Housing and Credit Markets

by

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Abstract

This thesis consists of three chapters on housing and credit markets.

Chapter 1 tests the "housing lock hypothesis": the conjecture that homeowners with limited or negative home equity, low levels of financial assets and restricted opportunities to borrow are unable to move. It employs unique, administrative population data on residential location, home-ownership, family structure, and household balance sheets from the Netherlands. The rapid rise in Dutch house prices during the 1995-2008 period, and their substantial decline thereafter, has generated large variation in the home equity of buyers who bought homes a few years apart. Buyers in the cohorts that purchased homes around the peak have higher Loan-To-Value (LTV) ratios than earlier buyers, and also have much lower mobility rates in every year after purchase. A decline in home equity is associated with large and statistically significant reductions in household mobility. A rise in the LTV ratio from 90 to 115% is associated with a 30% decline in household mobility. The reduction in mobility is observed both within and across labor markets. The mobility effects of falling home equity are substantially larger for households with low financial asset holdings. These results emerge from comparisons of mobility rates from different purchase cohorts after removing time and region effects, as well as from an analysis of homebuyers whose purchase timing was determined by arguably exogenous changes in family structure. Since Dutch mortgages are full recourse, which rules out strategic default behavior, the findings provide new support for the "housing lock hypothesis".

Chapter 2, co-authored with François Koulischer, studies the role of collateral in liquidity provision by central banks. Should central banks lend against low quality collateral? We characterize efficient central bank collateral policy in a model where a bank borrows from the interbank market or the central bank. Collateral has favorable incentive effects but is costly to transfer to lenders who value the collateral less because of imperfect collateral quality. We show that a fall in the quantity or the quality of the bank's collateral can increase interest rates in the economy even with a constant policy rate. A looser central bank collateral policy can reduce the spread, alleviate the credit crunch and increase output.

Chapter 3 studies the effects of LTV limits, Payment-To-Income (PTI) limits and the mortgage interest deduction on mortgage debt exploiting a series of policy changes in the Netherlands. As intended, regulatory loan limits reduce mortgage leverage ratios and they also induce bunching at the loan limits. Loan limits and restrictions of the mortgage interest deduction trigger large declines in mortgage volumes. The leverage- and volume responses are larger for young, borrowing-constrained households. The repeal of the mortgage interest deduction for non-amortizing mortgages decimates the market for non-amortizing mortgages. The PTI tightening is also associated with a substantial rise in the fraction of mortgages that have very short periods during which the interest rate is fixed. This unintended risk-shifting pattern to quasi- adjustable-rate mortgages (ARM) may increase income risk. The reform of the mortgage interest deduction, which boosts amortization, is also associated with a significant decline in principal amounts at origination. These findings highlight the distributional effects as well as the unintended potential consequences of macroprudential and fiscal policies aiming to reduce mortgage debt.

This thesis tries to cast light on the effects of shocks to the value of housing and other types of collateral on the broader economy. This work suggests that the combination of imperfections in credit markets and shocks to asset prices can exert a substantial, non-linear and heterogeneous influence on household and firm outcomes, such as residential mobility (Chapter 1) and business investment (Chapter 2). This thesis also investigates the role for monetary, macroprudential and fiscal policies to alleviate or prevent the negative spill-over effects to the real economy, both before (Chapter 3) as well as after (Chapter 2) the occurrence of financial shocks.

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I gratefully acknowledge financial support from the Bradley Foundation and the MIT Citi Foundation. I thank the MIT Center for Real Estate and the Shultz Fund in the MIT Economics Department for support in purchasing access to the extraordinary Statistics Netherlands data, used in Chapter 1 of this dissertation. I thank the Centre for Policy Related Statistics at Statistics Netherlands for providing and documenting the data from Chapter 1 and the Network for Mortgage Data (HDN) for the data used in Chapter 3.

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Dedication

This is for my parents, Hans and Ine, who did everything for our best possible education; and for Lynn, who created an atmosphere of love in which I could work hard on this dissertation.

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Chapter 1

Housing Lock: Dutch Evidence on the Impact of Negative Home Equity on Household Mobility

1.1 Introduction

Household mobility in several developed economies plummeted during the Great Recession. This coincided with the collapse of the housing and labor markets. Mobility among homeowners fell by 30% in the US and by 35% in the Netherlands. Stiglitz (2009), Krugman (2010), Katz (2010) and others have suggested that the house price crash contributed to the decline in mobility and in turn impaired the labor market. For example, Krugman (2010) wrote: "Workers are trapped in place by negative equity, and can't move to where jobs are." One account that could explain these patterns is the "housing lock" or "balance sheet channel", that was identified and studied by Stein (1995). This hypothesis recognizes that households with limited or negative home equity and low levels of financial asset holdings cannot secure the resources needed to pay off the balance on their existing mortgage and to make a downpayment on a new home. As a result, they cannot move. "Housing lock" may also be important for reasons unrelated to the labor market, including the quality of housing matches, the ability to smooth income shocks (Ejarque and Leth-Petersen (2014)), take entrepreneurial (Bracke, Hilber and Silva (2014)) or investment risk (Chetty and Szeidl (2014)) as well as the level of consumer spending. Best and Kleven (2013) point out that housing transactions trigger substantial additional spending.

Two influential recent studies investigate the relationship between home equity and mobility using American Housing Survey (AHS) data, and they reach different conclusions. While Ferreira, Gyourko and Tracy (2010) find 35% lower mobility for underwater owners, Schulhofer-Wohl (2012) detect higher mobility for underwater owners.[0] A more extensive survey of the literature also yields mixed findings. These conflicting findings are largely due to the absence of a representative panel database with precise information on household mobility decisions, homeownership status and balance sheets. Scholars such as Ferreira et al. (2011) and others also emphasize the endogeneity of home equity (as housing and labor markets co-move) and the difficulty of addressing this challenge given the data limitations in the US context.

This paper aims to address the challenges of testing the housing lock hypothesis by using unique administrative data from the Netherlands, which provide information on household mobility, housing, household balance sheets and family structure. The results based on household-level data suggest large, negative effects of high LTV ratios on household mobility, both within and across labor markets. The effects of falling home equity are substantially larger for households with low financial asset holdings. These results support the "balance sheet channel". After a long boom, Dutch house prices have experienced a sharp decline since 2008, and the fraction of underwater mortgages rose from 5% in 2007 to 30% in 2013. Property transaction volumes fell by 50%, and job-to-job transitions declined by 40% over the same period, aggregate facts consistent with the housing- and job-lock hypotheses.

The unique Dutch data allow me to track the administrative addresses and household balance sheets. The population addresses make it possible to define the destination of the move and to distinguish moves within and across local labor markets. Studies using the American Housing Survey (AHS) panel of properties (Ferreira et al. (2010), Schulhofer-Wohl (2012)) cannot follow movers, while papers that use the Panel Study of Income Dynamics (PSID) (Coulson and Grieco (2013)) use only the geographic information on the state of residence, which is an imperfect proxy for the local labor market. Papers exploiting mobility data from the Current Population Survey (CPS), which lacks balance sheet information, often rely on comparing owners and renters (Farber (2012)). Existing studies using survey data typically have a small number of underwater observations (125 in Henley (1998), 230 in Coulson and Grieco (2013), 1,800 in Ferreira et al. (2010) and Schulhofer-Wohl (2012)). The administrative data in this paper features more than 580,000 underwater person-year observations. This detailed data allows me to employ richer empirical strategies and to provide precise estimates, which I use to extrapolate the aggregate impact.

It is often argued that home equity affects household mobility through at least two channels. The balance sheet or housing lock channel suggests that credit market imperfections can cause lower mobility rates for underwater households. As mortgage lenders on a new property will typically demand a larger downpayment than underwater households have available, underwater households may be unable to move.[1] On the contrary, the strategic default channel predicts higher mobility rates for underwater owners, who can simply walk away

[0] The difference in results stems from a different definition of moving in the two studies due to the absence of person identifiers in the AHS. Ferreira et al. (2010) defines mobility as "selling property" by dropping observations where an owner-occupied house becomes vacant or occupied by renters in the subsequent survey. By including these observations the Schulhofer-Wohl (2012) definition finds 60% more "moves" including temporary moves and potentially a number of false positives Ferreira, Gyourko and Tracy (2011).

[1] Imperfections in the rental market may exacerbate the housing lock by making it difficult to rent the property.

from their mortgages in markets where mortgages are non-recourse, such as in the US.[2] In the Netherlands, mortgages are full recourse, as borrowers are liable for the remaining balance after a property's sale. In this full-recourse setting, the quasi-absence of defaults permits me to isolate the housing lock channel and shut down the strategic default channel.

The empirical strategy in this paper exploits the rapid rise in house prices during the period 1995-2008, as well as their substantial decline thereafter, which has generated large variation in the home equity of buyers who bought homes only a few years apart. Buyers in the cohorts that purchased homes around the peak have higher Loan-To-Value (LTV) ratios than do their peers who bought homes just a few years earlier. Consistent with the housing lock hypothesis, these peak cohorts also have much lower mobility rates in every year after purchase than do the earlier buyers. For instance, the cumulative fraction of the cohort that has moved within 4 years after purchase is 45% lower for the 2007 purchase cohort than for the 2004 purchase cohort. To address the possibility that these cohort patterns reflect that house prices decline precisely when labor markets and employment opportunities deteriorate, my empirical model eliminates local business-cycle effects. I estimate the effects of LTV ratios on mobility in a model that includes fixed effects for the interaction between the calendar year and the region.

This variation in home equity across purchase cohorts would be ideal if home purchases were randomly timed. However, changes in the credit market or in entry into homeownership over time may lead to the sorting of different mobility types into different purchase cohorts. To overcome this concern, I develop a more refined test focusing on life-events, such as divorces and cohabiting-couple splits, that exogenously shift purchase dates and make for quasi-exogenous variation in the LTV ratio of the new home after the split. I first show that divorce rates in the Netherlands are relatively unaffected by the state of labor and housing markets and the broader economy. I then demonstrate that home-purchase decisions are much more likely to take place in the year of divorce. Comparing the subsequent mobility of recent divorcees, who purchase homes at different points of the housing price cycle, confirms the large housing lock effects associated with high LTV ratios.

This paper robustly finds that high LTV ratios are associated with reduced mobility. In a flexible estimation of the effect of the LTV ratio on mobility, I uncover a non-linear but monotone pattern of mobility, which declines in the LTV ratio. An LTV ratio of between 100 and 110% is associated with a mobility rate that is 22% lower than a LTV ratio of between 50 and 90%. Consistent with Stein (1995)'s model featuring positive moving or downpayment costs, LTV ratios between 90 and 100% also hamper mobility, but the effect is smaller and amounts to 5%. When I study household mobility across local labor markets, I find negative effects of high LTV ratios of similar magnitude.

Stein (1995)'s balance sheet model also predicts that high LTV ratios hamper mobility more severely for

[2] The correlation between defaults, foreclosures and mobility in the US is large but not perfect (Molloy and Shan (2014)). Households can rent the home back after a forced sale or, if they are sufficiently liquid, sell the home and move to avoid the costs of default.

households with low Financial-Assets-To-Value ratios. I uncover compelling evidence for this prediction. A LTV ratio above 110 is associated with a large decline in mobility of 40% for owners with Financial-Assets-To-Value ratios below 15%. In contrast, high Financial-Assets-To-Value holdings above 35% allow households to "unlock the housing lock", as their mobility is not significantly altered by high LTV ratios. Tightening the link between the Stein (1995) balance sheet theory and the empirical models further, I then show that total net liquid assets after a potential house sale, defined as the sum of home equity and household liquid financial asset holdings, have larger predictive power than LTV ratios alone in explaining the housing lock. This last finding highlights the importance of an integrated view of household balance sheets in understanding household mobility.

In a battery of robustness tests, I show that the housing lock finding is resilient to the elimination of variation across purchase cohorts when I exploit regional variation in house price trajectories and LTV ratios within purchase cohorts. The results are also remarkably insensitive to excluding the Great Recession purchase cohorts as well as to using alternative definitions of household mobility, local business cycle effects and local labor markets.

