Essays on House Price Formation and Household Leverage

Inauguraldissertation

zur Erlangung des akademischen Grades

eines Doktors der Wirtschaftswissenschaften

der Universität Mannheim

vorgelegt von

WIELAND HOFFMANN

im Frühjahrssemester 2016

Abteilungssprecher:	Prof. Dr. Carsten Trenkler
Referent:	Prof. Dr. Klaus Adam
Korreferentin:	Prof. Dr. Michèle Tertilt

Verteidigung: 31.05.2016

Acknowledgments

First and foremost, I wish to thank my advisor, Klaus Adam, for his invaluable guidance and support. I have benefited tremendously from his insightful comments and suggestions as well as from his encouragement along the process of writing this thesis. I am also very grateful to Michèle Tertilt, Johannes Pfeiffer, Antonio Ciccone, Georg Dürnecker, Minchul Yum, Sang Yoon (Tim) Lee and the participants of the Macro brown-bag seminar for the valuable discussions on my research. I would also like to thank everyone who has contributed to establishing and developing the CDSE as a great research environment. I gratefully acknowledge financial support from the DAAD and support from the state of Baden-Württemberg through bwHPC.

One important benefit of the PhD experience is getting to know so many great people, and I want to thank all them for making the last years a memorable experience. Many thanks also go to all the people in Berlin and elsewhere who have remained close over the time I spent in Mannheim and New Haven. I thank my parents for all they have done for me and my brother and sister for being such great siblings.

There are no words to thank Dana for everything.

Contents

List of Tables

List of Figures

Chapter 1

General Introduction

In two self-contained essays, my dissertation investigates determinants of house price formation and mortgage borrowing with an emphasis on the United States. The exceptional growth in mortgage debt during the early part of this century is the focus of the second chapter. I use panel data on the evolution of debt and asset positions of a representative sample of U.S. households to assess to what extent the imposition of stricter collateral requirements could have contained debt growth. The third chapter is motivated by the observation that episodes where house prices grow faster than trend for several years and then contract have been a recurring pattern in the U.S. over the past decades. In a calibrated life cycle model of the market for owner-occupied real estate, I fully match the high degree of serial correlation and eventual mean reversion in house price growth rates, as well as much of their volatility, when allowing for subjective price beliefs.

Adjusting collateral requirements in the form of maximum loan-to-value (LTV) ratios on mortgage originations is the most commonly used macroprudential policy tool in a large sample of advanced and emerging economies studied by Akinci and Olmstead-Rumsey (2015). In a macroprudential framework, periods of rapid mortgage growth would call for stricter LTV limits, while in the U.S. the period leading up to the peak in mortgage debt was marked, if anything, by loosening collateral requirements. Based on the experience of several thousand U.S. households interviewed for the Panel Study of Income Dynamics (PSID) between 1999 and 2011, the second chapter of this dissertation asks what effect counterfactually imposing stricter LTV limits during the boom period would have had on the evolution of their mortgage debt. A distinguishing feature of this panel data set is that it allows me to track changes in the LTV distribution in terms of individual borrowing decisions and reported home price appreciation over time. I use the data to show that a large share of equity extraction, which is the focus of my analysis, came from households that either started from relatively low debt levels or experienced particularly strong house price appreciation. This is important because it means that collateral requirements were not likely to constrain these households' mortgage choices. To quantify the potential effect of stricter LTV limits, I use the data to conduct simulations where I cap all equity extraction between 2001 and 2007, carry capped balances forward, and adjust for subsequent repayments and new borrowing observed in the data. If an LTV limit of seventy percent is imposed on all equity extraction, this reduces mortgage debt outstanding in 2007 by just three percent. Also the unprecedented occurrence of negative or close to negative equity among homeowners after 2007 remains high.

By taking the observed house price movements as given, the analysis in Chapter 2 abstracts from a possible effect of the counterfactual changes in collateral requirements on house prices that could further limit debt growth. One interpretation of the results is that a more substantial reduction in equity extraction would need to occur through this channel then. However, it is fair to say that there is little academic consensus on how much house prices would respond to LTV caps. Outside the U.S., there are numerous episodes where LTV requirements were introduced, abandoned, or adjusted in response to developments in the housing market, and empirical studies of those events do not tend to find a significant price impact.[1] Also an important class of general equilibrium models with endogenous house price formation based on the framework developed in Iacoviello (2005) and Iacoviello and Neri (2010) tends to find small price effects of changing collateral requirements, as emphasized in Justiniano, Primiceri, and Tambalotti (2015). On the other hand, there is substantial empirical evidence for the narrative that exogenous shifts in the supply of credit fueled U.S. house price growth.[2] In that spirit, Favilukis, Ludvigson, and Van Nieuwerburgh (2016) develop a rich general equilibrium model where large capital inflows together with looser collateral requirements generate a strong house price boom that turns into a bust once collateral requirements tighten.

More generally, the volume and scope of new research in response to the recent boom and bust illustrate that there are many challenges in accounting for the determinants of house price formation. One pivotal challenge is understanding the role of households' expectations regarding future prices. Anecdotal evidence as well as existing survey evidence point to potentially important deviations from the rational expectations benchmark in the form of belief biases that lead to extrapolation of observed price movements. In the third chapter of this dissertation, I show that the incorporation of such subjective beliefs into a calibrated life cycle model can substantially contribute to account for the serial correlation and volatility of house price growth rates in the U.S. While the overall magnitude of price fluctuations has been most extreme during the first decade of this century, there have been several episodes over the past forty years where house prices grew much faster than trend for several years and then contracted. In a rational, frictionless market, such a high degree of serial correlation cannot be reconciled with the much lower momentum in fundamentals (Glaeser, Gyourko, Morales, and Nathanson (2014)).

---

[1] See for example Wong et al. (2011), Kuttner and Shim (2013), and Akinci and Olmstead-Rumsey (2015).

[2] See for example Favara and Imbs (2015) and the discussion in Chapter 6 of Mian and Sufi (2014).

The modeling framework I choose in Chapter 3 accounts for important dimensions of household heterogeneity and captures adjustment frictions in the form of transaction costs and down payment requirements. Based on the observation that the *level* of detrended per capita income correlates strongly with house price *growth rates* in the U.S. data, I use the model to study the impact of plausibly parametrized aggregate income shocks on the dynamics of market clearing house prices. Under rational expectations, momentum is about half of what is observed in the data. While the presence of adjustment frictions in the model doubles the volatility of price growth rates, it still amounts to just twenty percent of its data counterpart. These quantitative conclusions change significantly under subjective house price beliefs. When agents use past observations to update their expectations regarding future price growth, the same shocks to aggregate income induce dynamics in house price growth rates that are much closer to the data. The model fully matches the serial correlation and mean reversion in house price growth rates, and it generates seventy percent of the observed volatility. Importantly, these dynamics are not explosive, both because a household's demand can be saturated for fundamental reasons, and because new buyers face rising down payment requirements. The combination of income shocks and learning dynamics alone therefore only matches the high price growth rates during the early stage of the last housing boom. While realized price growth then tapers off in the model, the elevated price growth expectations could have amplified the impact of further stimulus to demand, such as relaxed credit standards and lower interest rates.

Going forward, the model's ability to endogenously replicate important aspects of the price fluctuations observed in the data could make it a useful framework for studying policies aimed at stabilizing house prices. The model dynamics that lead to a sequence of self-reinforcing innovations in the price level suggest that such policies might be more effective if moderate measures were already applied early in the cycle and then gradually adjusted.

Chapter 2

Equity Extraction and LTV Limits During the U.S. Housing Boom

2.1 Introduction

Between 1999 and 2006 the outstanding debt of households in the United States more than doubled, with home mortgages accounting for 83 percent of this increase. The subsequent surge in mortgage defaults sent the world financial system into disarray. Additionally, the deleveraging process of U.S. households is regarded as contributing significantly to the severity of the Great Recession. These developments make housing finance a focus of macroprudential policy reforms. One of the main instruments considered is to impose stricter maximum loan-to-value (LTV) ratios on home mortgage originations during housing market upswings.[1] Recent examples for the uptake of this policy include the introduction of LTV limits in New Zealand in response to rapid house price increases and the British government's decision to give powers of direction to the Bank of England regarding LTV ratios.

How would such countercyclical leverage caps have affected debt growth during the U.S. housing boom and bust? Aggregate data shows that the ratio of mortgage debt to the value of real estate hardly changed throughout the boom phase and remained consistently below its 1997 average of 38 percent. The fact that aggregate debt level and collateral value went up almost in lockstep over that period suggests a link through leverage ratios. Those vary widely among the population, however, so that I look at a representative sample of U.S. households to assess the potential impact of LTV caps, typically ranging from sixty to eighty percent, on such a heterogeneous group. The most basic dimension of household heterogeneity is home ownership status. Most U.S. households already owned real estate when the boom phase began, and their extraction of home equity through new mortgages has been an important component of subsequent debt growth. Also within this group, there was large heterogeneity regarding initial LTV levels as well as exposure to house price appreciation.

In this paper, I find that such heterogeneity can be important in assessing the effect of LTV caps. A large fraction of equity extraction came from households that were unlikely to be directly affected by caps, because they started from low LTV ratios or experienced particularly strong price appreciation. Therefore, even stringent limits yield only a moderate effect on aggregate equity extraction and also do little to prevent the occurrence of extremely high LTV ratios once prices start to decline. New homeowners, on the other hand, used very high LTV ratios to purchase their house, many of them holding little liquid wealth that could

---

[1] See for example Basel Committee on the Global Financial System (2010) and the analysis in Akinci and Olmstead-Rumsey (2015), who find that changes in LTV limits are the most commonly used macroprudential policy tool in a large sample of advanced and emerging economies.

additionally be used to increase the initial equity level. Given prices, strict LTV caps hence may strongly impact households' ability to acquire a suitable home.[2]

The analysis I conduct is based on the experience of all households interviewed for the Panel Study of Income Dynamics (PSID) between 1999 and 2011. Every two years they report the value of their home and other assets as well as details on the outstanding mortgage balance. The ability to provide periodic snapshots of asset and debt positions of a representative sample of U.S. households distinguishes the PSID from other data sources used by a growing class of empirical work that investigates the expansion and contraction of mortgage debt over the period. My analysis of the data augments and corroborates the picture emerging from a number of those studies that rely on consumer credit records and loan application data: The increase in mortgage debt was broad-based, where both new homeowners and equity extraction played an important role. Regular first mortgages were by far the most important component of debt growth, while second mortgages and especially home equity lines of credit played a much smaller role. Throughout the boom, the entire distribution of LTV ratios remained remarkably stable. Finally, the contraction in debt after 2007 was driven by a significant decline in new borrowing. Repayments continued at the same rate even though the house price drop had led to a significant increase in LTV ratios, and also the impact of defaults appears to be much less important than the decrease in new borrowing.

The panel structure of the data set makes it possible to track changes in the LTV distribution in terms of individual borrowing decisions and home price appreciation over time. In a first step, I counterfactually restrict equity extraction for each household to a given LTV limit for single two-year intervals. Capping all equity extraction at a maximum LTV ratio of 0.7 reduces overall equity extraction by about twenty percent. This implies a 1.5 percent reduction in total mortgage debt outstanding at the end of the two-year period. In a second step, I conduct simulations where I apply the LTV limits over the entire period from 2001 to 2007. I carry capped balances forward and continue to adjust them for subsequent repayments and new borrowing observed in the data. In my preferred specification this exercise yields a total debt reduction of 3.2 percent by 2007.[3] Also the unprecedented occurrence

---

[2] When home purchases are highly levered, changes in the LTV requirement disproportionately reduce the value that can be financed using the same cash.

[3] My preferred specification reduces the LTV for each transaction by up to ten percentage points. The overall effect is similar to imposing a maximum LTV ratio of 0.7, which would yield a reduction of three percent.

of negative or close to negative equity among homeowners after 2007 remains high when I analyze the resulting balances over the bust period.

The main part of the analysis imposes LTV caps only on equity extraction, thus avoiding the difficulty of predicting a counterfactual home purchase decision. Since the effect turns out to be rather limited, I also simulate a scenario where all homebuyers are able to provide enough equity to purchase the same house at a capped LTV ratio. While many of them may not have had the wealth to actually do so, the result can be seen as a lower bound estimate of the effect of applying stricter LTV caps to purchases. The decrease in outstanding debt by 2007 is 7.1 percent in my preferred specification. Any further reduction in borrowing would need to be driven by a reduction in home purchases.[4]

The analysis abstracts from interactions between LTV caps and prices, so that the reported figures do not incorporate potential additional equilibrium effects of the policy. Nevertheless, the approach allows detailed information on the evolution of debt and asset positions of thousands of U.S. households to be accessed and aggregated in a way pertinent to the mechanics of LTV caps. The findings can therefore complement or inform model-based studies. A frequently made assumption is, for example, that new borrowing in response to house price appreciation is concentrated among a relatively small group of agents who already have the highest LTV ratios, while the PSID data suggests that it was in fact pervasive. A salient feature of the data is the stability of the entire LTV distribution throughout the house price boom. Although the period is often associated with easing borrowing constraints, those did not manifest themselves as a trend toward higher leverage ratios among equity extracters or homeowners in general. Instead, most equity extraction came from households with low initial LTV ratios or high house price appreciation, so that the effect of caps on equity extraction is quite limited. The relatively small weight of constrained borrowers until 2007 is consistent with, for example, the influential study by Iacoviello and Neri (2010), but the data for 2009 and 2011 suggest that the swing in house prices considerably increases the size of the constrained group. While it does not appear as if increased LTV ratios forced households to repay their mortgage balances more quickly, the massive reduction in equity extraction may well be related to this increase.

---

[4] In practice, the Hong Kong Monetary Authority as a particularly active user of LTV policy has special programs in place that allow liquidity constrained but financially sound buyers to still afford a home by using much less equity than the official cap would require.

2.2 Related Literature

Maximum LTV ratios for borrowers are an important element in many studies of housing and mortgage debt. A number of them directly link fluctuations in this limit to what happened in the U.S. housing market over the past decades. Favilukis, Ludvigson, and Van Nieuwerburgh (2016) point to several developments in housing finance during or preceding the period of rapid house price appreciation from 2000 to 2006 that they interpret as having substantially raised maximum LTV ratios. A rich general equilibrium model shows how this exogenous increase, together with its subsequent reversal, may have been an important driver in mortgage debt and house prices. One important factor is that higher LTV limits facilitate risk sharing between households and cause a decrease in risk premia on housing wealth. An earlier paper that links the expansion in debt since the 1980s to higher LTV limits is Campbell and Hercowitz (2006), who emphasize that this also led to a moderation in how much debt and hours worked fluctuate over the business cycle. Iacoviello and Pavan (2013) generate the same effect but find that higher debt makes households more vulnerable when credit standards tighten along with a negative economic shock. The impact of lower down payment requirements on potential new homeowners and on increasing home ownership is studied in Chambers, Garriga, and Schlagenhauf (2009), while Corbae and Quintin (2015) connect increased availability of low down payment purchase mortgages to the subsequent surge in defaults. The overall finding that higher LTV limits drive up aggregate borrowing suggests a significant role for policies aiming to cap LTV ratios instead.

Studies that directly assess a countercyclical change in LTV limits include Christensen and Meh (2011) and Lambertini, Mendicino, and Punzi (2013). The analytical framework they use is based on the workhorse model developed in Iacoviello (2005) and Iacoviello and Neri (2010), where the borrowing constraint leads to an amplification and spillover of housing market developments because it always binds for a group of impatient households. The estimation conducted by Iacoviello and Neri only attributes a relatively small weight to these households, however, and finds that at most twelve percent of the total variance in consumption growth could be due to such spillovers. The stabilization effect found for LTV caps can only be a fraction of that and is quantitatively small in both studies. One can also turn to results from Justiniano, Primiceri, and Tambalotti (2015) who show that in a similar framework a credit liberalization cycle could not induce the dynamics of debt and house prices observed during the last boom-bust cycle. In fact, house prices hardly react at all to reduced down payment requirements and hence fail to sufficiently amplify the increase in debt. Laufer (2013) uses a structural model to assess the impact of a policy that caps equity extraction of existing homeowners at a 0.8 LTV ratio. In a very detailed analysis of the Los Angeles metropolitan area, he finds that about one third of all homeowners who defaulted after the sharp decline in house prices reached negative equity only because of mortgage balance increases after their purchase. The cap reduces the number of defaults by 28 percent and the volume of equity extraction by 23 percent. The maintained assumption that purchase prices fall strongly in response to the increased liquidity risk associated with limiting subsequent equity withdrawals appears to be critical for these conclusions, as it explains most of the decline in debt and defaults.

The importance of equity extraction is also documented by Mian and Sufi (2011). According to their estimates, seasoned homeowners increase debt by 34 percent from 2002 to 2006. For households with low credit scores, there is a clear relationship to local house price appreciation, which again points to the importance of LTV constraints. Mian and Sufi document that extracted equity is likely used to fund consumption and in the longer run significantly increases the default probability, findings that are confirmed by Bhutta and Keys (2016). Another estimate of sources and uses of extracted home equity is provided in Greenspan and Kennedy (2008). They estimate that it may have supported two to three percent of total personal consumption expenditure during the period from 2001 to 2006, which represents a considerable increase from previous years and drove down the measured savings rate. Demyanyk and van Hemert (2011) study the origination of subprime mortgages that went into securitization, a market segment that more than sextupled in volume between 2001 and 2006. The explosive growth is related to a continual deterioration in overall lending standards, where the slight upward trend in LTV ratios is only one factor.

A number of studies use PSID data to show how households rely on extracted equity to smooth consumption in response to income or expenditure shocks. Hurst and Stafford (2004) find that households are more likely to access home equity when they have endured an unemployment shock and have little other liquid wealth. Such a consumption smoothing motive may override financial considerations in mortgage refinancing. Hryshko, Luengo-Prado, and Sorensen (2010) show that homeowners' ability to maintain consumption after becoming displaced or disabled is impaired when house price growth is low. Cooper (2010) analyzes consumption and savings for all PSID households that extract equity. Only a small fraction of extracted equity can be systematically assigned to increased discretionary consumption expenditure, but idiosyncratic liquidity needs, such as healthcare expenditure, college-aged children, home maintenance, and income shocks, all seem to play a role for the decision to extract equity.

Outside the U.S., there are numerous episodes where countercyclical LTV regulation was adopted. Kuttner and Shim (2013) provide a very comprehensive analysis of the effects of several housing related credit and tax policies for a panel of 57 countries over a period going back as far as 1980. Overall, they find 94 instances where LTV requirements were introduced, abandoned, or adjusted. Importantly, LTV regulation is often observed in conjunction with a change in debt-service-to-income ratios. The latter seem to have a stronger impact on credit growth while several specifications find no significant effect of LTV caps. Neither policy can be shown to have a significant impact on prices, but controlling for the endogeneity of policy choices, i.e. that LTV caps are introduced when prices are expected to rise anyway, is challenging. Particularly active users of LTV regulation include Hong Kong, Korea, and Singapore. For those countries, Wong, Fong, Li, and Choi (2011) study property market activities for event windows around the dates when regulatory limits were adjusted. Again, there is evidence that credit growth is affected, while an impact on prices cannot be established.

2.3 Data Overview

The PSID is a long-established, nationally representative panel study of U.S. households. I use interview data from 1999 onwards in order to capture the entire housing cycle since its build-up stage.[5] The interviews are conducted at biannual frequency and contain details on wealth, housing, and debt at the family level. The data set provides family longitudinal weights, which can be used to analyze the evolution of aggregates over time. In general, families are linked between periods by having the same person classified as “Head” in all interviews. Given the formal criteria by which the role is assigned, in most instances this will allow making the connection between interviews for the same household. For the baseline analysis, I also make an effort to establish connections where the head changes in what could still be considered the same household - most notably if a female sample member’s relationship status changes accordingly. Results would be similar when restricting the analysis to households where head and spouse remain the same.

---

[5] This also happens to be the year when the last major update of the sample was completed.

The aggregates in the PSID reflect stylized facts on the housing cycle from other sources. In line with national house price indices, the average reported home value almost doubles between 1999 and 2007, and throughout this period mortgage debt rises strongly.[6] The average reported home value then falls by about fifteen percent until 2011, while the decline in the Freddie Mac House Price Index over the same period was thirty percent. Quintin and Davis (2014) observe similar differences for that period when comparing self-assessed home values from the American Housing Survey to the Case-Shiller-Weiss House Price Index at the city level. They argue that households are slow to incorporate information from other transactions, but that self-assessed home values are actually the variable of interest for decisions such as mortgage default. As in the flow of funds accounts, mortgage debt declines very slowly once prices begin to fall, so that the aggregate LTV ratio rises after 2007, while it had been declining slightly in prior years.

The household level data allows to split the change in total outstanding mortgage debt into its components. The most basic division is into gross additions and gross reductions, i.e. the total change in the mortgage balance of households who increase respectively decrease mortgage debt between two interviews. The sum of these two components is net growth over the period. The decomposition is shown in Panel a) of Table 2.1 and already makes it very clear that the cycle was driven by fluctuations in gross additions. During the boom, households were adding mortgage debt at an annual rate of fifteen percent of the mortgage base, and this rate was subsequently cut in half. Gross reductions as a fraction of the mortgage base remain almost constant throughout, so that the deleveraging process does not seem to represent an exceptional effort by households to reduce balances,[7] but rather an inability or unwillingness to take on new credit. This observation is consistent with the conclusions that Bhutta (2015) draws from consumer credit records.

