.

Mac policy had initially taken out high-DTI loans.

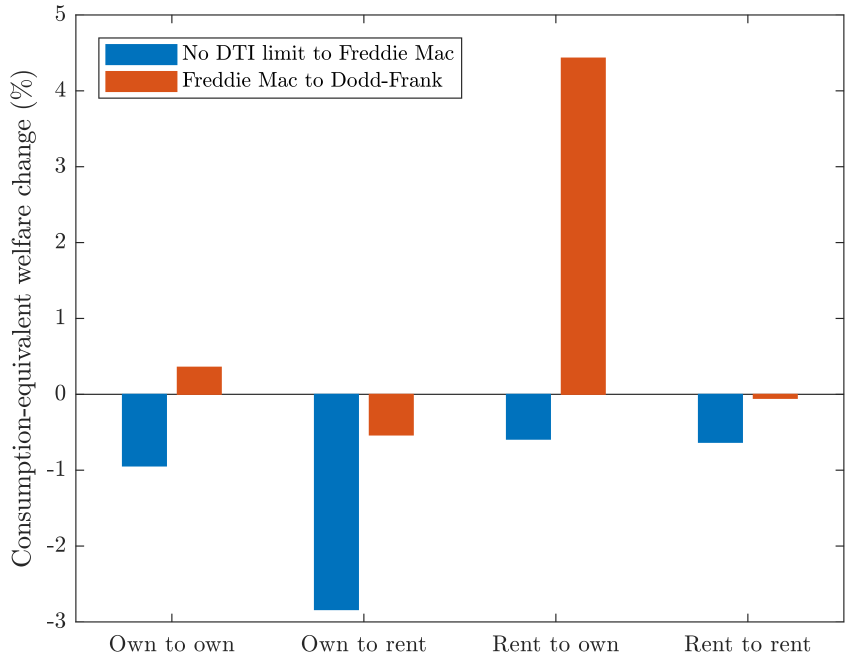

Figure 1.12

Welfare changes of own-to-own, own-to-rent, rent-to-own, and rent-to-rent households in the model. Blue bars depict the mean welfare change for each group when comparing the Freddie Mac policy to the no-DTI-limit baseline, and the red bars depict the mean welfare change for each group when comparing the Dodd-Frank policy to the Freddie Mac policy.

Relative to the Freddie Mac policy, welfare gains under the Dodd-Frank policy accrue to households who, after the new regulations are introduced, choose to own. Households who had chosen to rent under the Freddie Mac policy but now optimally own under Dodd-Frank experience an exceptionally large welfare gain of 4.45 percent. Of these rent-to-own households, a very small fraction—about 6 percent—are renters with a relatively large stock of liquid savings who need high-DTI loans in order to transition to homeownership. The remaining 94 percent consist of existing owners who, if they had not obtained a high-DTI loan, would have otherwise sold their homes. The option to sell is an alternative to default and exists as a way for households to convert their illiquid housing wealth to cash on hand. The fact that the high-DTI loan option under Dodd-Frank makes it optimal for this group of agents to keep their homes and do a cash-out refinance instead of selling suggests that they are liquidity constrained and value the option to obtain a less constrained loan. This finding accords with the pattern of borrower selection documented in Section 1.7.2, which demonstrated that the increase in high-DTI loans under Dodd-Frank is largely accounted for by households in the middle part of the wealth distribution who have low current income. Meanwhile, the group that experiences the largest welfare loss under the Dodd-Frank policy are those who had owned under Freddie Mac but now switch to renting. They correspond to poorer households for whom the tighter 43-percent DTI limit is binding and the option to obtain a high-DTI mortgage contract is either infeasible or suboptimal.

1.8 Conclusion

In this paper, I have evaluated the aggregate and distributional effects of post-crisis household leverage regulations that place limits on a borrower's debt payment-to-income ratio. I focused on two such policies, a uniformly applied 45-percent DTI limit introduced by Freddie Mac in 2009 and the Dodd-Frank Act's 43-percent DTI limit with a costly option to relax the limit will come into effect for the majority of the U.S. mortgage market in 2021. Using a calibrated heterogeneous-agent life-cycle model with a competitive mortgage market, endogenous default, and a discrete choice between mortgage contracts, I find that a limit on the DTI ratio is effective at lowering the aggregate default rate at the cost of reducing homeownership by improving the overall creditworthiness of the borrower population. I show that the strict but flexible approach embodied by the new Dodd-Frank DTI limit is valuable to households from a welfare perspective compared to a policy that imposes a DTI constraint on all borrowers. This option is largely used by households in the middle of the wealth distribution who have low incomes at the time of loan origination. These households value high-DTI loans for consumption smoothing purposes and have a sufficiently low probability of default for the financial intermediary to originate the more costly of the two mortgage contracts to them in equilibrium. Overall, my findings suggest that there is merit to incorporating greater flexibility in household leverage regulations.

Looking ahead, there are a number of ways in which the questions pursued in this paper could be explored further. In my theoretical environment, I have abstracted from movements in house prices. Incorporating them would permit a study of how effective the Dodd-Frank mortgage regulations would be at preventing foreclosures if there were to be a large drop in house prices like the one observed in the mid-2000s. I also abstract from changes in the risk-free rate, even though they are known to be a main driver of households' refinancing decisions and mortgage refinancing is an important mechanism by which monetary policy shocks are transmitted to the real economy. An environment in which the risk-free rate is determined endogenously would be more suitable for business cycle analysis. Finally, the model I have developed in this paper could be used to study the design of optimal limits on a borrower's debt payment-to-income ratio.

CHAPTER 2

THE CONSUMPTION INSURANCE ROLE OF HOMEOWNERSHIP

2.1 Introduction

The coincidence of a large decline in nondurable consumption and the collapse of the housing market during the Great Recession has generated renewed interest in the relationship between household consumption and housing wealth. Home equity extraction—defined as existing owners increasing the amount of debt they hold against their homes—is potentially an important link between nondurable consumption and homeownership. In a setting with incomplete markets and uninsurable income risk, home equity serves as an additional asset that may be used as a form of self-insurance in the face of earnings fluctuations. This paper uses a combination of reduced-form evidence and a structural model to quantify the consumption insurance role of homeownership.

Using household-level data in the Panel Study of Income Dynamics (PSID) from 1999 to 2017, I document a set of novel stylized facts that are consistent with the hypothesis that homeownership is a valuable but costly source of consumption insurance. First, I show that homeowners experience smaller declines in nondurable consumption during periods of low earnings relative to renters. Second, I show that, conditional on initially having low liquid wealth, the nondurable consumption of owners who extract equity decreases less in bad states compared to owners who do not extract equity. By contrast, among homeowners who have high initial liquid wealth, the consumption responses of extractors and non-extractors are not significantly different. This second finding suggests that homeowners use their home equity to smooth consumption only after exhausting more readily accessible stores of wealth.

These reduced-form estimates constitute empirical moments that can be used to inform the parameterization of a class of incomplete-markets life-cycle models with borrowing constraints, idiosyncratic uninsurable income risk, and costly home equity extraction that captures relevant institutional features of the U.S. mortgage market. Given that macroeconomists are increasingly using these models to study household consumption both in partial and general equilibrium settings, it is crucial for these models to produce empirically plausible consumption dynamics. Currently, many of these models are calibrated to match a vector of cross-sectional moments from the observed wealth distribution. In contrast, the stylized facts from my empirical analysis provide *dynamic* moments that can be used to calibrate these models. Ensuring that these models are consistent not only with cross-sectional measures of the wealth distribution but also within-household variation in nondurable consumption that results from the adjustment of illiquid home equity in response to income shocks will yield more quantitatively plausible frameworks in which to study household consumption behavior.

The rest of the paper proceeds as follows. I connect the paper to the related literature in Section 2.2. I discuss the data and present my stylized facts regarding homeownership, equity extraction, and consumption in Section 2.3. I describe a heterogeneous-agent life-cycle model with home equity extraction and outline a proposed calibration strategy in Section 2.4. Section 2.5 concludes.

2.2 Related literature

My paper draws on the burgeoning empirical and theoretical literatures that study the relationship between consumption and housing wealth.[1] On the empirical side, my paper builds on existing work that uses the PSID to investigate home equity extraction behavior. Hurst and Stafford (2004) find that households who suffered from initially low levels of liquid assets were more likely to refinance their mortgages in the early 1990s, then infer from changes in overall net worth that the additional debt from refinancing was directed towards current consumption. Cooper (2010) document that, in the mid-2000s, a one-dollar increase in equity extraction resulted in a 14-cent increase in household expenditures. Zhou (2018) argues that the most important use of extracted home equity is home improvement rather than consumer spending. Although his paper focuses on the design of optimal unemployment insurance policies, Saporta-Eksten (2014) also uses the PSID to study the behavior of nondurable consumption in response to income shocks. Relative to these existing papers, my main empirical contribution is to exploit the richer data on expenditures present from the post-1999 waves of the PSID to distinguish between state-dependent effects of equity extraction on nondurable consumption. To the best of my knowledge, it is the first paper to do so.

My paper also contributes to a recent body macroeconomic research that uses structural life-cycle models with illiquid housing wealth, borrowing constraints, and idiosyncratic income risk.[2] On this front, my contribution is to

[1]See Davis and Van Nieuwerburgh (2014) and Piazzesi and Schneider (2016) for overviews.

[2]See, for instance, Beraja et al. (2019), Berger et al. (2017), Gorea and Midrigan (2018), Guren, Krishnamurty and McQuade (2018), Kaplan and Violante (2014), Kaplan, Mitman and Violante (2017), and Wong (2019). Guren et al. (2018) lay out the "new canonical model" of housing and consumption.

use the stylized facts from my empirical analysis as a new set of moments on consumption dynamics to pin down the value of important parameters in these models, rather than relying entirely on cross-sectional moments computed from the observed wealth distribution. For example, in their paper on the consumption response to fiscal stimulus payments, Kaplan and Violante (2014) use the Survey of Consumer Finances to compute the share of U.S. households who are wealthy hand-to-mouth—defined as having an average balance of liquid wealth less than or equal to half of their earnings per pay period—then use this fraction to pin down the cost of illiquid asset adjustment in their model. Gorea and Midrigan (2018) target the same moment when calibrating their model, which is used to quantify the severity of liquidity constraints in the U.S. housing market.

2.3 Documenting the consumption insurance role of homeownership

2.3.1 Data description and sample construction

The Panel Study of Income Dynamics is a nationally representative survey that has tracked around 5,000 households and their split-off households since 1968. The survey was conducted annually through 1997 and switched to a biennial frequency thereafter. In 1999, the core questionnaire was expanded to include more detailed coverage of household expenditures and wealth holdings. The PSID is well suited for studying the relationship between homeownership, equity extraction, and nondurable consumption for a number of reasons. First, it permits me to directly observe changes in household expenditures and balance sheets while controlling for other household-level covariates. This distinguishes my work from existing papers that use loan-level and credit bureau datasets and rely on large jumps in consumer debt balances (e.g., balances on vehicle loans) to infer changes in consumption.[3] Second, the longitudinal nature of the survey allows me to track family units for potentially long periods of time and exploit within-household variation to estimate the relationship between homeownership, equity extraction, and consumption. This is in contrast to papers that use cross-sectional datasets such as the Survey of Consumer Finances.

I use the 1999-2017 waves of the PSID for my empirical analysis. I define *nondurable expenditures* as the sum of expenditures on food, gasoline, health insurance, health services, utilities, transportation, education, and childcare. *Net worth* is the sum of holdings in checking and savings accounts, stocks in publicly held equity, equity in the primary residence, net value of any businesses owned, net value of other real estate, net value of vehicles, and savings in retirement accounts, less non-mortgage debt. I compute *liquid assets* as the sum of balances in checking and savings accounts and holdings of stocks. All dollar amounts are deflated to 1999 dollars using the Consumer Price Index Research Series Using Current Methods index computed by the Bureau of Labor Statistics.[4] I winsorize all consumption, wealth, and income variables at the 1 percent and 99 percent levels in order to reduce the influence of measurement error and extreme outliers.

I define *equity extraction* as an increase in mortgage debt without an accompanying transaction of the primary residence. To identify instances of equity extraction in the data, I follow Bhutta and Keys (2016) and look for changes in

[3]Examples include Agarwal et al. (2017), Bhutta and Keys (2016), and Di Maggio et al. (2017).
[4]See https://www.bls.gov/cpi/research-series/home.htm.

outstanding mortgage debt over the previous wave that are at least 5 percent the size of the initial balance, amount to at least $1,000 in nominal terms, and are not accompanied by the transaction of the primary residence.[5] This procedure will pick up increased borrowing due to cash-out refinances, second-lien mortgages such as home equity loans or home equity lines of credit, or some combination of the two.[6]

Finally, in order to have a proxy for a negative income shock, I define the household as being in a *bad state* if the head reported being unemployed; out of the labor force; or too disabled to work since the previous wave of the PSID. For being out of the labor force or too disabled to work to qualify as a bad state, I further require that the head of household be less than 65 years old at the time of the survey. In this way, I exclude life cycle-related declines in income that are likely more attributable to retirement or the increasing morbidity that occurs with age than to unexpected adverse shocks.

	Δy_{it}	$\Delta \ln y_{it}$
Good state	$2,376	0.049
Bad state	-$3,883	-0.093

Table 2.1

Changes in annual household income in good versus bad states. The first column contains the mean level difference in annual household income, and the second column contains the mean level difference in log annual household income. Given the biennial frequency of the PSID, these changes are calculated over a two-year interval. All statistics are computed with PSID sample weights, and dollar figures are reported in 1999 dollars. Data: PSID, 1999-2017.

Although I do not claim that these bad states in the data are necessarily exogenous, they align closely with sharp declines in household income, as shown in Table 2.1. Households in bad states experience a 9.3 percent decrease ($3,883

[5]I look for changes in the nominal outstanding mortgage balance because mortgages are specified in nominal terms.

[6]A borrower who cash-out refinances obtains a new mortgage loan whose outstanding balance exceeds the remaining principal of the existing mortgage and keeps the difference in cash.

in 1999 dollars) in their annual household income, compared to a 4.9 percent increase enjoyed by households in good states.

I drop observations on heads of households that are missing data on age, race, state of residence, education, household income, and expenditures on nondurable goods and services. In all, my baseline sample consists of 80,011 observations, corresponding to 16,103 distinct households, in total.

2.3.2 Summary statistics

Household expenditures and balance sheets

Tables B.1 and B.2 in Section B.1 of the appendix contain summary statistics for household expenditures and balance sheets, respectively. They confirm that nondurable goods and services account for the vast majority of expenditures and that home equity is a large component of household net worth. Indeed, for the mean household, home equity is slightly less than one-third of total net worth, while, for the the median household, the home equity share of net worth is nearly one-half. Table B.2 also underscores the fact mortgage debt accounts for the overwhelming majority of liabilities on household balance sheets.

Owners versus renters

Table 2.2 presents a selection of summary statistics on household expenditures and balance sheets for homeowners and renters in the baseline sample. Homeowners are, on average, much wealthier than their renter counterparts. They also have higher household income and larger expenditures.

	Renters		Owners	
	Mean	Median	Mean	Median
Nondurable consumption	10,776	8,807	17,705	15,037
Durable consumption	1,375	48	2,737	576
Total consumption	12,150	9,863	20,441	17,139
Liquid assets	12,927	341	84,221	5,968
Equity in primary residence	0	0	111,610	67,756
Net worth	19,257	1,420	355,686	125,000
Household income	33,256	25,402	70,730	52,155
Observations	33,110	33,110	46,901	46,901

Table 2.2

Household consumption and balance sheets for homeowners and renters in the baseline sample. All statistics are computed with PSID sample weights and reported in 1999 dollars. Source: PSID, 1999-2017.

	Non-extractors		Extractors	
	Mean	Median	Mean	Median
Nondurable consumption	17,750	15,143	20,056	17,245
Durable consumption	2,708	500	2,925	881
Total consumption	20,458	17,206	22,981	19,529
Liquid assets	93,249	7,011	39,872	4,702
Equity in primary residence	121,431	72,945	88,738	51,806
Net worth	387,184	139,261	275,924	103,553
Household income	70,173	51,226	79,706	62,142
Observations	31,560	31,560	7,056	7,056

Table 2.3

Consumption summary statistics in the baseline sample. All statistics are computed with PSID sample weights and reported in 1999 dollars. Source: PSID, 1999-2017.