This paper concludes by simulating the partial equilibrium effects of counterfactual house price- and borrowing trajectories on household mobility. I use the estimates of the effects of LTV ratios on mobility as well as micro-data to demonstrate that the effect of the housing lock during recessions on total owner-occupied mobility can be substantial. These indicative simulations, which rely on a series of assumptions, suggest a contribution of the housing lock to the total decline in Dutch owner-occupied mobility during the Great Recession of 20 to 25%. Given the highly non-linear effects of LTV ratios on mobility, I find that relatively small shocks to house prices or borrowing levels can have large effects on aggregate mobility.

1.1.1 Related literature

An extensive literature from Kain (1968) to Andersson, Haltiwanger, Kutzbach, Pollakowski and Weinberg (2014) and Sahin, Song, Topa and Violante (2014) discusses the aggregate employment effects of spatial mismatches between supply and demand for work. Labor mobility across regions can allow the adjustment of employment and wages to negative local labor demand shocks, as the departure of workers reduces local labor supply (Blanchard and Katz (1992)). According to the Oswald (1997) hypothesis, high home-ownership rates increase the natural unemployment rate as home-owners are less able to simply move away in response to labor demand shocks. In an integrated view of labor and goods markets, the migration of workers-consumers out of depressed regions may also aid those who stay behind if the demand shortfall occurs in the tradable sector (Farhi and Werning (2014)). The insurance value of migration against local labor demand shocks depends on moving costs as well as on the access of moving workers to employment opportunities in well-performing regions (Yagan (2014)). As unemployed homeowners may turn down job offers that would require them to move, the decline in house prices and home equity and the associated reduction in geographical mobility could increase unemployment for a given level of vacancies (Sterk (2012)). The robust finding in this paper that lost home equity hampers mobility across local labor markets highlights the potential macroeconomic importance of the housing lock channel.

The relationship between home equity and mobility has been investigated in a prior literature, which arrives at mixed conclusions. This research uses either aggregate data or relatively small panel surveys of properties or households. On the one hand, Henley (1998), Chan (2001) and Ferreira et al. (2010) find an adverse impact of negative home equity on mobility using, respectively, British Household Panel Survey (BHPS) 1992-1994 data, prepayment data on loans originated in the Northeast of the US in the early 90s, and 1985-2007 data on properties from the AHS. On the other hand, Schulhofer-Wohl (2012) and Coulson and Grieco (2013) find that underwater owners move more through using the AHS and the 2001, 2005 and 2007 PSID data, respectively. A parallel line of inquiry uses aggregate data. Donovan and Schnure (2011) exploits the American Community Survey (ACS) and concludes that negative equity reduces intra-county migration but leaves out-of-state migration unaffected. Molloy, Smith and Wozniak (2011) finds no correlation between the 2006-2009 change in state-level migration and negative equity shares using the Census and Current Population Survey (CPS). Nenov (2012) employs state level Internal Revenue Service (IRS) and Corelogic data and finds that negative equity reduces out-migration rates, but has no impact on in-migration. To address the data availability and measurement challenges in this literature, this paper uses administrative population data on household mobility and household balance sheets for the Netherlands.

Researchers have investigated several mechanisms linking house prices and household mobility. First, the models in Stein (1995) and Ortalo-Magne and Rady (2006) suggest a critical role for household balance sheets and imperfections in credit and rental markets in explaining the decline in transactions when house prices decline. A second line of inquiry investigates the effects of nominal loss aversion on residential mobility (Genesove and Mayer (2001), Engelhardt (2003), Annenberg (2011)). Focusing on condominiums in Boston in the 1990s, Genesove and Mayer (2011) find that owners subject to nominal losses set and attain higher prices prices and are less likely to sell than other sellers. The impact of negative home equity on strategic defaults and associated moves constitutes the third channel. Ghent and Kudlyak (2011) demonstrate that this channel is relevant in non-recourse mortgage markets, such as the US, in particular when the recovery rate is relatively low. In an application of option theory, Deng, Quigley and Order (2000) construct a model where no-recourse borrowers default when home equity becomes sufficiently negative. The level of negative home equity that triggers default depends on the realization of income shocks (Bhutta, Dokko and Shan (2010)) and on the importance of borrowing constraints (Campbell and Cocco (2014)). By demonstrating the importance of household financial asset holdings, this paper supports the Stein (1995) balance sheet channel.

This study fits into the expanding international household finance literature (IMF (2011), Lea (2011), Campbell, Ramadorai and Ranish (2014), Giglio, Maggiori and Stroebel (2014)). The structure of housing finance varies considerably across countries. The high Dutch mortgage levels *ex ante* and the absence of strategic defaults *ex post* make the Netherlands particularly suitable to study the balance sheet channel. However, the finding of substantial housing lock when house prices fall and home equity declines must be recognized as conditional on the housing and mortgage institutions in the Netherlands, which therefore affect the transmission of house price shocks to household mobility and the macroeconomy.

This paper also contributes to the literature on the role of household balance sheet heterogeneity and liquidity constraints for household behavior and for the aggregate economy. Several studies have rejected the Modigliani-Miller prediction that household net worth is irrelevant for the response to financial shocks of consumption (Mian, Rao and Sufi (2013), Baker (2014)), debt repayments (Agarwal, Liu and Souleles (2007)) or small business creation (Adelino, Schoar and Severino (2013)). Focusing on another critical household outcome variable, this paper complements these studies by demonstrating the importance of balance sheet factors and liquidity constraints for residential mobility.

This paper is organized as follows. Section 1.2 describes aggregate Dutch mobility and house price patterns in the Great Recession and variation in home equity and mobility across purchase cohorts. Section 1.3 lays out the empirical strategy. Section 1.4 describes the institutions and the data. Section 1.5 first reports the results based on house price trajectory variation across purchase cohorts, then estimates the balance sheet effects and finally presents the estimates for the life-event buyers. Section 1.6 performs robustness checks. Section 1.7 simulates mobility under alternative trajectories for house prices and borrowing. Section 1.8 concludes.

1.2 Aggregate House Price and Mobility Patterns

This section presents aggregate information on Dutch housing mobility and pricing trends. As a starting point for analyzing house prices and mobility, Figure 1-1 presents the moving behavior of owners and renters over time using 7 waves of the Dutch housing survey. In the period 2009-2011, the mobility of homeowners declined by approximately 35%. Consistent with the housing lock hypothesis, the mobility of owners drops much more than the mobility of renters when house prices decline. Consistent with the Stein (1995) hypothesis of binding constraints on moving, the fraction of homeowners that would like to move rises by 30%, while moving intentions of renters are flat (see Appendix Figure A1.1). Both the large decline in household mobility as well as the rise in mobility intentions are thus concentrated among home-owners.[3]

[3]Both patterns are robust to restricting the sample to households with similar observables predictive of ownership.

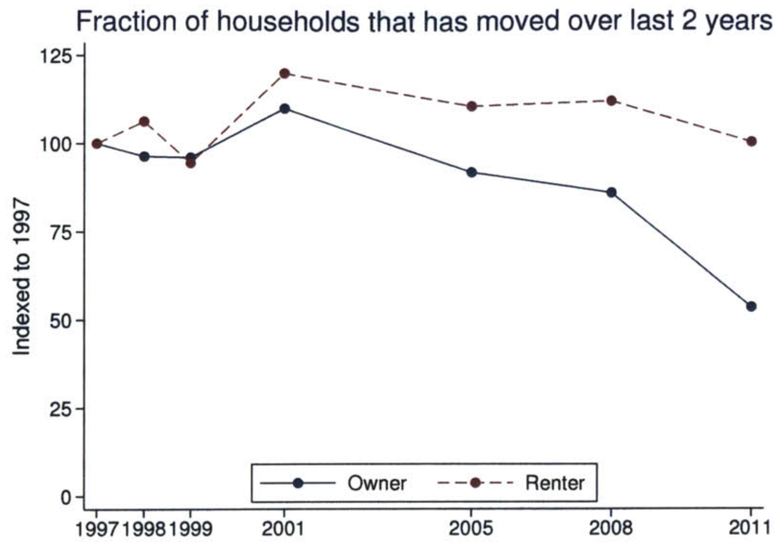


Figure 1-1: Mobility of owners and renters over time

Notes: The data are from the WBO 1998, 1999, 2000 and WoON 2002, 2006, 2009 and 2012 surveys. WoON (WoonOnderzoek Nederland) is a repeated, cross-sectional, nationally representative survey of about 70,000 individuals about their housing situations known as WBO (WoningBehoefteOnderzoek) until 2000.

Figure 1-2 presents house price trends for the Netherlands and the United States. It shows the long boom of Dutch house prices which rose faster than in the US from the 1995 starting point. Aggregate Dutch house prices continued to increase in 2007 and in the first half of 2008 and then began to decline from the fourth quarter of 2008 onwards until mid 2013. The cumulative decline of national nominal house prices from the peak to the trough equals 20%.

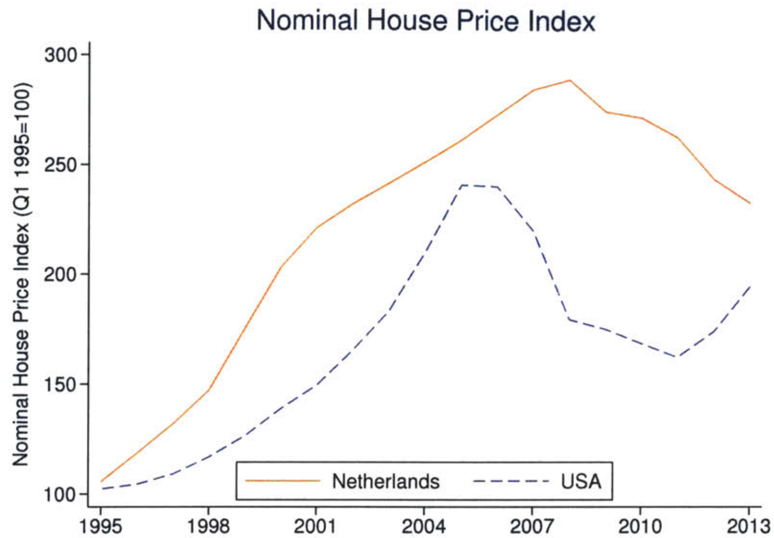


Figure 1-2: Nominal house price index for the US and the Netherlands

Notes: The source is the *The Economist* house price index which uses data from FHFA, OECD, S&P, Thomson Reuters, CBS and NVM.

Home equity and mobility patterns across purchase cohorts. I now turn to the graphical presentation of the main empirical strategy in this paper, which exploits variation in home equity across buyer purchase cohorts. Figure 1-3 visualizes the differential effect of house prices on purchase cohorts by plotting the share of underwater mortgages of each purchase cohort of borrowers over time. Rising house prices until the end of 2008 increased the denominator of the LTV ratio and reduced the LTV ratio as well as the share of loans underwater for the early cohorts. When house prices declined, the LTV ratio and the fraction of mortgages with high LTV ratios rose for all the cohorts. There is one important difference between cohorts that bought several years before the peak such as the 2002 cohort and cohorts that buy closer to the peak such as the 2007 cohort. The earlier cohorts have benefited from several years of rising house prices. The cumulative house price appreciation increased the denominator of the LTV ratio and reduced the LTV ratio for earlier cohorts.[4] The differential exposure to the rise in house prices has also generated substantial variation across purchase cohorts in the share of mortgages above 90, as shown in Appendix Figure A1.2. As the earlier purchase cohorts had substantially lower LTV ratios, the housing lock hypothesis suggests that these cohorts were less locked-in and moved more.

[4]Dutch mortgages amortize less than mortgages in most other countries. The accumulation of capital by early borrowers in the form of savings deposits or life insurances on associated accounts over a longer horizon also reduced the LTV ratio of the early cohorts more relative to later cohorts but is quantitatively less important. Finally, rising LTV ratios at origination may also have contributed to the pattern of high current LTV ratios for late cohorts.