Most of the analysis presented here requires households to report sufficient data in at least two subsequent interviews. Table 2.1 contains additional information on how changes in their balances, labeled “Regular Net Growth”, relate to total period growth in reported mortgage debt. A difference arises because households either provide insufficient or potentially erro-

---

[6] The total increase is 105 percent, which is less than the 140 percent increase recorded for mortgage debt in the flow of funds accounts. However, the PSID mortgage data does not cover loans for second homes and investment properties.

[7] The absolute amount of regular debt service and the effects of switching from ownership to renting of course increased with the outstanding balance.

neous information in one of the interviews[8] or have one missing interview. Regarding the former, it can be said that increases and decreases due to missing data roughly offset each other and display no trend. Missing the second of two consecutive interviews can be considered sample attrition and affects about 3.5 percent of the mortgage base. Due to recontact efforts, there is also an offsetting effect from interviews with households who missed the first interview but had been in the sample before. Because attrition is not offset fully by recontacts, the column labeled Sample Effects is slightly negative on average. Drilling down deeper, the positive value for the 2001-2003 period is related to a stronger contribution from recontacts, and indeed special efforts have been undertaken by the PSID staff during that time. In the later periods attrition rises slightly. This points to a potential distortion resulting from the wave of defaults during the financial crisis and a higher propensity of defaulters to drop from the sample. However, simple probability models show no significant connection between, for example, high leverage or mortgage distress indicators and dropping from the sample. Overall, fluctuations due to sample effects are an order of magnitude smaller than regular changes in the mortgage base.

It is important to note that households who split off from PSID families remain in the sample and have their own interview records from that time on. Typically, they are children moving out, so that new interview records resulting from split-offs constitute a systematic component of new home ownership. Therefore, I count mortgage balances from such interviews a new home ownership by default and do not subsume them under sample effects. Since there is also the possibility that split-offs move into a home that is already owned, for example by their partner, the exception are new records with a mortgage that has been originated before the year of the previous interview cycle or that has already been refinanced.[9] Overall, this is a very small group, but the differentiation seems more desirable than counting every new balance also as new home ownership.

The table also reports the total change in the longitudinal weight for all households that are in the sample in both consecutive interviews. There is a clear pattern how this quantity changes over a four year cycle. For example, it goes down between 2003 and 2005 and then up

---

[8] I require that a balance is reported for at least the first mortgage, that the total mortgage volume results in an LTV ratio no higher than three, and that the mortgage balance is at least $1,000. The latter is because of several instances where balances were obviously recorded with missing zeros in one period. Since the main analysis is focused on LTV ratios, I also require that the home value is reported.

[9] The latter is for technical reasons because the year of origination is only given for mortgages that have not yet been refinanced, although it is of course possible that even refinanced mortgages have been originated recently.

Table 2.1: Changes in the Outstanding Mortgage Base

Panel a) Overview

	Changes in Mortgage Base					Memo	
Year	*Gross Additions*	*Gross Reductions*	*Regular Net Growth*	*Sample Effects*	*Total Period Growth*	*Weight Adjustments*	*Implied Period Growth*
2001	32.4%	-14.7%	17.7%	-0.3%	17.4%	97.8%	15.5%
2003	35.9%	-14.4%	21.5%	1.4%	22.9%	102.7%	26.0%
2005	35.9%	-14.2%	21.7%	-0.4%	21.2%	98.7%	19.1%
2007	31.6%	-14.8%	16.8%	-3.6%	13.2%	104.5%	18.2%
2009	19.9%	-17.2%	2.7%	0.0%	2.7%	99.6%	3.2%
2011	14.4%	-17.6%	-3.2%	-3.2%	-6.5%	108.5%	1.3%

Panel b) Details

	Gross Additions			Gross Reductions	
Year	*New Homeowners*	*New Residence*	*Balance Increase*	*Balance Decrease*	*No Homeowner*
2001	15.4%	8.5%	8.5%	-10.7%	-4.0%
2003	16.6%	7.8%	11.4%	-9.9%	-4.4%
2005	15.4%	9.0%	11.5%	-8.4%	-5.8%
2007	13.6%	8.9%	9.2%	-9.9%	-4.9%
2009	8.6%	3.4%	7.9%	-10.5%	-6.8%
2011	6.3%	2.9%	5.2%	-10.4%	-7.2%

Panel c) Equity Extraction

			Refinancers		Others	
Year	*Total*	*New Mortgage*	*Change First Mortgage*	*Change Second Mortgage*	*Change First Mortgage*	*Change Second Mortgage*
2001	8.5%	1.9%	2.0%	0.1%	2.6%	1.9%
2003	11.4%	1.5%	6.9%	-0.2%	2.0%	1.2%
2005	11.5%	1.6%	5.9%	0.5%	2.2%	1.3%
2007	9.2%	1.2%	4.1%	0.1%	1.6%	2.2%
2009	7.9%	1.4%	2.4%	-0.1%	2.0%	2.2%
2011	5.2%	0.9%	2.0%	-0.1%	1.8%	0.6%

Note: Changes in total outstanding nominal mortgage balance since the previous interview period for all PSID households satisfying data quality criteria. Total period growth is the sum of gross additions, gross reductions, and sample effects. Sample effects collect attrition, missing values, and new mortgage balances that do not seem to belong to a mortgage taken out during the period. All changes are given as a percentage of the total mortgage balance outstanding as of the previous interview, excluding households that have dropped from the sample. All calculations apply the weight from the second interview, the memo columns indicate the effect of incorporating the weight change between the first and second interview. Panels b) and c) break down gross additions and reductions by the type of observed change.

between 2005 and 2007. This cycle corresponds to the four year intervals at which longitudinal weights are recalculated for all sample members. On average, these recalculations increase the weights attached to households that have remained in the sample. On the other hand, between recalculations updates to household weights mainly reflect composition changes. For most households, there is no change at all, but such adjustments tend to reduce the weight of households if they do occur. Details on the adjustment procedures can be found in Gouskova, Heeringa, McGonagle, and Schoeni (2008), but the effect seems to stem from the recalculation of the household weight as an average of all its members' individual weights. Any new members that have not been born in or adopted by sample families have a weight of zero and bring down this average. Limiting the sample to households with no such changes indeed eliminates the weight declines but also makes the increases more pronounced. These systematic interperiod weight changes are of importance for the analysis conducted here because they are large enough to notably affect the reported growth rates. When breaking growth down into categories, one would also have to account for what is induced by weight changes. Instead, in any such calculations I assign the same weight to the same household for both interviews. I decide to use the weight from the second interview, so that the results can interpreted as the mortgage balance changes for a sample representative for that period since the time of the first interview.[10] As they cannot show up in any component of regular growth, I will always exclude households that are lost to attrition from the base for calculating regular growth rates. The figures reported in Panel a) of Table 2.1 and the discussion in the previous paragraph show that attrition is unlikely to significantly distort what can be identified as regular mortgage growth.

To give an idea of the importance of equity extraction, I break gross additions further down by whether they come from new homeowners, movers, or households who do not move but increase their mortgage balance. Panel b) shows that the latter group accounts for about thirty percent of total gross additions. For several reasons this could be considered a lower bound estimate. As stated above, I cannot identify equity extraction by households entering or leaving the sample, but I do count some entrants as new homeowners. In addition, movers are identified based on whether the head has moved since the previous interview, but this

---

[10] This scheme also seems more proper regarding the treatment of households where a partner joins, but both approaches yield similar results.

does not seem to be related to a change in primary residence in all cases.[11] As for all gross additions, the estimate is net of the regular repayments that households make on their mortgage. The table also shows that what change there was in gross reductions after 2007 is largely due to households terminating home ownership as opposed to regular repayment increases.

Drilling down further, Panel c) in Table 2.1 shows that the refinancing of traditional mortgages was the most important means of equity extraction and also displays the clearest cyclicality.[12] Conditional on extracting equity through refinancing, the total volume of second mortgage debt barely changes. Existing second mortgages tend to be reduced, while other households split equity extraction between their first and a new second mortgage. This shows that LTV regulation should conceptually apply to the cumulative balance, which is also the way it is analyzed here. Total debt increases through second mortgages seem quantitatively less important than refinancing, and their cyclicality is less pronounced. One concern are balance increases on first mortgages that cannot be linked to refinancing. Only a small fraction of first mortgages are identified as line of credit type loans or unconventional mortgages, so that it is not clear how these balance increases occur. In part, they may be an artifact of reporting errors because upward deviations are not netted with downward deviations in this view. However, it is very rare to see that increases of at least $10,000 are followed by reductions of similar magnitude – which would be one sign of largely overstating a balance by mistake – but smaller deviations may add up. In any case, the fact that the increases are quite stable over time suggests that there may be less discretion involved on the side of borrowers or lenders, but I will include them in the LTV cap analysis in order to not understate the potential effect.

Given significant changes in debt levels and home values, it is interesting to see how stable the distribution of mortgage holders' LTV ratios remains between 1999 and 2007 in Table 2.2. The upper part of the LTV distribution is fed by the inflow of new homeowners, most of whom choose LTV ratios close to or over eighty percent. In total, they never make up more than ten percent of all mortgage holders, so that equity extraction must play an

---

[11] For example, some homeowners who have moved neither report selling their home nor owning other real estate. This would not be remedied by restricting the sample to households where the head and spouse have not changed.

[12] I define the refinancing event as observing that the first mortgage has that status and that the year recorded for question A26: "What year did you (obtain that loan/refinance)?" is larger than or equal to the year of the previous interview. If the the mortgage has been refinanced in that very year according to the information from the previous interview, the year in the second interview must be strictly larger.

important role as well in offsetting the steep increase in collateral values. Throughout the sample period, leverage ratios in excess of 0.8 are common, but until 2007 it is rare to see negative equity. The subsequent surge in underwater mortgages is one motivation for the analysis presented in the next sections. In 2009, nine percent of all leveraged homeowners owe more on their residence than its estimated value, despite the fact that new borrowing has gone down significantly after 2007. While reported house prices decline by less between 2009 and 2011, the share of underwater mortgages continues to rise over that period. Again, this can be taken as an indication that households do not drastically alter their repayment behavior when exceeding LTV thresholds. Given that the average reported home value falls by less than national house price indices, the table may understate the occurrence of negative equity after 2007. Indeed, CoreLogic estimated the share of underwater mortgages to be close to 23 percent by the end of 2011.[13] As stated above, self-assessed home values might be more relevant to a household's decision problem, but one can conjecture that also for the large number of homeowners close to negative equity proceeds from selling their house could fall short of the outstanding debt.

Table 2.2: LTV Distribution

Year	*LTV≤0.4*	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*
1999	25.0%	47.2%	76.7%	88.8%	97.4%
2001	27.6%	51.2%	79.1%	89.5%	97.5%
2003	26.0%	50.1%	78.5%	89.4%	97.6%
2005	29.4%	53.6%	79.2%	89.1%	97.6%
2007	31.0%	54.7%	79.4%	90.2%	97.5%
2009	25.0%	44.9%	68.3%	80.3%	91.1%
2011	23.6%	41.2%	64.8%	76.5%	89.1%

Note: The table shows the share of mortgage holders who are at or below the indicated LTV value. LTV is calculated as the sum of first and second mortgage over home value. Households who do not report the value of their home or mortgage principal are omitted.

2.4 LTV Caps and Equity Extraction

I define equity extraction as mortgage debt increases between consecutive interviews by homeowners who have not moved. For all those households, I look at the entire mortgage balance at the end of the two-year period and check whether it is above a specified LTV limit

---

[13] http://www.corelogic.com/about-us/news/corelogic-reports-negative-equity-increase-in-q4-2011.aspx, accessed on April 12, 2016.

relative to the home value reported at that time. If this is the case, I reduce the simulated value to the amount implied by the LTV cap, but never below the amount outstanding at the beginning of the period. The latter reflects that borrowers cannot easily be forced to reduce balances already outstanding, just as repayments did not increase once falling collateral values sent LTV ratios to unprecedented levels. Because I analyze caps only for periods of house price appreciation, the end-of-period home value should generally capture the highest borrowing limit the household has faced over the period. However, for the 2005-2007 interval the approach may miss an inter-period peak, making it somewhat stricter.[14]

Table 2.3: Effect of LTV Caps on Equity Extraction and Mortgage Debt

		Fraction Still Extracted Under Caps				Mortgage Debt Reduction		
Year	*Equity Extraction*	*0.6 Hard Cap*	*0.7 Hard Cap*	*0.8 Hard Cap*	*0.1 LTV Reduction*	*0.6 Hard Cap*	*0.7 Hard Cap*	*0.8 Hard Cap*
2001	8.5%	67.5%	80.5%	89.7%	80.5%	2.24%	1.35%	0.71%
2003	11.4%	66.6%	82.3%	92.1%	78.0%	2.95%	1.56%	0.70%
2005	11.5%	70.5%	83.3%	92.4%	80.7%	2.65%	1.50%	0.69%
2007	9.2%	63.9%	78.2%	90.5%	77.6%	2.72%	1.64%	0.71%

Note: Change in equity extraction since the previous interview period if the respective caps are applied to each transaction. In column 6 each transaction is adjusted such that LTV is reduced by ten percentage points, but never below sixty percent. The last three columns give the effect on total mortgage debt outstanding.

In a first step, I conduct this analysis separately for all of the two-year intervals between 1999 and 2007. For the U.S., 0.8 can be considered as a benchmark LTV ratio. To conform with the underwriting guidelines set out by government sponsored enterprises Freddie Mac and Fannie Mae, cash-out refinance mortgages cannot exceed this limit, for example.[15] Of course, it is by no means an official borrowing limit for the U.S., where even combined LTV ratios exceeding one are possible. Actual policies in other countries have tightened existing limits by ten to twenty percentage points, and also model-based policy analysis considers fluctuations of this magnitude relative to a benchmark level.[16] Table 2.3 shows that the 0.8 LTV cap would reduce extracted equity by eight to ten percent. A tightening to 0.7 yields a reduction by another ten percent. The effect is somewhat more pronounced when going to an LTV limit of 0.6. In total, this cap would reduce equity extraction by about one third, but

---

[14] Taking the maximum of the beginning- and end-of-period house value would hardly affect the results.

[15] Iacoviello and Neri (2010) use 0.85 in their influential calibration but mainly because of purchase mortgages, which can have higher LTV ratios.

[16] E.g. Lambertini et al. (2013), Table 6

it also represents a very strict policy. Even during the house price boom, about half of all mortgage holders had debt in excess of that limit at any given time. Unless their collateral appreciates sufficiently, these households could not have used equity extraction at all under the policy. Nevertheless, the decrease in the extracted volume has only a modest impact on outstanding debt and most additional borrowing observed in the data could still occur.

I also consider a version where the LTV cap is set individually for each household extracting equity. It is reduced by ten percentage points compared to the LTV ratio observed in the data, but never below sixty percent, the strictest cap considered above. Again, households are not forced to reduce existing balances. The approach is intended to capture a setting where LTV policy does not enforce one fixed limit for every transaction, but where the policy stance is such that borrowers find it more costly to go beyond a certain threshold and choose their leverage ratio accordingly.[17] The simulation shows the effect of a regulation that induces every household to lower the chosen ratio by up to ten percentage points. One can observe that this ten percentage point reduction for all high leverage transactions has a slightly stronger effect than a hard cap at 0.7. Relative to the hard cap, it eases the constraint for households that choose to extract equity in excess of the 0.8 benchmark, but this is more than offset by the opposite effect on borrowers choosing LTV ratios between 0.6 and 0.8.

So far, only the impact of imposing caps for a single two-year period has been discussed. The last housing boom went on for about a decade with double digit annual growth rates in mortgage debt from the early 2000's until the onset of the financial crisis. To what extent would the effect of limits imposed over this entire period accumulate over time? Could they have helped prevent the unprecedented surge in the number of mortgages with little or even negative equity once house prices began to fall? With these questions in mind, I simulate a scenario where the LTV caps apply over the entire 2001-2007 period. For 2003 this scenario means that the same values as reported above are generated, but then households enter the next period with the simulated and not with the observed mortgage value. If a household did not extract equity, those values are equal, but for others, the simulated value may be below the actual balance.

The households' subsequent behavior is derived from the change in mortgage balance observed in the data, which is then applied to the simulated value. If a household reduces its mortgage balance in the data, the outstanding simulated balance will be reduced by the same

---

[17] For example, banks in New Zealand only have to apply the cap to ninety percent of their new lending and have tended to charge higher prices for mortgages in excess of the cap.

factor. Using a factor instead of the absolute value reflects the structure of a typical mortgage, where repayments are such that the initial balance is repaid in a given time frame, for example thirty years. For a different initial balance, the level of repayments will be different, but the rate at which the balance decreases will be the same.[18] Mortgage balance decreases could also be due to extraordinary repayments, which I do not observe separately. Since capping equity extraction reduces a household's liquid funds in the first place, the assumption that extraordinary repayments are reduced as well does not seem unreasonable. I do not consider a scenario where capped households try to catch up in terms equity extraction if the value of their home rises in later periods. Such an approach could only result in finding even lower effects of LTV caps. Also for households extracting equity again, I assume that they will at most extract the amount observed in the data and not try to catch up further if they had previously been capped.

For the periods 2003-2005 and 2005-2007, the resulting simulated balance is subject to the LTV constraint, so that equity extraction may be capped again. After 2007, the cap is not applied any more, but I continue to carry simulated balances forward as described above to generate simulated values for 2009 and 2011. Since the cap does not apply to home purchases in this analysis, new homeowners will enter the sample with the LTV ratio they have actually chosen. Also homeowners changing residences are not subject to an LTV limit. They may have been capped in a previous period, however, resulting in higher wealth at the time of purchasing the new house. I assume that the additional equity is applied to the new home purchase, which again maximizes the policy's potential impact.

The results presented in Table 2.4 are for the scenario where a cap is set individually for each household at ten percentage points below the LTV ratio observed in the data. As above, the aggregate effects are similar, yet a bit stronger, when compared to a hard cap at 0.7. The results for the latter scenario are given in Appendix 2.A. The third column in Table 2.4 shows that applying LTV caps over the entire 2001-2007 period reduces outstanding mortgage debt by 3.2 percent. Hence, the effect of the multiperiod cap is considerably lower than what one might expect when simply adding up the effects of single period caps displayed in the second column.

Several factors inhibit the incremental effect of capping balances over time. First, there is a base effect due to regular increases in mortgage volume. Relative to the 2005 base, the

---

[18] The simulated value only differs from the value recorded in the data if the household has previously extracted equity. The predominant form of equity extraction is through refinancing, i.e. obtaining a new mortgage, so that the repayment schedule would indeed be reset.

Table 2.4: Debt Reduction from Multiperiod Cap

	Debt reduction		Composition of Debt Reduction		
Year	*Single Period Cap*	*Multi-period Caps*	*From Initial Balance*	*Reduced Extrac-tion*	*Reduced Repay-ments*
2003	1.95%	1.95%	0.00%	1.95%	0.00%
2005	1.74%	2.75%	1.54%	1.42%	-0.22%
2007	1.69%	3.21%	2.27%	1.28%	-0.35%
2009		2.56%	3.00%	0.00%	-0.44%
2011		2.21%	2.68%	0.00%	-0.47%

Note: Reduction in total mortgage debt outstanding from successively capping equity extraction between 2001 and 2007. Each transaction is adjusted such that the resulting LTV is reduced by ten percentage points but never below 0.6 or the initial balance. Capped balances are carried forward as described in the text. The last column shows the effect that reduced balances have on repayments.

impact of the 2003 cap is about 0.4 percentage points lower for example, as can be seen in Table 2.4 by comparing the second line in column four to the first line in column three.[19] Given the effect recorded for the single period cap, total debt reduction would still need to be higher than what is shown in the second line of column three. The remaining difference is due to how lower starting values affect balance changes during the period. Because households starting out with lower balances are less likely to hit the cap when trying to extract equity again, the debt reduction from capping equity extraction reported in column five is below the single period cap effect reported in column two. Also households that do not extract equity reduce their balances by less after having been capped once, which is shown in the last column. About half of this effect comes from how regular repayments are assumed to be affected. The remainder is due to capped homeowners either becoming renters or buying a new residence with more available equity. While each individual effect is small, in combination they mean that even under a regime that caps equity extraction over a six year period, the overall outstanding mortgage balance is reduced by only 3.2 percent in 2007, and that this distance begins to shrink once caps are removed.

Limiting equity extraction also moves the entire LTV distribution to the left. Table 2.5 shows the cumulative value at selected thresholds and by how much this deviates from the

---

[19] Most of the rise in the base stems from regular additions to the mortgage base. About six percent of the entire outstanding mortgage volume are new balances that cannot be clearly identified as new mortgages. While these are offset by attrition, they could not have been subject to a cap in previous simulation periods. To adjust for this, one could reduce the balances by a factor corresponding to the overall debt decrease, but the change would only be a fraction of a fraction. Attrition itself does not affect results because there is no systematic difference in how the cap has affected households leaving the sample.