Equity extractors versus non-extractors

Table 2.3 contains a snapshot of household expenditures and balance sheets for homeowners who extract equity versus those who do not in my baseline sample. On average, equity extractors have lower liquid wealth and home equity than non-extractors. Despite this, extractors have slightly higher household income and expenditures.

Homeownership and equity extraction across time

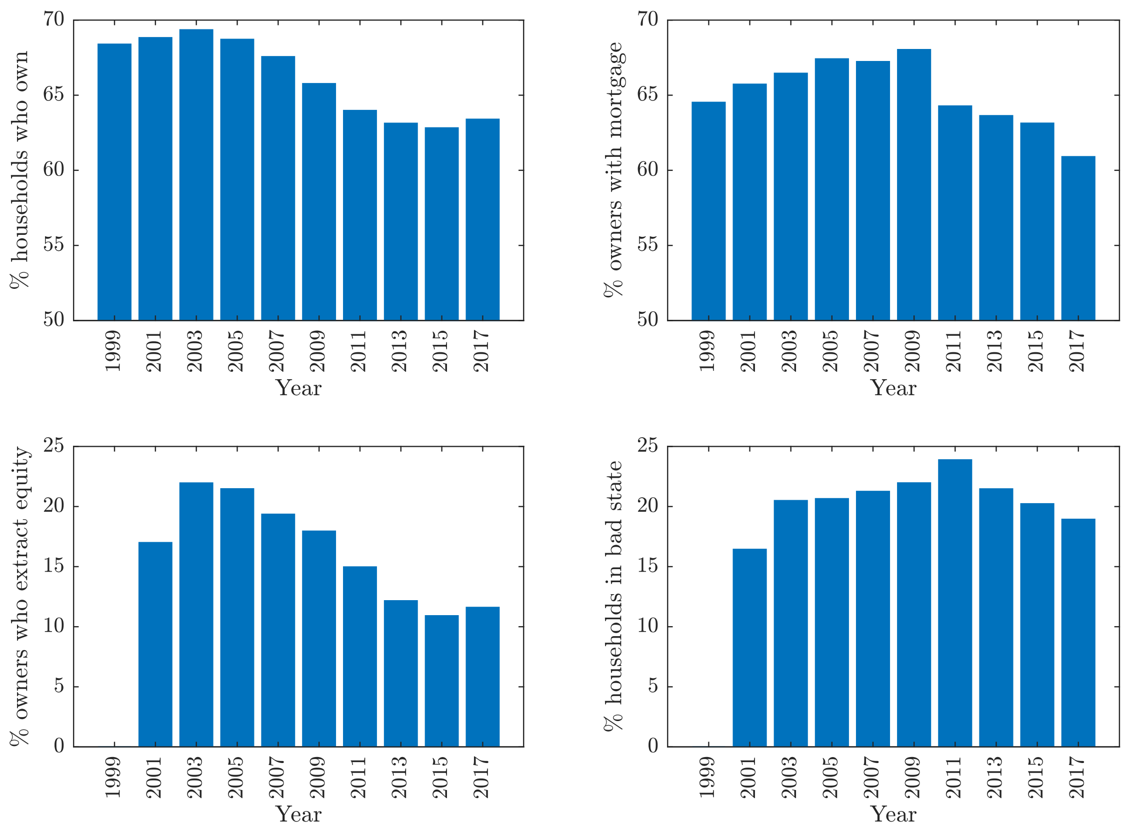

Figure 2.1

Homeownership rate, percent of owners with a mortgage, percent of equity extractors among owners, and share of households in a bad state in the baseline sample. All averages computed with sample weights. Data: PSID, 1999-2017.

Figure 2.1 plots for each wave of the PSID the homeownership rate, share of owners with outstanding mortgage debt, the share of owners who extract equity, and the fraction of households experiencing a bad state. Homeownership reaches its peak during the sample period of 1999-2017 in the mid-2000s before declining during the housing bust and the Great Recession. Consistent with aggregate data, homeownership has remained depressed in the post-crisis years and has only recently ticked upwards.[7] The fraction of homeowners with an outstanding mortgage on their primary residence peaked later in 2009 and has been falling since. My measure of equity extraction picks up the mortgage refinancing boom of the mid-2000s. The rate of equity extraction decreases significantly in the years immediately following the Great Recession. The fraction of households who are in a bad state goes up both in 2003 and 2009, presumably reflecting aggregate macroeconomic conditions.

2.3.3 The effect of homeownership on nondurable consumption

First, I document the effect of homeownership on nondurable consumption in bad states of the world. I find that the nondurable consumption of owners is unchanged in bad states, whereas that of renters falls sharply. To demonstrate this, I estimate the following difference-in-differences regression for my baseline sample:

$$\ln c_{it} = \beta_1 Own_{it} + \beta_2 Bad_{it} + \beta_3 \left(Own_{it} \times Bad_{it} \right) + X_{it}' \gamma + \delta_i + \eta_j + \varepsilon_{it}. \tag{2.1}$$

The dependent variable $\ln c_{it}$ is log nondurable expenditures for household i at time t. Own_{it} and Bad_{it} are indicator variables that take values of 1 if the household is a homeowner and in a bad state, respectively, and 0 otherwise. X_{it} is a vector of time-varying household characteristics, δ_i is a household fixed effect, and η_j is a vector of year dummy variables.[8] The variable of interest is

[7]See https://fred.stlouisfed.org/series/RHORUSQ156N for the aggregate homeownership rate.

[8]The time-varying household characteristics include marital status; state of residence; an indicator variable for change in residence; a quartic polynomial in age; a quadratic polynomial

β_3, which is interpreted as the difference between the percent change in owners' and renters' nondurable expenditures in bad states.

	(1) $\ln c_{it}$	(2) $\ln c_{it}$	(3) $\ln c_{it}$	(4) $\ln c_{it}$
Own	0.495***	0.202***	0.217***	0.125***
	(0.000)	(0.000)	(0.000)	(0.000)
Bad state	-0.280***	-0.254***	-0.258***	-0.091***
	(0.000)	(0.000)	(0.000)	(0.000)
Own $\times$ Bad state	0.148***	0.175***	0.175***	0.074***
	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta \ln c_{it}$ of owners	-0.132	-0.080	-0.083	-0.016
	(0.000)	(0.000)	(0.000)	(0.015)
$\Delta \ln c_{it}$ of renters	-0.280	-0.254	-0.258	-0.091
	(0.000)	(0.000)	(0.000)	(0.000)
Time-varying controls	N	Y	Y	Y
Time fixed effects	N	N	Y	Y
Household fixed effects	N	N	N	Y
Observations	60,914	60,914	60,914	60,914
Groups				13,108

p-value in parentheses.
* p < 0.10, ** p < 0.05, *** p < 0.01.

Table 2.4

The effect of homeownership on nondurable consumption in bad states. Dependent variable = natural log of nondurable expenditures. The figures for "Own," "Bad state", and "Own $\times$ Bad state" in each column correspond to estimates of β_1, β_2, and β_3 in Equation (2.1). $\Delta \ln c_{it}$ = level difference between log nondurable expenditures in a bad state and log nondurable expenditures in a good state for a given subsample of households. Standard errors are clustered at the household level. Data: PSID, 1999-2017.

The first section of Table 2.4 reports the estimated coefficient values, and the second section reports the percent change in nondurable consumption of homeowners and renters in bad states relative to good states implied by the regression estimates.[9] Each column corresponds to estimates of Equation (2.1)

in family size; liquid assets, net worth, household income, and value of primary residence in time $t-2$; and level changes in liquid assets, net worth, household income, and value of the primary residence between time $t-2$ and t.

[9]The "p-values" for each estimated nondurable consumption response are from an F-test in

with different sets of control variables, and standard errors are clustered at the household level throughout. The coefficient β_3 is significant at the 1 percent level in all four specifications, though I will focus my interpretation on the last column, which contains the full array of time-varying controls, year controls, and household fixed effects.

The regression estimates imply that the behavior of nondurable consumption of homeowners versus renters in bad states is markedly different. Relative to good states, the nondurable consumption of owners declines by 1.6 percent in bad states, but I fail to reject the null hypothesis that this decrease is significantly different from zero. By contrast, renters' nondurable consumption falls by 9.1 percent, and this decreases is significantly different from zero. These point estimates thus imply that the nondurable consumption of owners decreases by less than one-fifth compared to renters during periods of low earnings. This finding suggests that homeownership plays a critical role in determining households' capacity for self-insurance.

2.3.4 The effect of equity extraction on nondurable consumption of homeowners

Second, I test the hypothesis that equity extraction accounts for the smoother consumption profile of homeowners in bad states. Housing has obvious value as collateral, permitting owners to access mortgage debt and borrow at lower rates than would otherwise be possible.[10] Since the majority of mortgages is-

which the null hypothesis is that the given nondurable consumption response is equal to zero.

[10]Interest rates on unsecured debt—i.e., credit card debt—are much higher than those on mortgages.

sued in the United States are fully amortized loans, households accumulate equity in their homes over time as they make regular payments.[11] Under some circumstances, owners may want to use savings stored in the home to fund current consumption by either doing a cash-out mortgage refinance or obtaining a junior-lien mortgage.[12] To test this hypothesis, I estimate the following difference-in-differences regression among homeowners in my baseline sample:

$$\ln c_{it} = \beta_1 Extract_{it} + \beta_2 Bad_{it} + \beta_3 \left(Extract_{it} \times Bad_{it}\right) + X_{it}'\gamma + \delta_i + \eta_j + \varepsilon_{it}. \qquad (2.2)$$

This specification is identical to that in Equation (2.1) save for the indicator variable $Extract_{it}$, which takes a value of 1 if a homeowner extracted home equity according to the definition set out in Section 2.3.2 and 0 otherwise. The coefficient of interest is β_3, which is interpreted as the difference between the percent change in extractors' and non-extractors' nondurable expenditures in bad states.

Table 2.5 reports the estimated coefficient values for the specification in Equation (2.2). Again, each column corresponds to regression specifications with different sets of control variables, and standard errors are clustered at the household level throughout. The coefficient on the interaction term is significant at 10 percent for the pooled regression with time-varying and year controls in the third column. In the other specifications, however—including the fixed-effects regression that controls for unobserved household-level heterogeneity—I fail to reject the null hypothesis that the change in extractors' nondurable consumption in bad states differs from that of non-extractors. Thus, estimates from this regression indicate that equity extraction is insignificant in accounting for the consumption dynamics of homeowners in bad states.

[11] A fully amortized loan is one in which the balance on the loan is fully paid off once the borrower makes their final loan payment. In this way, each mortgage payment consists of both interest and principal.

[12] A junior-lien mortgage could be a home equity loan or home equity line of credit.

	(1) $\ln c_{it}$	(2) $\ln c_{it}$	(3) $\ln c_{it}$	(4) $\ln c_{it}$
Extract	0.112***	0.016***	0.034***	0.020***
	(0.000)	(0.006)	(0.000)	(0.000)
Bad state	-0.132***	-0.094***	-0.098***	-0.022***
	(0.000)	(0.000)	(0.000)	(0.002)
Extract × Bad state	0.005	0.022	0.029*	0.008
	(0.799)	(0.166)	(0.073)	(0.536)
$\Delta \ln c_{it}$ of extractors	-0.127	-0.072	-0.070	-0.014
	(0.000)	(0.000)	(0.000)	(0.256)
$\Delta \ln c_{it}$ of non-extractors	-0.132	-0.094	-0.098	-0.022
	(0.000)	(0.000)	(0.000)	(0.002)
Time-varying controls	N	Y	Y	Y
Year controls	N	N	Y	Y
Household fixed effects	N	N	N	Y
Observations	38,616	38,616	38,616	38,616
Groups				8,432

p-values in parentheses.
* p < 0.10, ** p < 0.05, *** p < 0.01.

Table 2.5

The effect of home equity extraction on the nondurable consumption of owners. Dependent variable = natural log of nondurable expenditures. The figures for "Extract," "Bad state," and "Extract × Bad state" in each column correspond to estimates of β_1, β_2, and β_3 in Equation (2.2). $\Delta \ln c_{it}$ = level difference between log nondurable expenditures in a bad state and log nondurable expenditures in a good state for a given subsample of households. Standard errors are clustered at the household level. Data: PSID, 1999-2017.

In light of the fact that owners pay significant costs—both pecuniary and non-pecuniary—to access their home equity, though, it may be the case that equity extraction may only be used for consumption smoothing purposes among owners who have a low initial stock of liquid assets.[13] To assess this possibility, I estimate a triple-difference specification that uses high-liquid asset homeown-

[13]For a discussion of the costs that may lead households to not refinance their mortgages, see Keys, Pope and Pope (2016). Earlier work by Hurst and Stafford (2004) also raises this point.

ers as an additional control group:

$$
\begin{aligned}
\ln c_{it} = {} & \beta_1 Extract_{it} + \beta_2 Bad_{it} + \beta_3 \left(Extract_{it} \times Bad_{it}\right) + \beta_4 Lowliq_{it} \\
& + \beta_5 \left(Lowliq_{it} \times Extract_{it}\right) + \beta_6 \left(Lowliq_{it} \times Bad_{it}\right) \\
& + \beta_7 \left(Lowliq_{it} \times Extract_{it} \times Bad_{it}\right) + X_{it}'\gamma + \delta_i + \eta_j + \varepsilon_{ij}.
\end{aligned} \tag{2.3}
$$

$Lowliq_{it}$ is an indicator variable that takes a value of 1 if household i's stock of liquid assets at time $t-2$ is below the median among owners and 0 otherwise, while the other variables in the regression remain defined as they were in Equation (2.2). The coefficient of interest is now β_7, which measures the percentage point change in nondurable expenditures due to equity extraction in bad states relative to good states among low-liquid asset owners, relative to the corresponding change among high-liquid asset owners.

Column 1 in Table 2.6 reproduces the estimated coefficients from the fixed-effects difference-in-differences specification in Equation (2.2) for purposes of comparison, while Column 2 reports the estimated coefficient values for the triple-difference specification in Equation (2.3) with all time-varying controls, year controls, and household fixed effects included.

In contrast to the difference-in-differences estimate in Column 1, which is not significantly different from zero, the coefficient on the triple interaction term in Equation (2.3) is much larger in magnitude and significant at the 5 percent level. This indicates that equity extraction is relevant in accounting for the relative change in nondurable consumption in bad states versus good only after conditioning on the owner's initial liquid wealth. The regression estimates imply that the average change in a low-liquid asset extractor's nondurable consumption in a bad state is not significantly from zero, while the nondurable consumption of low-liquid homeowners who do *not* extract equity falls by 4.5 percent.

	(1) $\ln c_{it}$	(2) $\ln c_{it}$
Extract	0.020***	0.015**
	(0.000)	(0.032)
Bad state	-0.022***	0.006
	(0.002)	(0.483)
Extract × Bad state	0.008	-0.023
	(0.536)	(0.214)
Low liq		-0.014**
		(0.018)
Low liq × Extract		0.010
		(0.325)
Low liq × Bad state		-0.052***
		(0.000)
Low liq × Extract × Bad state		0.051**
		(0.045)
$\Delta \ln c_{it}$ of extractors	-0.014	
	(0.256)	
$\Delta \ln c_{it}$ of non-extractors	-0.022	
	(0.002)	
$\Delta \ln c_{it}$ of low-liquid asset extractors		-0.017
		(0.315)
$\Delta \ln c_{it}$ of low-liquid asset non-extractors		-0.045
		(0.000)
$\Delta \ln c_{it}$ of high-liquid asset extractors		-0.016
		(0.336)
$\Delta \ln c_{it}$ of high-liquid asset non-extractors		0.006
		(0.483)
Time-varying controls	Y	Y
Year controls	Y	Y
Household fixed effects	Y	Y
Observations	38,616	38,616
Groups	8,432	8,432

p-values in parentheses.
* p < 0.10, ** p < 0.05, *** p < 0.01.