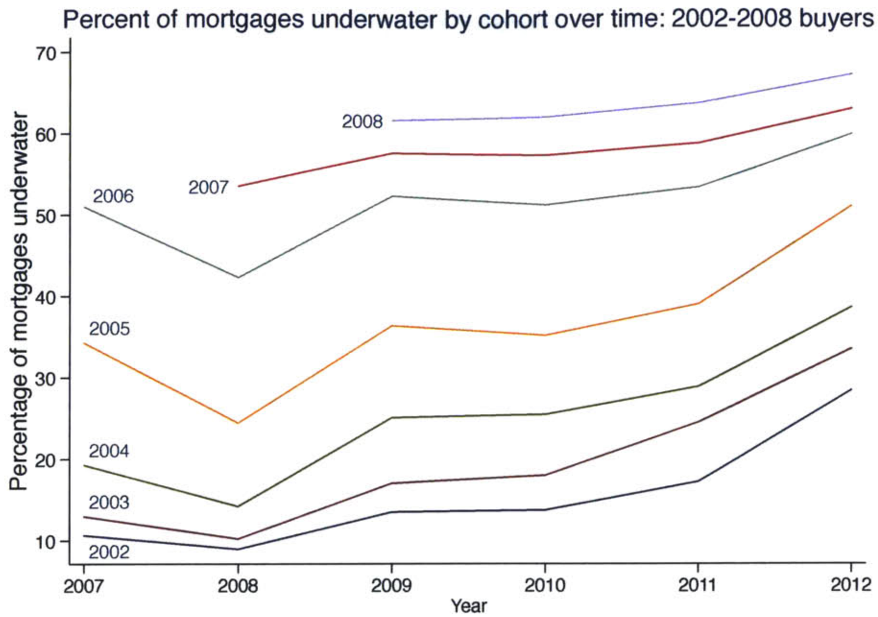


Figure 1-3: Percentage of mortgages underwater by purchase cohort over time

Notes: The percentage of mortgages underwater within a purchase cohort by year is based on CBS household balance sheet, transaction price and regional house price index data. See section 4 of the text for more details.

The top panel of Figure 1-4 presents the cumulative fraction of the purchase cohorts that has moved against the years since purchase for the 2002 until 2008 purchase cohorts. The closer individuals buy to the peak, the less they have subsequently moved out of their home within any number of years since purchase. The differences in mobility across cohorts are large and monotonic as predicted by the monotonic exposure to rising house prices in the run-up. For instance, within five years since purchase, 30% of the 2002 buyers have moved, in contrast to 15% of the 2007 buyers. The average household mobility rates of the various purchase cohorts are also very precisely estimated. While the home equity and mobility cohort patterns are consistent with the housing lock, one alternative explanation might be that cumulative moving patterns would have been unstable across cohorts in the absence of the negative shock to house prices. To investigate this explanation, the bottom panel of Figure 1-4 presents the cumulative moving patterns for the earlier 1996 until 2001 cohorts before the negative realization of house prices. During this period, the relationship between the cumulative moving probability and the years since purchase was remarkably stable across these placebo cohorts, in sharp contrast to the pronounced pattern in the top panel of Figure 1-4. Prices in the run-up did not increase at a constant rate. Hence, variation in mostly low LTV ratios also exists across the placebo purchase cohorts. The identical moving behavior of the placebo cohorts in the bottom panel is a foreshadowing of the asymmetric response of mobility to low and high LTV ratios, which this paper will demonstrate. Another alternative explanation is the sorting of low and high mobility types into different purchase cohorts. To overcome this concern, I will use life-events as shifters of purchase dates. Overall, the home equity and mobility patterns from Figures 1-3 and 1-4 provide compelling, suggestive evidence of the housing lock.

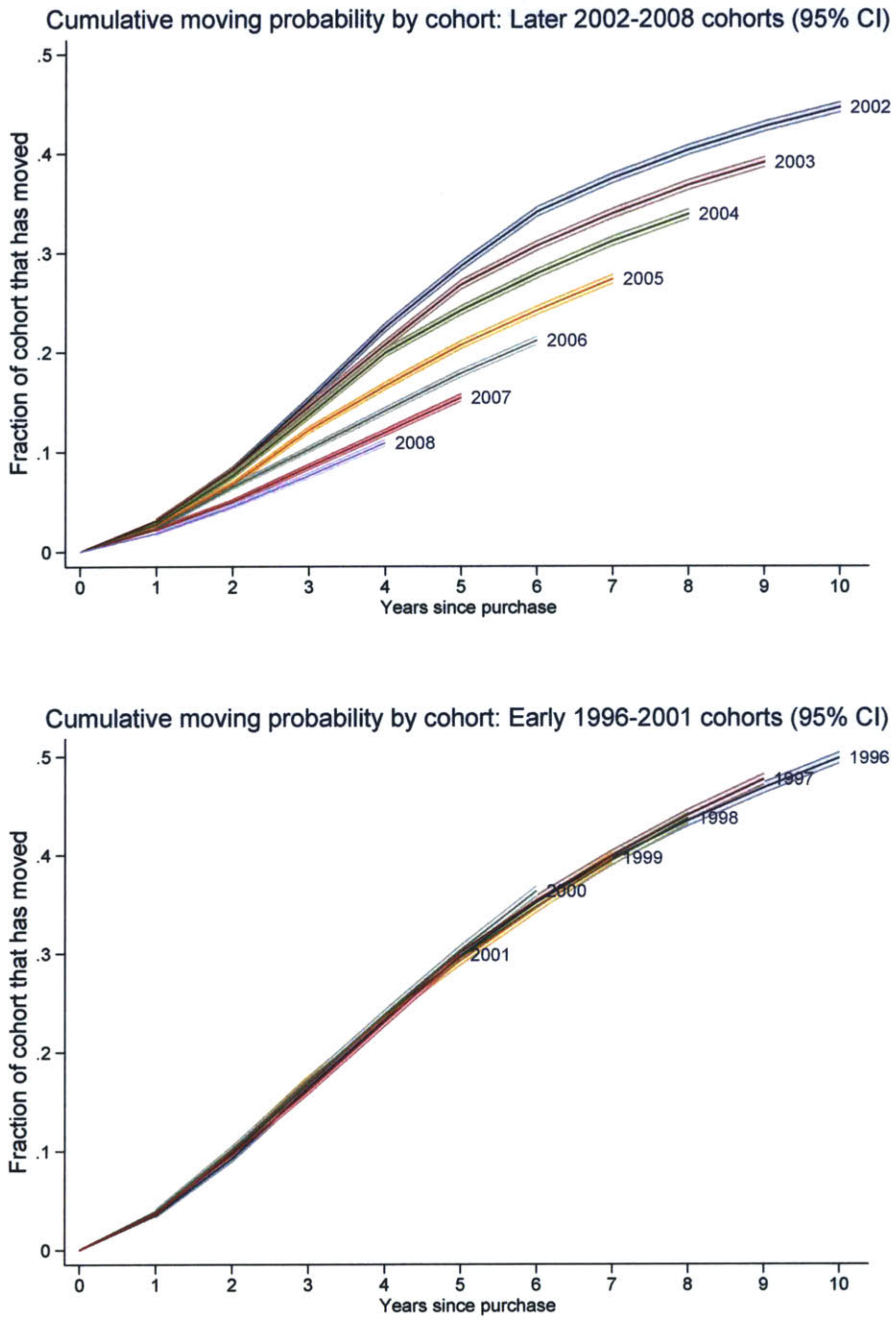


Figure 1-4: Mobility of purchase cohorts given the years since purchase

Notes: The top panel presents average cumulative moving probabilities and 95% confidence intervals for the "treated" later 2002-2008 cohorts, which are differentially exposed to declining house prices. For instance, while the 2008 cohort has only been exposed to declining prices, the 2002 cohort has benefited from 6 years of positive house price growth. The bottom panel presents cumulative moving probabilities and 95% confidence intervals for the placebo cohorts. The early 1996-2001 cohorts are placebo cohorts, as they all benefited only from rising house prices over the 1996-2006 calendar-year period (shown in the bottom panel), which reduced their LTV ratios to low levels. The moving data are based on the Transactions Registry and the Address Registry from Statisistics Netherlands (CBS). See section 1.4 of the text for more details.

Figure 1-4 compares the mobility of different purchase cohorts, holding the years since purchase constant, in *de facto* different calendar years. As mobility can vary over time for reasons other than the housing lock, my econometric analysis will compare different purchase cohorts in the same calendar year by including time fixed effects, for which Figure 1-5 provides intuition. The red curve plots the differential cumulative fraction that has moved since the end of 2008 by purchase cohort, for 2004 and 2007 buyers who did not move until the end of 2008. Over the period 2008-2012, the low-leverage 2004 purchase cohort moves significantly more than the high-leverage 2007 purchase cohort. In 2012, the loan age year of the 2004 purchase cohort was 8 (and 5 for the 2007 purchase cohort). The large 2004-2007 mobility gap, considered in isolation, may in principle be due both to the differential housing lock exposure and to the loan age effect. To investigate the latter, the differential cumulative moving fraction is plotted for the 1997 and 2000 cohorts in the same loan age space. The 1997-2000 differential mobility was much smaller than the 2004-2007 difference and even became negative. Relying on the 1995-2011 purchase cohorts, including those unaffected by the house price drop such as the 1997 and 2000 cohorts, I am thus able to rule out the loan age effect explanation and retain the housing lock as the most compelling explanation for the cohort patterns. The next section formalizes the empirical strategy.

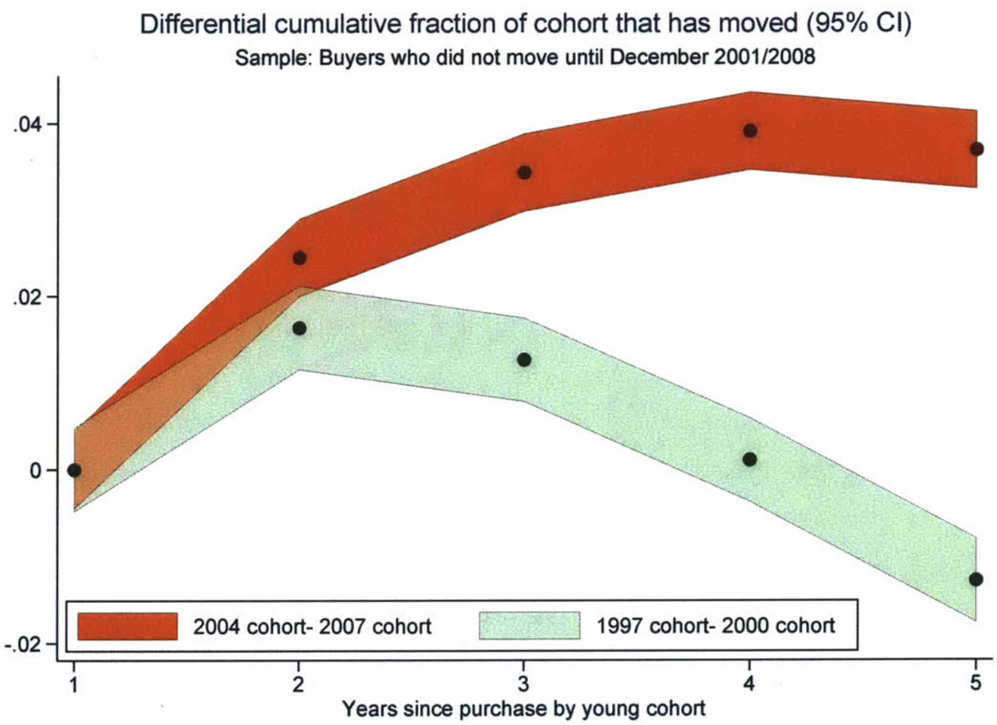


Figure 1-5: Mobility of cohorts fixing the calendar year

Notes: The moving data are based on the Transactions- and Address Registries from Statisistics Netherlands (CBS). See See section 1.4 of the text for more details.