Table 2.5: Impact of Multiperiod Cap on the LTV Distribution

	LTV Distribution Under Cap				Distance to Actual Distribution			
Year	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*
2003	50.1%	81.8%	91.0%	98.2%	0.0%	3.4%	1.7%	0.5%
2005	55.2%	83.0%	91.3%	98.3%	1.6%	3.8%	2.2%	0.7%
2007	57.5%	83.4%	92.6%	98.1%	2.7%	4.0%	2.4%	0.7%
2009	47.8%	72.3%	82.8%	92.1%	2.9%	4.0%	2.5%	0.9%
2011	43.4%	68.0%	78.6%	89.9%	2.2%	3.3%	2.1%	0.8%

Note: Share of mortgage holders who are at or below the indicated LTV value if equity extraction is capped successively between 2001 and 2007 as in the previous table. The last four columns show the percentage point reduction compared to the actual distribution.

actual distribution that has been outlined in Table 2.2. The share of households with LTV ratios in excess of 0.8 is reduced by about four percentage points. As Table 2.5 shows, this reduction already happens while the caps are active and then largely persists after 2007. Up to 2007, negative equity was rarely reported, so that the reduction for this bracket cannot be large either. But also when declining house prices shift the actual LTV distribution to the right, the previously applied LTV caps can hardly mute the sharp increase in underwater mortgages. In 2009, about nine percent of homeowners had LTV ratios exceeding one. As shown in the table, the simulation reduces this fraction by 0.9 percentage points, which corresponds to a ten percent reduction in underwater mortgages. One part of this group are households who only bought their house after the 2005 interview and could therefore not have been affected by the cap. However, the larger share of negative equity mortgages in 2009 is due to seasoned homeowners who have held a mortgage since at least 2005. When I restrict the analysis to include only those seasoned homeowners, the fraction of underwater mortgages is about seven percent in 2009, and the simulated reduction is 1.3 percentage points. Hence, among the group potentially affected by the cap, the occurrence of negative equity is reduced by about 18 percent.

To understand why the effect of caps on equity extraction is relatively small, one can also look at how much different groups contribute to overall equity extraction. First of all, Table 2.6 shows that the larger part of equity extraction is indeed affected by the cap. As described above, any household going beyond an LTV ratio of 0.6 has its transaction volume reduced in the scenario considered here. This corresponds to all transactions from the two highest main brackets in Panel a).[20] Hence, the effect of the cap is limited despite the fact that it is tight enough to affect more than half of all transactions. The reason is that, for most of them, the amount extracted is reduced by only a fraction. This is especially the case for larger transactions which tend to be conducted by households who have little debt initially.

The importance of equity extraction by households with low initial LTV ratios is shown in Panel b). There, the transaction volume is assigned to the leverage brackets based on households' beginning-of-period LTV ratio. Note that, as shown in in Table 2.2, each of the main brackets contains roughly the same share of mortgage holders before the house price bust. The highest bracket is made up of households that are already above the 0.8 threshold. Their share in equity extraction remained small throughout the housing boom. In that sense, those with the highest debt ratios were not disproportionately affected by easing financing conditions or the general rise in collateral values. The intermediate bracket with LTV ratios between 0.6 and 0.8 displays a clearer cycle in equity extraction over the sample period. However, the bracket represents only a quarter of total equity extraction and the absolute increase for the lower LTV ratios is more pronounced. This means that households with LTV ratios below 0.6 account for the largest share of equity extraction across all periods, and they also contribute most to the increase toward the 2005 peak.

Panel c) illustrates the important role that house prices have played in relaxing potential LTV constraints. The extraction volume is grouped according to the LTV ratio that would have resulted from the transaction if the beginning-of-period home value had not changed. I label the result as cross leverage ratio because it relates the end-of-period balance to the beginning-of-period collateral value. According to this measure, more than twenty percent of all transactions would result in LTV ratios above one. Such high LTV levels are rarely observed in the data, suggesting that absent house price increases those transactions would have occurred differently. Also the share of extraction leading to ratios above 0.8 doubles if house price growth is not considered.

One could further ask to what extent the fact that most equity is extracted by households with low initial debt ratios is driven by a lagged response to past price appreciation. To assess this, I calculate a modified initial LTV ratio that relates the mortgage balance in the beginning of the period to the home value reported two years earlier if a household has neither moved nor extracted equity since then. For all other households, including those

---

[20] The tables are based on extracted volumes, so that the shares are value weighted. The share of transactions in the higher brackets is generally smaller, but it still amounts to about fifty percent in this case.

Table 2.6: Extracted Equity by LTV Bracket

Panel a) Share of Extracted Volume by Resulting LTV Bracket

	Main Brackets				Memo	
Year	*0<LTV ≤ 0.4*	*0.4<LTV ≤ 0.6*	*0.6<LTV ≤ 0.8*	*0.8<LTV*	*LTV=0*	*1<LTV*
2001	20.7%	21.3%	33.3%	24.7%	0.0%	6.0%
2003	13.0%	28.6%	35.1%	23.4%	0.0%	2.5%
2005	18.9%	27.1%	34.9%	19.1%	0.0%	3.3%
2007	19.2%	22.8%	32.7%	25.3%	0.0%	4.8%
2009	13.3%	22.8%	20.6%	43.3%	0.0%	19.2%
2011	17.5%	22.6%	27.1%	32.8%	0.0%	16.3%

Panel b) Share of Extracted Volume by Initial LTV Bracket

	Main Brackets				Memo	
Year	*0<LTV ≤ 0.4*	*0.4<LTV ≤ 0.6*	*0.6<LTV ≤ 0.8*	*0.8<LTV*	*LTV=0*	*1<LTV*
2001	26.6%	19.1%	21.6%	10.7%	22.0%	0.5%
2003	25.2%	30.4%	24.2%	7.5%	12.8%	0.4%
2005	28.5%	21.7%	26.2%	9.7%	13.9%	1.3%
2007	28.0%	26.5%	20.3%	12.0%	13.2%	0.2%
2009	39.7%	20.6%	16.0%	6.4%	17.3%	0.2%
2011	33.0%	25.7%	10.0%	14.1%	17.2%	3.1%

Panel c) Share of Extracted Volume by Cross Leverage Bracket

	Main Brackets				Memo	
Year	*0<LTV ≤ 0.4*	*0.4<LTV ≤ 0.6*	*0.6<LTV ≤ 0.8*	*0.8<LTV*	*LTV=0*	*1<LTV*
2001	13.0%	19.3%	22.1%	45.7%	0.0%	22.5%
2003	9.4%	18.4%	24.9%	47.3%	0.0%	18.6%
2005	10.2%	14.7%	21.5%	53.5%	0.0%	25.2%
2007	12.9%	19.3%	20.8%	47.0%	0.0%	24.9%
2009	19.7%	23.4%	25.9%	31.0%	0.0%	11.2%
2011	20.3%	23.1%	27.0%	29.6%	0.0%	16.3%

Note: Split of total equity extracted (see Table 2.1, Panel c) according to the extracter's LTV ratio after and before the transaction. Panel c) assigns the amount according to the LTV bracket that would have resulted absent house price changes. All amounts are weighted using household weights.

that have become homeowners during the period, the regular LTV ratio is used instead. Grouping extracted volume by this modified initial LTV ratio, the contribution by the upper two leverage brackets is considerably larger than in Panel b). Until 2005 it even exceeds extraction from the lower brackets, but those continue to play an important role, both in terms of volume and cyclicality.

In summary, LTV caps on equity extraction would only play a small role in limiting debt growth. While equity extraction has been a significant driver in the increase of total mortgage balances outstanding, most of it comes from households with low initial leverage who are less affected by a cap. Of course, specific targeting of transactions by highly levered households can be seen as an advantage of the policy. Indeed, it reduces the occurrence of LTV ratios above the 0.8 benchmark by four percentage points. On the other hand, the share of underwater mortgages remains high after 2007. Strong fluctuations in home values mitigate most of the effects of LTV regulation. During the pre-crisis period, only households above the 0.8 threshold extract disproportionately little equity, which is consistent with the low weight that Iacoviello and Neri (2010) assign to households that are borrowing constrained due to their leverage ratio. However, with falling house prices this group appears to become much larger. Not only does the fraction of homeowners with LTVs in excess of 0.8 increase considerably, but also borrowing from the intermediate leverage bracket shrinks much more than among other homeowners. This happens despite the fact that, conditional on equity extraction, it becomes more likely to see high resulting LTV ratios. On the other hand, there was no trend toward higher realized LTV ratios among equity extracters during the phase of home price appreciation.

The observation that equity extraction predominantly comes from households with lower LTV ratios augments the picture emerging from recent work by Adelino, Schoar, and Severino (2015) and Albanesi, DeGiorgi, and Nosal (2016). These authors challenge the narrative that “The expansion of mortgage credit to marginal borrowers kicked off an explosion in household debt in the U.S. between 2000 and 2007” (Mian and Sufi (2014), page 76) by providing evidence from credit record and loan application data that most additional borrowing came from middle class and high income households with good credit scores. The PSID data allows to look at the asset side as well and suggests that it was neither the case that additional borrowing was concentrated among low net worth households.[21]

---

[21] The finding that borrowers with low income and bad credit rating were not driving credit growth also means that it is unlikely that LTV ratios among extracters were low because they had not been able to borrow more before.

2.5 LTV Caps and Purchase Mortgages

The analysis so far has excluded purchase mortgages. The basic conceptual difficulty is to formulate a counterfactual purchase decision if it is not possible for the household to borrow as recorded in the data. Most purchases are highly levered. The median LTV ratio is around 0.8 over the entire sample period, and more than 25 percent of households report values in excess of 0.9. Through a leverage effect, a tighter cap would massively reduce purchase values households could still afford unless they used additional equity. In a scenario where all purchase LTV ratios are reduced by ten percentage points, households at the median would have to buy a house that is 33 percent cheaper, and the highest quartile could at most afford half of the reported value of their home. It is unclear whether a purchase would still occur in such cases. On the other hand, many households may not be able or willing to supply significantly more equity. As an indicator, I calculate the liquid assets that new homeowners with LTV ratios of at least 0.6 still have available after a purchase. At the median, they correspond to only 2.5 percent of their home value. Only about twenty percent of households have sufficient liquid assets to match an increase of their down payment by ten percent of the home value.

In this framework, it is not possible to assess how much more equity new homeowners would be able to generate by increasing saving or through additional labor supply. Therefore, I will only present results for an extreme scenario where all households manage to purchase the same home at the same price but with a lower LTV ratio. In terms of the reduction of aggregate debt this can be seen as a lower bound. Because households supply that much additional equity, they are still able to take out a mortgage of similar magnitude as observed in the data. Nevertheless, the results illustrate to what extent LTV caps on purchase mortgages would be effective without impairing new home ownership. Any further decrease in aggregate debt would require that households either purchase less housing or no housing at all. Again, I abstract from a general equilibrium effect via prices. In terms of the occurrence of negative equity, the simulation results would be the same even if households chose to purchase cheaper homes as long as one assumes only regular repayments and the same relative price fluctuations.

As displayed in Table 2.7, expanding the class of transactions subject to the cap noticeably reduces the total simulated mortgage balance. Gross additions from new homeowners are decreased by almost exactly ten percent in each period where the cap is applied. This

Table 2.7: Debt Reduction When Capping All Balance Increases

		Composition of Debt Reduction				
Year	*Total Debt Reduction*	*From Initial Balance*	*New Homeowners*	*Movers*	*Equity Extraction*	*Reduced Repayments*
2003	4.24%	0.00%	1.28%	1.01%	1.95%	0.00%
2005	6.01%	3.36%	1.08%	0.81%	1.13%	-0.37%
2007	7.10%	4.93%	1.14%	0.86%	0.84%	-0.66%
2009	5.41%	6.66%	0.00%	0.00%	0.00%	-1.24%
2011	4.53%	5.53%	0.00%	0.00%	0.00%	-1.00%

Note: Reduction in total mortgage debt outstanding from successively capping equity extraction as well as purchase mortgages between 2001 and 2007. Each transaction is adjusted such that the resulting LTV is reduced by ten percentage points but never below 0.6 or the initial balance. Capped balances are carried forward as described in the text. The last column shows the effect that reduced balances have on repayments.

mechanically results from the fact that all of them start at a zero balance, and most go to an LTV ratio close to one, meaning that a ten percentage point reduction of the LTV ratio brings down the mortgage balance by just a little more than ten percent. While there is a considerable number of new homeowners with LTV ratios below 0.6 in the data, their balances tend to be smaller, so that they account for only ten percent of the purchase mortgage volume. The cap hence applies for a large share of the transaction volume, but each individual transaction is reduced by just a fraction. This moderating effect is even more pronounced than for equity extracters. Therefore, the cap on new purchases initially contributes less to the reduction in mortgage debt than the cap on equity extraction, although loans to new homeowners make up a much larger share of gross additions. In later periods, capped equity extraction falls considerably below the single period benchmark. This is mainly driven by the fact that, because of prior caps, households can extract more before hitting their LTV limit. One can directly compare the value in column six of Table 2.7 to what is reported in column five of Table 2.4 to see how capping balances from purchase mortgages contributes to this. The table also shows the effects of capping mortgage debt for homeowners who move to a new residence. Because gross additions from moving homeowners contribute least to mortgage debt growth in Table 2.7, also their share in total debt reduction from the cap is smallest. One should note that movers have more liquid wealth relative to their new home's value than first time buyers or even other seasoned homeowners. The assumption that they can rely on own equity in response to an LTV cap may therefore be more appropriate for them.

The additional equity provided for home purchases also shows up in the simulated LTV distribution shown in Table 2.8. Compared to the previous scenario, more than twice as many mortgages are moved below the 0.8 threshold while the cap is active. Also the reduction in mortgages with LTV ratios above 0.9 is more pronounced. Typically, those are purchase mortgages which are now also subject to the cap. The reduction almost carries over to 2009, and the share of mortgages below 0.8 is now comparable to the pre-crisis value from the data. Nevertheless, there is still a surge in underwater mortgages and the gap to the actual values closes toward 2011.

Table 2.8: Impact of Multiperiod Cap for All Balance Increases on the LTV Distribution

	LTV Distribution Under Cap				Distance to Actual Distribution			
Year	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*
2003	50.1%	85.8%	94.9%	98.5%	0.0%	7.3%	5.5%	0.9%
2005	56.9%	87.7%	96.1%	98.8%	3.3%	8.5%	7.0%	1.2%
2007	60.3%	89.1%	96.9%	98.5%	5.5%	9.7%	6.7%	1.1%
2009	50.1%	76.0%	86.5%	93.2%	5.1%	7.7%	6.2%	2.1%
2011	44.7%	70.5%	81.2%	90.9%	3.6%	5.7%	4.7%	1.7%

Note: Share of mortgage holders who are at or below the indicated LTV value if equity extraction as well as purchase mortgages are capped successively between 2001 and 2007 as in the previous table. The last four columns give the percentage point increase in homeowners at or below the indicated threshold relative to the actual distribution.

2.6 Conclusion

This paper takes a detailed look at the mortgage choices of a panel of several thousand U.S. households. Applying plausible LTV caps to all equity extraction observed since 2001 reduces debt outstanding in 2007 by just 3.2 percent. Given that total mortgage debt doubled over that period, the direct effect of applying LTV caps to equity extraction appears to be small. The data suggest that, due to rapid house price appreciation, only a minority of homeowners were genuinely borrowing constrained in terms of their leverage ratio. Even the artificially imposed constraints do not bind very tightly then for most equity extracters. The surge in underwater mortgages after 2007 was caused by massive drops in the reported value of many homes. These were often too large to be offset by moderate debt decreases, so that the caps hardly reduce the occurrence of negative equity. Applying the cap also to purchase mortgages strengthens its effectiveness, so that it would be of interest to better understand the implications for home ownership and equilibrium prices.

The details of how the LTV distribution evolves over time yield some observations that could inform the model-based analysis of housing and mortgage debt. Since borrowing is pervasive among homeowners with moderate leverage ratios during the boom, the drop in house prices seems to considerably expand the fraction of households that are borrowing constrained. This extensive margin could be important for assessing the effects of house price fluctuations. It would also be of interest whether studies that find exogenous changes in LTV limits to be an important driver of the housing cycle replicate the stability of the LTV distribution over the boom phase and the persistent right shift following the bust.

2.A Appendix A: Results for a Multiperiod LTV Cap at 0.7

The multiperiod benchmark scenario from the main text caps each household at an LTV ratio ten percentage points below what is observed in the data. This appendix presents additional results for the scenario where a hard cap of 0.7 is used instead for all households. The following table is the equivalent of Table 2.4 in the main text.

Table 2.9: Debt Reduction from Multiperiod Hard Cap at 0.7

	Debt reduction		Composition of Debt Reduction		
Year	*Single Period Cap*	*Multi-period Caps*	*From Initial Balance*	*Reduced Extrac-tion*	*Reduced Repay-ments*
2003	1.56%	1.56%	0.00%	1.56%	0.00%
2005	1.50%	2.35%	1.20%	1.35%	-0.20%
2007	1.64%	3.00%	1.94%	1.38%	-0.33%
2009		2.31%	2.80%	0.00%	-0.49%
2011		1.94%	2.41%	0.00%	-0.48%

Note: Reduction in total mortgage debt outstanding from successively capping equity extraction between 2001 and 2007. Each transaction is adjusted such that the resulting LTV is at most 0.7 but never below the initial balance. Capped balances are carried forward as described in the text. The last column shows the effect that reduced balances have on repayments.

The resulting reduction in debt is very similar to what is reported in the main text. The LTV distribution looks somewhat different because the hard cap bunches many households at the 0.7 threshold. During the bust period, the difference in how many households have LTVs in excess of 0.9 in both scenarios almost vanishes, however.

Table 2.10: Impact of Multiperiod Hard Cap on the LTV Distribution

	LTV Distribution Under Cap				Distance to Actual Distribution			
Year	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*
2003	50.1%	83.2%	91.6%	98.4%	0.0%	4.7%	2.2%	0.7%
2005	54.9%	84.6%	92.1%	98.5%	1.3%	5.4%	3.0%	0.9%
2007	56.8%	85.1%	93.5%	98.6%	2.1%	5.8%	3.3%	1.1%
2009	47.4%	72.4%	82.9%	92.2%	2.5%	4.1%	2.6%	1.0%
2011	43.0%	67.7%	78.5%	90.1%	1.8%	3.0%	2.0%	0.9%

Note: Share of mortgage holders who are at or below the indicated LTV value if equity extraction is capped successively between 2001 and 2007 as in the previous table. The last four columns show the percentage point reduction compared to the actual distribution.

.

Because new homeowners use higher LTV ratios, the difference between the scenarios is more noticeable when purchase mortgages are capped as well. The debt reduction by 2007 in Table 2.11 is 8.8 percent, while it was 7.1 percent in Table 2.7.

Table 2.11: Debt Reduction from Hard Cap on All Balance Increases

		Composition of Debt Reduction				
Year	*Total Debt Reduction*	*From Initial Balance*	*New Homeowners*	*Movers*	*Equity Extraction*	*Reduced Repayments*
2003	4.59%	0.00%	1.87%	1.16%	1.56%	0.00%
2005	6.95%	3.60%	1.76%	0.85%	1.19%	-0.45%
2007	8.81%	5.69%	1.76%	1.21%	1.07%	-0.91%
2009	6.55%	8.19%	0.00%	0.00%	0.00%	-1.64%
2011	5.36%	6.63%	0.00%	0.00%	0.00%	-1.27%

Note: Reduction in total mortgage debt outstanding from successively capping equity extraction as well as purchase mortgages between 2001 and 2007. Each transaction is adjusted such that the resulting LTV is at most 0.7 but never below the initial balance. Capped balances are carried forward as described in the text. The last column shows the effect that reduced balances have on repayments.

Accordingly, there is also a stronger shift in the distribution of LTV ratios. Comparing Table 2.10 and Table 2.12 illustrates how many homebuyers use LTV ratios in excess of 0.8, as they are all capped to 0.7 till 2007 in Table 2.12. Afterwards, the difference to the distribution in Table 2.8 shrinks considerably.

Table 2.12: Impact of Multiperiod Hard Cap for all Balance Increases on the LTV Distribution

	LTV Distribution Under Cap				Distance to Actual Distribution			
Year	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*	*LTV≤0.6*	*LTV≤0.8*	*LTV≤0.9*	*LTV≤1*
2003	50.1%	91.4%	96.0%	98.9%	0.0%	13.0%	6.6%	1.30%
2005	57.4%	95.5%	97.7%	99.4%	3.7%	16.3%	8.7%	1.8%
2007	60.7%	96.9%	98.6%	99.3%	6.0%	17.5%	8.4%	1.85%
2009	50.9%	79.7%	87.8%	94.1%	5.9%	11.3%	7.6%	3.0%
2011	46.0%	72.9%	82.2%	91.8%	4.8%	8.2%	5.7%	2.7%

Note: Share of mortgage holders who are at or below the indicated LTV value if equity extraction as well as purchase mortgages are capped successively between 2001 and 2007 as in the previous table. The last four columns give the percentage point increase in homeowners at or below the indicated threshold relative to the actual distribution.

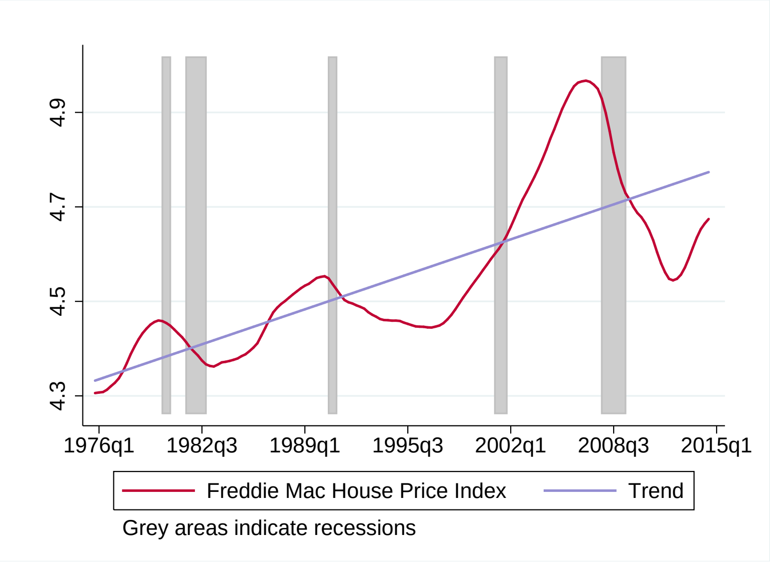
Chapter 3

What Drives the Volatility and Persistence of House Price Growth?