Table 2.6

The effect of equity extraction on nondurable expenditures, conditional on initial liquid wealth. Dependent variable = natural log of nondurable expenditures. The estimated coefficients in Column 1 correspond to β_1, β_2, and β_3 in Equation (2.2). The estimate coefficients in Column 2 correspond to $\{\beta_1, \beta_2, \ldots, \beta_7\}$ in Equation (2.3). $\Delta \ln c_{it}$ = level difference between log nondurable consumption in a bad state and log nondurable consumption in a good state for a given subsample of households. Standard errors are clustered at the household level. Data: PSID, 1999-2017.

These estimates also make clear that the nondurable consumption of high-liquid asset owners is neither significantly affected by equity extraction nor different from one another. Incidentally, the consumption responses of both high- and low-liquid asset extractors are practically identical, suggesting that the act of equity extraction is what permits households with a limited buffer of liquid savings to maintain a smoother consumption path.

Taken together, the results in this section are consistent with the theory that equity extraction is a relatively costly form of consumption insurance and is only used after more liquid sources of wealth have been exhausted. While this is not a novel idea—indeed, these "wealthy hand-to-mouth" households who have low liquid wealth but high net worth feature prominently in the recent structural literature on household consumption behavior—my paper provides the first direct empirical estimates of the dynamics between illiquid asset adjustment, liquidity constraints, and nondurable consumption.[14]

2.4 An incomplete-markets life-cycle model with costly home equity extraction

In this section, I present an incomplete-markets life-cycle model with costly home equity extraction, borrowing constraints, and idiosyncratic income risk. This model is purposefully kept as parsimonious as possible, while still capturing salient institutional features of the U.S. residential mortgage market, and closely resembles the models in Berger et al. (2017), Gorea and Midrigan (2018),

[14]See Kaplan, Violante and Weidner (2014) for a discussion of wealthy hand-to-mouth households and their characteristics.

and Guren et al. (2018), among other papers, insofar as it is a partial equilibrium model of household consumption and savings behavior and abstracts from mechanisms like default risk.

2.4.1 Model environment

Preferences and endowments

The model features overlapping generations of households. A household discounts the future at the rate β and has preferences given by

$$\max \ \mathbb{E}\left\{\sum_{j=1}^{T}\left[\beta^{j-1}u\left(c_j, s_j\right)\right]+\beta^{T}\nu\left(W_T\right)\right\},$$

where j indexes the household's age and $u(\cdot)$ is the flow utility function satisfying standard Inada conditions. I assume that the flow utility function takes the form

$$u(c,s)=\frac{1}{1-\sigma}\left(c^{\alpha}s^{1-\alpha}\right)^{1-\sigma},$$

where c is nondurable consumption and s is housing services. σ is the coefficient of relative risk aversion, and α is the preference weight on nondurable consumption. Households have a bequest motive so that, in the terminal period of life T, they receive utility from end-of-life wealth W_T according to the function

$$\nu\left(W_T\right)=B\frac{W_T^{1-\sigma}}{1-\sigma},$$

where B is a parameter that governs the strength of the bequest motive.

A household supplies labor inelastically from age 1 until they retire at age

T_R. The log income received by a household of age j is

$$\log y_j(z) = \begin{cases} \chi_j + z & \text{if } 1 \leq j < T_R \\ \Phi\left(y_{T_R-1}(z)\right) & \text{if } T_R \leq j \leq T. \end{cases}$$

While working, log income is the sum of a deterministic component indexed by age χ_j and an idiosyncratic component z. The idiosyncratic component of income follows the first-order Markov process

$$z' = \rho z + \varepsilon', \ \varepsilon' \overset{i.i.d.}{\sim} \mathcal{N}\left(0, \sigma_\varepsilon^2\right),$$

where ρ governs the persistence of the income shock and σ_ε^2 is its variance.

Following Guvenen and Smith (2014), income uncertainty is resolved once a household reaches retirement age. They thereafter receive a constant pension income that is a function $\Phi(\cdot)$ of the income received in the last year of their working life $y_{T_R-1}(z)$.

Asset technology

All households can save in a one-period liquid asset a. A household earns the exogenous risk-free rate of return r on their liquid wealth. Additionally, holdings of the liquid asset are subject to a no-borrowing constraint.

Households obtain housing services through the rental or owner-occupied housing markets. A household can rent s units of housing services at an exogenous rental rate R each period or purchase a house of size h at an exogenous price p. While an owner, the household receives a flow of housing services that is equal to the size of the housing stock (i.e., $s = h$) but must pay a maintenance cost equal to δph, where δ is the housing depreciation rate. Adjusting the housing stock incurs a transaction cost κ_h, and agents may only own one house at any given time. Adjusting the stock of rented housing services is costless.

An owner can use their house as collateral for mortgage debt m. A mortgage loan in the model is a fixed-rate, long-term debt contract amortized over the remaining the lifetime of a borrower.[15] I assume that a household may only hold one mortgage loan at a time. When an owner obtains a new mortgage loan, they pay a loan adjustment cost κ_m. The face value of a mortgage is subject to two constraints at origination. The first is a loan-to-value constraint,

$$m \leq \theta ph,$$

which states that the size of the loan cannot exceed a fraction θ of the house value ph. The second is a debt payment-to-income constraint,

$$\pi_{min,j}(m) = \lambda y_j(z),$$

which states that the minimum mortgage payment implied by the face value of the loan cannot exceed a fraction λ of the household's contemporaneous income $y_j(z)$. The minimum mortgage payment is defined by the standard amortization formula,

$$\pi_{min,j}(m) = \frac{(1 + r_m)^{T-(j-1)}}{(1 + r_m)^{T-(j-1)}} r_m m,$$

where r_m is the exogenous mortgage interest rate. In each period that an owner has a positive amount of mortgage debt, they are required to make at least the minimum mortgage payment, i.e.,

$$\pi_j(m) \geq \pi_{min,j}(m).$$

[15] I follow other papers in this literature, such as Kaplan, Mitman and Violante (2017) and Wong (2019), in amortizing mortgages over the remaining life of the household. This convention is consistent with the observed negative correlation between age and loan duration and ensures that I do not have to track loan maturity as an additional state variable in the model.

The law of motion of the balance on an outstanding mortgage loan can therefore be written as

$$m' = (1 + r_m)\, m - \pi_j\,(m)\,.$$

2.4.2 Household's optimization problem

Households maximize expected discounted lifetime utility. The household's optimization problem can be written in recursive form. The current state of an age-j household is summarized by the vector (a, h, m, z), and the value function of an age-j household in a given state is

$$V_j\,(a, h, m, z) = \max\left\{V_j^R\,(a, h, m, z)\,, V_j^M\,(a, h, m, z)\,, V_j^P\,(a, h, m, z)\right\}. \tag{2.4}$$

The value functions inside the maximum operator correspond to the discrete choices available to a household in the current period. V_j^R is the value of renting, V_j^M is the value of owning and obtaining a new mortgage loan, and V_j^P is the value of owning and making a payment on a existing loan. A household who is a renter today can continue as renter or become a homeowner by obtaining a new mortgage. A household who is an owner today can continue with their current home and mortgage by making a mortgage payment (conditional on having positive debt); staying in their home and refinancing their mortgage; adjusting their housing stock by selling their home and purchasing a new one in the same period; or transition to renting by selling their home.

At the beginning of each period, a household receives their income shock (conditional on being of working age), then makes a decision over the available discrete choices by solving their associated optimization problems and selecting the one that yields the highest lifetime utility. Consumption occurs at the end of the period.

If a household chooses to rent, they choose nondurable consumption, rented housing services, and liquid savings to solve

$$
\begin{aligned}
&V_j^R(a,h,m,z) = \max_{c,s,a'} \; u(c,s) + \beta \mathbb{E}_{z'|z} \left\{ V_{j+1}^R(a',0,0,z'), V_{j+1}^M(a',0,0,z') \right\} \\
&\qquad \text{s.t.} \\
&c + Rs + a' \leq y_j(z) + (1+r)a + (1-\delta)ph - (1+r_m)m - \mathbb{1}_{h\neq 0}\kappa_h \\
&a' \geq 0.
\end{aligned}
\tag{2.5}
$$

The right-hand side of the flow budget constraint encompasses the household's sources of cash on hand, which include current income, liquid savings, and—if the household is transitioning from owning to renting—the sale value of the house net of maintenance costs, repayment of remaining mortgage debt plus interest, and the housing transaction cost. The continuation value in the Bellman equation reflects the fact that a household who rents today can choose to continue as a renter or become a homeowner in the next period.

If the household chooses to own and obtain a new mortgage, they choose nondurable consumption, liquid savings, house size, and mortgage debt to solve

$$
\begin{aligned}
&V_j^M(a,h,m,z) = \max_{c,a',h',m'} \; u(c,h') + \beta \mathbb{E}_{z'|z} V_{j+1}(a',h',m',z') \\
&\qquad \text{s.t.} \\
&c + a' + ph' \leq y_j(z) + (1+r)a + (1-\delta)ph - (1+r_m)m + m' - \mathbb{1}_{h'\neq h}\kappa_h - \mathbb{1}_{m'>0}\kappa_m \\
&m' \leq \theta ph' \\
&\pi_{min,j}(m') \leq \lambda y_j(z) \\
&a' \geq 0.
\end{aligned}
\tag{2.6}
$$

The flow budget constraint accommodates the cases of an existing renter becoming a homeowner, an existing owner adjusting their housing stock, or an existing owner leaving their housing stock unchanged but obtaining a new mortgage loan. Note that the optimal choice of mortgage debt must respect both the loan-to-value and debt payment-to-income constraints.

If a household chooses to own and continue with an existing mortgage loan, they choose nondurable consumption, liquid savings, and a mortgage payment to solve

$$\begin{aligned} V_j^P(a,h,m,z) &= \max_{c,a',m'} u(c,h) + \beta \mathbb{E}_{z'|z} V_{j+1}(a',h,m',z') \\ &\quad \text{s.t.} \\ &c + \delta p h + a' \leq y_j(z) + (1+r)a - (1+r_m)m + m' \\ &m' \leq (1+r_m)m - \pi_{min,j}(m) \\ &a' \geq 0. \end{aligned} \tag{2.7}$$

The inequality in the law of motion for mortgage debt accounts for the fact that a borrower can choose to make a mortgage payment in excess of the required minimum.

In the final period of life, a household must repay any outstanding mortgage debt and is prohibited from further borrowing. This imposes the restriction that $m' = 0$ on the problem in Equation (2.6), but the optimization problems solved by an age-T household are otherwise unchanged. The end-of-life wealth that enters the bequest function is given by

$$W_T = (1+r)a' + p'h'.$$

2.4.3 Equilibrium definition

To establish notation, I define the state space of the model W as the Cartesian product $A \times H \times M \times Z$, and let the σ-algebra Σ_W be defined as $B_A \otimes B_H \otimes B_M \otimes P(Z)$, where B_A, B_H, and B_M are the Borel σ-algebras on A, H, and M, respectively, and $P(Z)$ is the power set of Z. Let $\Omega = \mathcal{A} \times \mathcal{H} \times \mathcal{M}$ be the typical subset of Σ_W and $\omega \equiv (a, h, m, z)$ denote the current state of an age-j household.

For a given model parameterization and distribution of age-1 households μ_1, a stationary recursive equilibrium consists of

1. household value functions $\left\{V_j^R(\omega), V_j^M(\omega), V_j^P(\omega)\right\}$,
2. household policy functions $\left\{c_j(\omega), s_j(\omega), a_j'(\omega), h_j'(\omega), m_j'(\omega)\right\}$, and
3. a stationary measure $\Lambda_j^*(\Omega)$

such that

1. household value and policy functions solve the optimization problems in Equations (2.4), (2.5), (2.6), and (2.7); and
2. the invariant probability measure satisfies

$$\Lambda_{j+1}^*(\Omega) = \int_\Omega Q_j(\omega, \Omega)\left[\Lambda_j^*(d\omega) + \mu_1(d\omega)\right] \tag{2.8}$$

   for all $\Omega \in \Sigma_W$ and where the transition function $Q_j(\omega, \Omega)$ is defined as

$$Q_j(\omega, \Omega) = \mathbb{1}_{a_j'(\omega)\in\mathcal{A}, h_j'(\omega)\in\mathcal{H}, m_j'(\omega)\in\mathcal{M}} \sum_{z'} \pi(z'|z). \tag{2.9}$$

I solve numerically for the recursive stationary equilibrium using backwards induction.

A subset of model parameters will be calibrated externally, and the remainder will be calibrated internally to match moments in the data. Among these moments will be the state-dependent responses of nondurable consumption to home equity extraction that I estimated from PSID data in Section 2.3. The model equivalent of home equity extraction occurs when an existing obtains a new mortgage loan (i.e., when $V_j^P(a, h, m, z)$ yields the highest value conditional on $h > 0$).

2.5 Conclusion

In this paper, I have documented a novel set of stylized facts regarding the consumption insurance role of homeownership. First, I showed that the nondurable consumption of homeowners declines by much less, relative to renters, in bad states of the world. Second, I demonstrated that the smoother consumption profile of owners can be accounted for by home equity extraction by homeowners who enter into bad states of the world with low liquid wealth. These findings lend credence to the idea that, as a store of wealth, home equity serves as an important but costly form of consumption insurance.

I then outlined a standard incomplete-markets life-cycle model of household consumption with costly home equity extraction that has increasingly come to the fore in macroeconomic research. My empirical estimates of the dynamic response of consumption to equity extraction provide additional moments that this class of models should be calibrated to match. They should be especially informative about model parameters related to the costliness of equity extraction that are not straightforward to calibrate externally with either institutional details or existing micro-level evidence. These moments can also be used to validate other commonly assumed features of these models, such as the income process.

Going forward, I will solve and calibrate the model in the manner described above. After parameterizing the model and verifying its fit, I can use the model as a laboratory for studying the role of home equity extraction as a transmission mechanism of different macroeconomic shocks to household consumption.

CHAPTER 3

THE TRANSMISSION OF MONETARY POLICY SHOCKS TO THE U.S. MORTGAGE MARKET

3.1 Introduction

Residential housing wealth is central to the modern workings of the United States economy: two-thirds of households in the U.S. own their primary residence, a further two-thirds of homeowners hold a mortgage collateralized by their house, and half of the median household's net worth consists of home equity.[1] In the United States, the most commonly used mortgage instrument is a fully amortized 30-year loan whose interest rate is fixed at the time of origination. These mortgages are also typically free of prepayment penalties, which means that borrowers are permitted to repay their loans before maturity without occurring any additional costs. If the prevailing interest rate in the mortgage market falls below the interest rate associated with an existing loan, a borrower may therefore find it advantageous to refinance their mortgage—i.e., replace their existing loan with a new one—in order to reduce the present discounted value of outstanding mortgage payments. A borrower may also engage in a cash-out refinance in which the balance on the new mortgage exceeds the remaining principal on the existing mortgage and the borrower receives the difference in cash. To the extent that refinancing decisions are driven by fluctuations in the mortgage interest rate and the latter, in turn, responds to changes in the risk-free rate, monetary policy is of first-order importance when thinking about the composition of household balance sheets.

[1]See Davis and Van Nieuwerburgh (2014) for a fuller set of stylized facts regarding housing and the U.S. macroeconomy.

A large literature has shown that changes in household balance sheets and the present discounted value of debt service obligations affect household consumption. The residential mortgage market could therefore provide a plausible channel by which monetary policy shocks affect the real economy. Recent papers in the macroeconomic literature, such as Kaplan, Moll and Violante (2018), have argued that monetary transmission in the representative-agent models traditionally used to analyze monetary policy rely almost entirely on the direct effects of interest rate shocks on intertemporal substitution in spite of a substantial body of empirical evidence indicating that these direct effects are weak.[2] This paper contributes additional evidence in favor of monetary transmission occurring through an alternative indirect channel, the mortgage market.