1.3 Empirical Strategy

The main strategy to identify the impact of the housing lock on residential mobility is to exploit the differential effect of house prices on LTV ratios of different purchase cohorts. The unit of observation is a buyer-year for buyer i in calendar year t. A buyer-year always belongs to a purchase cohort year c and a region r where he/she lives in a property from January 1st of the year t. For this buyer-year, who has not moved until year t from a given home, I code an annual mobility indicator y_{icrt} equal to 1 when the buyer moves in year t. Consider the following model of the relationship between the mobility indicator y_{icrt} and indicator variables for different LTV ratio categories $\mathbf{1}\left[l_k < LTV_{it} \leq h_k\right]$:

$$y_{icrt} = \lambda_{tr} + \sum_k \delta_{1k} \mathbf{1}\left[l_k < LTV_{icrt} \leq h_k\right] + X_{it}^{'}\beta + \epsilon_{icrt} \tag{1.1}$$

The parameters of interest in equation (1.1) are the coefficients δ_{1k}, which flexibly measure the effect of the LTV ratio on moving probability. Equation (1.1) features a rich set of covariates $X_{it}^{'}$ to control for the multiple factors determining moving risk. Households typically move into a new home, either for a job, for family reasons, or to match their housing consumption with their expected income and preferences. The controls comprise 5 person age category fixed effects, 5 household size fixed effects, family structure characteristics, indicators for changes in the family size as well as 3 household financial assets category fixed effects. I also include loan age year indicators $\sum_a \mathbf{1}\left[a = t - c\right]$, since the empirical moving rate depends on the length of time a that individual i has lived in that home.[5] Intuitively, both very recent owners and historical owners are unlikely to move in a given year, with the rate being higher between these two low-moving probability regions.

Regarding job and income motives for moving, the identification challenge is that labor and housing markets co-move. Shocks to regional labor demand can affect both unobservable job opportunities in the error term ϵ_{icrt} as well as house price appreciation $\frac{V_{it}}{V_{ior}}$, which is a critical factor in the LTV ratio (together with the LTV ratio at origination and the current to original loan balance). The specification in equation (1.1) includes fixed effects λ_{tr} for the interaction between the region r and calendar year t. These fixed effects account flexibly for regional labor market incentives to move out, regional new income opportunities, and regional time-varying future income prospects, which may motivate moves to trade-up homes. The regression estimates δ_{1k} correspond to the causal effect of the LTV ratio category on mobility if the conditional independence assumption is verified. The conditional independence assumption implies that, conditional on observables X_{it} and region-time interactions, potential mobility rates $y_i(k)$ at which individual i would move, are independent from LTV ratio categories k. The housing lock hypothesis predicts that the coefficients δ_{1k} will decline in the LTV ratio for ratios close to and above the 100% threshold.

I will test predictions of the Stein (1995) balance sheet mechanism by analyzing the role of household liquidity

[5]Previous studies typically allow for less flexibility including one up to three polynomials of the loan age.

in section 1.5.2. First, I will estimate equation (1.1) for subsamples of household-years as a function of the Financial-Assets-To-Value ratio. I then study the effect of the net liquid assets after a potential house sale, the sum of home equity and financial assets, on mobility. I will thus exploit variation across purchase cohorts in Net Liquid Assets after a potential house Sale (NLAS) by estimating the following model:

$$y_{icrt} = \lambda_{tr} + \sum_{j} \delta_{2j} \mathbf{1} \left[l_j < NLAS_{icrt} \leq h_j \right] + X_{it}^{'} \beta + \epsilon_{icrt} \tag{1.2}$$

The Stein (1995) balance sheet hypothesis leads to two predictions. First, high LTV ratios should hamper mobility more for households with low Financial Assets-To-Value ratios (i.e. those households feature lower coeffficients δ_{1k} in the critical LTV region). Second, the marginal effect of extra liquidity on mobility should be large and positive in regions where the liquidity constraint binds for many households (i.e. the coefficients δ_{2j} should rise quickly in the NLAS value in the critical region).

To address the possibility that property buyers near the peak were somehow different from those who bought homes at other times, Section 1.5.3 examines the post-purchase mobility patterns of individuals who were part of married couples that divorced, or cohabiting couples who split up, in various years. Such family structure shocks are a valuable source of arguably exogenous variation in when individuals purchase homes, as the Dutch split rates are very stable over time. In practice, I restrict the estimation of equation (1.1) to the subsample of life-event buyers, who start their period of ownership in a given year because of a divorce or a cohabitation split.

While equations (1.1) and (1.2) shut down all variation over time and across regions and are identfied based on the remaining variation, they, however, do not include fixed effects λ_{tc} for the interaction between the calendar year t and the purchase cohort year c, as I want to exploit variation in LTV ratios across different purchase cohorts. To account for the potential endogeneity of the purchase date, section 1.5.4 performs within cohort-year comparisons of buyers across different regions and exploits variation in regional house prices. I thus deal with the potential sorting of low and high mobility types for a given LTV ratio into different purchase cohorts. Sorting may, for instance, occur if credit market conditions change over time. Alternatively, financially less sophisticated buyers may be less likely to anticipate the bust, more likely to buy closer to the peak, and may also be more likely to be laid off and forced to move during a crisis. To overcome these potential concerns, I thus include fixed effects λ_{tc} for the interaction between the calendar year t and the purchase cohort year c and estimate the following linear probability model:

$$y_{icrt} = \lambda_{tc} + \sum_{k} \delta_{3k} \mathbf{1} \left[l_k < LTV_{icrt} \leq h_k \right] + X_{it}^{'} \beta + \epsilon_{icrt} \tag{1.3}$$

1.4 Institutional Setting and Data

Mortgage, housing and labor market institutions. With high LTV ratios at origination and limited amortization, the current Dutch residential mortgage-to-GDP ratio of approximately 120% is the highest in the world, which is approximately 45 percentage points higher than in the US, as shown in Appendix Figure A1.3. LTV ratios at origination around 100 or even slightly above 100% are not unusual in the Netherlands. In the latter case, the loan proceeds can finance the entire purchase price of the house, transaction costs such as the 6% stamp duty (reduced to 2% in July 2011) or home improvements. High LTV mortgages are originated in an environment that provides relatively low incentives to default at a given LTV ratio, as lenders have full recourse. Therefore, like in most countries, the defaulting Dutch borrower is personally liable for the remaining mortgage balance after a property sale. If the lender forecloses the property and the borrower cannot repay, the borrower faces the risk of personal bankruptcy. When entering this debt consolidation scheme, the debtor has to exert a maximum effort to generate funds to repay his creditors in a period of three years and limit consumption to the subsistence level. Lender recourse, priority of mortgages in bankruptcy and high recovery rates reduce incentives for borrowers to default strategically (Ghent and Kudlyak (2011)). Dutch foreclosure rates are equal to approximately 1% of US rates. The share of the housing stock going into foreclosure in 2010 was equal to 0.03% in the Netherlands and 2.23% in the US (RealtyTrac(2014)).

The vast majority of mortgages for the 1995-2011 purchase cohorts that I study are non-amortizing. Interest-only loans are frequently combined with associated, pledged accounts where capital is built up in the form of savings deposits, life insurance or investment funds. Mortgage contracts often combine multiple loans with different repayment types, for instance a plain vanilla interest-only loan, combined with a second interest-only loan with an associated savings deposit account. Contracts with associated tax-exempt accounts allow borrowers to build up capital while maximizing the unlimited deduction of interest payments on the constant loan balance.[6] As owner-occupied homes are considered a source of income, an imputed rental income of 0.6% of the value of the house is included in taxable income. Relative to the US, both relatively high marginal tax rates on personal income, that rise from 36 to 42% at €19,646 of taxable income and to 52% at €56,532 of taxable income[7] and the absence of the itemizing precondition for claiming the deduction, increase the economic importance of the deduction. The typical mortgage features a maturity of 30 years and an interest rate that is fixed for 10 years and then periodically reset.

How can a household relocate if the full recourse mortgage is underwater in the Netherlands? To come up with the cash to cover the shortfall in funds to pay off the mortgage balance, there are four options. First, the household can reimburse the shortfall out of its own savings or savings in the family system.[8]

[6] As of January 2013, new mortgages have to fully amortize to benefit from interest tax deduction.

[7] The maximum rate for interest deduction is reduced gradually since 2014 from 52% to 38% by 50 basis points a year.

[8] A parent can give his/her child under age forty a one-off tax exempt gift of €51,407 to amortize the mortgage or buy a home.

Second, the household can borrow the shortfall through an unsecured, personal loan. Third, in principle, the household could carry over the shortfall to a new mortgage. Carrying over negative equity constitutes in theory an exceptional circumstance that allows mortgages to exceed the norm on maximum LTV ratios at origination from the Code of Conduct for Mortgages (CCM), that is equal to 106% in 2012. However, survey evidence suggests that this third option is rarely pursued in practice (Conijn and Schilder (2012)) and that mortgages are hence *de facto* not assumable, a key credit market friction in the Stein (1995) model.[9] Fourth the household may sublet the property it owns and simultaneously rent another. This occurs very rarely, perhaps because of frictions in the rental market.[10]

The homeownership rate in the Netherlands is 60%. With estimated times until half of the buyers move from their homes of around 12 to 13 years, the mobility of Dutch homeowners is comparable to US levels (Emrath (2009)). The government plays an important role in the rental market, which is subject to rent controls and which makes up 80% of public housing. In the European Union the Netherlands is classified as a high-geographical and high-job-mobility country, together with the UK, the Scandinavian and Baltic states (Vandenbrande, Coppin and Van der Hallen (2006)). The average Dutch job duration is approximately 6 years compared to 8 years in the EU with shorter durations only for Denmark, the UK, Latvia and Lithuania.

Panel data on buyers. The sample consists of a large, random sample of buyers of owner-occupied existing homes who are the unique heads of household when they move in.[11] Appendix Figure A1.4 visualizes the construction of the panel of buying heads of existing homes. The sample of 549,066 buyers have moved into their purchased properties in the cohort years 1995-2011. The econometric analysis of the impact of home equity relies on a 2007-2012 panel that includes household balance sheet information on the subsample of buyers who had not moved out of their properties before 2007. The graphical analysis of mobility patterns relies on a 1995-2012 panel, which follows all the 549,066 buyers prior, during and after their residence spell in the selected purchased home, exploiting 17 years of address data for the population. I construct the panel using several administrative datasets from Statistics Netherlands (CBS). The datasets are the transactions of the existing purchase dwellings Registry (*Bestaande Koopwoningen*), the universes of individual address- (*Adresbus*) and family structure (*Huishoudensbus*) spells, the household balance sheets (*Integraal Vermogen*) and the population socio-demographic characteristics (*Persoontab*). I now summarize the selection of transactions, the construction of the buyers panel and the variable definitions.

[9] Only 15% of the mortgage requests from households with negative equity are passed along by mortgage brokers to lenders, who reject 69% of the received requests. More than two-thirds of the mortgage brokers report that the maximum amont of negative equity that can be carried over for a house purchase of €235,000 by a household with sufficient income is lower than €5,000 (Conijn and Schilder (2012)). LTI norms from the CCM, which cap charges (including the cost of carry-over debt which is deductible for 10 years) given income, contribute to the rare nature of negative equity carry-overs (Conijn and Schilder (2013a), de Vries (2014)).

[10] The frictions on the Dutch rental market include the restriction of the mortgage interest deduction to owner-occupied homes, mortgage clauses forbidding subleases and rental supply competition from the public sector.

[11] As the Transactions Registry records the transactions of existing homes (on average 180,000 per year) as opposed to the construction of new homes (on average approximately 60,000 per year), the Registry covers approximately 75% of the moves into owner-occupied homes.

First, I select a random 25% of the 1995-2011 transactions of existing homes from the Transactions Registry, given CBS server memory constraints. From the obtained 747,554 house purchases, which have an address and a purchase date as identifiers, I match 630,947 purchases to the address spell of at least one individual/encrypted Social Security Number (SSN) moving into the address in the quarter of purchase, the subsequent quarter or two quarters after the purchase. When multiple individuals move to the property, I use the household head dummy from the household spell Registry, which has a SSN-household spell as its unit of observation. To keep things simple and non-arbitrary, I focus on transactions for which I identify one household head that moves in. From the initial 747,554 purchases, I obtain 574,337 purchases (76.83%) with one head. These 574,337 matched transactions correspond to 549,066 distinct individuals, as some buyers purchase multiple selected properties. I then add the month and year of birth, gender and origin of the 549,066 selected buyers from the Person Registry.