3.1 Introduction

Residential real estate is the largest asset class on U.S. households' balance sheets and subject to substantial price fluctuations. Figure 3.1 shows a recurring pattern where real house prices grow faster than trend for several years and then contract.[1] This results in considerable volatility and strong momentum in price changes. The standard deviation of annual price growth rates is five percentage points, and the serial correlation is 0.7, meaning that a five percent increase in house prices is associated, on average, with another 3.5 percent increase in the following year. This high degree of predictability in price growth sets housing apart from other important asset classes. For the S&P 500 stock price index, for example, the serial correlation in annual growth rates is only 0.3, while the standard deviation is thirteen percentage points. Also factors that are typically considered as drivers of house prices, such as per capita income or interest rates, exhibit much less serial correlation in their rate of change. Glaeser, Gyourko, Morales, and Nathanson (2014) show that the momentum in fundamentals cannot explain the momentum in house prices in a rational, frictionless market.

Figure 3.1: Freddie Mac House Price Index



Notes: Logarithm of the national price index deflated by the CPI urban excluding shelter.

In this paper I study the house price dynamics generated by a calibrated life cycle model where heterogeneous households trade owner-occupied real estate. To capture important frictions in the housing market, I introduce transaction costs and a down payment requirement. Households are subject to idiosyncratic as well as aggregate income shocks that affect

---

[1] Appendix 3.A gives a detailed description of the data that is used to construct all figures and statistics.

their purchase decisions. The consideration of aggregate income shocks is motivated by the observation that the *level* of detrended per capita income correlates strongly not only with the level of detrended house prices, but also with house price *growth rates.*[2] Therefore, I use the model to ask to what extent the fluctuations in real per capita income in the U.S. over the past forty years can account for the observed pattern in price growth rates. This is a nontrivial issue because the income process is moderately persistent and mean reverting. In order to replicate the observed momentum of annual price growth, a rise in the income level not only has to generate house price growth on impact, but also in subsequent periods.

The modeling framework explicitly accounts for the fact that the market for single family homes is dominated by individuals infrequently trading in the homes they live in,[3] and a main contribution is the incorporation of subjective price beliefs in such a setting. Valuation of properties is subject to large uncertainty (Quan and Quigley (1991)), and in a series of surveys conducted since 1988 in different U.S. metropolitan areas, Case, Shiller, and Thompson (2012) find that past house price movements play an important role in shaping both short and long term price expectations of homebuyers. Similarly, Piazzesi and Schneider (2009) document that during the last housing boom optimism regarding future house price growth peaked when prices had already reached their all time high. Such biases do not seem to be unique to prices for real estate, but it is of interest to study their effect within the particular structure of the housing market. As chairman of the Federal Reserve, Greenspan (2004) argued that large transaction costs and the necessity to move when trading properties were important restraints on the development of house price bubbles. On the other hand, Adam, Marcet, Merkel, and Beutel (2015b) find that with belief biases that lead to extrapolation transaction costs in the form of a linear transaction tax would increase the volatility of prices and the likelihood of booms and busts in the stock market.

As part of the analysis, I find that in a version of the model with fully elastic housing supply and constant prices the transaction cost and down payment requirement themselves play an important role in shaping a persistent response of housing expenditures. In contrast to a model without these adjustment frictions, housing purchase volume rises over several years when the aggregate income level is above trend, and the subsequent decline is drawn-

---

[2] The latter correlation is 0.45, while the correlation between the house price level and income growth is slightly negative and insignificant.

[3] Already Linneman (1986) and Case and Shiller (1989) point out that there is good reason to think that this makes the housing market less efficient than other financial markets. Regarding the difficulties of arbitrage by outside investors see also the detailed discussion in Glaeser and Gyourko (2007).

out over several periods as well. Adjustment frictions hence lead to positive serial correlation in the growth rate of housing expenditures. The result is reminiscent of Berger and Vavra (2015), who show that lumpy adjustment patterns make aggregate durable expenditures highly procyclical. During booms, the fraction of households close to adjusting increases over time, so that the response of expenditures to further positive shocks in their model can be twice as large as during other periods. In my model, this applies in particular to rent-to-own transitions, as more and more households pass the threshold to buying a home each year.

I then address the question how this pattern translates into equilibrium prices when there is a constant stock of owner-occupied real estate. The assumption of a constant housing supply maximizes the potential price impact of income shocks and is motivated by the fact that metropolitan areas with low supply elasticities are indeed an important driver of the the national index depicted in Figure 3.1.[4] I find that if expectations are fully rational, both serial correlation and volatility of price growth rates are significantly smaller than in the data despite the adjustment frictions. In high income periods, potential buyers become wealthier each period and prices rise to ensure market clearing. Yet, a sequence of aggregate income shocks chosen in line with the fluctuations observed in per capita income over the past forty years implies that the serial correlation of annual price growth rates in the model is about half of its data counterpart, and the standard deviation is less than one percentage point – just twenty percent of the value observed in the data. While relatively small income shocks can elicit a strong nonlinear response in purchase volume under constant prices, small changes in equilibrium prices are also sufficient to contain the adjustment impulse.

Nevertheless, in a model without adjustment frictions the standard deviation of price growth rates would be even lower at 0.5 percentage points. This is due to rent-to-own transitions in the benchmark model, where buying a house generally offers a superior return on the equity invested. Therefore, expected mean reversion in prices plays a smaller role for new homeowners than for existing homeowners who are more apt to pay down relatively expensive mortgage debt and delay upgrades. Even if prices are likely to increase for several periods, homeowners can expect to upgrade at a lower price eventually. The trading dynamics

---

[4] The correlation between the average price index for the 25 metropolitan areas with the lowest supply elasticity according to the measure developed by Saiz (2010) and the national index is 0.998, and the degree of persistence and mean reversion in growth rates are very similar. An example is the San Francisco metropolitan area, where the housing stock on average grew by just 0.5 percent per year between 1984 and 2008 (Paciorek (2013)).

in the model reveal that their purchase volume declines during high income periods, while that of new homeowners increases.

To explore the possibility that subjective house price beliefs contribute to house price dynamics, I build on the framework developed in Adam and Marcet (2011) and Adam, Marcet, and Beutel (2015a). The setup maintains internal rationality in the sense that decisions are optimal given a well-defined system of subjective probability beliefs about future house prices. It emphasizes agents' uncertainty about the relationship between house prices and economic fundamentals, giving rise to a learning problem, where optimal behavior implies that past observations are used to update beliefs regarding future prices. In line with the evidence from household surveys, this introduces an extrapolative component into price growth expectations. Given that beliefs are expressed as an entire probability distribution over future prices, agents nevertheless assign some weight to the possibility of sharp price declines even during booms.

I find that with subjective beliefs that lead to extrapolation income shocks give rise to price dynamics that are much closer to the data. The serial correlation of price growth rates is 0.83, and the standard deviation is 3.5 percentage points – about seventy percent of the observed value. Overall, the correlation between actual price growth rates and the ones implied by feeding the time series of observed income shocks into the model is 0.6. A notable deviation occurs during the last housing boom, where the model only matches the high growth rates during the early stage. More generally, the extrapolative component in expectations does not generate explosive house price dynamics, but amplifies price responses to fundamental shocks. The presence of adjustment frictions means that only a fraction of households are in the market each period, and all of them plan large adjustments that do not change by much in response to an income shock. This leads to a dampened, drawn-out price response compared to a scenario where households adjust more frequently.

The remainder of this paper is organized as follows. Section 3.2 discusses some of the related literature. Section 3.3 describes the model setup and how expectations are formed. Section 3.4 presents the calibration approach and the fit between the model and cross-sectional facts on savings, home ownership, and the composition of homebuyers. Section 3.5 discusses the model results under both rational expectations and subjective beliefs. Section 3.6 concludes.

3.2 Related Literature

There are a number of studies emphasizing the role of systematic biases in beliefs for house price dynamics. Agents' uncertainty regarding fundamentals leads them to extrapolate from past prices in a way that is consistent with the survey evidence in Case et al. (2012) and Piazzesi and Schneider (2009). In Glaeser and Nathanson (2015), a "convenient approximation" by agents induces significant momentum following unobserved innovations in the growth rate of fundamentals. Gelain, Lansing, and Mendicino (2013) introduce an adaptive component into forecasts for all variables in agents' decision problems, which generates excess volatility in prices. They find that the nature of agents' expectations is important for policy assessment. Adam, Kuang, and Marcet (2011) also use the subjective beliefs framework from Adam and Marcet (2011) and study the impact of the decline in real interest rates starting in 2001. My model adds to that literature by studying market clearing in a heterogeneous agent economy, where agents trade for fundamental reasons, face significant transaction costs, and switch between renting and owning. It documents that in such a setting realistic level changes in income can explain much of the observed patterns in price growth rates, provided that one incorporates subjective beliefs that lead to extrapolation. The fact that the model generates the high price growth observed during the early years of the last housing boom is an interesting connection to Adam et al. (2011), where high initial price growth due to exogenous preference shocks amplifies the price response to the interest rate decline after the year 2000. My setting abstracts from time variation in financial conditions.

The emphasis on trade that occurs for fundamental reasons is also of interest with respect to the literature that studies the effect of extrapolative expectations on stock prices. While there is no trade in the representative agent model of Adam et al. (2015a), the stock market model of Adam et al. (2015b) considers trading that is due to belief disagreement. They find that a linear transaction tax would increase price volatility during normal times and the probability of boom-bust scenarios. The reason is that, due to investors' inaction regions, it may take relatively large price adjustments to absorb small supply shocks. With richer heterogeneity, there are many potential buyers and sellers close to their adjustment threshold who could absorb small disturbances. The main effect of adjustment frictions in my model is that the response to an income shock is smaller when households adjust less frequently.

Even with a comprehensive set of shocks, many rational expectations models have difficulty matching the volatility of house prices. Iacoviello and Neri (2010), for example, require a volatile and very persistent exogenous process driving housing preferences. However, Favilukis, Ludvigson, and Van Nieuwerburgh (2016) present a rich general equilibrium model with heterogeneous agents and adjustment frictions that can match the volatility of HP filtered house prices along with other business cycle moments. They do not focus on the serial correlation in price growth rates but emphasize the importance of time-varying risk premia in their model. High house prices are hence associated with lower expected returns. This corresponds well with the data but less well with survey evidence on expectations. While my model is less rich than Favilukis et al. (2016) along several dimensions, I do add rent-to-own transitions and find that they play a role in inducing additional price volatility under rational expectations. The trading patterns that arise also suggest a role for relaxing the common assumption that the size distribution of the housing stock can be rearranged each period. This is consistent with findings in the more stylized models by Ortalo-Magné and Rady (2006) and Landvoigt, Piazzesi, and Schneider (2015).

Favilukis et al. (2016) is also one of several papers that calculate the transition path to a new steady state following a change in fundamentals. Such transitions are another mechanism to generate high price growth over several consecutive years. One factor is that agents typically take the change in fundamentals to be permanent.[5] While there can be overshooting along the transition path, such as in Chu (2014), mean reversion requires a revision in fundamentals. The fact that this is not anticipated by agents can be seen as another type of belief bias driving house price dynamics, but the approach focuses on single episodes.

Finally, models that take into account search frictions in the housing market have been successful at generating serial correlation in price growth rates. Head, Lloyd-Ellis, and Sun (2014) empirically document serial correlation and excess volatility in house price growth rates in response to mean reverting income shocks at the city level. Relocation of agents can generate this pattern for single cities in their model, but they do not address the implications for national house price trends. In Hedlund (2015b) the combination of search frictions and long-term, defaultable mortgages generates considerable volatility and momentum in house prices, which is a significant achievement relative to the literature. It is nevertheless of interest to study the role of systematic belief biases, since policy conclusions may differ. For

---

[5] In current work by Kaplan, Violante, and Mitman (2015), fundamentals such as credit conditions and housing preferences are expected to follow a unit root process, and a particular sequence of innovations causes a large swing in house prices as well.

example, Hedlund (2015a) finds in related work that countercyclical borrowing limits reduce welfare, but extrapolative price expectations may produce a different assessment.

3.3 The Model

3.3.1 Environment

Time is discrete and infinite and measured in years. Each period, a constant mass of households enters the economy and starts working for N years. Income $y_{i,n,t}$ of household i aged $n \leq N$ in period t is measured in units of the numeraire good. It depends on a deterministic age-specific component $\bar{y}_n$, an idiosyncratic component $z_{i,t}$, an aggregate component Z_t, and the deterministic growth rate λ:

$$\ln y_{i,n,t} = \ln \bar{y}_n + z_{i,t} + Z_t + \lambda t.$$

Both $z_{i,t}$ and Z_t follow Markov chains defined on the finite sets Ω_z and Ω_Z, and $\bar{y}_n$ is hump shaped in age. Households have time-separable preferences and discount the future at rate β. Their per-period utility function is given by

$$u(c,h) = \frac{1}{1-\gamma}\left(c^{1-\nu}h^{\nu}\right)^{1-\gamma},$$

where c denotes how much of the numeraire good is consumed and h measures the quantity of housing services available to the household. Those are derived from either renting or owning a housing unit of size h in that period.[6]

Owner-occupied housing and rental housing are traded in separate markets. The stock of owner-occupied housing is fixed and owned by working age households in the economy. The menu of different sizes available for purchase is given by Ω_h, and households own at most one of these units. Owners pay a maintenance cost $\mu_t h$ each period that fully offsets depreciation. To adjust their housing space, owners must sell the unit they currently own and newly purchase or rent a unit of the desired size. Each seller incurs a transaction cost that is a fraction φ of the sales price. The outlined life cycle income profile will nevertheless lead homeowners to move to larger or smaller units occasionally to adapt to changes in income and wealth. In order to account for other reasons to reenter the housing market, I also include

---

[6] While I will always refer to it as size, h could also be interpreted more broadly as a composite of size and location for example.

exogenous moving shocks. With probability π_ε, a household must move to a different location and, as a homeowner, incurs the selling cost. I assume that the size distribution going into the market can be converted at no further cost into the size distribution that agents want to purchase. This reduces market clearing to the single condition that the total quantity of owner-occupied housing does not change. It also means that the value of a home is directly proportional to its size and given by $p_t h$.

Rental housing is owned and operated by firms that fund themselves in the international financial market. In each period, they are able to supply the desired quantity of apartment space at a rental rate q_t. The rental rate is not explicitly linked to a market clearing condition, but it can fluctuate with the price for owner-occupied housing and grows with per capita income. Moving between rental units is costless for households, and renters can choose any unit size between $h_{min} = \min(\Omega_h)$ and $h_{max} = \max(\Omega_h)$.

Households can invest their surplus funds in the international financial market at riskless rate r. They can also borrow at rate $r^b > r$ when posting housing collateral. Upon origination of the loan, the amount outstanding (including the first interest payment) cannot exceed a fraction θ of the current home value. A loan must be fully repaid whenever the house is sold, but the borrower can also decide to default on the outstanding amount by handing over the collateral. The house is then put on the market immediately, but the lender has no further claims against the borrower. A household cannot buy a new house in the period of default.[7] As long as debt is below the borrowing limit $\frac{\theta p_t h}{1+r^b}$, a homeowner is free to increase the outstanding debt. If prices fall, this threshold may be exceeded. In such a case, the only requirement regarding repayment is that the amount outstanding grows at most at the exogenous growth rate λ, but it is not necessary to supply additional equity. This setup reflects the pattern that equity extraction is often observed in response to house price increases, while households' leverage ratios can remain high after a price drop (compare for example Justiniano, Primiceri, and Tambalotti (2015)). In summary, the lower bound for financial assets a_{t+1} at the beginning of period $t+1$ is given by

$$a_{t+1}\exp(-\lambda) \quad \geq \quad \min\left(-\frac{\theta p_t o_t h_t}{1+r^b}, a_t \mathbb{1}_{[o_t h_t = o_{t-1} h_{t-1} \wedge \varepsilon_t = 0]}\right)$$

---

[7] Actual defaults play a quantitatively small role in the model, so that the setup is deliberately coarse. As discussed in Section 3.3.3 and Section 3.5.2, under subjective beliefs agents always take into account large future losses with a very small probability, and having some option to potentially walk away from mortgage debt limits the impact of this contingency on households' decisions.

where o_t is one if the household owns a house in period t and zero otherwise, ε_t is one if the household experiences a moving shock in period t and zero otherwise, and $\mathbb{1}_x$ is the indicator function for condition x. Here, the indicator function is one if a household does not move, and borrowing corresponds to a negative value for a.

Similar to Corbae and Quintin (2015), I assume that upon retirement all agents exit the housing market that is studied here. They immediately sell their home and derive utility from consuming out of their financial wealth and a pension benefit b_t that also grows at rate λ. Retirees' probability of dying is constant at π_d and there is an asset that allows them to annuitize financial wealth at the actuarially fair rate $\frac{1+r}{1-\pi_d} - 1$. They procure housing services at a rental rate q_t^r that may be correlated with the rental rate for working age households. This very stylized setup maximizes the potential for autocorrelation in house price growth by making an important component of net supply independent of price expectations, but it neglects the role that price fluctuations may play in the slow decumulation of housing wealth during retirement.

Finally, taxation corresponds to the benchmark setup in Díaz and Luengo-Prado (2008). Labor as well as interest income and retirement benefits are subject to a flat tax rate τ. Since the implicit rental income from owning a house is not taxed, this makes home ownership more attractive given a price-rent ratio. In addition, mortgage interest expenditure is fully deductible from taxable income and capital gains on housing are not taxed.

3.3.2 Decision problems

To bound the state space for y, all variables expressed in terms of the numeraire good are normalized by trend growth when setting up the decision problems. Specifically, the detrended analogues of $y_t, a_t, p_t, q_t, q_t^r, \mu_t, b_t$, and c_t are defined by the following rule:

$$\grave{x}_t = x_t \exp(-\lambda t).$$

The resulting value functions can be normalized by a factor $\exp[-\lambda t(1-\nu)(1-\gamma)]$ without affecting the decision problem. The baseline specification of the retirees' problem also assumes that benefits and the rental rate grow deterministically at rate λ, so that $\grave{b}_t = b$ and $\grave{q}_t^r = q^r$. In that case, the normalized value of retirement is a function of just the beginning-of-period financial assets $\grave{a}_t$, which for notational convenience are defined net of the tax liability on accrued interest:

$$
\begin{aligned}
V^r(\grave{a}_t) &= \max_{\{\grave{c}_t, h_t, \grave{a}_{t+1}\}} \left[u(\grave{c}_t, h_t) + \tilde{\beta}(1-\pi_d) V^r(\grave{a}_{t+1}) \right] \\
\text{s.t. } \grave{c}_t &= (1-\tau)b + \grave{a}_t - \frac{\exp(\lambda)(1-\pi_d)}{1+r-\tau(r+\pi_d)} \grave{a}_{t+1} - h_t q^r \\
\grave{a}_{t+1} &\geq 0 \\
h_t &\in [h_{min}, h_{max}].
\end{aligned}
$$

The adjusted discount factor $\tilde{\beta} = \beta \exp[\lambda(1-\nu)(1-\gamma)]$ reflects the normalization of future consumption.

An agent aged $n \leq N$ in period t will retire in period $R = t + N - n + 1$ and solves the following problem:

$$
\max_{\{\grave{c}_s, \grave{a}_{s+1}, h_s, o_s\}_{s=t}^{R-1}} E_t \left[\sum_{s=t}^{R-1} \tilde{\beta}^{s-t} u(\grave{c}_s, h_s) + \tilde{\beta}^{N+1-n} V^r \left(\grave{a}_R + (1-\varphi) o_{R-1} h_{R-1} \grave{p}_R \right) \right] \tag{3.1}
$$

s.t. $\forall s = t ... R$

$$
\begin{aligned}
\grave{c}_s &= (1-\tau)\grave{y}_s + \grave{a}_s - \left(\frac{\exp(\lambda)}{1+(1-\tau)r} \mathbb{1}_{\grave{a}_{s+1} \geq 0} + \frac{\exp(\lambda)}{1+(1-\tau)r^b} \mathbb{1}_{\grave{a}_{s+1} < 0} \right) \grave{a}_{s+1} \\
&\quad -(1-o_s) h_s \grave{q}_s - o_s h_s \grave{\mu}_s - (o_s h_s - o_{s-1} h_{s-1}) \grave{p}_s \\
&\quad -\varphi o_{s-1} h_{s-1} \grave{p}_s \mathbb{1}_{[o_s h_s \neq o_{s-1} h_{s-1} \vee \varepsilon_s = 1]} \\
&\quad + \max\left(0, -(1-\varphi) o_{s-1} h_{s-1} \grave{p}_s - o_{s-1} \grave{a}_s\right) (1-o_s) \qquad (3.2) \\
\grave{y}_s &= \bar{y}_{n+s-t} \exp(z_s + Z_s) \\
\grave{a}_{s+1} &\geq \min\left(-\theta \frac{1+(1-\tau)r^b}{1+r^b} \grave{p}_s o_s h_s, \grave{a}_s \mathbb{1}_{[o_s h_s = o_{s-1} h_{s-1} \wedge \varepsilon_s = 0]} \right) \\
o_s h_s \in \Omega_h &\quad \wedge \quad (1-o_s) h_s \in [h_{min}, h_{max}];
\end{aligned}
$$

$\grave{a}_t, \grave{p}_t, \grave{q}_t, \grave{\mu}_t, o_{t-1}, h_{t-1}, \varepsilon_t, z_t, Z_t$ given.

The last line in the budget constraint (3.2) reflects the option to walk away from mortgage debt. It is greater than zero if a homeowner has sufficiently negative assets and defaults by becoming a renter. In that case, overall beginning-of-period wealth is exactly zero.