To do so, I use a proxy structural vector autoregression (VAR) to study the transmission of monetary policy shocks to the U.S. residential mortgage market. Using monthly data from 1975 to 2007, I find strong evidence for the pass-through of monetary policy shocks to mortgage interest rates, originations, and repayment. Specifically, for my baseline sample, I find that, following a positive 25-basis point shock to the target federal funds rate, the 30-year conventional mortgage rate increases by 17 basis points, mortgage originations decrease by 3 percent, and the mortgage repayment rate decreases by 5 basis points. I also find that the sensitivity of these mortgage market variables has increased since the mid-1980s, suggesting that the mortgage market channel of monetary transmission has strengthened in recent decades. To ensure the robustness of my results, I demonstrate that they survive the application of other commonly used identification strategies. The remainder of the paper proceeds as follows. Section 3.2 provides an overview of the relevant literature. I describe the data used

[2] See Campbell and Mankiw (1989) for an early overview of this argument.

in my empirical analyses in Section 3.3, then discuss my identification strategy and regression specifications in Section 3.4. I present impulse responses from an estimated proxy structural VAR in Section 3.5. Section 3.6 concludes and remarks upon avenues for future work.

3.2 Related literature

At its broadest level, my paper belongs to a substantial literature studying the effect of monetary policy on the real economy in the United States.[3] In particular, my paper explores the extent to which aggregate outcomes in the U.S. residential mortgage market may be affected by monetary policy shocks. Although policymakers have long discussed the role of housing finance in the transmission of monetary policy—see, for instance, Mishkin (2007) and Sellon (2002)—my paper is the first to systematically analyze the issue in a structural VAR framework with a focus on both mortgage prices and quantities.[4] Furthermore, my work exploits longer time-series data than is typically used when studying aggregate outcomes in the mortgage market. These data allow me to assess if and how the transmission of monetary policy to the mortgage market has changed over time.

This paper complements a growing body of research that uses microeco-

[3]Ramey (2016) provides a guide to methodologies for identifying shocks in macroeconomic data and discusses their application to monetary policy. Coibion (2012) covers in greater detail the monetary policy VAR literature and sources for differences in the estimated effects of monetary policy shocks.

[4]Gertler and Karadi (2015) find evidence for the pass-through of monetary policy shocks to the mortgage interest rate but do not address mortgage originations or repayment activity. Di Maggio, Kermani and Palmer (2016) study the effect of large-scale asset purchases on mortgage interest rates and origination volumes, while this paper focuses on conventional monetary policy.

nomic data to study interest rate shocks and their effects on mortgage borrowing and household consumption. Using credit-bureau data, Bhutta and Keys (2016) estimate that a 100-basis point decline in mortgage interest rates during the housing boom accounted for a 27-percent increase in equity extraction and provide suggestive evidence in favor of owners using those extracted funds for current consumption or illiquid investment. Wong (2019) uses the Consumer Expenditure Survey to document that younger households are more likely to refinance their mortgages in response to monetary policy shocks than older households, and their higher propensity for loan adjustment accounts for the greater sensitivity of younger households' consumption to monetary policy shocks. Berger et al. (2018) and Eichenbaum, Rebelo and Wong (2018) use loan-level data to study how the effect of monetary policy on mortgage prepayment varies with the size of potential savings from refinancing. My results supplement these findings by demonstrating that these micro-level responses add up to significant movements in mortgage market variables at the aggregate level as well.

My paper is also informed by existing research on the effects of the structure of mortgage finance on monetary transmission. Rubio (2011) and Garriga, Kydland and Sustek (2017) both show in their respective structural models that the real effects of monetary policy shocks are greater under adjustable-rate mortgage than fixed-rate mortgages.[5] Greenwald (2018) demonstrates in a spender-saver New Keynesian model how endogenous mortgage prepayment can amplify the transmission of monetary policy shocks to output. My findings lend empirical validation to macroeconomic models that predict strong pass-through

[5]Rubio (2011) develops a borrower-saver New Keynesian model with fixed proportions of fixed- and variable-rate borrowers, while Garriga, Kydland and Sustek (2017) use a model without nominal rigidities.

of monetary policy shocks to the mortgage market.

3.3 Data description

3.3.1 Data sources

My empirical analysis uses time series data on the U.S. housing and mortgage markets, as well as standard macroeconomic aggregates. The former consist of mortgage originations, mortgage debt outstanding, the 30-year conventional mortgage rate, and house prices. The latter include industrial production, consumer prices, commodity prices, and the target federal funds rate. I use monthly data from January 1975 to December 2007. I truncate the sample period at December 2007 in order to avoid complications introduced by the federal funds rate hitting the zero lower bound.

Historical data on mortgage originations and outstanding debt are from Fieldhouse, Mertens and Ravn (2018). The series on mortgage originations combines those for 1- to 4-family units and are gathered from the U.S. Department of Housing and Urban Development's Survey of Mortgage Lending Activity and the Mortgage Bankers Association.[6] The series for outstanding mortgage debt covers 1- to 4-family and multifamily units throughout and is interpolated from quarterly data obtained from the U.S. Flow of Funds Accounts.[7]

I use these two series to compute the implied mortgage repayment rate,

[6]Prior to 1997, this series also includes mortgages on multifamily units such as condominiums, apartment buildings, etc.

[7]The online appendix of Fieldhouse, Mertens and Ravn (2018) contains additional details regarding the interpolation procedure.

which is defined as the amount of mortgage debt repaid in month t as a share of total mortgage debt outstanding in month $t-1$:

$$repayrate_t = \frac{repay_t}{debt_{t-1}}. \tag{3.1}$$

I calculate the amount of mortgage debt repaid each period using the following accounting identity:

$$debt_{t-1} + originations_t - repay_t = debt_t. \tag{3.2}$$

It should be noted that the mortgage *repayment* rate does not correspond exactly to the mortgage *refinancing* rate because repayment consists of both the prepayment of existing loans that occurs during refinancing and the gradual reduction in the balances of existing mortgage loans due to amortization. As long as the latter component does not vary systematically with the business cycle, however, short-run fluctuations in the repayment rate should be largely driven by endogenous changes in refinancing behavior.

I use the Freddie Mac House Price Index as my measure of house prices. Data on the 30-year conventional mortgage rate, industrial production, the consumer price index, and the effective federal funds rate are downloaded from Federal Reserve Economic Data (FRED).[8] I use the Commodity Research Bureau Index as my measure of commodity prices.

Finally, I compute the target federal funds rate by summing the narratively identified monetary policy shocks from Romer and Romer (2004), which cover the period from 1969 to 1996, and later extended through the end of 2007 by Wieland and Yang (2019). Romer and Romer (2004) identify shocks to monetary policy by constructing a series of intended federal funds rate changes from the

[8]The exact series used are MORTG, INDPRO, CPIUCSL, and FEDFUNDS, respectively.

narrative record and backing out the residuals from a regression of the target federal funds rate on the Federal Reserve's internal "Greenbook" forecasts of inflation and real economic activity. The residuals therefore yield changes to the target federal funds rate that are orthogonal to the Federal Reserve's information set.

3.3.2 Time-series behavior of mortgage interest rates, originations, and repayment

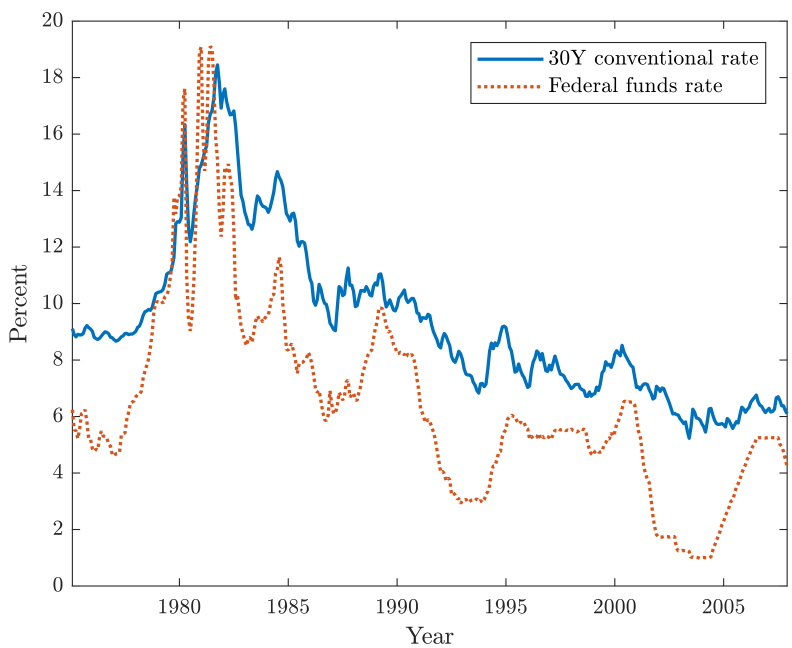

Figure 3.1

30-year conventional mortgage rate (solid blue line) vs. effective federal funds rate (dotted red line), 1975-2007. Source: FRED.

This subsection provides some historical context for the behavior of U.S. monetary policy, mortgage prices, and mortgage quantities since 1975. Although the following figures only document correlations, the patterns that emerge from them provide the motivation for the structural VAR regressions that follow. As a first pass at the data, Figure 3.1 plots the 30-year conventional mortgage rate against the effective federal funds rate for the sample period of 1975 to 2009. Both interest rates reached a peak during the Volcker era of the 1980s but have declined steadily since. The visual evidence indicates strong co-movement between these two interest rates, consistent with the hypothesis that monetary policy shocks affect prices in the mortgage market.

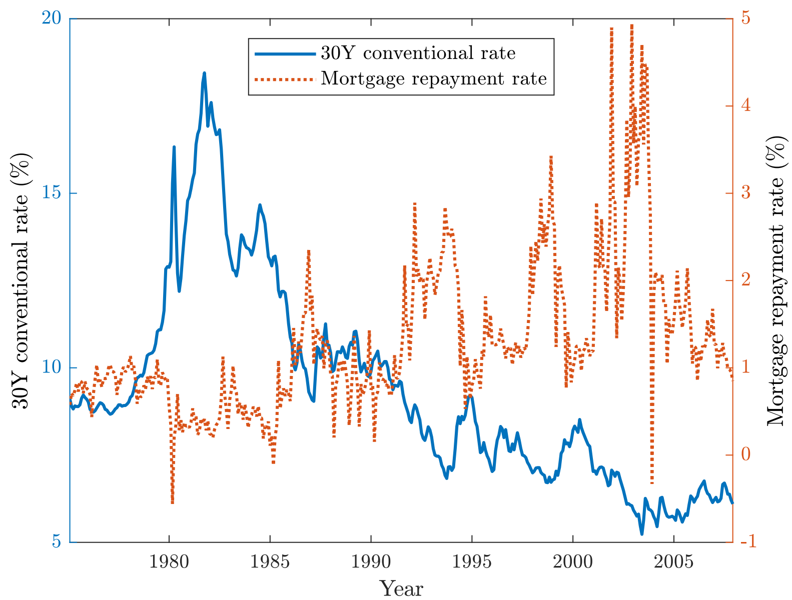

Figure 3.2

30-year conventional mortgage rate (solid blue line) vs. mortgage repayment rate (dotted red line), 1975-2007. Source: FRED and Fieldhouse, Mertens and Ravn (2018).

Next, Figure 3.2 plots the 30-year conventional mortgage rate against the mortgage repayment rate computed using Equations (3.1) and (3.2). A few striking features emerge. First, the mortgage repayment rate displays considerable volatility over time. Second, although the mortgage interest rate exhibits short-run fluctuations, it appears to have experienced a secular increase between the early 1990s and mid-2000s. Third, there seems to be a negative correlation between changes in the 30-year mortgage rate and changes in the mortgage repayment.

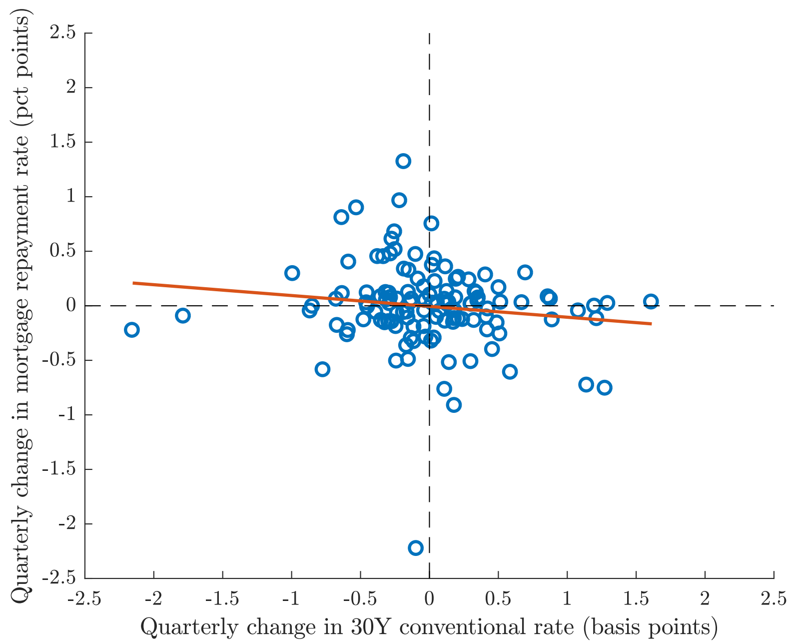

Figure 3.3

Level change in mortgage repayment rate vs. level change in 30-year conventional mortgage rate, 1975-2007. Blue circles correspond to data aggregated to quarterly frequency, and solid red line is the line of best fit. Source: FRED and Fieldhouse, Mertens and Ravn (2018).

To depict this correlation more clearly, Figure 3.3 plots quarterly level changes in the repayment rate against quarterly level changes in the 30-year conventional mortgage rate, along with the line of best fit. This figure emphasizes that decreases in the 30-year conventional rate are associated with increases in the rate of mortgage repayment.

3.3.3 The link between mortgage repayment and refinances

To provide some suggestive evidence that the observed negative correlation between changes in the mortgage interest rate and the mortgage repayment rate is associated with fluctuations in refinances, Figure 3.4 plots the share of refinance

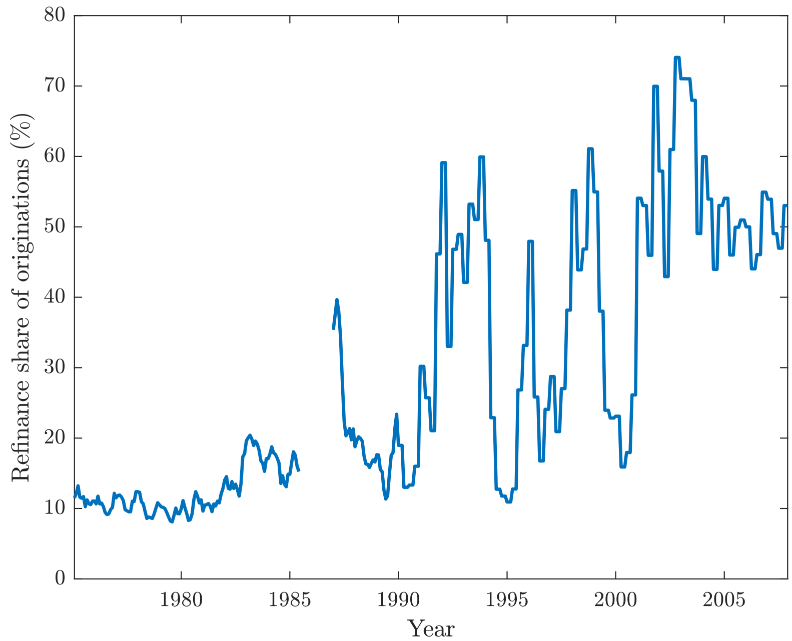

Figure 3.4

Refinance share of mortgage originations, 1975-2007. Source: Fieldhouse, Mertens and Ravn (2018).

loans among new mortgage originations.[9] Aggregate mortgage refinancing behavior increased noticeably in the early 1990s and accounted for more than half of all mortgage originations during the housing boom in the mid-2000s.

Figure 3.5 presents the mortgage repayment rate and refinance share of originations in the same graph with both series normalized with respect to their respective initial observations in January 1975. This graph makes clear that mortgage repayment rates and the intensity of refinancing behavior are strongly correlated with each other. Finally, Figure 3.6 plots level changes in the refinance share of originations against level changes in the 30-year conventional mortgage rate, and, again, there is a clear negative correlation between the two.