Second, I construct a 1995-2012 panel for the 549,066 buyers with 9,883,188 person-years tracking mobility and controls over time. I record the addresses on December 31st for each person-year from the Address Spell Registry. The models of owner mobility and home equity are estimated in 2007-2012 for the approximately 1,950,000 person-years with balance sheet data and where the buyer lives in the selected property on January 1st. The graphical owner-occupied mobility analysis relies on the 3,780,00 person-years in 1996-2012 where the buyer lived in the selected property on January 1st. I also record addresses prior to and after spells from 1995 to 2012 to define moves across local labor markets. From the Household Spell Registry, I obtain variables such as the household size, the type of household (e.g. married without children) as well as the position of the individual in the household (e.g. partner in married couple without children). These household structure variables allow me to define shocks to family structure and home purchase dates. I then add for the address-years the associated province, the local labor market and the municipality. The Netherlands consists of 12 provinces, 40 so-called COROP local labor markets and approximately 400 municipalities.[12] The COROP local labor markets are areas with a core centre and a surrounding catchment commuting zone defined such that the working population and employment in each area overlap for at least 70%. As the COROP local labor markets are time-consistent and cover the entire country, Commuting Zones (CSs) (Tolbert and Sizer (1996), Autor and Dorn (2013)) rather than Metropolitan Statistical Areas (MSAs) constitute the US analogue. The data Appendix provides further details on the construction of the buyer panel dataset. I will now define and present summary statistics for buyer variables.

An individual is considered to have moved in a given year when the addresses on December 31st of that year and on December 31st of the previous year differ and is considered not to have moved when they remain the same. The moving dummy is recorded as missing when either of the two addresses is missing.[13] For a given ownership spell of a buyer, the cohort year is defined as the year prior to the first year in which the

[12]COROP is the abbreviation of the commission that defined the local labor markets: Coördinatie Commissie Regionaal OnderzoeksProgramma. I use the *Gemeente Wijk Buurt* address-municipality and the *Gebieden In Nederlanden* municipality-province-COROP linkage files.

[13]Among the 3,810,114 spell person-years respectively 0.70 and 0.76% of of the observations have a missing mobility indicator and a missing inter labor market mobility indicator.

buyer lived at the selected address on January 1st. The loan age year is the calendar year minus the cohort year. For instance, if a buyer purchased a house in March 2002 and moved in in May 2002 and moved out in October 2005, then the cohort is equal to 2002 in the years 2003, 2004 and 2005. The annual mobility model is estimated for this buyer-address in 2003 (0), 2004 (0) and 2005 (1) with loan age years equal to 1 in 2003, 2 in 2004 and 3 in 2005. The current Loan-To-Value ratio in a given year is the ratio between the assessed net mortgage balance on the primary residential property where the person lives at the beginning of the year and the estimated market value of the property. The mortgage balance is net of estimated capital built up in associated mortgage savings or investment accounts.[14] The current market value of the property is estimated using the administrative purchase price multiplied by the appreciation of the CBS provincial house price index. I trim the data by coding the LTV ratio as missing for values below zero or above 150, which leaves more than 97% of the buyer-years in the estimation sample. I will report that the results are very similar when keeping the trimmed observations in the sample. The indicator for negative home equity is equal to one when the current LTV ratio is larger than 100%. Household financial asset holdings include the amounts in checkings and savings accounts and the values of equity and bond holdings. I define the Financial-Assets-To-Value (FATV) ratio as the ratio between household financial asset holdings and the estimated market value of the property. Net liquid assets after a potential house sale are defined as the sum of home equity and household financial assets. I define individuals with the position of partner in a married couple as married. A person is defined to belong to a cohabiting couple when he or she has the position of partner in a cohabiting couple. Partners in a cohabiting couple need to be a real couple and do not include, for instance, roommates or two siblings living together as the "position in the household" variable would be equal to "single" for roommates or "other member of the household" for two siblings living together. A person is newly divorced when the person was married last year but is not married this year. A person loses his or her status as a partner in a cohabiting couple when he or she was part of a cohabiting couple last year but not this year.

Table 1.1 presents descriptive statistics for buyers. The top panel presents mobility rates for all buyer-years in the 1995-2012 panel. The average mobility rate is 5.31 percentage points, of which approximately 26% are moves across labor markets. The middle panel presents summary statistics for the 2007-2012 panel of buyers with balance sheet data. The average mobility rate is equal to 4.31 percentage points of which, again, 26% are moves across labor markets. The average and median LTV are respectively equal to 75 and 81%. The LTV ratio is below 50 for 25% of the observations, between 50 and 90 for 33% of the buyer-years and between 90 and 100 for 12% of the observations. 12% of the buyer-years have a LTV ratio between 100 and 110 while 17% of the observations feature a LTV ratio between 110 and 150. 30% of the person-years thus have negative home equity. The mean home equity amounts to €74,000, while the median equals €41,000. Among the owners with negative home equity, the average home equity is - €29,000. 7% of the

[14] As the household balance sheets do not include the capital built up in associated mortgage accounts, I randomly select 55% of the mortgages, which corresponds to the market share of mortgages with associated accounts, for which I estimate the capital built up applying the standard amortization formula with a 4% interest rate.

owners have zero outstanding mortgage balance. Financial asset holdings are on average equal to €77,000, while the median of €17,000 is significantly smaller. The bottom 37% of the households own less than €10,000 of financial assets, and the top 36% have financial asset holdings above €30,000. The net liquid assets after a potential house sale are on average equal to €151,000 and the median value is €74,000. The Financial-Assets-To-Value ratio features a median value of 8% and a mean of 23%. More than two-thirds of the observations have a Financial-Assets-To-Value ratio below 15, while 15% of the observations have a Financial- Assets-To-Value ratio above 35.

The bottom panel of Table 1.1 shows descriptive statistics for buyer variables measured when they move into the property. A buyer is on average approximately 37 years old, lives in a household of 2.4 individuals and 86% of the buyer household heads are male. Fewer than half of the buyers are married and around a third have children. Respectively 3% and 7% of the moves into the selected properties occur in years of, respectively, a divorce and a cohabiting-couple split. According to American Housing Survey (AHS) 2001-2011 data, the typical American buyer is on average 4 years older, belongs to a household with 0.4 more members and is 10% more likely to be married than his Dutch counterpart (Taylor (2013)). The average age of Dutch first-time homebuyers of 28 is low from an international perspective relative to approximately 29 in the UK and Ireland, 31 in France, 34 in the US and 36 in Germany.

Table 1.2 reports descriptive statistics for buyers by purchase cohort. The distribution of buyer characteristics is quite stable across cohorts. The increase (decrease) of the average age (household size) from 1995 until 2007 is slow, small and continuous and consistent with secular population demographic trends. The continuous reduction in the fraction of married buyers is consistent with a population-wide increase in the average age at marriage. When we zoom in on pairs of cohorts such as 2004 and 2007 or 2003 and 2006, we observe small differences in buyer observables relative to the much larger differences in the fraction with high LTV ratios in the 2009-2012 bust, as shown in Figure 1-3. The drop of the average age since 2008 is driven by an increasing share of first-time home buyers relative to trade-up buyers in the transaction volume during the Great Recession (Conijn and Schilder (2013b)), as first-time home buyers are not directly affected by the housing lock. The number of transactions by cohort in the sample rises gradually from approximately 30,000 in the late 1990s to a peak in 2006 at around 41,000 and a drop back to approximately 23,000 in 2011.

Other data. To estimate house value appreciation, I use the Statistics Netherlands price index of existing purchase dwellings for the 12 provinces. Statistics Netherlands (CBS) and the Land Registry Office (*Kadaster*) construct the Sales Price Appraisal Ratio index using assessed values of the universe of transacted proprerties to control for differences between the properties and obtain a constant quality price index.

1.5 Results

1.5.1 Estimates based on house price trajectory variation across purchase cohorts

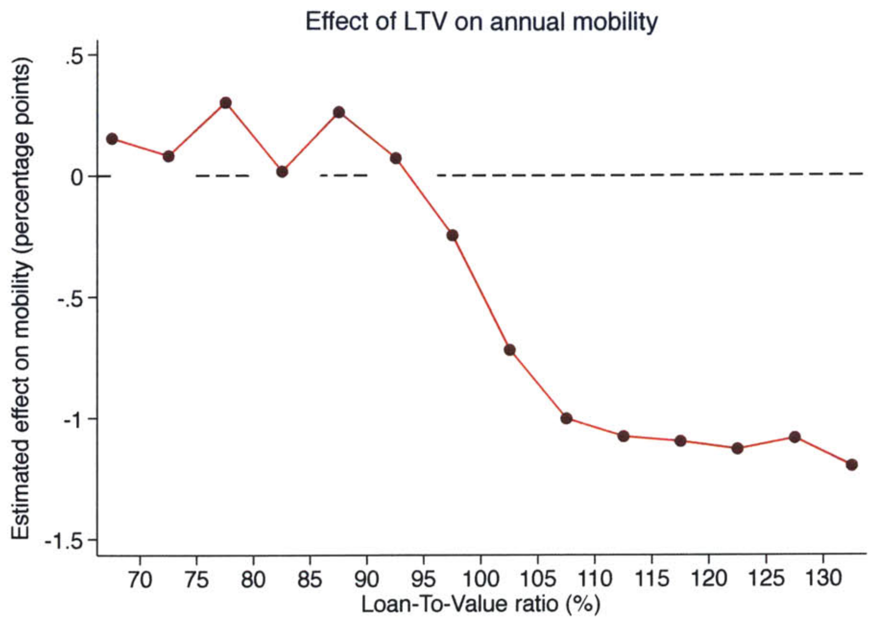
The relationship between annual mobility and LTV ratios from equation (1.1) is now estimated in the sample of buyer-years during the period 2007-2012. Table 1.3 presents the effects of the LTV ratio, grouped in 5 categories, on annual total mobility and on annual mobility across labor markets. Column 1 of Table 1.3 presents the results for total annual mobility by including the minimal set of controls: only loan age year- as well as five person age category fixed effects. In particular, this specification in Column 1 excludes time fixed effects. The estimates in Column 1 suggest a negative, large and monotone association between mobility and LTV ratios. The coefficient of -1.57 percentage points on the $100 < LTV \leq 110$- indicator in Column 1 can be interpreted as the annual mobility rate of 100-110 LTV owners relative to the reference group with a LTV ratio below 50, controlling for the person age category and the loan age year.

While Column 1 of Table 1.3 exploits time-series variation in home equity, Columns 2-4 exploit variation in home equity across purchase cohorts within a calendar year-region by including time-region interaction fixed effects. Standard errrors are clustered at the region-year level in Table 1.3 (except for Column 1) to account for any local shocks to moving risk. Column 2 also indicates a pattern of negative, large and monotone effects of high LTV ratios on mobility. The decline in absolute value of the high-LTV ratio category coefficients in Column 2 as compared to Column 1 is intuive, as pro-cyclical mobility declines in less favourable economic times (and areas) for other reasons than the housing lock, such as more uncertainty and fewer income opportunities. Column 3 adds all the remaining controls, namely fixed effects for household sizes, financial asset holdings categories and indicators for gender, marital status, migration status and changes in family size. Column 3 provides evidence for the housing lock hypothesis in the pattern of large, negative and monotone effects of LTV on mobility. LTV ratios do not alter mobility in a significant way in the 50-90 category. The negative, small and significant coefficient of -0.24 on the 90-100 category is fully consistent with the housing lock hypothesis as downpayment requirements, the cost of mobilizing non-home equity or moving costs can be positive. The housing lock effect becomes large in the 100-110 category, which features a coefficient of -1.01. With an average annual mobility of 4.31 percentage, the decline in the coefficient by 0.77 percentage points from the 90-100 to the 100-110 category, which corresponds to 18% (=0.77/4.31), is large. The coefficient on the LTV ratio indicator declines further in the 110-150 category, consistent with the balance sheet channel. Relative to Column 2, the addition of the observable controls in Column 3 leaves the coefficients on the LTV ratios materially unaffected. For instance, the coefficient on the LTV above 110 indicator remains identical and is equal to -1.22 percentage points. The stability of these coefficients makes it also less plausible that the housing lock hypothesis is confounded by the selection of different mobility types on unobservables into different purchase cohorts.