Denoting the vector of normalized beginning-of-period state variables $(n, z, a, h, o, \varepsilon)$ by ω, the decision problem gives rise to time dependent decision rules $c_t^*(\omega), a_t^*(\omega), h_t^*(\omega)$, and $o_t^*(\omega)$ for all $\omega \in \Omega = \Omega_n \times \Omega_a \times \Omega_h \times \Omega_o \times \Omega_\varepsilon \times \Omega_z$ where $\Omega_n = \{1, ..., N\}, \Omega_a = [a_{min}, a_{max}]$, and

$\Omega_o = \Omega_\varepsilon = \{0, 1\}$. I index all objects by t to account for the potential time dependence of the expectations operator E_t. In the next section I outline how I model the evolution of agents' expectations regarding payoff relevant variables over time.

3.3.3 Expectations

Throughout, expectations for z and Z are formed according to the corresponding Markov processes. Due to aggregate shocks, also housing demand and hence $\grave{p}$ change over time. In principle, agents would therefore need to predict how the distribution of agents over Ω evolves conditional on the aggregate shocks and how it translates into a market clearing price for housing. This approach does not only put a large cognitive burden on agents, but it also makes the model computationally intractable. Instead, I assume that agents have a system of beliefs that allows them to consistently assign joint probabilities to all future sequences of payoff relevant variables based on a much smaller set of states. This system of beliefs governs how expectations are updated each period, and while it may not reflect the true probabilities, agents act optimally given their beliefs. I consider two established approaches from the literature to specify such a system of beliefs.

In order to approximate a rational expectations equilibrium, I follow a strategy based on Krusell and Smith (1998).[8] Specifically, I use a forecasting rule of the form

$$\ln \grave{p}_{t+1} - \ln \bar{p} = \alpha_1(Z_t, Z_{t+1}) + \alpha_2(Z_t, Z_{t+1})(\ln \grave{p}_t - \ln \bar{p}). \tag{3.3}$$

The forecasting rule is written in terms of deviations from a steady state value $\bar{p}$, and the coefficients are indexed by the contemporaneous and next period realization of the aggregate shock. They are chosen in a way that maximizes the forecasting performance with respect to $\grave{p}$, given that all agents use this very rule to form expectations. Appendix 3.C.1 reports more details on the iterative procedure employed to find such a set of coefficients. With an R^2 of at least 0.996, the forecasting performance of the rules employed here is high. Equation (3.3) implies that agents' decision rules depend on time only through the state variables Z_t and $\grave{p}_t$, which are hence sufficient to assign probabilities to all future sequences of payoff relevant variables.

The alternative approach I employ follows Adam et al. (2011). Agents are uncertain about the exact relationship between house prices and economic fundamentals, meaning

---

[8] See Favilukis et al. (2016) for an application involving house prices.

that their beliefs are characterized by a non-degenerate distribution over future prices given any sequence of aggregate shocks. The underlying system of beliefs emphasizes uncertainty about the future growth rate of house prices. More specifically, log house prices are believed to evolve as a random walk with an unobservable time-varying drift δ_t:

$$\begin{aligned} \ln \grave{p}_t &= \ln \grave{p}_{t-1} + \ln \delta_t + \ln \epsilon_t && (3.4) \\ \ln \delta_t &= \ln \delta_{t-1} + \ln \phi_t && (3.5) \\ \begin{pmatrix} \ln \epsilon_t \\ \ln \phi_t \end{pmatrix} &\sim iiN\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\epsilon^2 & 0 \\ 0 & \sigma_\phi^2 \end{pmatrix} \right). \end{aligned}$$

Since neither the drift nor the innovations ϵ_t and ϕ_t can directly be observed, this setting gives rise to a learning problem. Agents use Bayesian updating to adjust their estimate of δ_t and hence their beliefs regarding future prices based on observed price growth. Adam et al. (2015a) show that, under suitable assumptions regarding priors and the information structure, the evolution of beliefs under the optimal Bayesian filter has the following recursive representation:

$$\begin{aligned} \ln \delta_t &\sim N(\ln m_t, \sigma^2) && (3.6) \\ \ln m_t &= \ln m_{t-1} + g\left(\ln \grave{p}_{t-1} - \ln \grave{p}_{t-2} - \ln m_{t-1}\right). && (3.7) \end{aligned}$$

The uncertainty regarding the estimate for $\ln \delta_t$ corresponds to its Kalman filter steady state value

$$\sigma^2 = \frac{1}{2}\left(-\sigma_\phi^2 + \sqrt{\left(\sigma_\phi^2\right)^2 + 4\sigma_\phi^2 \sigma_\epsilon^2} \right).$$

and results from the unobservability of the initial drift and subsequent innovations. The learning gain captures by how much agents adjust their estimate of the growth rate given an observed deviation and can be written as $g = \frac{\sigma^2}{\sigma^2 + \sigma_\epsilon^2}$.

Equation (3.7) is a key determinant of the model's price dynamics. Observed price growth feeds back into higher price growth expectations. This raises agents' willingness to pay for housing, so that higher price growth expectations can be justified ex post and may even be revised further upwards. The information structure implies that beliefs about m_{t+1} are only updated after agents have made their choices and observed equilibrium prices in period t. This circumvents the possibility of multiple equilibria which may result from concurrent changes in the expected growth rate. Combining Equation (3.4), Equation (3.5), and Equation (3.6), agents' beliefs for house prices in the next period can be written as

$$\ln \grave{p}_{t+1} \quad = \quad \ln \grave{p}_t + \ln m_t + \ln \tilde{\epsilon}_{t+1}. \tag{3.8}$$

The uncertainty $\ln \tilde{\epsilon}_{t+1}$ regarding next period's price level combines the uncertainty regarding m_t and the uncertainty regarding future persistent and transitory innovations. It is normally distributed with variance $\tilde{\sigma}^2 = \sigma^2 + \sigma_\epsilon^2 + \sigma_\phi^2$. Even if agents are optimistic regarding m_t, they always take into account the possibility of falling prices.[9] Their decision rules depend on time only through $\grave{p}_t$ and the additional state variable m_t.

3.3.4 Equilibrium

Based on the decision problem, an equilibrium consists of an initial distribution $\pi_0(\omega)$ of working age households over individual states, the corresponding housing stock $H = \int_\Omega \omega_h \omega_o \pi_0(\omega) d\omega$, a system of beliefs over all possible sequences of payoff relevant variables with the associated probability measure P, a sequence of aggregate shocks $\{Z_t\}$, sequences of house prices $\{\grave{p}_t\}$, maintenance costs $\{\grave{\mu}_t\}$, and rental rates $\{\grave{q}_t\}$, sequences of decision rules, and a sequence of distributions $\{\pi_t(\omega)\}$ such that

1. Each period, the decision rules are optimal given $\grave{p}_t, \grave{q}_t, \grave{\mu}_t, Z_t$, and P.
2. Each period, the housing market clears

$$\int_\Omega h_t^*(\omega) o_t^*(\omega) \pi_t(\omega) d\omega = H.$$

3. The sequence of distributions $\{\pi_t(\omega)\}$ is implied by the sequence of decision rules, the initial distribution, and the distribution of new workers in each period.

3.4 Parameter Selection and Calibration

My objective is to produce a good fit between the model and cross-sectional data on savings, home ownership, and the composition of homebuyers. I choose a number of parameters

---

[9] Given the log-normality assumptions, the price could fall arbitrarily close to zero with very small probability. For computations (see Appendix 3.C.2), I use Gauss-Hermite quadrature nodes, which effectively limits the anticipated one-period loss. One motivation for allowing agents to default on their debt is that model results are less sensitive to the exact assumptions about small probability events than in a scenario where agents have to honor their debt in any state of the world.

in a standard way and in line with evidence presented in other studies. The remaining parameters are then jointly calibrated to match selected moments from the Panel Study of Income Dynamics (PSID). A succinct overview is given in Table 3.5 in Appendix 3.B. The specification for the aggregate shock process is based on real per capita income.

3.4.1 Parameters Selected Independently

Agents' working life goes from age 21 to age 65, so that $N = 45$. Like Iacoviello and Pavan (2013), I approximate their earnings profile $\bar{y}_n$ with a quadratic polynomial that is normalized at 1 at age 21, peaks at 1.82 at the age of 50, and reaches 1.61 at the age of 65. Based on the estimates in Storesletten et al. (2004), I construct a nine state Markov chain for the idiosyncratic component of earnings by discretizing an AR(1) process with persistence $\rho_z = 0.95$ and conditional volatility $\sigma_z = 0.17$ using the Rouwenhorst method. I set the risk aversion parameter γ in the utility function to the standard value of 2. The unit elasticity of substitution between housing and consumption is based on evidence in Davis and Ortalo-Magné (2011) that housing expenditure shares are approximately constant over time and across U.S. metropolitan areas. The minimum house size is set such that the poorest agents in the economy spend fifty percent of their income on rents, and the maximum size is set sufficiently large to not be chosen by any agent. To parametrize the process for μ_t, I impose that maintenance makes up 2.4 percent of the home value during a phase of normal income shocks. This is average depreciation of the residential housing stock from BEA fixed asset tables between 1975 and 2014.

To obtain a measure of the riskless real rate, I adjust the 10-Year Treasury Constant Maturity Rate by CPI inflation and average over the sample period 1975 to 2014. This yields $r = 0.026$. I determine the borrowing premium $r^b - r$ as the average difference between the 30-Year Conventional Mortgage Rate and the 10-Year Treasury Constant Maturity Rate over the same period,[10] yielding $r^b = 0.043$. The borrowing constraint is set at $\theta = 0.8$. The data in Bokhari et al. (2013) shows that there has been considerable bunching of mortgage origination at exactly this threshold for several decades. While households have always used higher leverage ratios as well, this observation seems to indicate that for many it becomes more difficult or costly beyond this point.[11] The typical commission charged by real estate

---

[10] Due to refinancings and home sales, the average actual duration of a mortgage is 7.5 years (Case et al. (2012)), so that effective maturities roughly match.

[11] For example, they must buy private mortgage insurance in order to conform with loan requirements by government sponsored enterprises.

agents is six percent of the home value, which I take as the parameter value for φ. A value of this magnitude is used in many studies and is similar to the transaction cost parameter estimated in Berger and Vavra (2015) based on the observed frequency of durable adjustments in the PSID. For the tax rate, I take $\tau = 0.2$ from the benchmark setup in Díaz and Luengo-Prado (2008). Finally, trend growth in the log deflated Freddie Mac House Price Index has been 0.01. This is the value I use for the growth rate λ. Because I have a constant housing stock, I cannot match the higher growth rate of per capita income at the same time.[12]

3.4.2 Joint Parameter Selection

The remaining parameters are the discount rate β, the weight of housing in the utility function ν, the normalized retirement benefit b, and the probability of an exogenous moving shock π_ε. In addition, the process for the rental rate q_t has to be specified. While the house price can fluctuate in response to aggregate shocks, a long sequence of identical aggregate shocks will result in a constant normalized house price level. This also leads to a constant price-rent ratio, independent of what I assume regarding the comovement between house prices and rents. I denote the constant price-rent ratio following a long series of normal shocks by $\bar{p}$ and use it as a fifth calibration parameter. Normalizing the corresponding rental payment to one, this parameter and the degree to which rents comove with market clearing house prices pin down q_t.

I determine the five parameters by matching five selected cross-sectional moments. For the financial variables, I use median values since my model will not be able to generate a thick right tail in the wealth distribution, and I normalize by median income to make numbers comparable between the model and the data. Because the process for retirement is very stylized, I target median net worth of households aged 61 to 65 to have some comparability of wealth accumulation over the life cycle. For the other moments, I restrict calculations to the group between ages 26 and 60, since there are relatively few households below 26 in the data and because of the stylized nature of the retirement process. I target median net worth across all households, median financial wealth net of all debts across all homeowners, the home ownership rate, and the value of houses acquired by new homeowners relative to

---

[12] Iacoviello and Neri (2010) estimate that the difference in annual productivity growth between the housing and non-housing sector is about one percentage point.

the value of all houses acquired by movers within twelve months. The latter is included to ensure that both groups have plausible weights in the housing market.[13]

The cross-sectional moments are derived from the 1999 PSID interviews. The survey's panel structure has the benefit that I can determine the previous home ownership status of the household from its 1997 interview.[14] Together with the reported most recent moving date, this allows me to derive estimates of the fraction of homeowners who have bought a new residence within twelve months and whether they are new homeowners or not. The interviews were conducted during the first months of 1999, and I interpret the data as representative of the distribution arising after a long sequence of normal income shocks. According to my calibration of the aggregate income process described in the next section, the nineties have indeed the longest sequence of normal shock realizations in the sample. Even though this sequence ends in 1998, while 1999 already falls into the dot-com boom phase, I still consider the above interpretation reasonable.

I generate the parameter estimates from a version of the model where aggregate income shocks are present but where the housing supply is flexible, so that normalized house prices remain constant. For each of the specifications in the next section, I use these parameter estimates. Calibrating each of the flexible price models separately would require considerable additional computational effort and would result in models with different preference parameters. As Table 3.1 shows, aggregate moments in both the rational expectations and the subjective beliefs benchmark specifications nevertheless come close to the calibration targets.[15] The option to default on mortgage debt by turning over the collateral seems to drive the slightly higher home ownership rate in the subjective beliefs framework. As documented in Appendix 3.D, a version of the model where debt must always be fully repaid results in a home ownership rate of 63 percent, where homeowners also have slightly less debt. While all parameters are determined jointly, each row in Table 3.1 lists the one that mainly drives the corresponding statistic.

Overall, the parameters look very reasonable. The price-rent ratio is within the range documented by Davis, Lehnert, and Martin (2008) for the period from 1960-1995. The estimate for π_ε implies that about fifty percent of all moves are not induced by the exogenous moving

---

[13] As documented in the next section, their reaction to price fluctuations is quite different.

[14] Appendix 3.A.2 discusses how I match interview data from both survey waves and how I handle cases where previous data is missing.

[15] I do not show the moments for the flexible supply model used in the calibration separately, because there is no difference between model and data moments at the precision used in Table 3.1.

Table 3.1: Calibration Results

Targeted Moment	*Data*	*Rational Expectations*	*Subjective Beliefs*	*Parameter*	*Value*
Home ownership rate	63.7%	63.6%	64.2%	$\bar{p}$	18.7
Purchase volume new homeowners	63.9%	63.7%	61.9%	π_ε	0.017
Median net worth	101.3%	101.2%	100.5%	β	0.976
Median net financial wealth HO	-52.7%	-52.9%	-55.1%	ν	0.161
Median net worth before retirement	343.0%	342.5%	342.0%	b	59.5%

Note: Median net worth before retirement is calculated based on households between age 61 and age 65, the other rows are calculated based on households between age 26 and age 60. Net worth, financial wealth, and the retirement benefit b are given as a percentage of median income. The purchase volume of new homeowners is given as a percentage of the value of new homes purchased by existing homeowners.

shock. In the PSID, about 44 percent of moving homeowners report as their primary reason for moving the desire to expand or contract housing or to move to a better neighborhood. The discount factor β falls in the range of values routinely employed in the literature. While the average share of housing expenditure in total personal consumption expenditure is 15 percent, Davis and Ortalo-Magné (2011) document that renters on average spend 18 percent of their income on rents. My estimate for ν, the weight of housing in the utility function, falls within this range. The retirement benefit b is about fifty percent of average income.[16] To also assess life cycle patterns implied by the calibration, I compare home ownership rates and median net worth by five year age bins. Figure 3.2 shows that the model matches their increase over the life cycle well.

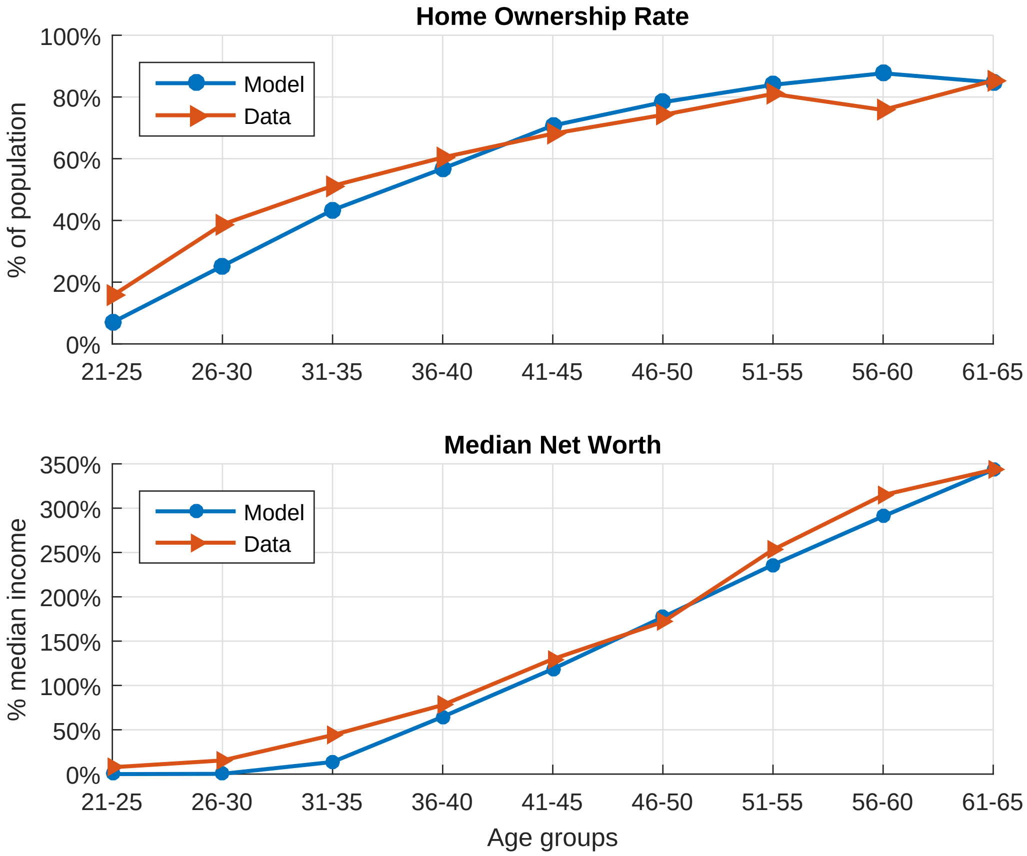
3.4.3 Aggregate Income Shocks

My parametrization of the aggregate shock process is based on personal income from the national income and product accounts (NIPA). I adjust the series by taking out income receipts on assets and rental income of persons. Then I deflate the series with the consumer price index excluding shelter, convert it to per capita terms and take logs. The deviations of this series from a linear trend can be interpreted as the Z_t process in my model. I group them into three categories. I assign all values between -0.02 and 0.02 to the normal state with $Z_{normal} = 0$ which is almost exactly their average value. The average value of all values above 0.02 is 0.04 which I take as the realization for Z_{high}. The low realization is set to

---

[16] While this is above the typical replacement rate for Social Security alone, one has to consider the additional healthcare and spousal benefits and preferential tax treatment not modeled here.

Figure 3.2: Evolution of Assets by Age Group

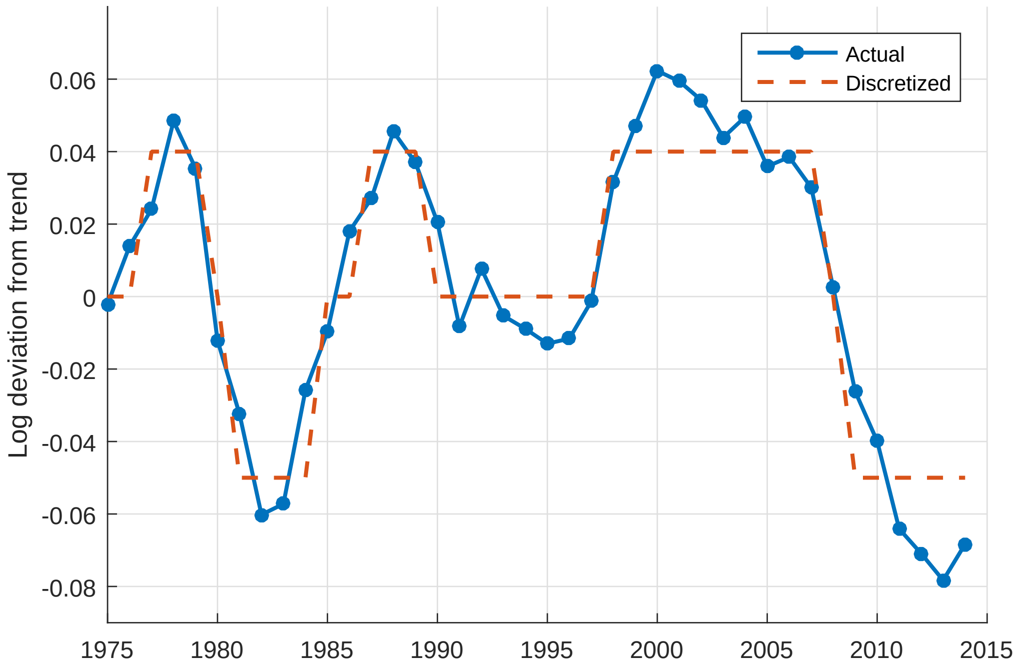


Notes: Home ownership rate is the fraction of all households of a given age group owning a house. Net worth is the sum of the value of all assets net of liabilities and expressed as a percentage of median income in either the data or the model. The data is taken from the 1999 PSID survey.