[9]The remaining mortgage originations can be attributed to purchase loans, i.e., newly originated mortgage loans associated with the purchase of new residential housing. These historical data are also from Fieldhouse, Mertens and Ravn (2018).

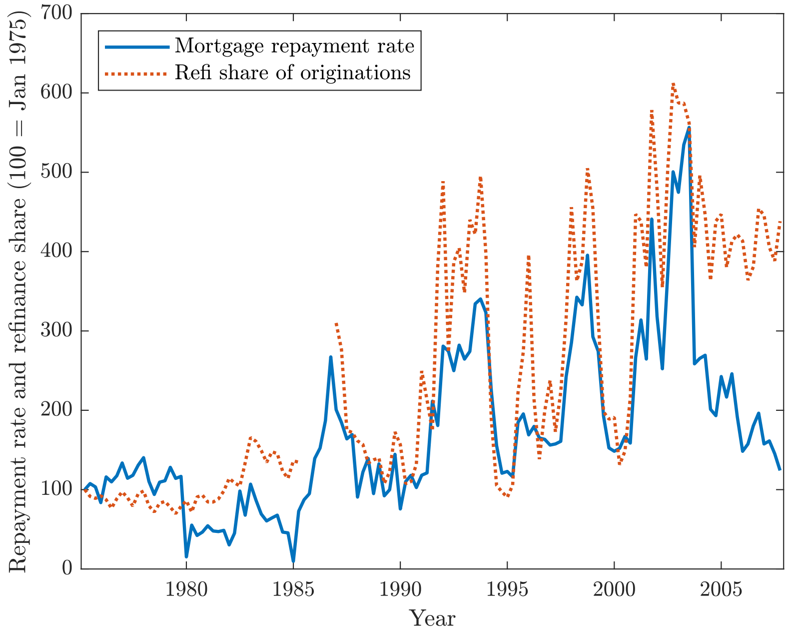

Figure 3.5

Mortgage repayment rate (solid blue line) vs. refinance share of originations (dotted red line), 1975-2007. Both series are normalized so the value of each in January 1975 is equal to 100. Source: Fieldhouse, Mertens and Ravn (2018).

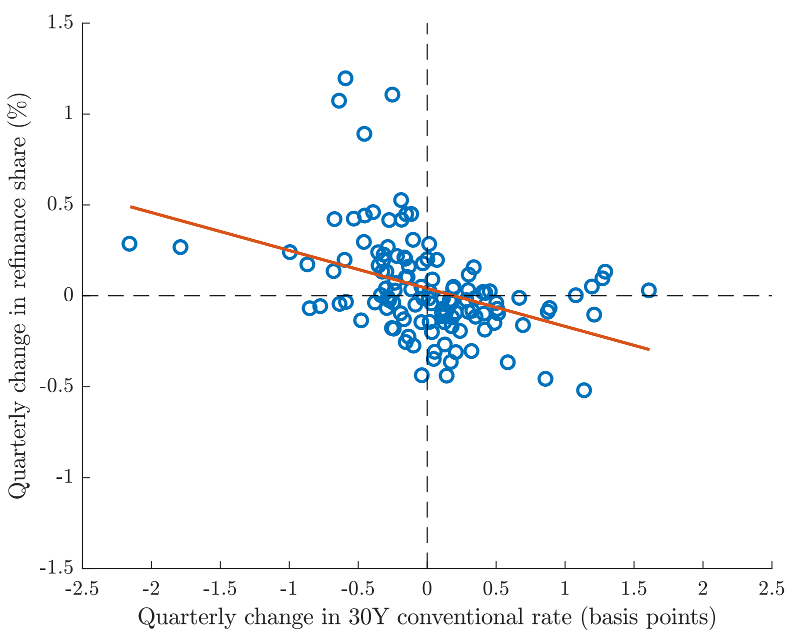

Figure 3.6

Level change in refinance share of mortgage originations vs. level change in 30-year conventional mortgage rate, 1975-2007. Blue circles correspond to data aggregated to quarterly frequency, and the solid red line is the line of best fit. Source: FRED and Fieldhouse, Mertens and Ravn (2018).

3.4 Identification of monetary policy shocks

3.4.1 Primary identification strategy: proxy structural VAR

My primary identification strategy relies on the estimation of a proxy structural VAR, employing the method developed by Mertens and Ravn (2013). This identification strategy uses the narratively identified monetary policy shocks in Romer and Romer (2004) as an instrument for the effective federal funds rate. The proxy structural VAR sidesteps the need to place *a priori* timing restrictions with regards to the response of macroeconomic variables to structural shocks and, additionally, is robust to the measurement error that typically accompanies narratively identified shocks.

Letting m_t be the narratively identified "event" at time t, ε_{1t} be the structural shocks of interest at time t, and ε_{2t} be other contemporaneous structural shocks at time t, the identification assumptions are

$$\mathbb{E}\left[m_t \varepsilon_{1t}'\right] \neq 0 \tag{3.3a}$$

$$\mathbb{E}\left[m_t \varepsilon_{2t}'\right] = 0. \tag{3.3b}$$

Equation (3.3a) states that the narrative instrument must be correlated with the structural shocks of interest, and Equation (3.3b) states that the instrument cannot be correlated with any other contemporaneous structural shocks.

To obtain the VAR in structural form, I begin by estimating a reduced-form VAR with a lag order of 12 using the following specification:

$$z_t = \sum_{p=1}^{12} A_p z_{t-p} + u_t. \tag{3.4}$$

z_t is an array of observable variables that consist of the mortgage repayment rate, mortgage originations, the 30-year conventional mortgage rate, house price index, industrial production, consumer price index, commodity price index, and the target federal funds rate in month t; z_{t-p} is the p-th lag of z_t; $\{A_1, A_2, \ldots, A_{12}\}$ are the VAR coefficients; and u_t is an array of reduced-form residuals.[10] After estimating the reduced-form VAR and assuming that Equation (3.3a) holds, I impose the covariance restrictions implied by Equation (3.3b) to obtain the impact matrix of the structural shocks.

3.4.2 Alternative identification strategies

In addition to estimating the proxy structural VAR, I employ two alternative identification strategies to check the robustness of my results. First, I use the short-run timing restrictions first proposed by Sims (1980) and assume that only the target federal funds rate responds contemporaneously to shocks to the target federal funds rate. This is tantamount to assuming that the structural VAR is recursive, with the target federal funds rate ordered last in the vector of observable variables z_t, and that impact matrix is lower triangular. The recursiveness assumption allows me to recover the impact matrix on the structural shocks by performing a Choleski decomposition on the variance-covariance matrix of the reduced-form residuals from Equation (3.4).

Second, I use a local projection method introduced by Jordà (2005) to estimate impulse responses to the narratively identified monetary policy shocks.

[10]The inclusion of the commodity price index is motivated by the "price puzzle" in the monetary VAR literature, in which a contractionary monetary policy shock is followed by an increase in the price level. See Christiano, Eichenbaum and Evans (1999).

This is accomplished by estimating for each forecast horizon of interest h

$$z_{t+h} = \theta_h \varepsilon_{1t} + \sum_{p=0}^{2} A_p z_{t-p} + u_t. \tag{3.5}$$

The estimated values in the vector θ_h provide the impulse response of z_t at horizon h to the structural shock ε_{1t}, where I use the Romer and Romer (2004) shocks as a direct measure for the structural shock.

The advantage of the local projection method is that it estimates impulse responses at each horizon of interest separately, whereas impulse responses computed with structural VARs will compound any initial misspecification errors with each successive horizon. However, as Ramey (2016) observes, estimates from the local projection method will typically be less precise due to the fewer restrictions it imposes.

3.5 Effects of monetary policy shocks on the residential mortgage market

In this section, I present impulse responses estimated from the proxy structural VAR described in Section 3.4.1. The main findings are that, in response to a contractionary monetary policy shock, the 30-year mortgage rate increases, mortgage originations decrease, and the mortgage repayment rate decreases. I also show that these mortgage market variables have become more sensitive to monetary policy shocks since the mid-1980s. These results are generally robust to use other alternative identification strategies discussed in Section 3.4.2.

3.5.1 Impulse responses during the full sample period

The panels in Figure 3.7 plot the impulse responses of the endogenous variables in the proxy structural VAR to a positive (i.e., contractionary) 25-basis point shock to the target federal funds rate, aggregated to quarterly frequency. The 30-year conventional mortgage rate jumps on impact by about 17 basis points and remains persistently above the steady state for roughly five quarters. Mortgage originations also decrease on impact and are about 3 percent below their steady state value for a few quarters after the monetary policy shock. The decrease in mortgage originations is reflected in the mortgage repayment rate, which declines by 5 basis points. The house price index is much slower to react, and I cannot at any horizon reject the null hypothesis the change in house prices resulting from a monetary policy shock is zero.

3.5.2 Impulse responses during the Great Moderation sample period

Next, I estimate the proxy structural VAR only for data from 1984 onwards. This exercise is motivated by the observation that, beginning in the early 1980s, many structural changes occurred in the market for housing finance that likely made refinancing less costly for borrowers. These include the broad deregulation of mortgage lending, the increased securitization of mortgage loans, and falling loan origination costs due to cheaper screening technology. More moderate inflation rates may have also made lenders more willing to originate long-term nominal debt contracts.[11]

[11] Sellon (2002) discusses these changes.

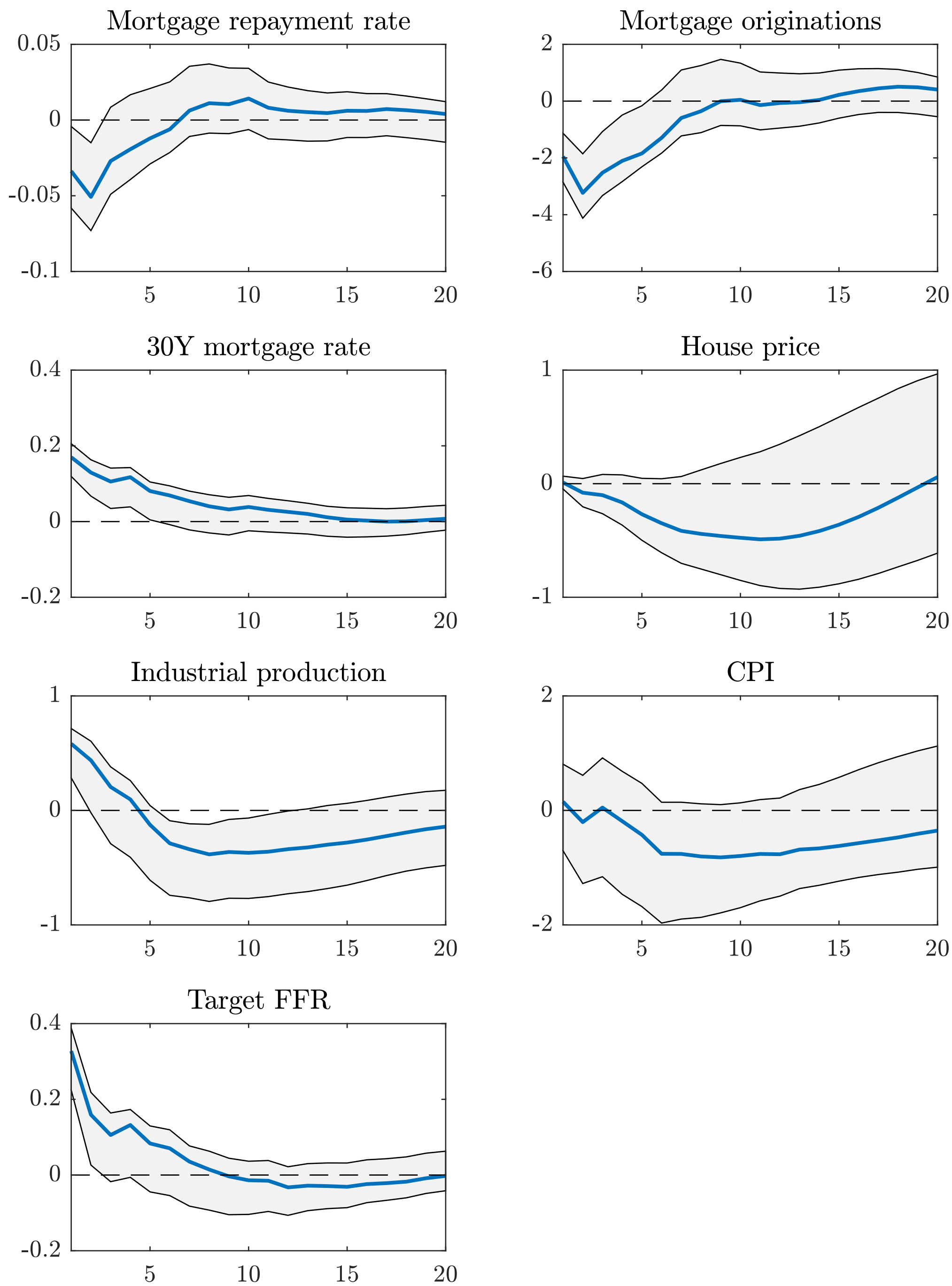

Figure 3.7

Impulse responses to a 25-basis point shock to target federal funds rate from a proxy structural VAR estimated on the full sample period (1975-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90 percent confidence interval, computed using the wild bootstrap with 10,000 resamples. Impulse responses are aggregated to quarterly frequency.

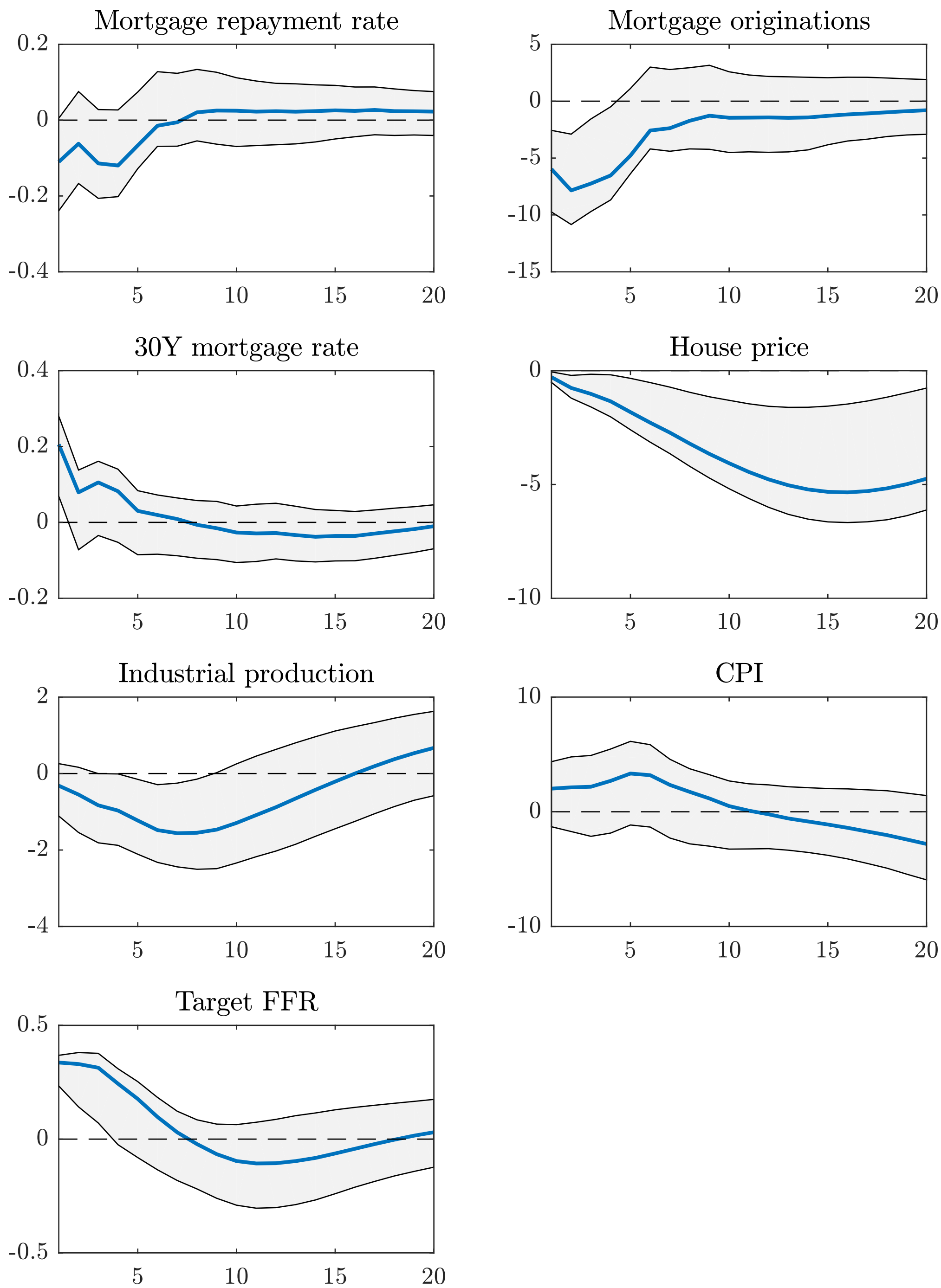

Figure 3.8

Impulse responses to a 25-basis point shock to target federal funds rate from a proxy structural VAR estimated on the Great Moderation sample period (1984-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90 percent confidence interval, computed using the wild bootstrap with 10,000 resamples. Impulse responses are aggregated to a quarterly frequency.