The tables in this study mostly present the results by distinguishing 5 categories for LTV ratios, using as maximum LTV values for each category respectively 50, 90, 100, 110 and 150. Figure 1-6 reports the estimated coefficients of the model from equation (1.1) with even more granular LTV ratio categories of size 5. We observe a "hockey-stick pattern" consistent with the housing lock predictions. Mobility is initially quite flat for various LTV ratios in the non-critical regions and then declines steeply in LTV ratio, starting in the 90-95 category.

In contrast with the fully flexible estimation of the effects of the LTV ratio on mobility from Figure 1-6, I also estimate models which solely distinguish "underwater" and "abovewater" owners, an approach that has been used in a number of previous studies. When estimating the binary version of equation (1.1), I obtain a coefficient of -1.02 on the $LTV > 100$ indicator and a standard error of 0.07. The binary effect of -24% (=-1.02/4.31) is comparable but somewhat smaller in absolute value than the effect of -35% found by Ferreira et al. (2011) in the different US setting. Abstracting from all other institutional differences, one may *a priori* expect effects of negative home equity on mobility which are larger in absolute value in full recourse markets such as the Netherlands. While the Dutch full-recourse setting allows me to isolate balance sheet housing lock effects, negative housing lock effects of high LTV ratios on mobility in non-recourse markets such as the United States can be diluted or overturned by the positive effects of high LTV ratios on mobility through the strategic default channel.

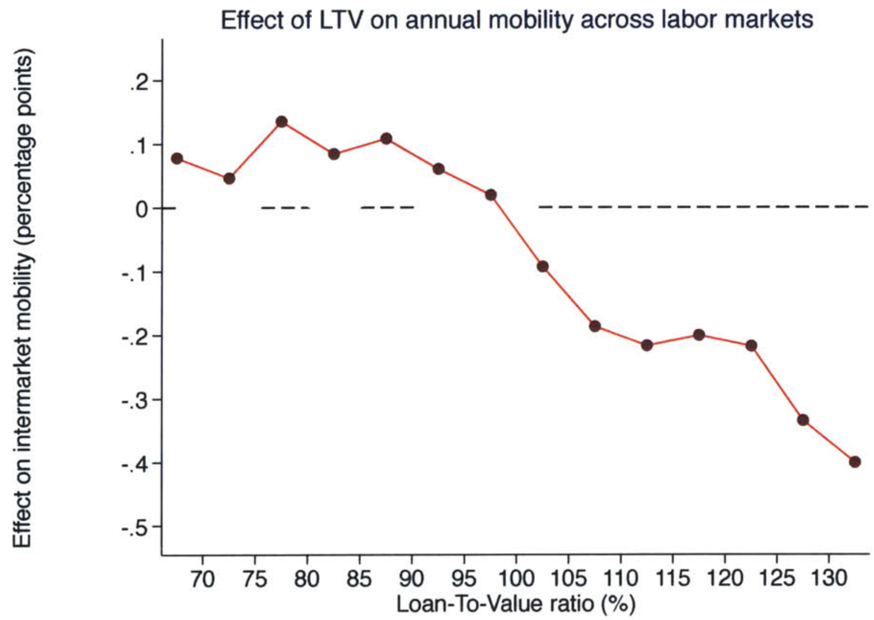
Figure 1-6: Estimated effect of Loan-To-Value ratio on total annual mobility



Notes: This figure visualizes the 95% confidence intervals around the coefficients on LTV ratio categories $\mathbf{1}\left[l_k < LTV_{it} \leq h_k\right]$ from the following equation estimating the effects of LTV ratios on annual mobility indicators: $y_{icrt} = \lambda_{tr} + \sum_k \delta_{1k}\mathbf{1}\left[l_k < LTV_{icrt} \leq h_k\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. The model is estimated in the sample of 1,956,003 buyer-years in the 2007-2012 period with balance sheet data.

Table 1.3 also reports the estimation of the model of mobility across local labor markets. Column 4 estimates equation (1.1), where the dependent variable is an annual indicator for mobility across local labor markets. Column 4 illustrates that the mobility rate across local labor markets also declines monotonically in LTV ratios, with a large decline from the 90-100 category to the 100-110 category. To facilitate comparisons of results across outcomes and other studies, I also estimate a binary model of mobility across labor markets and obtain a coefficient of -0.24 percentage points (and a standard error of 0.03) on negative home equity, which corresponds to a -21% effect given the 1.12 percentage points intermarket mobility mean. The binary effect of -21% for mobility across labor markets is somewhat smaller but of a similar order of magnitude as the binary effect on total mobility. The relative importance of negative home equity for local versus non-local mobility is theoretically ambiguous, and is an empirical question this study sheds light on. Both moving costs (monetary, psychological and time opportunity costs) and mean benefits (e.g. better job in another market) are arguably higher for longer-distance moves than for local moves. In some cases, the household may want to borrow more, for instance, through a personal loan or mobilize more non-home liquidity to realize the potentially higher benefits of the intermarket move. Figure 1-7 presents fully flexible estimations of the cross market mobility model and confirms the lock-in pattern of mobility, which declines monotonically in LTV ratios. Overall, the findings in Table 1.3 and Figures 1-6 and 1-7, which exploit variation in home equity across purchase cohorts, provide compelling evidence for the housing lock, both for total mobility as well as for mobility across local labor markets.

Figure 1-7: Estimated effect of Loan-To-Value ratio on total annual mobility across labor markets



Notes: This figure visualizes the 95% confidence intervals around the coefficients on LTV ratio categories $\mathbf{1}\left[l_k < LTV_{it} \leq h_k\right]$ from the following equation estimating the effects of LTV ratios on annual mobility indicators across local labor markets: $y_{icrt} = \lambda_{tr} + \sum_k \delta_{1k} \mathbf{1}\left[l_k < LTV_{icrt} \leq h_k\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. The model is estimated in the sample of 1,955,2940 buyer-years in the 2007-2012 period with balance sheet data.

1.5.2 Estimating balance sheet effects

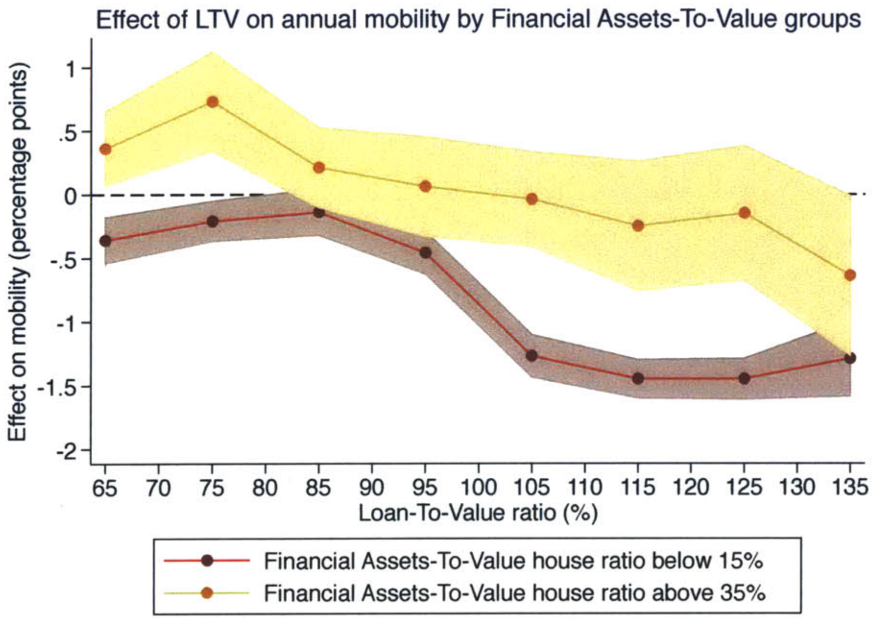
I now test the prediction of the Stein (1995) balance sheet channel according to which both home equity as well as household financial assets are critical factors in permitting moves. Tables 1.4 and 1.5 study the heterogeneous effects of home equity on mobility as a function of the Financial-Assets-To-Value (FATV) ratio. The prediction is that high-LTV ratios will hamper mobility more for households with low Financial-Assets-To-Value ratios. I distinguish 3 categories of Financial-Assets-To-Value ratios: low FATV ratios (below 15), medium FATV ratios (between 15 and 35) and high FATV ratios (above 35). The 15- and 35 thresholds correspond to, respectively, the percentiles 68 and 85 of Financial-Assets-To-Value ratios in the estimation sample. Household financial asset holdings, the numerator in the Financial-Assets-To-Value ratio, include checkings and savings accounts, equity holdings and bond holdings. Future pension rights are not included; Dutch households cannot borrow against their pensions. The definition of the Financial-Assets-To-Value ratio therefore captures the liquid savings that can be mobilized by underwater households to pay off the remaining mortgage balance relative to the value of the property.

Table 1.4 studies balance sheet effects for total annual mobility by estimating equation (1.1) for the full sample in Column 1 and for the 3 subsamples of high, medium and low Financial-Assets-To-Value ratio observations in, respectively, Columns 2, 3 and 4.[15] Table 1.4 reveals a striking double monotonicity of the housing lock effects consistent with the ? model. First, for each household category, displayed vertically in a column, mobility declines monotonically in the LTV ratio. Second, for each LTV category, shown horizontally, the housing lock effects of high LTV ratios become much more pronounced when households become asset poorer relative to the value of the house. For instance, the coefficient on the $LTV > 110$ category indicator is equal to -0.22 and not significant in Column 2 for the high FATV ratio observations but quite large, negative and significant and equal to -1.64 for the low FATV ratio observations in Column 4. Given the average mobility levels of those two FATV groups, these coefficients can be interpreted as follows. While a LTV ratio above 110 is associated with an insignificant and small decline in mobility of 5% for the high FATV owners, a LTV ratio above 110 is associated with a very large and significant drop in mobility of 40% for low FATV owners. The estimated effects are thus approximately eight times larger for low FATV owners than for high FATV owners.

Figure 1-8 reports the point estimates and 95% confidence intervals for the coefficients from the same model in equation (1.1) but with more flexible LTV bins for the subsamples of high and low Financial-Assets-to-Value Ratios. On the one hand, high LTV ratios are not associated with significant declines in mobility for the high FATV ratio (above 35) subsample (except for very high LTV ratios above 130). On the other hand, the rise of LTV ratios is associated with an important reduction in mobility for the low FATV ratio subsample.

[15]The only difference between Column 1 of Table 1.4 and Column 3 of Table 1.3 is that the model in Table 1.4 does not include fixed effects for financial asset holdings categories. The housing lock effects in Column 1 of Table 1.4 are a bit larger in absolute value than the housing lock effects in Column 3 of Table 1.3, as underwater households with high LTV ratios are more likely to have limited financial asset holdings.

Figure 1-8: Estimated effect of LTV on annual mobility by Financial-Assets-To-Value ratio groups



Notes: This figure visualizes the 95% confidence intervals around the coefficients on LTV ratio categories $\mathbf{1}\left[l_k < LTV_{it} \leq h_k\right]$ from the following equation estimating the effects of LTV ratios on annual mobility indicators:
$y_{icrt} = \lambda_{tr} + \sum_k \delta_{1k}\mathbf{1}\left[l_k < LTV_{icrt} \leq h_k\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. This figure shows the coefficients for models estimated in the subsamples of respectively low Financial-Assets-To-Value (below 15) and high Financial-Assets-To-Value (above 35) buyer-years.

Table 1.5 reports the effects of LTV ratios on mobility across local labor markets by estimating equation (1.1) for the full sample in Column 1 and for the 3 subsamples of Financial-Assets-To-Value ratio observations in Columns 2 (high FATV ratio), 3 (medium FATV) and 4 (low FATV). The cross-market mobility-LTV pattern is quite flat for the high FTA subsample in Column 2. For the medium FTV ratio subsample in Column 3, the coefficients on the LTV category indicators decline a bit for high LTV ratios, and the coefficient turns negative and significant for the $LTV > 110$ category and is equal to -0.16. Finally, the effects of high LTV ratios become much more pronounced in Column 4 for the low FATV ratio category with a coefficient on the $LTV > 110$ category indicator equal to -0.37 percentage points. Table 1.5 thus shows that high LTV ratios hamper mobility across local labor markets more for households with low Financial Assets-To-Value ratios.