$Z_{low} = -0.05$, again based on the average of the corresponding deviations. Figure 3.3 shows the original series and my discretization. Notably, income remains high during the 2001 recession. The process would be similar when working with all components of per capita income instead.

From the discretized series, I estimate transition probabilities between states under the assumption that the last sequence of income realizations below trend ends in 2015. Based on the estimation results, I use the values in Table 3.2 as Markov transition probabilities Π_Z in my model.

Figure 3.3: Aggregate Income Process



Notes: Log deviations of the real per capita income series from trend and a three state discretization.

Table 3.2: Aggregate Income States

		Transition Probabilities		
Income State	*Value*	to Z_{low}	to Z_{norm}	to Z_{high}
Z_{low}	-0.05	0.8	0.2	0
Z_{norm}	0	0.15	0.65	0.2
Z_{high}	0.04	0	0.2	0.8

3.5 Results

3.5.1 Rational Expectations Benchmark

The benchmark setting is chosen in a way that ensures the maximum possible price impact of innovations in the aggregate income process. To that end, I impose that in each period the percentage change in the exogenous rental rate corresponds to the percentage change in the equilibrium house price and that maintenance costs do not fluctuate with income. Figure 3.4 shows the resulting price path, expressed as log deviations from trend, in response to the aggregate income shock series described in Section 3.4.3.[17] The largest innovations in the

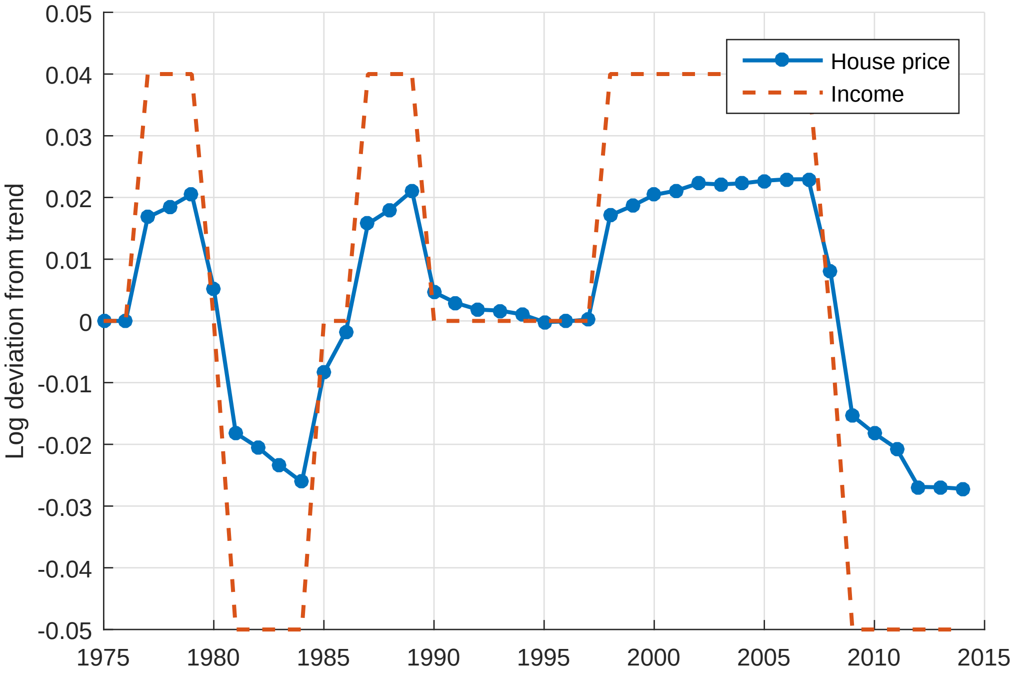
---

[17] These are market clearing house prices in a simulation with 540,000 households. The initial distribution of households over the state space is the one resulting from a long series of normal income realizations. The computational details of the solution procedure are discussed in Appendix 3.C.

price series happen in direct response to changes in the income level. Nevertheless, while income remains at the new level, prices tend to drift further in the direction of the initial change. Overall, the correlation in annual price growth rates is 0.37 – about fifty percent of what is observed in the data.

It is apparent that fluctuations in the price level are of smaller magnitude than fluctuations in the aggregate income level. The standard deviations are 0.017 and 0.036 respectively. The standard deviations of the data counterparts of the price and income series are 0.114 and 0.040, so that aggregate income shocks of plausible magnitude can generate only a small fraction of the observed house price volatility. The low volatility in the level of house prices also means that the volatility in price growth rates is small. At 0.9 percentage points it is about twenty percent of its data counterpart.

Figure 3.4: Simulated House Price Series under Rational Expectations



Notes: Deviations of log house prices and log aggregate income from trend.

One important feature of the model studied here are micro-level adjustment frictions in combination with a rent-or-own decision. How do these affect market clearing and house prices? Table 3.3 compares the volatility and momentum of price growth rates in the benchmark model to a version where the borrowing constraint is relaxed and the sales fee φ is zero. The absence of these frictions implies that all households become homeowners immediately. The volatility of price growth rates is about half of what I find in the benchmark version. The results for a hybrid model, where only the sales fee is zero, indicate that both frictions

Table 3.3: Moments of Price Growth Rates under Rational Expectations

		Model Results		
		$\varphi = 0.06$	$\varphi = 0$	$\varphi = 0$
Moment	*Data*	$\theta = 0.8$	$\theta = 0.8$	$\theta = 1$
One year correlation	0.72	0.37	0.32	0.30
Three year correlation	0.05	-0.21	-0.16	-0.14
Five year correlation	-0.50	-0.08	-0.03	0.00
Standard deviation	0.051	0.009	0.007	0.005

Notes: Price growth rates are changes in the detrended log price index. Data: Freddie Mac House Price Index deflated by CPI urban excluding shelter. Model: rational expectations benchmark calibration with different parametrizations for the LTV limit θ and the transaction cost φ.

contribute to the increased volatility. The main difference induced by adjustment frictions is a larger price increase on impact of the shock, while the subsequent drift and also the overall serial correlation in price growth rates are similar across all specifications.

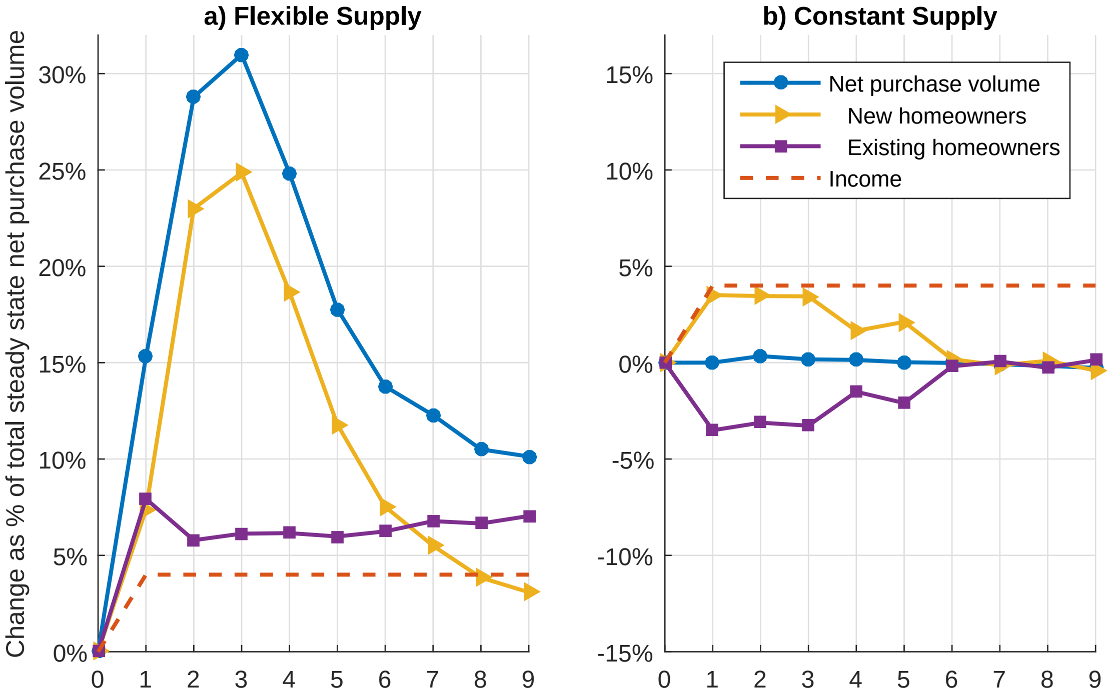
The role of rent-to-own transitions is illustrated in Figure 3.5. First, I solve a version of the model where the housing supply is fully flexible, so that the price level remains constant. Panel a) shows by how much households increase their net purchase volume in response to a sequence of high income realizations in this model. Absent a price response, net housing purchases would be up to thirty percent above their steady state level[18] and growth in purchase volume displays high serial correlation. The response is driven by rent-to-own transitions, as the split by buyer groups shows, and it happens almost entirely on the extensive margin. On average, new homeowners buy a house that is worth about twice their annual income, so that the down payment requirement is about forty percent of their annual income. The aggregate income shock is hence a substantial fraction of the cash needed to transition to home ownership, and for several periods more and more households pass the adjustment threshold. This pattern would be very different in a frictionless model, where all households become homeowners immediately. The bulk of the adjustment happens directly on impact of the income shock then, and, absent an extensive margin, the overall increase in owner-occupied housing is much less pronounced.

Panel b) shows how total net purchases evolve when the housing stock is instead constant and prices adjust to ensure market clearing. Because the only source of net supply is the largely predetermined housing stock of retirees, total net purchases are also essentially

---

[18] In the steady state, net housing purchases equal the supply from retiring homeowners and correspond to about 3.2 percent of the entire housing stock.

Figure 3.5: Impulse Responses for Net Purchase Volume



Notes: Net purchase volume is the size difference between the new housing unit and the one owned previously, where rental units are assigned a zero size. The benchmark is net purchase volume following a long period of normal income shocks (steady state). The graph shows the deviations of net purchase volume split by whether a household transitions from renting or already owns a home. For both groups, these deviations are normalized by total steady state net purchase volume, so that the depicted series add up to the change in total net purchase volume.

constant. Nevertheless, their composition varies considerably in response to income shocks, as the split by buyer groups shows. The group that increases net purchases during the boom state are new homeowners. The endogenous price increase is sufficient to induce existing homeowners to delay their upgrades, so that the group's decrease in net purchase volume accomodates increased purchases by new homeowners. Because existing homeowners are the wealthier of the two groups, this different pattern is not explained by how price changes affect households' ability to afford home purchases. Instead, it can be seen as a manifestation of different return considerations.

In order to generate a realistic home ownership rate in this model, owning a house must yield a greater total return than renting a house and investing all net worth in financial assets.[19] Buying a home enables a household to put all of its cash savings into this superior investment technology. Existing homeowners, on the other hand, have already invested all

---

[19] This is also true if housing yields a utility premium, which makes owning a house equivalent to renting a unit of a larger size. It is not necessary if rental units come only in sizes too small for the majority of households.

their equity and can use surplus funds to pay down mortgage debt, which carries an interest rate premium. They are hence less likely to invest in more housing in times where higher prices and expected mean reversion lower expected returns. In a frictionless model, upgrades by existing homeowners make up more than ninety percent of the net purchase volume, so that their return considerations dominate. The benchmark version, on the other hand, has been calibrated to have a plausible ratio of purchases by new and existing homeowners, so that new homeowners play a much larger role in determining the market clearing price. Nevertheless, the more elastic response by existing homeowners continues to limit price movements.

To assess the relatively small fluctuations in house prices, one can also look at innovations in life-time income caused by the aggregate income shock. As an approximation, I compare the discounted earnings difference between the different values for Z for an infinitely lived agent with no idiosyncratic earnings risk. Similar to Díaz and Luengo-Prado (2010), for each realization of Z I calculate "permanent" earnings $\hat{Z}$ as

$$\hat{Z} \quad = \quad Z + \frac{\exp(\lambda)}{1 + r^b} \sum_{Z'} \Pi_Z(Z, Z')\hat{Z}'.$$

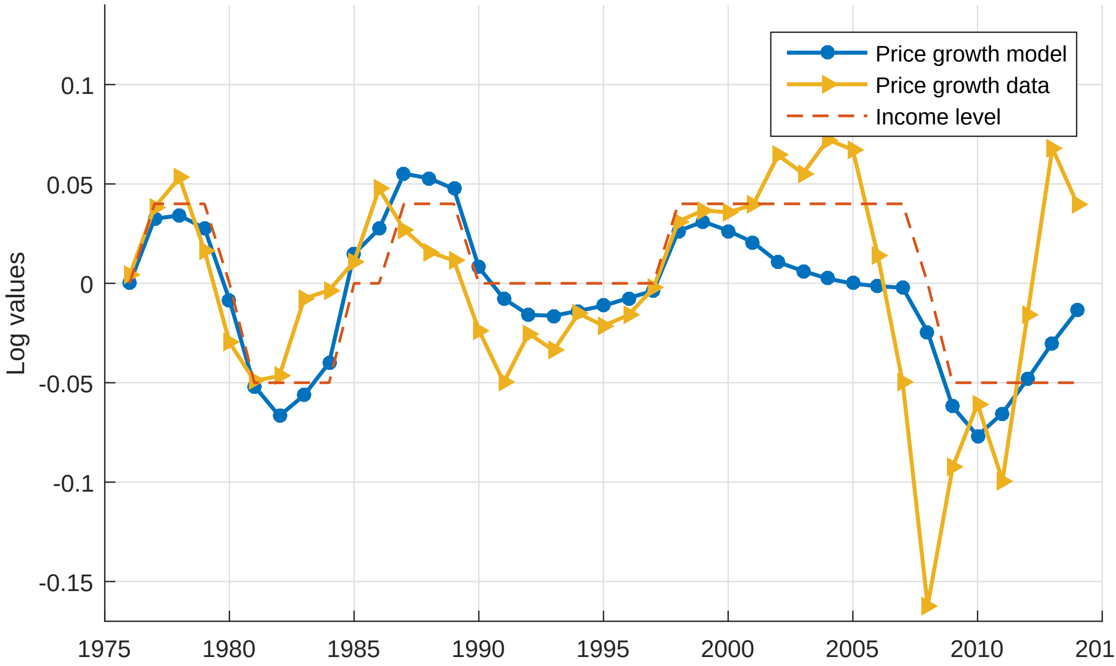
While Z_{high} is about nine percent greater than Z_{low}, expected mean reversion in the income process means that the difference between $\hat{Z}_{high}$ and $\hat{Z}_{low}$ is just 1.2 percent.

In summary, under rational expectations only a fraction of the observed house price fluctuations could be attributed to aggregate income shocks. With fully flexible housing supply, adjustment frictions and a rent-or-own decision do lead to volatile net housing purchases with strongly correlated growth rates, but small price responses are sufficient to make net purchases constant over time. Nevertheless, adjustment frictions and a rent-or-own decision double the volatility of price growth rates compared to a frictionless model. Despite some serial correlation in price growth rates, expected mean reversion dominates, so that households who have already invested in a home tend to delay upgrades to periods with low prices.

3.5.2 Subjective Beliefs

In the subjective beliefs framework, expected price dynamics are described by Equation (3.8) and Equation (3.7) as fluctuations around a stochastic trend. They are parametrized by the standard deviation of expected fluctuations $\tilde{\sigma}$ and by the gain parameter g. I set $\tilde{\sigma} = 0.04$, which is slightly below the volatility of price growth rates in the data but close to the volatility ultimately implied by the model. The baseline value for g is 0.0235. This is close to the value of 0.0252 that Adam et al. (2015a) estimate based on surveys of stock market investors. The effect of choosing other values for g is shown in Table 3.4. I deviate from the setup in the previous section by imposing that normalized rental rates are constant. This specification reflects the empirical fact that rents fluctuate much less than house prices. While the choice of rental rates that fully comove with house prices was motivated by maximizing price movements in the rational expectations framework, here I choose the most conservative specification.

Figure 3.6: Price Growth Rates: Subjective Beliefs Framework and Data



Price growth rates are changes in the detrended log price index. Data: Freddie Mac House Price Index deflated by CPI excluding shelter. Model: subjective beliefs benchmark calibration. The income series is a discretization of the level of real per capita income relative to trend.

Figure 3.6 plots simulated house price growth rates under subjective beliefs together with house price growth rates from the data. Both series are strongly correlated (0.60) and also similar in terms of magnitude. As shown in Table 3.4, the model therefore comes much closer to the data in terms of the serial correlation, mean reversion, and volatility of price growth rates. Because the model-generated series is smoother, the serial correlation actually exceeds the high value observed in the data. Table 3.4 also shows results for different values of g, indicating that similar dynamics can be observed for a range of values. One notable difference between the two series in Figure 3.6 are growth rates during the most recent housing boom and bust. Personal income is above trend over the entire period, but price growth slowly declines in the model, while it remains exceptionally high in the data. There is a lot of evidence that several factors beyond the model's scope contributed to these developments. The model illustrates, however, that a moderate increase in aggregate income could have contributed to the early stages of the boom and to elevated price growth expectations.

Table 3.4: Moments of Price Growth Rates under Subjective Beliefs

		Model Results				
Moment	*Data*	$g = 0$	$g = 0.01$	$g = 0.02$	$g = 0.0235$	$g = 0.025$
One year correlation	0.72	0.63	0.73	0.81	0.83	0.84
Three year correlation	0.05	-0.15	-0.09	0.03	0.08	0.12
Five year correlation	-0.50	-0.45	-0.49	-0.48	-0.47	-0.44
Standard deviation	0.051	0.020	0.025	0.032	0.035	0.037

Notes: Price growth rates are changes in the detrended log price index. Data: Freddie Mac House Price Index deflated by CPI excluding shelter. Model: subjective beliefs benchmark calibration with different values for the gain parameter g.

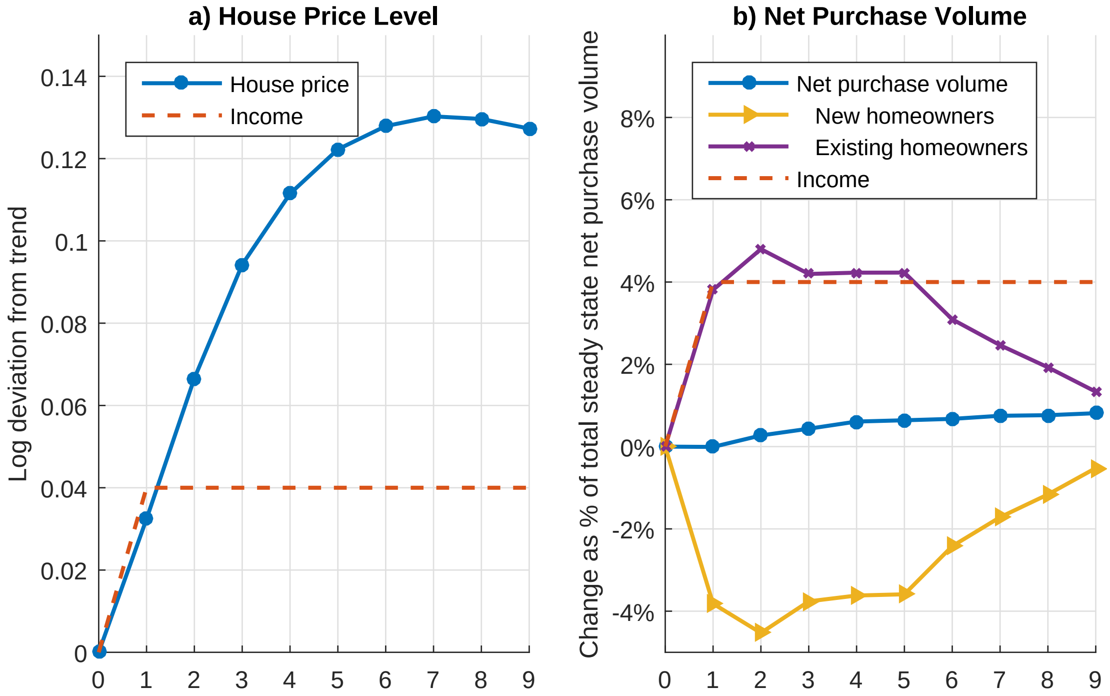
Price dynamics markedly differ from the ones observed under rational expectations because subjective beliefs are such that households do not associate innovations in the price level with inevitable future reversals. Instead, they tend to adjust their expectation regarding future price changes in the direction of the observed change. This difference in return expectations also manifests itself in different trading patterns. Figure 3.7 displays the response of prices and net housing purchases to a sequence of high income realizations in the baseline subjective beliefs model. In contrast to the results presented in Figure 3.5, the split by buyer groups in Panel b) shows that net purchases by existing homeowners do not give way to those of new homeowners. Existing homeowners are wealthier in general, and house price increases further add to their net worth. Absent expected mean reversion, they have no reason to delay upgrades or bring downgrades forward,[20] so that prices rise to a point where sufficiently many potential new buyers cannot afford the down payment on a new house. Along with the number of potential buyers and their wealth, this threshold rises for several periods, and the perceived profitability of housing investment increases as m grows according to Equation (3.7). My conjecture from this pattern is that policies that gradually limit the ability of new buyers to pay high prices, such as stricter caps on purchase LTV ratios, would have a considerable effect on the observed increase. If applied early during the cycle, they would also limit the additional impulse from rising price growth expectations. Importantly,

---

[20] One part of the increase in existing homeowners' net purchases is that homeowners with low net worth are less likely to sell their home when prices rise. Instead, this group extracts equity and does not move. This is also the reason why total net purchase volume slowly rises in Figure 3.7: net supply, which is housing owned by retirees, goes up.

the dynamics are not explosive. Housing requires maintenance, and an important part of the return on owning a house is the implicit rental income, so that homeowners' demand can be saturated. In addition, potential buyers face rising down payment requirements. Eventually, realized price growth falls below expected price growth and m shrinks. Hence, over a long period of high income realizations, prices first overshoot and then slowly decline.