The panels in Figure 3.8 plot the impulse responses to a 25-basis point shock to the target federal funds rate for the Great Moderation period, aggregated to quarterly frequency. Due to the fewer number of observations and the large number of parameters that need to be estimated, the error bands are much wider; nevertheless, the point estimates are still illustrative. Since the mid-1980s, mortgage originations and repayment have become more sensitive to monetary policy shocks. Note that the degree of pass-through of monetary policy shocks to the mortgage interest rate is still roughly the same. Despite this, however, mortgage originations during the Great Moderation sample period fall by 8 percent. This response is almost three times larger than the effect estimated using the full sample period. Similarly, the mortgage repayment rate now declines by 13 basis points after a contractionary monetary policy shock. During this period, monetary policy shocks now have a significant effect on house prices: the house price index, after a lag, undergoes a persistent decline of about 5 percent following a contractionary monetary policy shock.

3.5.3 Robustness of results to identification strategy

The results in Section 3.5.1 and 3.5.2—that monetary policy shocks pass through to mortgage market variables and the transmission of these shocks has strengthened since the mid-1980s—are broadly robust to the use of alternative identification strategies. Impulse responses for the full sample and the Great Moderation period, estimated both with short-run timing restrictions and local projections, can be found in Sections C.1 and C.2 of the appendix, respectively.

The impulses responses computed from the recursive structural VAR largely replicate those from the proxy structural VAR but imply a much larger fall in mortgage originations in response to a contractionary monetary policy shock. The impulse responses estimated via local projection are noisy, especially for the the Great Moderation sample period, but they are qualitatively similar to those from the proxy structural VAR.

3.6 Conclusion

This paper studied the transmission of monetary policy shocks to the U.S. mortgage market since the mid-1970s. Using a proxy structural vector autoregression with narratively identified shocks to the federal funds rate as as an instrument for the true structural shock, I established that contractionary monetary policy shocks increase the mortgage interest rate, decrease mortgage originations, and decrease the mortgage repayment rate. I also found that the pass-through of monetary policy shocks to the mortgage market strengthened after the mid-1980s, suggesting that its role in the monetary transmission mechanism has become more salient in recent decades.

There are many ways in which the questions asked in this paper could be further extended. For instance, it is reasonable to hypothesize that there could be an asymmetry in the response of mortgage refinancing to interest rate shocks: the incentives to refinance when mortgage interest rates fall are clear, while it is less clear that borrowers would refinance their loans if interest rates rise. Additional work can also be done to explicitly link changes in mortgage originations and repayment to household consumption, residential investment, or other macroeconomic variables of interest.

APPENDIX A

SUPPLEMENTARY MATERIAL FOR CHAPTER 1

A.1 Summary statistics from the Freddie Mac Single Family Loan-Level Dataset

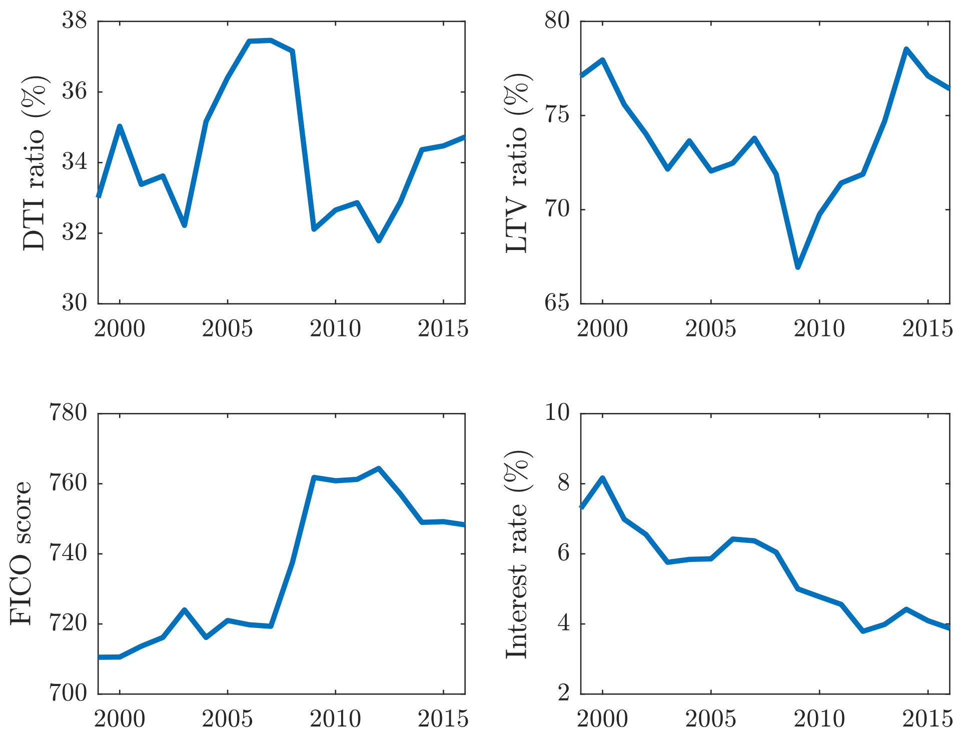

Figure A.1

Average DTI ratio, LTV ratio, FICO score, and interest rate at origination, 1999-2016. Source: Freddie Mac Single Family Loan-Level Dataset.

To provide some context for the empirical analysis, Figure A.1 plots annual mean DTI ratio, LTV ratio, FICO score, and interest rate at origination for loans that were purchased or guaranteed by Freddie Mac between 1999 and 2016. These time series trace out a familiar tale: the DTI ratio rose and then fell with the housing boom and bust, the LTV ratio declined during the housing crisis before recovering, the average creditworthiness of a borrower has been much higher in the post-crisis era, and mortgage interest rates have followed a downward trend since the early 2000s.

A.2 Distribution of loan-to-value ratios in the Freddie Mac Single Family Loan-Level Dataset

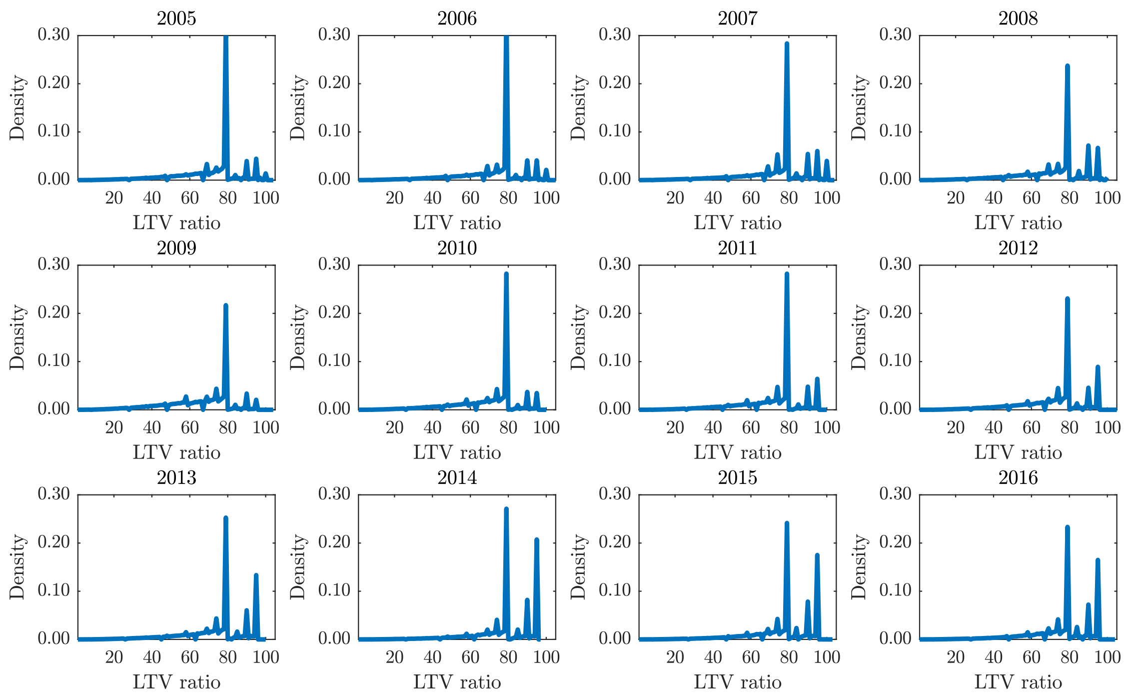

Figure A.2

Distribution of loan-to-value (LTV) ratios, 2005-2016. Source: Freddie-Mac Single Family Loan-Level Dataset.

Figure A.2 plots the distribution of LTV ratios at origination from 2005-2016 in the Freddie Mac data. Large spikes occur at GSE institutional limits. The overall shape of the distribution stays fairly constant over time in spite of significant macroeconomic upheaval during this period.

A.3 Effect of the Freddie Mac DTI limit on mortgage originations: a flexible difference-in-differences approach

To ensure that the results presented in Section 1.4.3 are not driven simply by the fact that the DTI ratio on a particular loan is large but rather a change precisely at the 45-percent limit, I again follow DeFusco, Johnson and Mondragon (2017) in estimating a more flexible difference-in-differences specification that allows the effect of the policy to vary with the DTI ratio:

$$y_{it} = \alpha + \sum_{k=40}^{50} \left[\beta_1^k \mathbb{1}_{\{\mathrm{DTI}_i = k\}} + \beta_2^k \left(\mathbb{1}_{\{\mathrm{DTI}_i = k\}} \times \mathrm{Policy}_t\right)\right] + \gamma_t + X_i'\delta + \varepsilon_{it}. \tag{A.1}$$

$\mathbb{1}_{\{\mathrm{DTI}_i = k\}}$ is an indicator variable that takes a value of 1 if the DTI ratio of loan i at origination is equal to k; all other regressors are as previously defined. The interpretation of β_2^k is now the differential change in the dependent variable for loans a DTI ratio of k after the 45-percent DTI limit is implemented. Like DeFusco, Johnson and Mondragon (2017), I make $k = 45$ the omitted DTI category so that the coefficients β_2^k on all other DTI categories estimate the effect of the DTI limit relative to loans exactly at the limit.

Figures A.3, A.4, and A.5 plot point estimates for β_2^k with their respective 95-percent confidence intervals from the flexible difference-in-differences specification with the interest rate, LTV ratio, and FICO score in turn. These figures indicate that the effects documented in Section 1.4.3 are indeed the result of a change exactly at the 45-percent DTI ratio.

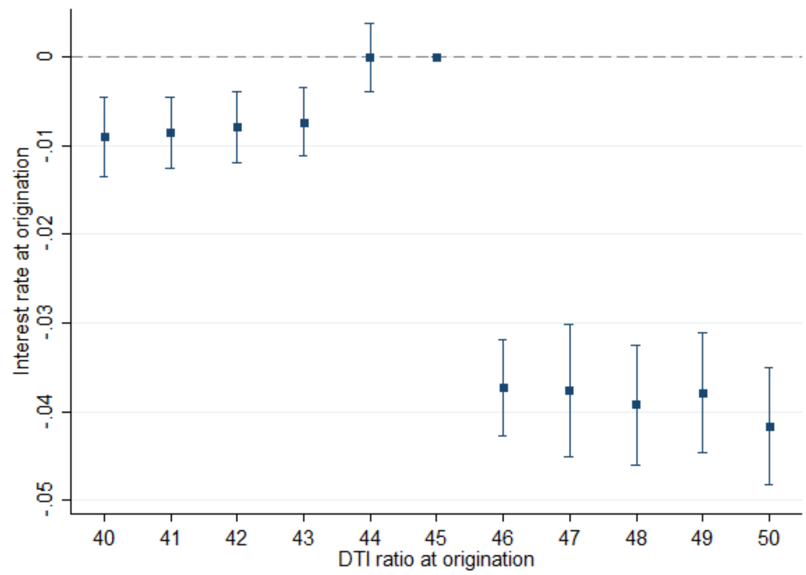

Figure A.3

Change in interest rate for loans with DTI = k after the introduction of the 45-percent DTI limit. Blue squares correspond to estimates of β_2^k for $k \in \{40, 41, \ldots, 50\}$ in Equation (A.1), and bars represent the 95-percent confidence interval around those point estimates. Source: Freddie Mac Single Family Loan-Level Dataset.

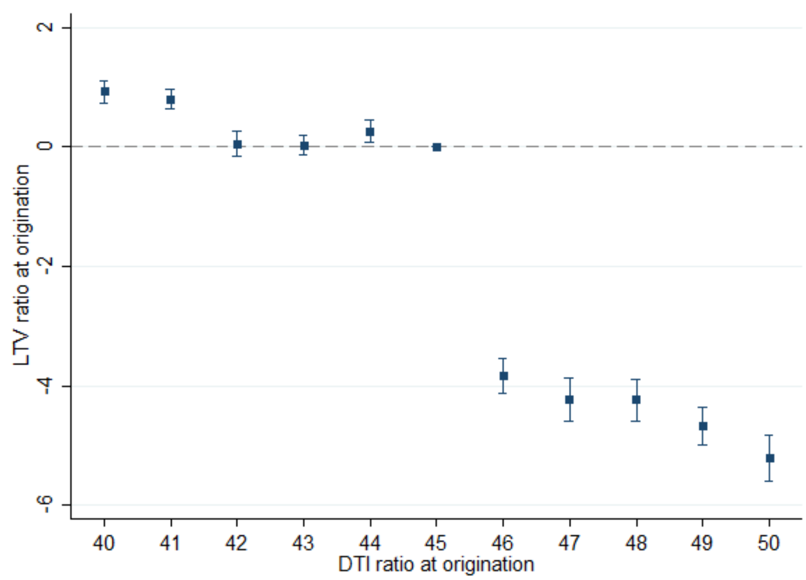

Figure A.4

Change in the LTV ratio for loans with DTI = k after the introduction of the 45-percent DTI limit. Blue squares correspond to estimates of β_2^k for $k \in \{40, 41, \ldots, 50\}$ in Equation (A.1), and bars represent the 95-percent confidence interval around those point estimates. Source: Freddie Mac Single Family Loan-Level Dataset.