Tables 1.4 and 1.5 document important interaction effects between home equity and household financial asset holdings. This finding as well as the Stein (1995) model call for an investigation of the importance of total liquid assets for mobility. The Stein (1995) model predicts that households move when (i) the benefit of moving exceeds the moving cost, and (ii) the total net liquid assets are larger than the required downpayment and moving cost (i.e. when the liquidity constraint does not bind).[16] In addition to home

[16] In the static, one-region model the net effect of house prices on housing consumption operates through the liquidity

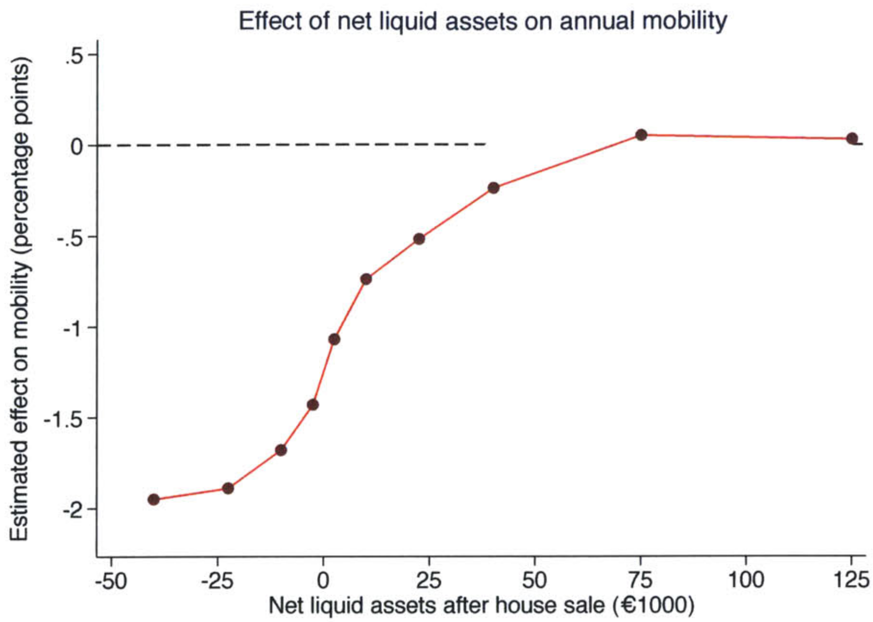
equity, downpayment constraints and other moving costs, the critical variable in the Stein (1995) model to predict whether a household can move is the net liquid assets level a household has after having sold the house. I thus define net liquid assets after a potential house sale as the sum of home equity and household financial assets. The intuition is that a dollar of liquidity facilites paying for moving. And, unless households are subject to mental accounting or other frictions disturb the home sale process, it should not matter too much whether this marginal dollar comes out of home equity or out of other household savings.

Figure 1-9 investigates the effects of net liquid assets on mobility. This figure reports point estimates and 95% confidence intervals for the coefficients δ_{2j} on net liquid assets after house sale categories from the model in equation (1.2). The only two differences with the model in equation (1.1) are: (i) the inclusion of net liquid asset levels, instead of Loan-To-Value ratio categories, and (ii) the absence of financial asset holdings group indicators in equation (1.2). In addition, the inclusion of household financial assets in the net liquid assets after a house sale as a variable of interest as opposed to Loan-To-Value ratios makes it arguably less likely that the conditional independence assumption is verified. In addition to exploiting relatively exogenous factors such as the timing of purchase, these regressions *de facto* compare asset-rich to asset-poor households and will provide descriptive evidence of the balance sheet mechanism driving the lock-in.

The relationship between mobility and net liquid assets in Figure 1-9 is S-shaped, consisting of four regions, consistent with a Stein (1995) balance sheet model. In the first region, for very negative net liquid assets after a house sale (or shortened as net liquid assets) below approximately -€25,000, a marginal euro of net liquid assets does foster mobility only to a limited extent, as the owner is relatively far away from filling the funding gap. Then, in the second region, when we are closer to the zero net liquid assets point, the curve starts to rise very quickly and becomes almost vertical around zero. In this second, steep region, extra liquidity provides a "big moving bang for the buck." In the third region, between approximately €0 and €25,000, extra liquidity still contributes to higher mobility, even if the owner already has positive net liquid assets. This is consistent with models with positive moving costs and/or borrowing constraints where a euro of savings has a precautionary value above and beyond its current consumption value. This seems plausible in the Netherlands, where there is almost no credit card or consumption credit. This finding is consistent with models of precautionary savings to insure against near-term fluctuations in income (Zeldes (1989), Deaton (1991), Carroll (1997)) or models of credit constraints (Bernanke and Gertler (1989), Kiyotaki and Moore (1997)), where agents with relatively positive but small net worth can also be constrained in their behavior. Finally, in the fourth region, once total liquid assets exceed approximately €75,000, then the marginal mobility value of a euro of liquidity converges to zero as the curve flattens out.

constraint. In a dynamic model (where some households are long housing and others short) or multipe-regions model (where house prices changes differ across regions), changes in house prices can also affect mobility through other channels as the positive wealth effect of rising houses prices does not have to exactly offset the negative effect of the higher cost of housing services consumption.

Figure 1-9: Estimated effect of net liquid assets on total annual mobility



Notes: This figure visualizes the 95% confidence intervals around the coefficients on "net liquid assets after house sale (NLAS)" categories $\mathbf{1}\left[l_k < NLAS_{it} \leq h_k\right]$ from the following equation estimating the effects of net liquid assets on annual mobility indicators: $y_{icrt} = \lambda_{tr} + \sum_j \delta_{2j}\mathbf{1}\left[l_j < NLAS_{icrt} \leq h_j\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. Net liquid assets after a house sale are defined as the sum of home equity and household financial assets. The model is estimated using the full sample of 1,956,003 buyer-years with balance sheet data.

1.5.3 Estimates for life-event buyers using quasi-exogenous purchase dates

The main empirical strategy in this paper has been to exploit variation across purchase cohorts in home equity and net liquid assets by estimating respectively equations (1.1) and (1.2). To address the possibility that house buyers near the peak were somehow different from those who bought homes at other times, this section refines and restricts the analysis to buyers who bought in a given year because of a divorce or a cohabiting-couple split. The goal is to rule out alternative hypotheses based on differential sorting of individuals of high- and low-future-mobility types across purchase cohorts. Peak buyers may, for instance, be financially less sophisticated (if the timing of house price busts can be anticipated by earlier buyers) or less creditworthy (if credit market conditions are relaxed over time). While the direction of this potential bias seems to lead to an understatement of the housing lock estimates (less sophisticated people and less creditworthy buyers may be more likely to be laid off during the Great Recession and therefore be forced to move), other stories of sorting across cohorts may be possible. To show the validity of divorces as a source of exogenous variation in purchase dates, I will first document that the divorce rate is actually relatively unaffected by the state of housing and labor markets. I will then demonstrate that divorces and cohabiting-couple splits shift the timing of purchase.

Figures 1-10 and 1-11 show that the annual Dutch divorce rate of approximately 9 divorces per thousand married people is quite stable over time. The largest annual change in the divorce rate from 0.93% to 1.00% occurred in 2001 when a faster divorce procedure was introduced. While the economic cycle may in principle alter the benefits of marriage such as production complementarities or risk-sharing (Becker (1981), Stevenson and Wolfers (2007)) or the affordability of divorce, the stable Dutch aggregate divorce rate is also almost uncorrelated with cyclical movements in the housing and labor markets. Figure 1-10 shows that the aggregate divorce rate remains relatively stable, both when housing transaction volumes rise and when they drop over time. Figure 1-11 visualizes the absence of any clear comovement between the divorce rate and the unemployment rate. The lack of any economically-significant relationship between the divorce rate and housing markets or labor market dynamics is also confirmed in simple regressions.[17]

The US literature on the cyclicality of divorces typically finds zero or very small business cycle effects. Using state-level data on unemployment and divorce rates from 1960 to 2005, Amato and Beattie (2001) find zero association between unemployment and divorce rates in models as soon as state and year fixed effects are included. Hellerstein, Morrill and Zou (2013) use micro-data from retrospective marital histories in the Survey of Income and Program Participation (SIPP). These authors document a small pro-cyclicality of divorce rates. When the unemployment rate rises by one percentage point (e.g. from 6 to 7%), the divorce rate is estimated to decline by 0.34 divorces per 1000 married women. As the mean unemployment and annual divorce rates are equal to respectively 6 and 1.8%, this corresponds to a small elasticity of the divorce rate with respect to unemployment rates of approximately -0.1. Hellerstein, Morrill and Zou (2013) also show that divorce rates are a-cyclical for women who married after the age of 24. The divorce rate is also found to be a-cyclical for women with college degrees. Nothing guarantees a full extrapolation of these US relationships to the specific Dutch setting. However, the general finding that the pro-cyclicality of divorce rates is limited to individuals with lower levels of education or who married at a younger age is encouraging for the exogeneity of the timing of purchase in my sample of homeowners (who are typically more educated than renters) in the Netherlands (a country with relatively high ages of first marriage). Suggestive international surveys typically also find that only approximately 5% of the respondents report economic factors such as financial or employment problems as the cause of divorce, while the vast majority perceives idiosyncratic, affective issues to be the main reason for marriage breakdown (Wolcott and Hughes (1999), Amato and Previti (2003)). The stability of the aggregate divorce rate, its independence from housing and labor-market-cycle indicators, and the literature on the relationship between divorce and the general economic environment all suggest that the timing of divorce is largely driven by idiosyncratic shocks.

[17]The R^2 - and adjusted R^2- values of simple regressions of the aggregate divorce rate are respectively equal to 0.02 and -0.4 for the transaction volume, 0.05 and -0.02 for the growth rate of the CBS house price index and 0.05 and 0.06 and -0.06 for the unemployment rate.

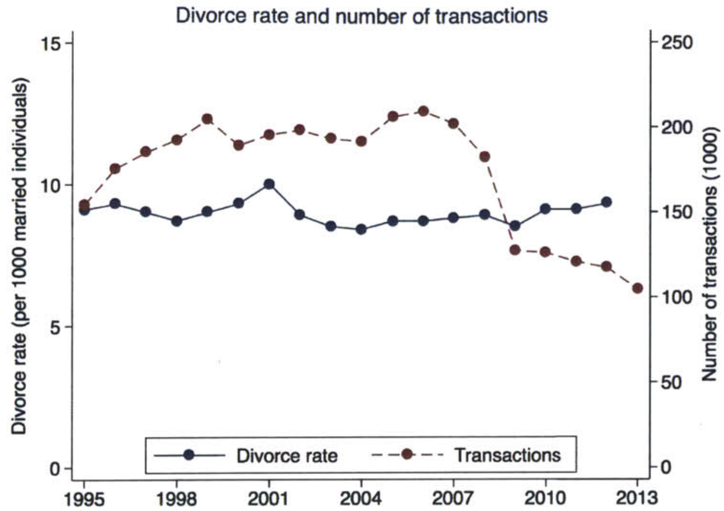


Figure 1-10: Divorce rate and number of transactions

Notes: The divorce rate is from Statistics Netherlands Statline (CBS). The number of transactions of existing owner-occupied homes is from the Transactions Registry.