Figure 3.7: Impulse Responses with $g = 0.0235$ (Benchmark)



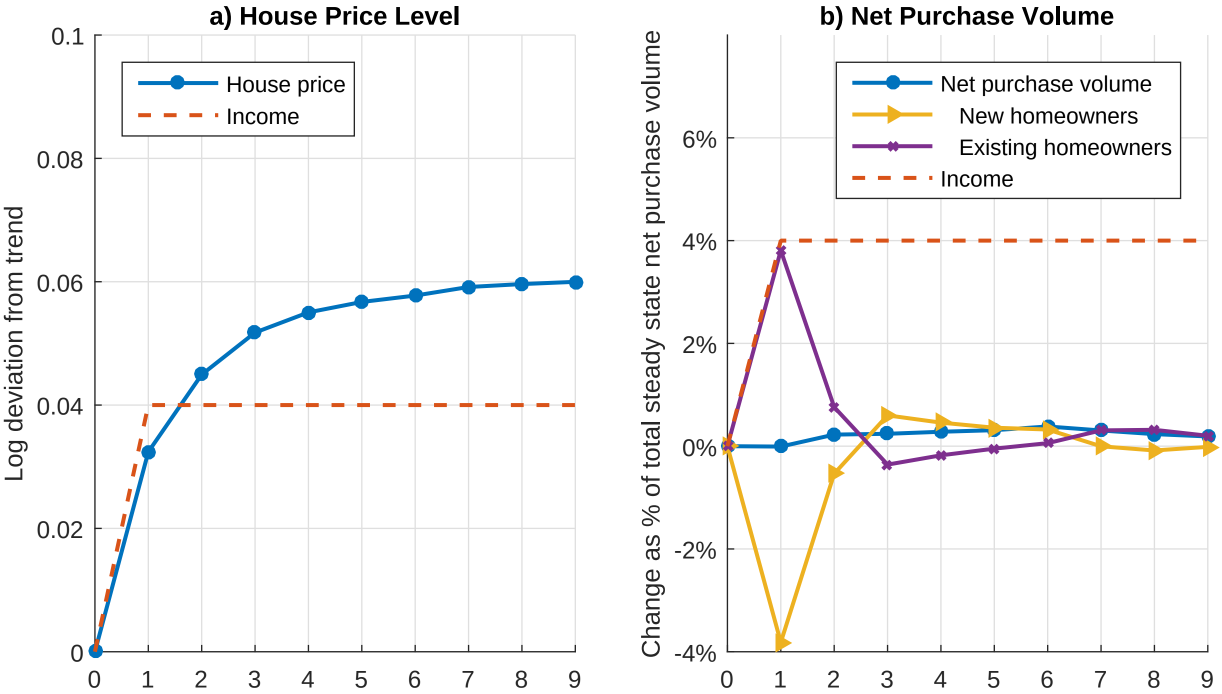
Notes: Panel a) shows deviations of log house prices and log aggregate income from trend. Panel b) shows changes in net purchase volume as a fraction of total steady state net purchase volume as in Figure 3.5

To assess the importance of changes in the expected price growth rate for this pattern, I also plot the price path for a model with $g = 0$. This makes m constant over time, and Equation (3.8) implies that agents expect normalized house prices to follow a random walk, an assumption that is also routinely used in the literature.[21] Panel a) in Figure 3.8 shows that, without innovations in m, the overall price increase is less than half of what is observed in Figure 3.7 for the benchmark specification. After the initial impulse, price growth rates decline much more quickly. This decline is associated with lower net purchases by existing homeowners, as shown in Panel b). Overall, both the absence of expected mean reversion implied by the unit root in Equation (3.8) and the extrapolation of observed price movements contribute significantly to the volatility of price growth rates in the model.

---

[21] See for example Campbell and Cocco (2015) or Berger, Guerrieri, Lorenzoni, and Vavra (2015).

Figure 3.8: Impulse Responses with $g = 0$ (Random Walk)



Notes: Panel a) shows deviations of log house prices and log aggregate income from trend. Panel b) shows changes in net purchase volume as a fraction of total steady state net purchase volume as in Figure 3.5

Subjective beliefs also change how transaction costs impact price dynamics. Extrapolation especially affects existing homeowners' willingness to pay, and a lower transaction cost means that they enter the housing market more frequently and have a higher weight relative to new buyers. In addition, a higher adjustment frequency also means that homeowners have payed down less of the debt from the previous purchase and have higher leverage ratios, which increases the impact of price changes on net worth. When prices rise, it becomes easier to satisfy the down payment requirement for a larger house, while falling prices may wipe out existing home equity and make an upgrade impossible. Because lower transaction costs increase the weight of existing homeowners in the market and make their demand more inelastic, larger price movements are required to ensure market clearing. When I set $\varphi = 0.02$, the adjustment frequency of existing homeowners almost doubles and the volatility of price growth rates rises from 3.5 percentage points to 5.8 percentage points.

As stated in Section 3.3, all borrowing is collateralized by houses, and homeowners can walk away from their debt by turning over the house to the lender. In contrast to the rational expectations framework, price fluctuations are now sufficiently strong that some households make use of this option, but the volume of defaults remains small. Given that households have to supply twenty percent equity when purchasing their home, the option to walk away from mortgage debt is only attractive after significant price declines. In most periods, there is no default at all, so that over the entire simulation just 0.09 percent of outstanding mortgage balances are affected. Assuming a recovery rate of fifty percent (cp. Corbae and Quintin (2015)), the resulting cost of five basis points is hence easily absorbed by the mortgage rate premium. Peak losses for a single period are about 0.5 percent of the mortgage balance outstanding.

While the role of actual defaults is quantitatively small in the model, the option to walk away from outstanding debt still affects price dynamics in an important way. According to Equation (3.8), households always take into account the possibility of significant future price drops. Without the option to walk away, they must ensure that mortgage debt is sustainable even in the worst possible contingency. If prices are low enough, another significant drop, together with a series of low idiosyncratic income realizations, may leave them unable to ever fully repay the outstanding debt. Even if the probability of such a scenario is low, any household must sell their house as soon as it even becomes conceivable. This makes price drops more pronounced because some homeowners will increase their supply with falling prices. Appendix 3.D presents the results for a specification of the model where moving households must always fully repay the outstanding mortgage balance. Importantly, learning gains must be smaller then because the mechanism outlined above will otherwise lead to excessive price declines. However, also the specification where households may not walk away from their debt can generate high volatility and serial correlation in price growth rates. Because price drops are steeper, the corresponding statistics actually come even closer to the data.

In summary, the subjective beliefs setup generates price dynamics that differ significantly from the rational expectations solution. It implies that a calibrated series of aggregate income shocks can generate dynamics in house prices that are much closer to the data. The increase in volatility is driven both by the lack of expected mean reversion that is already implied by a unit root process for the price level and by the learning dynamics that are triggered by observed price changes. These learning dynamics do not lead to an explosive path for prices because agents' demand for housing can be saturated, and eventually realized price growth fails to keep up with expectations. Nevertheless, after a series of high income realizations growth expectations are high, and further stimulus to housing demand, such as easing credit conditions, would likely fuel the boom in prices.

3.6 Conclusion

I present a calibrated life cycle model and study the house price dynamics generated by purchase decisions of optimizing households. In line with survey evidence pertinent to the housing market as well as other asset markets, I consider a specification where households extrapolate observed house price growth when forming their expectations. This significantly alters the model's predictions compared to the rational expectations solution. In particular, the observed fluctuations in U.S. per capita income over the past forty years generate price dynamics that pick up much of the fluctuations observed in the data. House price growth rates are volatile and match both the observed degree of serial correlation and mean reversion. The combination of income shocks and learning dynamics also matches the early stage of the last housing boom and leads to high growth expectations that could have amplified the impact of further stimulus to housing demand.

Going forward, the model's ability to endogenously replicate important aspects of the price fluctuations observed in the data could make it a useful framework for studying policies aimed at stabilizing house prices. One conjecture from the model dynamics is that such policies might be more effective if moderate measures were already applied early in the cycle and then gradually adjusted.

3.A Appendix A: Data Definitions

3.A.1 Aggregate Data

Consumption good prices: I use the monthly values for the "Consumer Price Index for All Urban Consumers: All items less shelter" published by the U.S. Department of Labor (FRED Series ID CUUR0000SA0L2). Since the consumption good is the numeraire in my model, I deflate house prices as well as income data with this series. Since I focus on annual values, none of the series I use are seasonally adjusted.

House prices: I use the monthly values from the national Freddie Mac House Price Index available at http://www.freddiemac.com/finance/fmhpi/archive.html which start in January 1975. This is a commonly used repeat sales index covering single family homes with a mortgage that has been purchased by the government sponsored enterprises Freddie Mac or Fannie Mae. I deflate the series by the consumption price index described above, normalize so that December 2000 equals 100, and take logs. Annual values used to calculate the growth rate statistics are the average value for each year. Figure 3.1 plots a quarterly series of twelve month rolling averages.

Stock prices: I use the monthly closing values of the series "S&P 500 Composite Price Index (w/GFD extension)" from https://www.globalfinancialdata.com. I deflate the series by the consumption price index described above, normalize so that December 2000 equals 100, and take logs. Annual values used to calculate the growth rate statistics are the average value for each year.

Income data: I use annual values from NIPA table 2.1 published by the U.S. Bureau of Economic Analysis and deflate by the average consumption price index for the year. For my preferred specification, I add "Compensation of employees" (FRED Series ID W209RC1A027-NBEA), "Proprietors' income with inventory valuation and capital consumption adjustments" (FRED Series ID A041RC1A027NBEA), and "Personal current transfer receipts" (FRED Series ID A577RC1A027NBEA), thus excluding capital and (imputed) rental income. To calculate per capita values, I use the ratio between the reported values for personal income (FRED Series ID A065RC1A027NBEA) and personal income per capita (FRED Series ID A792RC0A052NBEA). I take logs and calculate a linear trend for the log series based on the time window 1965-2014. The correlation between the detrended income level and price growth rates is not affected by choosing a shorter time window for detrending. It is at least 0.36 for different specifications of the income series I employ.

Interest rates and depreciation: The savings rate I use is the "10-Year Treasury Constant Maturity Rate" reported by the Federal Reserve (FRED Series ID DGS10) which I adjust by comsumer price index inflation. For the borrowing rate I use the "30-Year Conventional Mortgage Rate" reported by the Federal Reserve (FRED Series ID MORTG). I calculate depreciation as the ratio of "Current-Cost Depreciation of Fixed Assets: Residential" (FRED Series ID M1R53101ES000) and the beginning of year value of "Current-Cost Net Stock of Fixed Assets: Residential" (K1R53101ES000), both of which are provided by the U.S. Bureau of Economic Analysis.

3.A.2 PSID Data

The PSID is a long established, nationally representative panel study of U.S. households. After 1997, the interviews have been conducted at biannual frequency and all contain details on wealth, housing, and debt at the family level. The dataset provides family longitudinal weights, which I use throughout. In general, families are linked between periods by having the same person classified as "Head" in all interviews. Given the formal criteria by which the role is assigned, in most instances this will allow to make the connection between interviews for the same household. The interview data also indicates composition changes within the family. For the analysis of movers, I require for existing households that head and spouse remained the same between interviews, so that the link via the family head is comprehensive.

To calculate the home ownership rate, I use the answer to the corresponding question A19 from all 1999 interviews where the head falls in the specified age range. Net worth (WEALTH2) is imputed by the PSID staff in case of missing data, so that I use all interviews as well. I identify movers as households who report having moved in response to question A42. I require that the calendar month and year are provided and count moves that have occurred in the twelve months prior to the interview month. I also require that the value of the home is reported in order to calculate overall purchase volumes for each group. To classify whether a household newly became homeowners, I first look at the same household's ownership status in the 1997 interview. In such cases I require that head and spouse did not change, because otherwise it is not clear what kind of move is reported. For some households there is no previous interview. I cannot discard this group, since so called split-offs from existing families (e.g. children moving out) are a key feature of maintaining the panel and potentially also a relevant source of new homeowners. Therefore, I include in the analysis all households who either have a previous interview and where the head and spouse have not changed, or who are split-offs according to the composition change indicator.[22] All split-offs who report moving within the twelve months prior to the interview and now own a home are counted as new homeowners. Together, they make up about twelve percent of all new homeowners. A large majority of them indeed reports a recent mortgage origination date, so that further refining the approach would not yield materially different results. There may be a downward bias in the fraction of movers among all homeowners, because I do not count moves where the date has not been reported, but for the ratio between rent-to-own and own-to-own transitions which I calibrate to this should not be relevant. I check that the ratio is also not materially affected by the other selection criteria.

---

[22] There is no explicit split-off indicator for 1999, and I use the condition that family composition change is either 5 or 6, codes which are primarily used for split-offs.

3.B Appendix B: Model Parameters

Table 3.5: Model Parameters

Parameter		*Value*	*Source*
$\bar{p}$	Price-rent ratio	18.7	Calibration PSID 99
β	Discount rate	0.976	Calibration PSID 99
ν	Housing share in utility	0.16	Calibration PSID 99
π_m	Probability of having to move	1.6%	Calibration PSID 99
b	Retirement benefit (% of median income)	59%	Calibration PSID 99
φ	Sales fee	0.06	Agent fees
θ	LTV limit	0.8	Bokhari et al. (2013)
μ	Maintenance (% of $\bar{p}h$)	2.4%	NIPA Depreciation
γ	Risk aversion	2	Standard
r	Real return on savings	2.6%	10-year Treasury Rate
r^m	Real mortgage rate	4.3%	30-Year Conventional Mortgage Rate
τ	Tax rate	20%	Díaz and Luengo-Prado (2008)
π_d	Retirees' probability of dying	5%	Corbae and Quintin (2015)
ρ_z	Persistence and	0.95	Storesletten et al. (2004)
σ_z	volatility of idiosyncratic income shocks	0.17	
λ	Growth rate	1%	FMHPI
$\tilde{\sigma}$	Expected volatility (subjective beliefs)	0.04	See Section 3.5.2
g	Learning gain (subjective beliefs)	0.0235	See Section 3.5.2

Note: Overview of parameters used in the benchmark models used in Section 3.5. For a discussion of the parameter choices and calibration see Section 3.4. Nominal interest rates are adjusted using the consumer price index for the U.S.

3.C Appendix C: Computation

3.C.1 Rational Expectations

Given the grids for housing and income realizations, I solve the households' problem on a fine grid for assets a and the house price p. The asset grid consists of 780 points where the distribution of the 780 points is chosen differently for each of the possible house sizes.[23] It is denser where the utility of a typical owner of the particular house size has more curvature and in particular around the borrowing limit. The price grid is made up of 71 points where the range of the 71 points is chosen differently for each level of the aggregate income shock. This means that there are 175 distinct points covering the relevant range of prices. This implies a step size of only about 0.05 percent between grid points. The advantage of the setup is that the large number of grid points helps to address the non-convexities induced by the linear adjustment cost. However, it also means that I restrict the savings policy to values on the asset grid.

For each grid point, I derive the housing policy based on comparing the value of saving optimally given the current house and the value of selling the current house. The value of selling the house is the same as the value of beginning the period as a renter with the level of cash that would result after selling the house.[24] This is in turn given by the maximum of either remaining a renter and saving optimally or buying a house of any size. The value of buying a house can be derived from the problem of a household who already enters the period with that house and the level of cash that remains after the purchase. I ensure that new buyers always at least meet the leverage constraint however, and, because the level of cash after the purchase will not exactly be on the grid, I compare the policies for the left and right grid point. Overall, the approach means that the savings problem only has to be solved for each (a, h) combination, but not for each (a, h, h') combination separately, which is a large computational advantage.

I simulate the economy with 12,000 households in each cohort, i.e. 540,000 households living at each point in time. All households start with no assets or housing and with a draw from the stationary distribution for z. The initial draw and all subsequent draws are the same for each cohort. Each simulation is initialized by calculating choices for one cohort from

---

[23] The grid for renters has 1300 points.

[24] This value may not be a point on the asset grid for renters. I randomly assign the household to the left or the right point based on the relative distance and calculate the expected value of selling accordingly.

birth to retirement given the specified value for $\bar{p}$ and normal income realizations. The state of that cohort in each year of their life makes up the initial economy. The same distribution will reemerge after a long sequence of normal income realizations. The aggregate housing stock H is the sum over the cohorts' housing choices in each period.

Starting from the initial distribution that would result from a long sequence of normal income realizations, I calculate market clearing prices in response to a sequence of aggregate income shocks. The tolerance for market clearing is h_{max}, since any household will either buy a house around a given size or not buy it, but only buying a fraction of the desired house would usually not be optimal. While the price grid is very fine, no point on the grid will imply exact market clearing. Instead, I place all households randomly on the interval between the two points with the lowest positive and highest negative excess demand. I then locate a threshold such that all households to the left are assigned to the left grid point and all households on the right are assigned to the right grid point and the market clears. The position of the threshold is interpreted as the exact market clearing price for the period. However, all households to the left act as if the price was slightly lower and all households to right act as if the price was slightly higher. Given the that the points are only 0.05 percent apart this seems acceptable.[25] It also matches the way expectations are formed: prices are forecasted as a continuous variable according to Equation (3.3), and for any expected price households linearly interpolate between the values of the grid points to the left and to the right.

To determine the forecasting rule (3.3), I start from an initial guess, solve for all policy functions given these expectations and use the policy functions to simulate the economy for 2,400 periods. I discard the initial 400 periods, and for the simulated data from the remaining 2000 periods I run the following regressions

$$\ln \grave{p}_{t+1} - \ln \bar{p} = \hat{\alpha}_1(Z_t, Z_{t+1}) + \hat{\alpha}_2(Z_t, Z_{t+1})(\ln \grave{p}_t - \ln \bar{p}).$$

I use the estimated coefficients $\hat{\alpha}$ to update the guess for α and resolve and resimulate the model to obtain new coefficient estimates. After a number of iterations the estimated forecasting rules fit the simulation results well with an R^2 of at least 0.996. The R^2 and the aggregate statistics remain virtually constant across iterations, and the maximum difference

---

[25] The alternative would be to interpolate all value functions on a much coarser price grid.

between estimated and used coefficients is below 0.01.[26] Table 3.6 reports the coefficient estimates for the three different scenarios discussed in the text.

Table 3.6: Forecasting Rule Coefficients

	Model specifications		
Coefficient	$\varphi = 0.06$, $\theta = 0.8$	$\varphi = 0$, $\theta = 0.8$	$\varphi = 0$, $\theta = 1$
$\alpha_1(Z_{low}, Z_{low})$	-0.0081	-0.0049	-0.0030
$\alpha_2(Z_{low}, Z_{low})$	0.7567	0.8331	0.8951
$\alpha_1(Z_{low}, Z_{norm})$	0.0096	0.0103	0.0094
$\alpha_2(Z_{low}, Z_{norm})$	0.5996	0.8001	0.9067
$\alpha_1(Z_{norm}, Z_{low})$	-0.0210	-0.0162	-0.0116
$\alpha_2(Z_{norm}, Z_{low})$	0.7201	0.8613	0.8945
$\alpha_1(Z_{norm}, Z_{norm})$	0.0005	0.0001	-0.0002
$\alpha_2(Z_{norm}, Z_{norm})$	0.7081	0.8338	0.9115
$\alpha_1(Z_{norm}, Z_{high})$	0.0166	0.0122	0.0087
$\alpha_2(Z_{norm}, Z_{high})$	0.6070	0.7740	0.9024
$\alpha_1(Z_{high}, Z_{norm})$	-0.0094	-0.0088	-0.0059
$\alpha_2(Z_{high}, Z_{norm})$	0.7618	0.8866	0.8890
$\alpha_1(Z_{high}, Z_{high})$	0.0077	0.0041	0.0019
$\alpha_2(Z_{high}, Z_{high})$	0.6921	0.8061	0.9230
$\frac{\alpha_1(Z_{low},Z_{low})}{1-\alpha_2(Z_{low},Z_{low})}$	-0.0334	-0.0293	-0.0284
$\frac{\alpha_1(Z_{high},Z_{high})}{1-\alpha_2(Z_{high},Z_{high})}$	0.0249	0.0211	0.0248

Notes: Coefficient values for forecasting rule (3.3) for specifications of the model with different degrees of adjustment frictions in terms of the leverage ratio θ and the transaction cost φ. Coefficients are indexed by the current and future aggregate state.

One can see that the coefficient estimate for $\alpha_1(Z_{norm}, Z_{norm})$ is very close to zero as should be expected. To interpret the other coefficients, I report the log difference between the fixed point of (3.3) and $\bar{p}$ for the other states which is given by $\frac{\alpha_1(Z_s,Z_s)}{1-\alpha_2(Z_s,Z_s)}$. For $s = high$ prices are expected to rise till they are that much above $\bar{p}$ and for $s = low$ they fall until they reach that level. Consistent with the reported volatilities, the model with adjustment frictions generates the largest absolute values for the fixed points. The coefficients $\alpha_1(Z_{norm}, Z_{high})$ and $\alpha_1(Z_{norm}, Z_{low})$ indicate how much of the distance to the fixed points is covered on impact of the income shock.