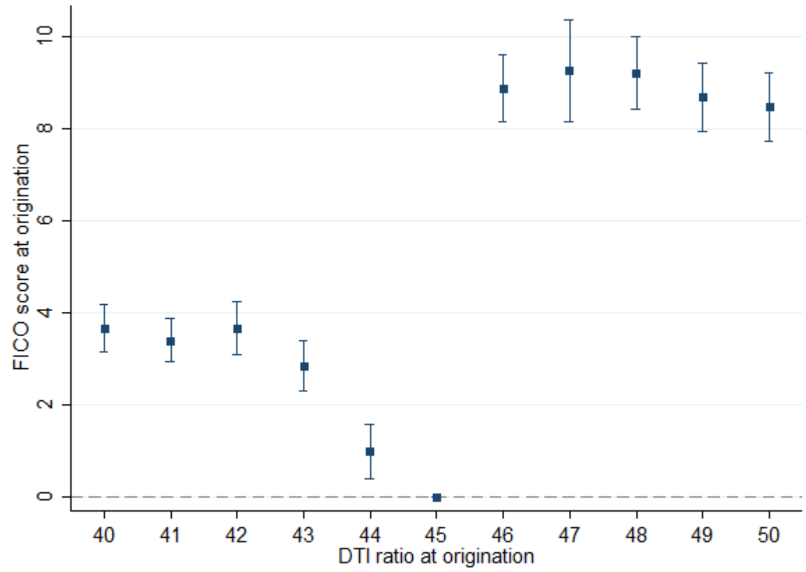

Figure A.5

Change in the FICO score for loans with DTI = k after the introduction of the 45-percent DTI limit. Blue squares correspond to estimates of β_2^k for $k \in \{40, 41, \ldots, 50\}$ in Equation (A.1), and bars represent the 95-percent confidence interval around those point estimates. Source: Freddie Mac Single Family Loan-Level Dataset.

A.4 Parameterization

Income process

To parameterize the deterministic component of income, I regress a quartic polynomial in age on log annual household income using a sample of households from the 1999-2015 waves of the Panel Study of Income Dynamics whose heads are between ages 22 and 64. I use the estimated coefficients to calculate the fitted values for log household income. These fitted values are the sequence $\{\chi_j\}_{j=1}^{T}$, and I normalize them so that $\chi_1 = 0$.

To parameterize pension income received in retirement, I follow the procedure from Guvenen and Smith (2014). I simulate for a given (ρ, σ_ϵ) pair the earnings of a panel of 10,000 households during their working years and regress average labor earnings on earnings in the last period of working life. I use the regression coefficients to predict average lifetime earnings for each possible realization of income in the last period of working life in the model, $\log y_{T_R-1} = \chi_{T_R-1} + z$. Letting $\log \hat{y}$ be the predicted average lifetime earnings, $\log \bar{y}$ be the economy-wide average annual labor earnings, and $\log \tilde{y} = \log \hat{y} / \log \bar{y}$, the function $\Phi\left(y_{T_R-1}\right)$ is given by

$$\Phi\left(y_{T_R-1}\right) = \begin{cases} 0.9 \log \hat{y} & \text{if } \log \tilde{y} \leq 0.3 \\ \log \bar{y}\left[0.27 + 0.32\left(\log \tilde{y} - 0.3\right)\right] & \text{if } 0.3 < \log \tilde{y} \leq 2 \\ \log \bar{y}\left[0.81 + 0.15\left(\log \tilde{y} - 2\right)\right] & \text{if } 2 < \log \tilde{y} \leq 4.1 \\ 1.13 \log \bar{y} & \text{if } \log \tilde{y} > 4.1. \end{cases}$$

Cross-sectional moments

I use the 2016 Survey of Consumer Finances (SCF) to compute cross-sectional moments targeted in the calibration procedure. Net worth is defined as the sum of liquid assets and equity in the primary residence. Following Kaplan and Violante (2014), I define liquid assets as the sum of assets held in checking accounts, savings accounts, call accounts, directly held mutual accounts, directly held bonds, and directly held stocks. Equity in the primary residence is defined as the difference between the value of primary residential real estate and debt outstanding on the first mortgage secured by the primary residence. I use only the value of the primary residence and the first mortgage secured by it when calculating home equity because households in the model are only able to hold one property and mortgage at a time. Since relatively few households in the SCF report having more than one loan secured by their primary residence or owning a second home, however, the inclusion of these second mortgages (e.g., home equity loans or home equity lines of credit) is not quantitatively important for my results. I use labor income as my measure of household income. All means are computed with the sample weights included with the data, and I exclude households in the top 5 percent of the net worth distribution (where net worth is defined as above).

A.5 Solution algorithm

I use the Rouwenhorst method described by Kopecky and Suen (2010) to discretize the idiosyncratic income process and generate the transition matrix for z. I create linearly spaced grids for housing wealth h, mortgage debt m, and the mortgage interest rate r_m. The grid for liquid assets a features more points clustered near the borrowing constraint. The grid for the depreciation shock δ_h consists of two points, 0 and δ, and the grid for q also consists of two points, L and H.

Choices of a', m', and r'_m are permitted to lie off the grid, and I use linear interpolation to evaluate the value and policy functions at off-grid points. I constrain the choice of h' to be on the grid for housing in order to capture the indivisibility of housing as an asset. I interpolate the policy and value functions arising from the household's problem over finer grids for the three continuous state variables. I use the finer policy and value functions when computing the stationary distribution Λ_j^* and the associated transition function Q_j.

1. Solve the problem of a household in the last period of life to obtain $V_T^R(\omega)$, $V_T^M(\omega)$, $V_T^P(\omega)$, and $V_T^D(\omega)$, along with all associated policy functions. By definition, $m_T'(\omega) = 0$. Also compute the present value of cash flows associated with a mortgage held by an age-T household. If the household repays their debt, then

$$\Pi_T(\omega) = (1 + r_m)\, m.$$

If the household defaults on their debt, then

$$\Pi_T(\omega) = (1 - \delta_h)\, h - \gamma(q).$$

2. Use backward induction to solve for value functions in Equations (1.9), (1.10), (1.11), and (1.12) for ages $j \in \{1, 2, \ldots, T-1\}$.

   (a) *Solving the problem of a renter,* $V_j^R(\omega)$:

      (i) This option is available to all households.

      (ii) The assumption of Cobb-Douglas preferences over nondurable consumption and housing services implies

$$s = \frac{1-\alpha}{\alpha R} c. \tag{A.2}$$

      Use this expression to substitute out s in the household's problem, and use the budget constraint to substitute out c from the flow utility function.

      (iii) Solve for $V_j^R(\omega)$ and $a_j'^R(\omega)$ using Brent's method. Let c_{min} be the lowest possible value of nondurable consumption.[1] The requirement that $c \geq c_{min}$ characterizes the set of feasible solutions,

$$a'_{min} \leq a' \leq y_j(z) + (1+r)\, a + (1-\delta_h)\, h - (1+r_m)\, m - \mathbb{1}_{h \neq 0} \kappa_h - \frac{1}{\alpha} c_{min},$$

[1] In the computation, c_{min} is set to 0.001.

where the no-borrowing constraint on the liquid asset implies $a'_{min} = 0$.

(iv) Back $c^R_j(\omega)$ out from the flow budget constraint and use Equation (A.2) to find $s_j(\omega)$.

(v) By definition, $h'^R_j(\omega) = 0$ and $m'^R_j(\omega) = 0$. Since the household does not have any mortgage debt, $q'^R_{m,j}(\omega)$ and $r'^R_{m,j}(\omega)$ can be set to any arbitrary value.

(b) *Solving the problem of an owner who obtains a new mortgage,* $V^M_j(\omega)$:

(i) This option is available to all households.

(ii) For a given $r'_{m,j}(\omega)$, loop through all feasible pairs of (h', q').[2] For each feasible (h', q'), solve for $a'^M_j(\omega)$, $m'^M_j(\omega)$, and $V^M_j(\omega)$ using Nelder-Mead. Maximum feasible borrowing is determined by the LTV and DTI constraints. If $q' = L$, then

$$m'_{max} = \min\left\{\theta h', \lambda(q')\, y_j(z) \left(r'_{m,j}(\omega) \frac{\left(1 + r'_{m,j}(\omega)\right)^{T-j}}{\left(1 + r'_{m,j}(\omega)\right)^{T-j} - 1} \right)^{-1} \right\},$$

where $\lambda(q')$ is defined in Equation (1.5). If $q' = H$, then

$$m'_{max} = \theta h'.$$

The non-negativity constraint on nondurable consumption implies that the set of feasible solutions is characterized by

$$a'_{min} \le a' \le y_j(z) + (1 + r)\, a + (1 - \delta_h)\, h - (1 + r_m)\, m + m'_{max} - \mathbb{1}_{h' \neq h}\kappa_h - \kappa_m - h' - c_{min}$$

and

$$\max\{c_{min} + h' + a'_{min} + \mathbb{1}_{h' \neq h}\kappa_h + \kappa_m + (1 + r_m)\, m - y_j(z) - (1 + r)\, a - (1 - \delta_h)\, h, 0\} \le m' \le m'_{max}.$$

[2] In this context, feasibility means that h' is in the household's budget set assuming the smallest possible down payment, liquid savings, and mortgage interest rate.

Use the budget constraint to find $c_j^M(\omega)$. Select the (h', q') pair (and its associated choices of a', m', and V_j^M) that yields the highest value for the household.

(iii) For a given solution to the household's problem in the previous step, compute the financial intermediary's profit using Equation (1.14).

(iv) A bisection algorithm is used to find the mortgage interest rate offered to the household, $r'_{m,j}(\omega)$, that makes the financial intermediary break even on a newly originated mortgage. This algorithm exploits the fact that the financial intermediary's profit is increasing in $r'_{m,j}(\omega)$ and searches over the interval $[r_{m,min}, r_{m,max}]$, where $r_{m,min} = r + \phi$ and $r_{m,max}$ are the smallest and largest points on the grid for r_m, respectively.

(A) The interest rate received by a household of age $T-1$ who obtains a new mortgage loan $r'_{m,T-1}(\omega)$ is $r+\phi$. This follows from the fact that, if an age-T household repays their outstanding mortgage debt, then the zero profit condition is

$$\frac{1}{1+r+\phi}\left(1+r'_{m,T-1}(\omega)\right)m'_{T-1} = m'_{T-1},$$

implying $r'_{m,T-1}(\omega) = r + \phi$. Note that, if an age-$T$ household defaults, then, in equilibrium, an intermediary will not sell that household a mortgage contract when they are of age $T-1$.

(B) If the financial intermediary's profit is negative when $r'_{m,j}(\omega) = r_{m,max}$, then the option to obtain a mortgage is not available to the household. Likewise, if the intermediary's profit is positive when $r'_{m,j}(\omega) = r_{m,min}$, then the household borrows at the rate $r + \phi$.

(c) *Solving the problem of an owner who makes a mortgage payment, $V_j^P(\omega)$:*

(i) This option is only available to existing homeowners ($h > 0$). Note that this problem is also solved by homeowners who do not have any debt. In this case, $m_j'^P(\omega) = 0$ and the owner only needs to solve for $a_j'^P(\omega)$.

(ii) Use the budget constraint to substitute c out of the flow utility function.

(iii) Solve for $V_j^P(\omega)$, $a_j'^P(\omega)$, and $m_j'^P(\omega)$ using Nelder-Mead. From the law of motion for mortgage debt, we have

$$m'_{max} = (1 + r_m)\, m - \pi_{min,j}(m, r_m),$$

where $\pi_{min,j}(m, r_m)$ is defined by Equation (1.4). The requirement that $c \geq c_{min}$, combined with the fact that $a'_{min} = 0$, means that the feasible set of solutions is characterized by

$$a'_{min} \leq a' \leq y_j(z) + (1 + r)\, a - (1 + r_m)\, m + m'_{max} - \delta_h h - c_{min}$$

and

$$\max\left\{c_{min} + a'_{min} + \delta_h h - y_j(z) - (1 + r)\, a, 0\right\} \leq m' \leq m'_{max}.$$

(iv) Use the budget constraint to find $c_j^P(\omega)$. By definition, $h_j'^P(\omega) = h$, $q_j'^P(\omega) = q$, and $r_{m,j}'^P(\omega) = r_m$.

(d) *Solving the problem of a borrower who defaults, $V_j^D(\omega)$:*

(i) This option is only available to existing borrowers ($h > 0$ and $m > 0$).

(ii) Since a borrower who defaults in the current period must rent, Equation (A.2) can be used to substitute out s from the flow utility function and the budget constraint.

(iii) Solve for $V_j^D(\omega)$ and $a_j'^R(\omega)$ using Brent's method. Non-negativity requirements on consumption and liquid savings characterize the set of feasible solutions:

$$a'_{min} \leq a' \leq y_j(z) + (1+r)a - \frac{1}{\alpha}c_{min}.$$

(iv) Back $c_j^D(\omega)$ out from the flow budget constraint and use Equation (A.2) to find $s_j^D(\omega)$.

(v) By definition, $h_j'^D(\omega) = 0$ and $m_j'^D(\omega) = 0$. Since the household does not have any mortgage debt, $q_{m,j}'^D(\omega)$ and $r_{m,j}'^D(\omega)$ can be set to any arbitrary value.

(e) Determine $V_j(\omega) = \max\left\{V_j^R(\omega), V_j^M(\omega), V_j^P(\omega), V_j^D(\omega)\right\}$.

(f) Compute $\Pi_j(\omega)$ using Equation (1.13).

3. Given the policy functions and the invariant distributions of z and δ_h, construct the $ns \times ns$ transition matrix Q_j for the distribution of agents over states according to Equation (1.16), where ns denotes the number of states.

4. Iterate on the transition matrix Q_j using the law of motion in Equation (1.15) until $\left\|\Lambda_{j+1} - \Lambda_j\right\| < \epsilon$ for some small ϵ.

APPENDIX B

SUPPLEMENTARY MATERIAL FOR CHAPTER 2

B.1 Summary statistics from the PSID

To provide an overview of my baseline sample, I present disaggregated summary statistics for household expenditures in Table B.1 and household balance sheets in Table B.2. Sample weights provided by the PSID are used throughout, and all figures are reported in 1999 dollars.

	Mean	Median
Nondurable consumption	15,348	12,819
Goods	5,156	4,501
Food at home	3,769	3,295
Gasoline	1,388	1,010
Services	10,192	7,775
Childcare	313	0
Education	1,127	0
Food out	1,667	1,094
Health insurance	1,125	280
Health services	1,169	388
Home insurance	393	263
Transportation	1,501	931
Utilities	2,896	2,571
Durable consumption	2,273	362
Vehicles	2,273	362
Total consumption	17,621	14,539
Observations	80,011	80,011
Households	16,187	16,187

Table B.1

Consumption summary statistics in the baseline sample. All statistics are computed with PSID sample weights and reported in 1999 dollars. Source: PSID, 1999-2017.

	Mean	Median
Assets	291,088	108,500
Liquid assets	59,975	2,558
Checking and savings accounts	20,113	2,033
Stocks	39,861	0
Illiquid assets	231,114	96,362
Business/farm (net)	31,002	0
Other real estate (net)	33,839	0
Primary residence	116,217	70,106
Private annuities/IRAs	31,838	0
Vehicle (net)	10,745	5,608
Other assets	7,473	0
Liabilities	49,817	7,401
Mortgages	42,565	0
1st mortgage	40,758	0
2nd mortgage	1,807	0
Other debt	7,253	0
Net worth	241,271	54,027
Equity in primary residence	73,653	24,996
Household income	57,985	40,928
Observations	80,011	80,011
Households	16,187	16,187

Table B.2

Wealth and income summary statistics in the baseline sample. All statistics are computed with PSID sample weights and reported in 1999 dollars. Source: PSID, 1999-2017.

APPENDIX C

SUPPLEMENTARY MATERIAL FOR CHAPTER 3

C.1 Recursive structural VAR: impulse responses

This section present impulse responses estimated from a structural VAR identified under the recursiveness assumption, which is described in Section 3.4.2. Figure C.1 plots impulse responses estimated from the full sample period, while Figure C.2 does so for impulse responses estimated from the Great Moderation sample period. The 90 percent confidence bands are computed using the wild boostrap with 10,000 resamples. They largely mirror the impulse responses obtained from the proxy structural VAR approach.

C.2 Local projection: impulse responses

This section presents impulse responses estimated using the local projection method described by Jordà (2005). Figure C.3 plots these local projection impulse responses estimated using for the full sample period, while Figure C.4 does so for local projection impulse responses estimated using the Great Moderation sample period. Standard errors corrected for serial correlation using the method of Newey and West (1987) are used throughout. Although erratic, these impulse responses are qualitatively similar to those obtained from the proxy structural VAR.

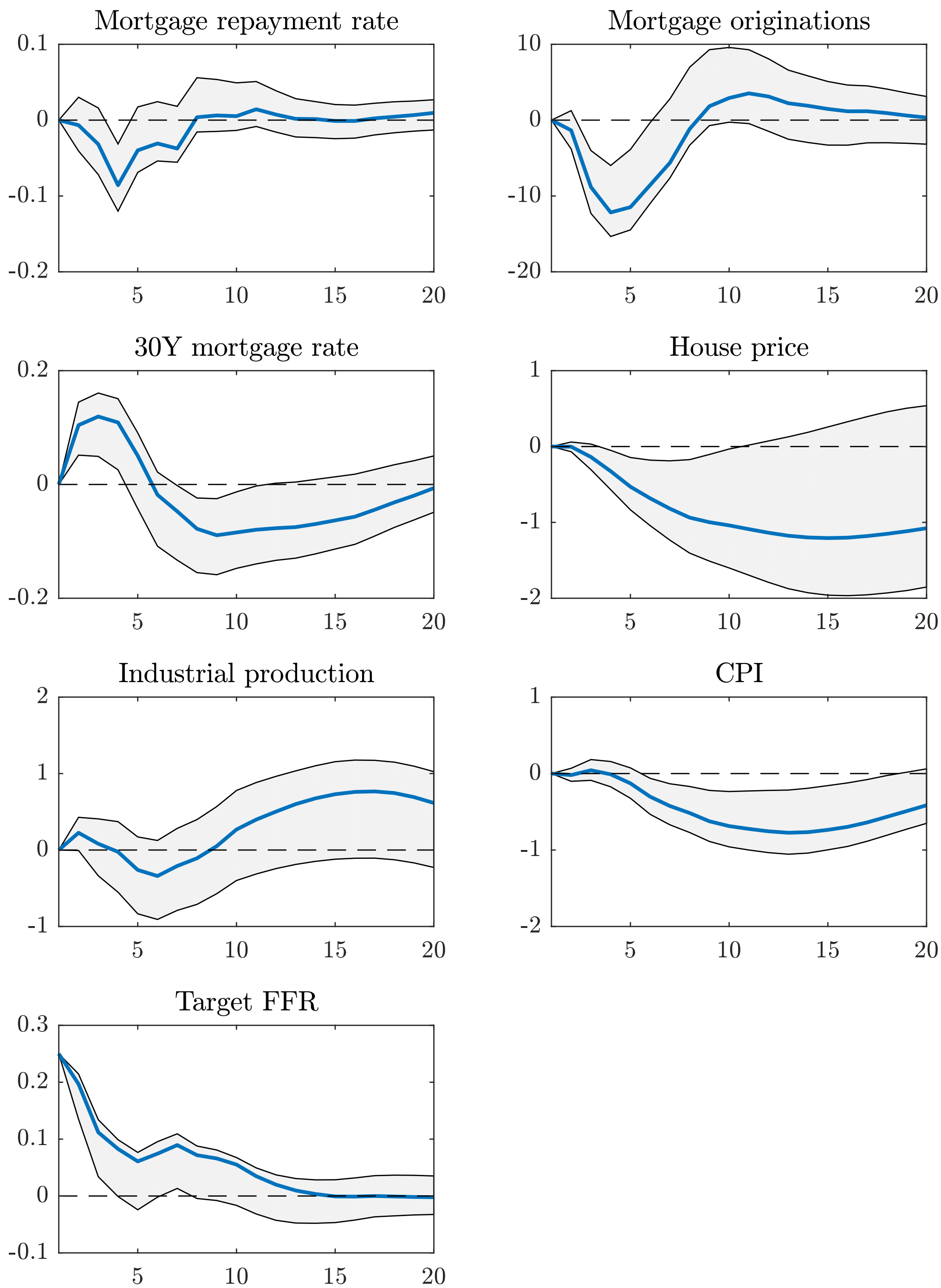

Figure C.1

Impulse responses to a 25-basis point shock to target federal funds rate from a recursive structural VAR estimated on the full sample period (1975-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90 percent confidence interval, computed using the wild bootstrap with 10,000 resamples. Impulse responses are aggregated to a quarterly frequency.

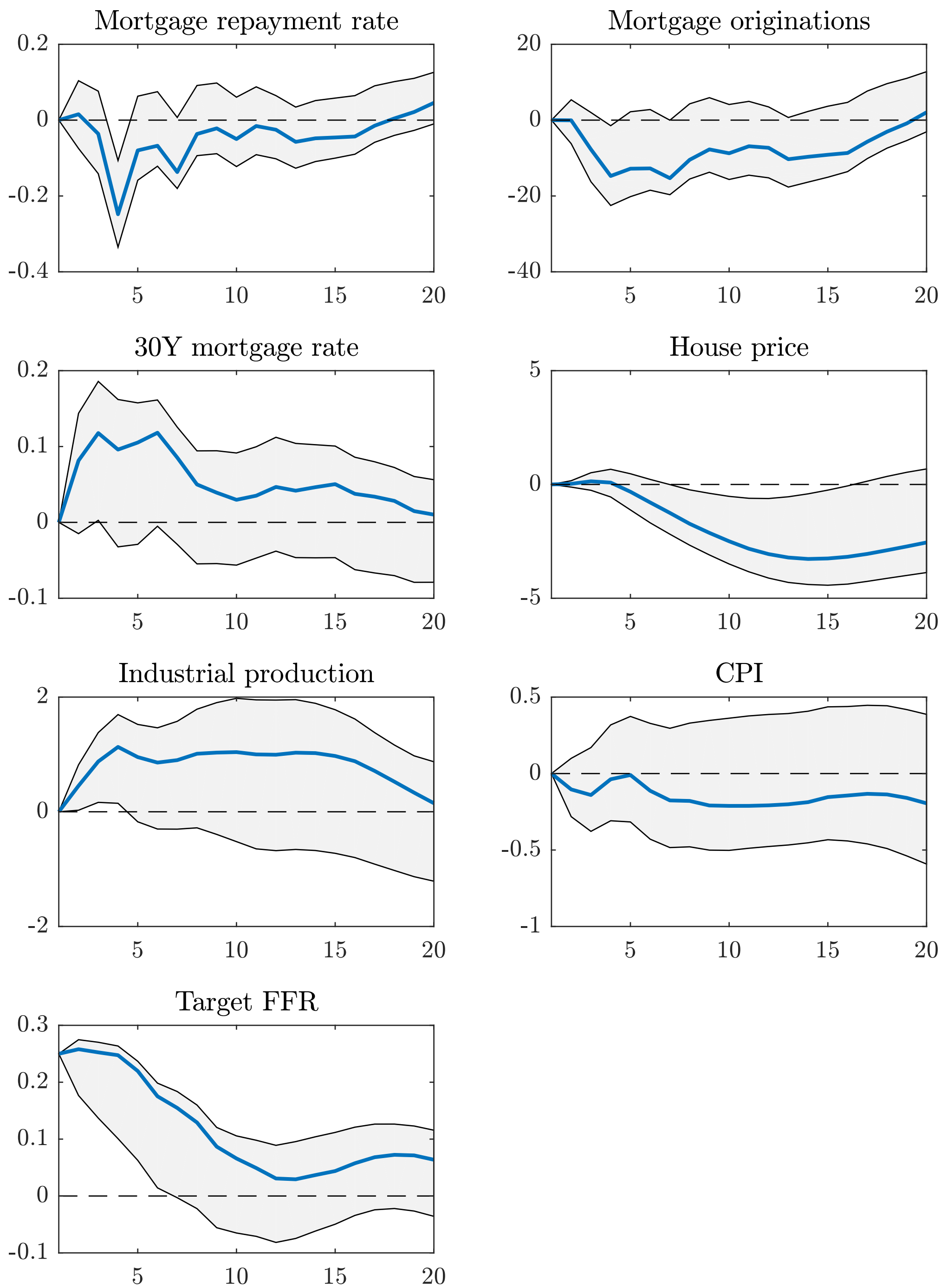

Figure C.2

Impulse responses to a 25-basis point shock to target federal funds rate from a recursive structural VAR estimated on the Great Moderation sample period (1984-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90 percent confidence interval, computed using the wild bootstrap with 10,000 resamples. Impulse responses are aggregated to a quarterly frequency.

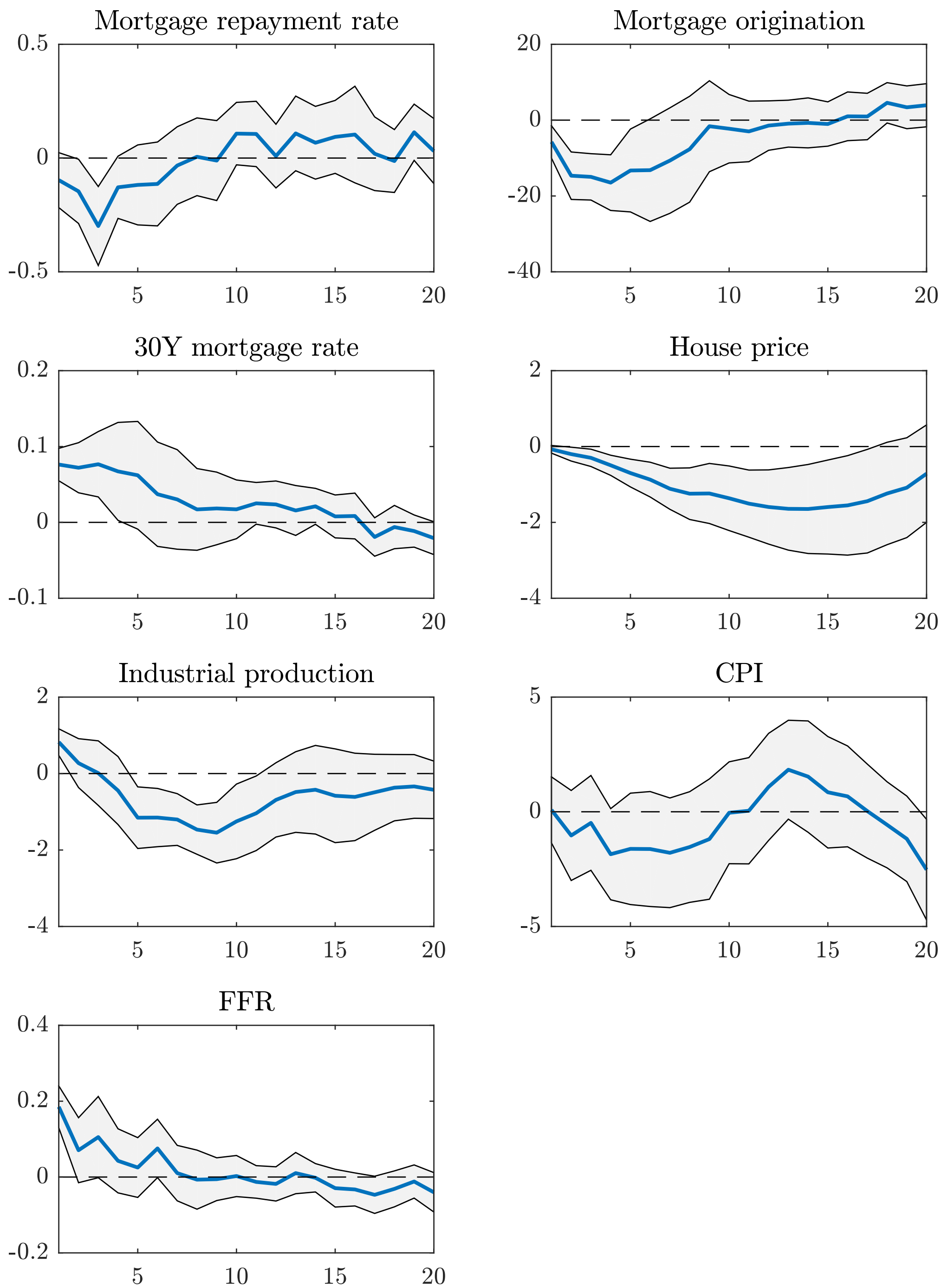

Figure C.3

Impulse responses to a contractionary monetary policy shock using local projections on the full sample period (1975-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90% confidence interval using Newey and West (1987) standard errors. Impulse responses are aggregated to a quarterly frequency.

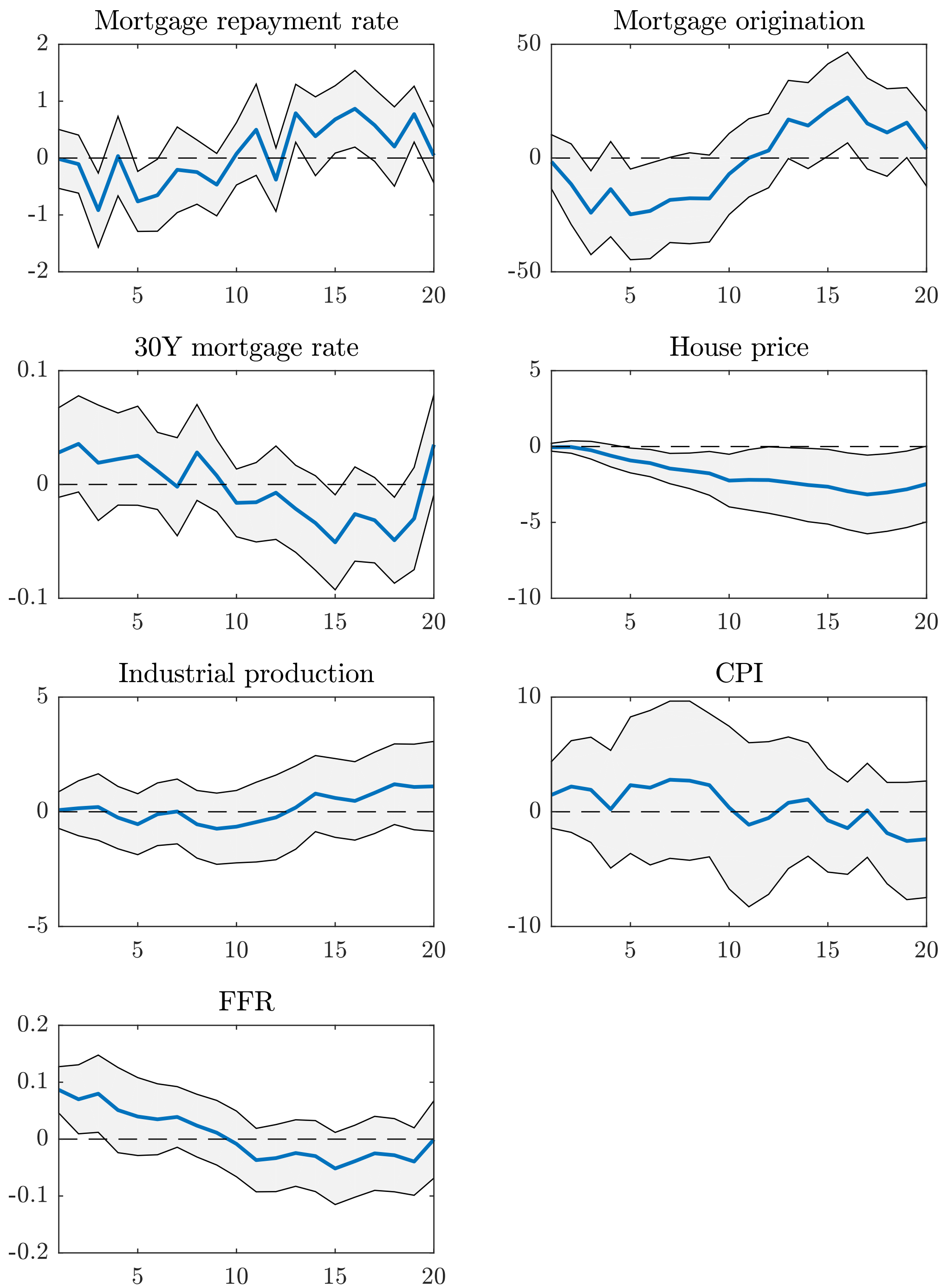

Figure C.4

Impulse responses to a contractionary monetary policy shock using local projections on the Great Moderation sample period (1984-2007). Solid blue lines correspond to the estimated impulse response, and the light gray bands denote the 90% confidence interval using Newey and West (1987) standard errors. Impulse responses are aggregated to a quarterly frequency.

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