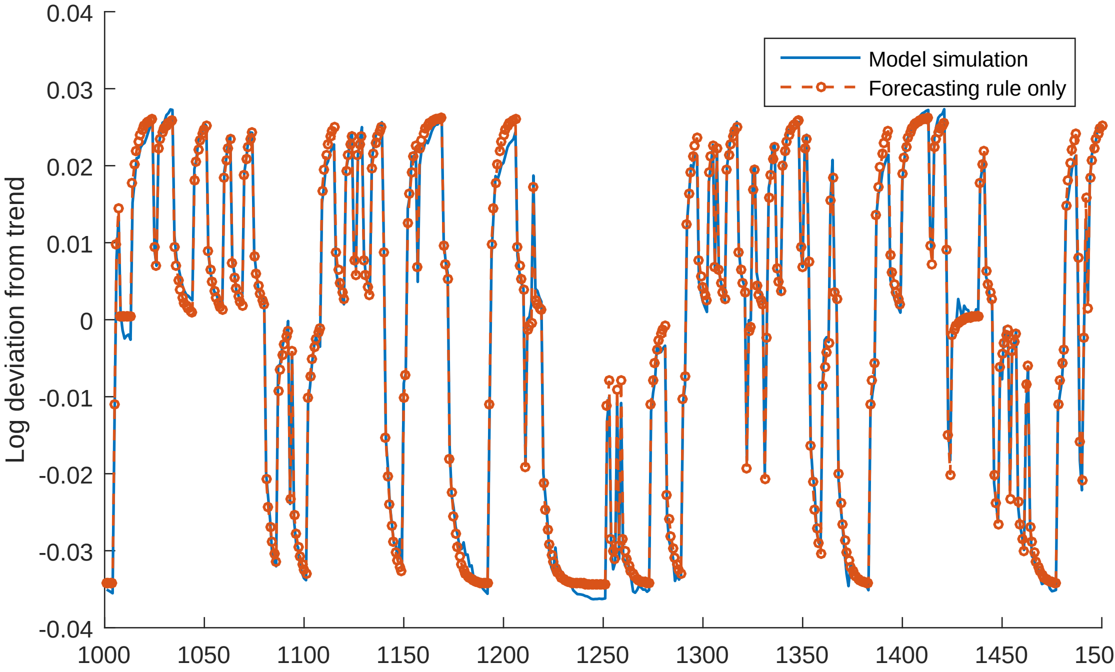
To assess the quality of the solution, I also compare the result of simply iterating on the forecast rule given a sequence of income shocks to the model solution for the same sequence of

---

[26] For the α_1-cofficients it is considerably below that threshold. Both the R^2 and the fluctuations in coefficients could be further improved by using more points for the idiosyncratic income grid.

shocks. Figure 3.9 shows that both series remain close the entire time. The largest deviation is 0.4 percent. The data is for the model with both frictions. Without lumpy adjustment, forecasting errors are somewhat smaller.

Figure 3.9: Simulated House Price Series



Comparison of market clearing prices in a long model simulation to a prediction that just uses the sequence of aggregate shocks and iterates on the forecasting rule.

3.C.2 Extrapolative Expectations

As shown in Equation (3.8), extrapolative price expectations depend on an additional state m_t. Due to the additional state and because a larger price range has to be accommodated, I use coarser grids and interpolate on value and policy functions. The asset grid now has 60 points that again have values specific to the different house sizes. The price grid has 21 points and the grid for m has 9 points. I treat these three dimensions as continuous and use linear interpolation in all steps. I continue to use discrete values for h and y based on the the same grids as before. The logic for calculating the grid point values for value and policy functions is then essentially the same as discussed above.

For $\ln \tilde{\epsilon}_{t+1}\mathrm{m}$, which expresses agents' uncertainty regarding future prices, I use seven Gaussian quadrature nodes. Given a standard deviation of four percentage points, this means that agents always explicitly take a 14 percent price drop for the next period into account with a very small probability. This anticipated loss is higher than any price drops in the benchmark model, but slightly below the 2008 price drop in the data.

Importantly, the choice whether to buy or change owner-occupied housing remains a discrete choice, which I do not interpolate. In simulations, I explicitly compare the values of remaining a renter and buying a house. I consider all house sizes implied by the policy function for adjacent grid points. For existing homeowners, I compare the value of keeping the house to the value of selling the house. Sellers can then be treated the same as renters to determine whether they buy a new house.

In a version of the model where prices are constant, I can directly compare the results for the different algorithms I use for the rational and extrapolative expectations framework. In terms of aggregate outcomes and individual histories the results are almost identical. The policies derived from the entirely grid based approach seem to be slightly more accurate because realized utility is higher on average. The difference corresponds to about 0.01 percent of consumption.

3.D Appendix D: Price Dynamics without Default

This appendix gives the results for a version of the benchmark subjective beliefs model where homeowners always fully have to repay their mortgage debt. According to Equation (3.8), households always take into account the possibility of significant future price drops. Without the option to default, they must ensure that mortgage debt is sustainable even in the worst possible contingency. Table 3.7 compares the aggregate moments resulting from a long period of normal income realizations in both models and compares them to the PSID analogues from 1999. It can be seen that without the option to default households are more reluctant to buy a home and use less debt. The fact that the data moments fall in between both versions suggests that a specification that attaches a higher penalty to default than the benchmark version but still allows for the option to walk away from high debt would also be of interest. The differences are not large, however, indicating that under normal circumstances the option to default has only a limited impact on agents' behavior in the model.

Table 3.7: Aggregate Moments with and without Default

Moment	*Data*	*Benchmark*	*No Default*
Home ownership rate	63.7%	64.2%	63.0%
Home value new homeowners	63.9%	61.9%	62.7%
Median net worth	101.3%	100.5%	100.7%
Median net financial wealth HO	-52.7%	-55.1%	-51.7%
Median net worth before retirement	343.0%	342.0%	342.0%

Note: Median net worth before retirement is calculated based on households between age 61 and age 65, the other rows are calculated based on households between age 26 and age 60. Net worth, financial wealth, and the retirement benefit b are given as a percentage of median income. The home value of new homeowners is given as a percentage of the value of new homes purchased by existing homeowners.

Default becomes much more important after sharp price declines. If prices are low enough, another significant drop, together with a series of low idiosyncratic income realizations, may leave agents unable to ever fully repay the outstanding debt. Even if the probability of such a scenario is low, any household must sell their house as soon as it even becomes conceivable. This channel can lead to pronounced price declines if there are sufficiently many homeowners who increase their supply with falling prices. The reported volatility of price growth rates in Table 3.8 is generally higher than what is reported in Table 3.4 for comparable learning gains for exactly this reason. Price declines become excessive for higher values of g in the sense that they are above the highest value anticipated by homeowners, so that some of them would have insufficient funds after selling their house in response to a moving shock.[27] These spikes also begin to dominate the reported serial correlation of growth rates.

Table 3.8: Moments of Price Growth Rates without Default

		Model Results				
Moment	*Data*	$g = 0$	$g = 0.01$	$g = 0.016$	$g = 0.018$	$g = 0.02$
One year correlation	0.72	0.64	0.74	0.70	0.60	0.44
Three year correlation	0.05	-0.14	-0.10	-0.08	-0.11	0.21
Five year correlation	-0.50	-0.45	-0.50	-0.46	-0.43	-0.36
Standard deviation	0.051	0.022	0.028	0.038	0.045	0.067

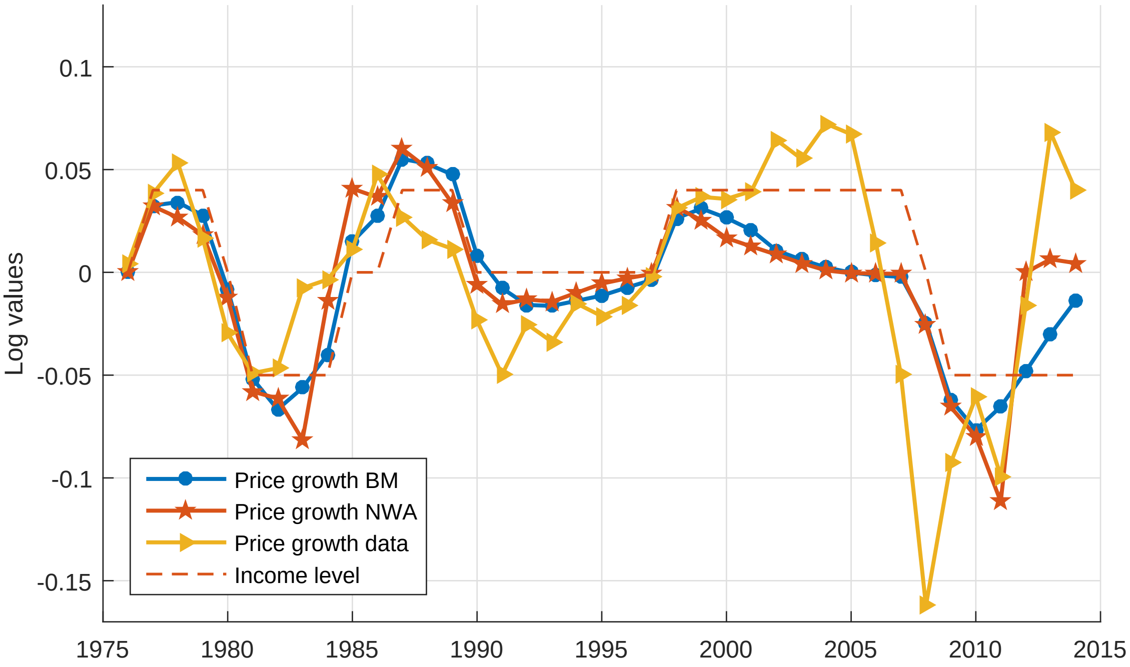
Notes: Price growth rates are changes in the detrended log price index. Data: Freddie Mac House Price Index deflated by CPI excluding shelter. Model: subjective beliefs calibration without the option to walk away from mortgage debt with different values for the gain parameter g.

Nevertheless, under moderate learning gains, price dynamics are such that agents can always repay their debt and the moments of price growth rates match the data well. For $g = 0.016$, for example, they are even closer to the data than the benchmark calibration in terms of serial correlation and volatility. Figure 3.10 compares the underlying series. Overall, they are quite close except for the spikes during low income periods. These add to the volatility and slightly decrease serial correlation.

---

[27] More generally, results are more sensitive to modeling choices for small probability events, such as the parametrization of the Gauss-Hermite quadrature rule, when default is not possible.

Figure 3.10: Price Growth Rates: Benchmark and No Default



Price growth rates are changes in the detrended log price index. Data: Freddie Mac House Price Index deflated by CPI excluding shelter. BM: subjective beliefs benchmark calibration. NWA: subjective beliefs calibration with $g = 0.016$ and without the option to walk away from mortgage debt. The income series is a discretization of the level of real per capita income relative to trend.

References

Adam, K., P. Kuang, and A. Marcet (2011): "House Price Booms and the Current Account," *NBER Macroeconomics Annual*, 26, 77 – 122.

Adam, K. and A. Marcet (2011): "Internal Rationality, Imperfect Market Knowledge and Asset Prices," *Journal of Economic Theory*, 146, 1224–1252.

Adam, K., A. Marcet, and J. Beutel (2015a): "Stock Price Booms and Expected Capital Gains," Working paper, University of Mannheim.

Adam, K., A. Marcet, S. Merkel, and J. Beutel (2015b): "Can a Financial Transaction Tax Prevent Stock Price Booms?" *Journal of Monetary Economics*, 18, S90 – S109.

Adelino, M., A. Schoar, and F. Severino (2015): "Loan Originations and Defaults in the Mortgage Crisis: The Role of the Middle Class," NBER Working Papers 20848, National Bureau of Economic Research, Inc.

Akinci, O. and J. Olmstead-Rumsey (2015): "How Effective are Macroprudential Policies? An Empirical Investigation," International Finance Discussion Papers 1136, Board of Governors of the Federal Reserve System (U.S.).

Albanesi, S., G. DeGiorgi, and J. Nosal (2016): "Credit Growth and the Financial Crisis: A New Narrative," Manuscript.

Basel Committee on the Global Financial System (2010): "Macro-Prudential Instruments and Frameworks: A Stock Taking of Issues and Experiences," CGFS Publications 38.

Berger, D., V. Guerrieri, G. Lorenzoni, and J. Vavra (2015): "House Prices and Consumer Spending," Working Paper 21667, National Bureau of Economic Research.

BERGER, D. AND J. VAVRA (2015): "Consumption Dynamics During Recessions," *Econometrica*, 83, 101–154.

BHUTTA, N. (2015): "The Ins and Outs of Mortgage Debt During the Housing Boom and Bust," *Journal of Monetary Economics*, 76, 284–298.

BHUTTA, N. AND B. J. KEYS (2016): "Interest Rates and Equity Extraction During the Housing Boom," *American Economic Review, forthcoming.*

BOKHARI, S., W. TOROUS, AND W. WHEATON (2013): "Why did Household Mortgage Leverage Rise from the mid-1980s until the Great Recession?" Working paper, Massachusetts Institute of Technology.

CAMPBELL, J. R. AND Z. HERCOWITZ (2006): "The Role of Collateralized Household Debt in Macroeconomic Stabilization," WorkingPaper 16-2006, Foerder Institute for Economic Research.

CAMPBELL, J. Y. AND J. F. COCCO (2015): "A Model of Mortgage Default," *Journal of Finance*, 70, 14951554.

CASE, K. E. AND R. J. SHILLER (1989): "The Efficiency of the Market for Single-Family Homes," *American Economic Review*, 79, 125–37.

CASE, K. E., R. J. SHILLER, AND A. K. THOMPSON (2012): "What Have They Been Thinking? Homebuyer Behavior in Hot and Cold Markets," *Brookings Papers on Economic Activity*, 45, 265–315.

CHAMBERS, M., C. GARRIGA, AND D. E. SCHLAGENHAUF (2009): "Accounting for Changes in the Homeownership Rate," *International Economic Review*, 50, 677–726.

CHRISTENSEN, I. AND C. A. MEH (2011): "Countercyclical Loan-to-Value Ratios and Monetary Policy," Manuscript.

CHU, Y. (2014): "Credit Constraints, Inelastic Supply, and the Housing Boom," *Review of Economic Dynamics*, 17, 52–69.

COOPER, D. (2010): "Did Easy Credit Lead to Overspending? Home Equity Borrowing and Household Behavior in the Early 2000s," Public Policy Discussion Paper Series 09-7, FRB Boston.

Corbae, D. and E. Quintin (2015): “Leverage and the Foreclosure Crisis,” *Journal of Political Economy*, 123, 1–65.

Davis, M. A., A. Lehnert, and R. F. Martin (2008): “The Rent-Price Ratio For The Aggregate Stock Of Owner-Occupied Housing,” *Review of Income and Wealth*, 54, 279–284.

Davis, M. A. and F. Ortalo-Magné (2011): “Household Expenditures, Wages, Rents,” *Review of Economic Dynamics*, 14, 248–261.

Demyanyk, Y. and O. van Hemert (2011): “Understanding the Subprime Mortgage Crisis,” *The Review of Financial Studies*, 24, 1848–80.

Díaz, A. and M. J. Luengo-Prado (2008): “On the User Cost and Homeownership,” *Review of Economic Dynamics*, 11, 584–613.

——— (2010): “The Wealth Distribution With Durable Goods,” *International Economic Review*, 51, 143–170.

Favara, G. and J. Imbs (2015): “Credit Supply and the Price of Housing,” *American Economic Review*, 105, 958–92.

Favilukis, J., S. C. Ludvigson, and S. Van Nieuwerburgh (2016): “The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk-Sharing in General Equilibrium,” *Journal of Political Economy, forthcoming.*

Gelain, P., K. J. Lansing, and C. Mendicino (2013): “House Prices, Credit Growth, and Excess Volatility: Implications for Monetary and Macroprudential Policy,” *International Journal of Central Banking*, 9, 219–276.

Glaeser, E. L. and J. Gyourko (2007): “Arbitrage in Housing Markets,” Working Paper 13704, National Bureau of Economic Research.

Glaeser, E. L., J. Gyourko, E. Morales, and C. G. Nathanson (2014): “Housing Dynamics: An Urban Approach,” *Journal of Urban Economics*, 81, 45–56.

Glaeser, E. L. and C. G. Nathanson (2015): “An Extrapolative Model of House Price Dynamics,” NBER Working Papers 21037, National Bureau of Economic Research, Inc.

Gouskova, E., S. G. Heeringa, K. McGonagle, and R. F. Schoeni (2008): “Panel Study of Income Dynamics Revised Longitudinal Weights 2007,” PSID Technical Report 08-05, ISR, University of Michigan.

GREENSPAN, A. (2004): "The Mortgage Market and Consumer Debt," Remarks by Chairman Alan Greenspan at the Americas Community Bankers Annual Convention, Washington, D.C.

GREENSPAN, A. AND J. KENNEDY (2008): "Sources and Uses of Equity Extracted from Homes," *Oxford Review of Economic Policy*, 24, 120–144.

HEAD, A., H. LLOYD-ELLIS, AND H. SUN (2014): "Search, Liquidity, and the Dynamics of House Prices and Construction," *American Economic Review*, 104, 1172–1210.

HEDLUND, A. (2015a): "Illiquidity and its Discontents: Trading Delays and Foreclosures in the Housing Market," Working Papers 1417, Department of Economics, University of Missouri.

——— (2015b): "The Cyclical Dynamics of Illiquid Housing, Debt, and Foreclosures," Working Papers 1416, Department of Economics, University of Missouri.

HRYSHKO, D., M. J. LUENGO-PRADO, AND B. E. SORENSEN (2010): "House Prices and Risk Sharing," *Journal of Monetary Economics*, 57, 975 – 987.

HURST, E. AND F. P. STAFFORD (2004): "Home Is Where the Equity Is: Mortgage Refinancing and Household Consumption," *Journal of Money, Credit and Banking*, 36, 985–1014.

IACOVIELLO, M. (2005): "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle," *American Economic Review*, 95, 739–764.

IACOVIELLO, M. AND S. NERI (2010): "Housing Market Spillovers: Evidence from an Estimated DSGE Model," *American Economic Journal: Macroeconomics*, 2, 125–64.

IACOVIELLO, M. AND M. PAVAN (2013): "Housing and Debt over the Life Cycle and over the Business Cycle," *Journal of Monetary Economics*, 60, 221 – 238.

JUSTINIANO, A., G. PRIMICERI, AND A. TAMBALOTTI (2015): "Household leveraging and deleveraging," *Review of Economic Dynamics*, 18, 3–20.

KAPLAN, G., G. L. VIOLANTE, AND K. MITMAN (2015): "Consumption and House Prices in the Great Recession: Model Meets Evidence," Manuscript.

KRUSELL, P. AND A. A. SMITH (1998): "Income and Wealth Heterogeneity in the Macroeconomy," *Journal of Political Economy*, 106, 867–896.

Kuttner, K. N. and I. Shim (2013): "Can Non-Interest Rate Policies Stabilize Housing Markets? Evidence from a Panel of 57 Economies," Working Paper 19723, National Bureau of Economic Research.

Lambertini, L., C. Mendicino, and M. T. Punzi (2013): "Leaning Against BoomBust Cycles in Credit and Housing Prices," *Journal of Economic Dynamics and Control*, 37, 1500 – 1522.

Landvoigt, T., M. Piazzesi, and M. Schneider (2015): "The Housing Market(s) of San Diego," *American Economic Review*, 105, 1371–1407.

Laufer, S. M. (2013): "Equity Extraction and Mortgage Default," Finance and Economics Discussion Series 2013-30, Board of Governors of the Federal Reserve System (U.S.).

Linneman, P. (1986): "An Empirical Test of the Efficiency of the Housing Market," *Journal of Urban Economics*, 20, 140–154.

Mian, A. and A. Sufi (2011): "House Prices, Home Equity-Based Borrowing, and the U.S. Household Leverage Crisis," *American Economic Review*, 101, 2132–56.

——— (2014): *House of Debt*, Chicago: University of Chicago Press.

Ortalo-Magné, F. and S. Rady (2006): "Housing Market Dynamics: On the Contribution of Income Shocks and Credit Constraints ," *Review of Economic Studies*, 73, 459–485.

Paciorek, A. (2013): "Supply Constraints and Housing Market Dynamics," *Journal of Urban Economics*, 77, 11 – 26.

Piazzesi, M. and M. Schneider (2009): "Momentum Traders in the Housing Market: Survey Evidence and a Search Model," *American Economic Review*, 99, 406–11.

Quan, D. and J. Quigley (1991): "Price Formation and the Appraisal Function in Real Estate Markets," *The Journal of Real Estate Finance and Economics*, 4, 127–146.

Quintin, E. and M. Davis (2014): "Default When House Prices are Uncertain," 2014 Meeting Papers 246, Society for Economic Dynamics.

Saiz, A. (2010): "The Geographic Determinants of Housing Supply," *The Quarterly Journal of Economics*, 125, 1253–1296.

Storesletten, K., C. I. Telmer, and A. Yaron (2004): "Cyclical Dynamics in Idiosyncratic Labor Market Risk," *Journal of Political Economy*, 112, 695–717.

Wong, E., T. Fong, K. Li, and H. Choi (2011): "Loan-to-Value Ratio as a Macro-Prudential Tool - Hong Kong's Experience and Cross-Country Evidence," Working Paper 01/2011, Hong Kong Monetary Authority.

Lebenslauf

2011-2016	Promotion Volkswirtschaftslehre Universität Mannheim, Graduate School of Economic and Social Sciences
2009-2011	Masterstudiengang Volkswirtschaftslehre Humboldt-Universität zu Berlin
2006-2009	Consultant SAP Business Solutions – Finance & Controlling Capgemini Deutschland GmbH
2005-2006	Masterstudiengang Information Systems University of Arkansas, Sam M. Walton College of Business
2001-2006	Diplomstudiengang Wirtschaftsingenieurwesen Technische Universität Berlin