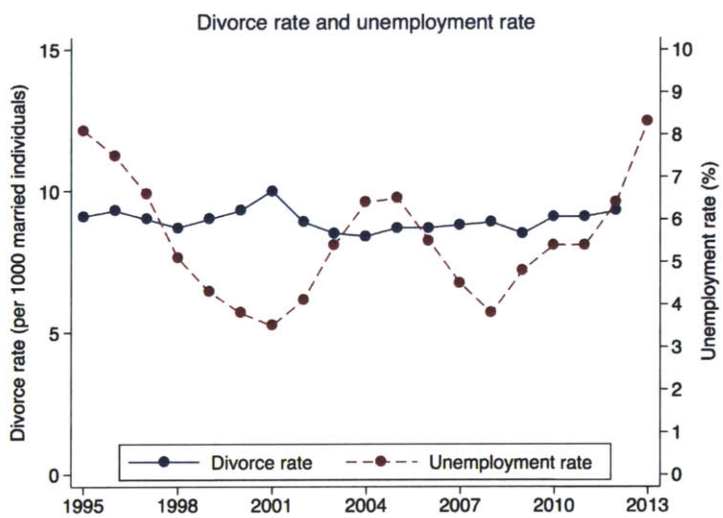
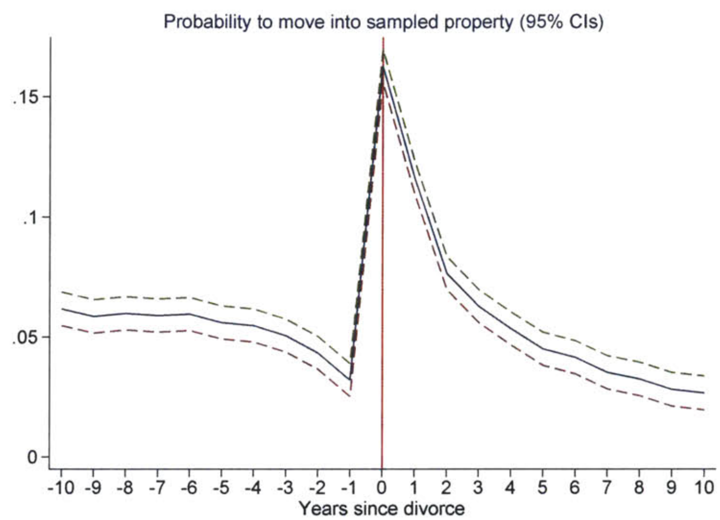


Figure 1-11: Divorce rate and unemployment rate

Notes: The divorce- and unemployment rate series are from from Statistics Netherlands Statline (CBS).

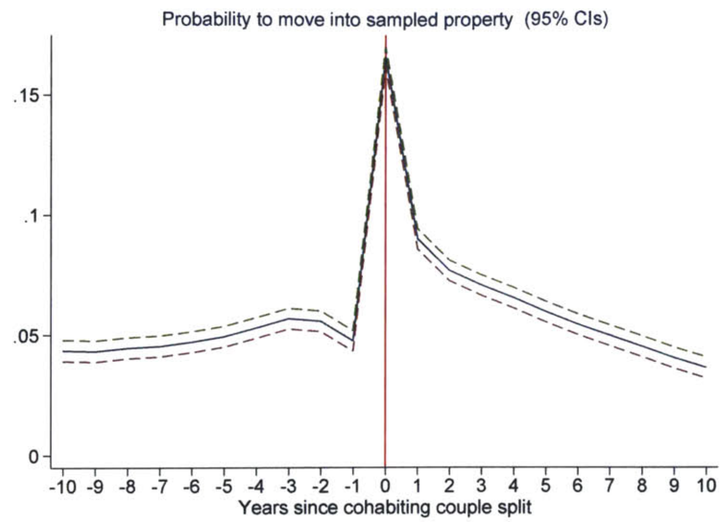
How does the occurrence of a divorce impact the probability of buying a property in my sample of buyers? Figure 1-12 plots the probability of moving into a sampled purchased property as a function of the timing of the divorce for the individuals in the sample, who were divorced during the period 1996-2011. The probability of purchasing a sampled property quadruples in the year of the divorce relative to the previous year and then drops again relatively quickly. Figure 1-13 plots the probability of purchasing a sampled property as a function of the timing of the cohabiting couple split for the individuals in the sample, who split as cohabiting couples in the period 1996-2011. The probability of purchasing a sampled property also peaks strongly in the year of the split. Given the sampling procedure which samples 25% of existing home sales, the probability of a move into a sampled property is a lower bound on the probability for individuals in the sample of moving into an owner-occupied home in a given year. In fact, conditional on experiencing a life event, approximately 40% of the individuals in the sample move into an owner-occupied home, as shown in Appendix Figure A1.2. Figures 1-12,1-13 and A1.2 thus provide compelling evidence that life-events shift the timing of purchase.

Figure 1-12: Divorces and the timing of purchase



Notes: The probability of purchasing a property from the sample of selected transactions is plotted for all household heads in the sample of buyers who divorced during the sample period.

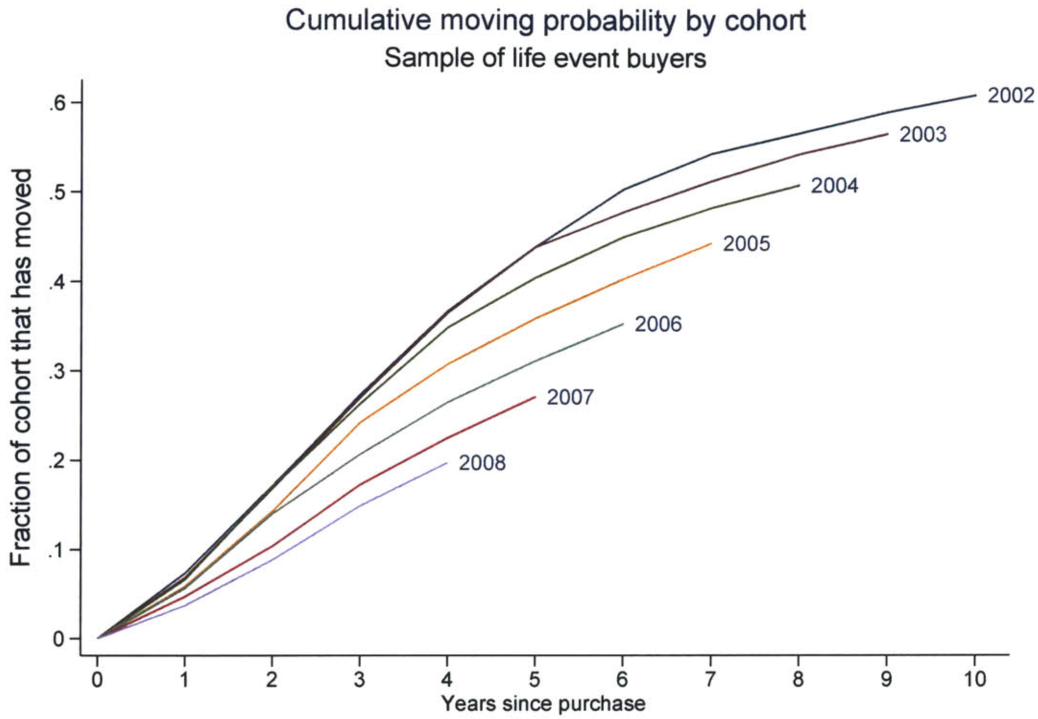
Figure 1-13: Cohabiting couple splits and the timing of purchase



Notes: The probability of purchasing a property from the sample of selected transactions is plotted for all household heads in the sample of buyers who were part of a cohabiting couple that split during the sample period.

Among the sampled 574,337 transactions in 1995-2011, 16,844 transactions occurred in the year of the buyer's divorce and 32,276 transactions occurred in the year of a cohabiting couple split. I now restrict the analysis to these 16,844 so-called divorce buyers as well as the 32,276 split-couple buyers. The former are on average 43 years old and 49% male, whereas the latter are on average 39 years old and 50% male. The life-event buyers are on average approximately 4 years older and more likely to be single than are the buyers in the full sample. I now analyze the effect of Loan-To-Value ratios on subsequent mobility for these life-event buyers, who started their ownership spells because of plausibly exogenous, idiosyncratic life events. This analysis estimates equation (1.1), which shuts down variation within calendar year-regions for this subgroup of life-event buyers. The housing lock results for these life-event buyers will turn out to be a robust feature of the compelling mobility patterns across purchase cohorts, as shown in Figure 1-14. The subsequent mobility patterns for the life-event buyers are consistent with the housing lock hypothesis. Early cohorts, those who were exposed to rising house prices for a longer period and less exposed to high LTV ratios, moved substantially and significantly more often than the later cohorts. The mobility patterns across purchase cohorts for the life-event buyers are remarkably similar to those in the full sample from Figure 1-4.

Figure 1-14: Cumulative moving probability for the sample of life-event buyers



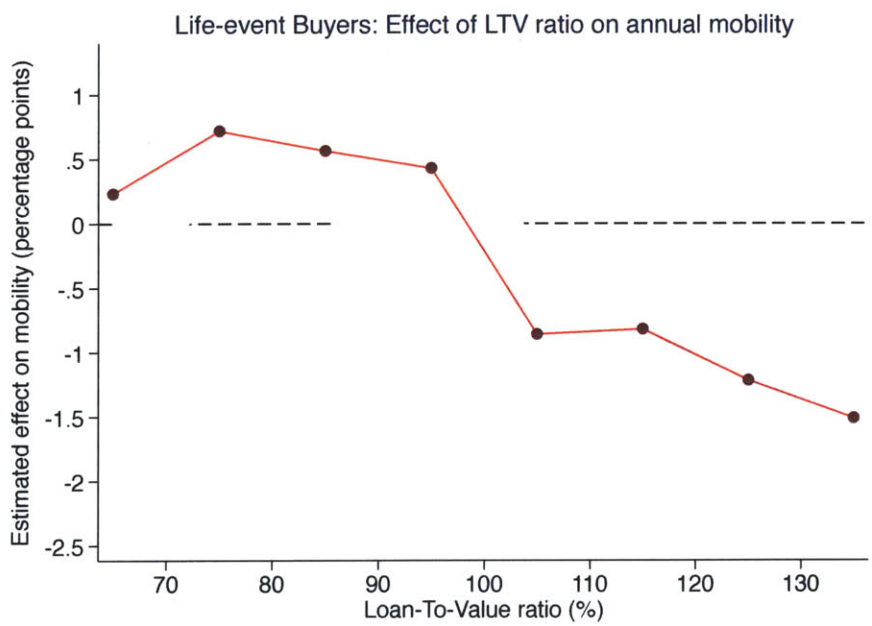
Notes: The moving data are based on the Transactions Registry and Address Registry from Statisistics Netherlands (CBS). The sample is restricted to transactions of buyers who started their ownership spell at the time of the occurence of life-events (a divorce or a cohabiting-couple split).

Table 1.6 presents the estimation of the model in equation (1.1) for total mobility, in Columns 1 and 2, and for mobility across labor markets, in Columns 3 and 4. The model with 5 LTV ratio categories in Column 1 finds again a pattern of mobility that declines when LTV ratios are high. The coefficient on the LTV 110-150 category indicator is precisely estimated and equal to -1.09. Given the smaller subsample and associated lower level of precision, Columns 2 and 4 also present binary models, which contrast the mobility of "underwater" and "abovewater" owners. Column 2 reveals an estimate of -1.27 on the underwater coefficient in the binary model. Overall, the coefficients on the LTV ratios in the total mobility regressions for the life-event buyers in columns 1 and 2 are comparable in absolute terms to the coefficients in the corresponding Columns 3 and 4 of the full sample depicted in Table 1.3. The life-event buyer housing lock effects are somewhat smaller in relative terms, as the mean mobility hazard rate for the life-event buyers of 6.93 percentage points per year exceeds the full sample mobility mean of 4.31 percentage points. Columns 3 and 4 estimate the impact of LTV ratios on inter labor market mobility for life-event buyers in models with respectively 5 and 2 LTV ratio categories. Column 3 documents a pattern of mobility across local labor markets, which declines monotonically in LTV ratios for buyer-years with exogenous purchase dates. Given the smaller sample size, the housing lock effects are less precisely estimated for mobility across local labor markets for life-event buyers. Column 4 confirms that underwater buyers with exogenous purchase dates also move less frequently to different local labor markets.

In addition to the models with respectively 5 and 2 LTV ratio categories in Table 1.6, I also estimate the model for total mobility from equation (1.1) with smaller LTV ratio categories. Figure 1-15 reveals a pattern of initially flat LTV effects which then start to decline in a relatively monotone way when LTV ratios exceed approximately 95.

I will now test balance sheet predictions for buyers with quasi-exogenous purchase dates. I estimate the effect of net liquid assets (after a potential house sale) on mobility from equation (1.2) in the subgroup of life-event buyers. The curve of mobility against net liquid assets is S-shaped in Figure 1-16, which resembles the pattern for the full sample from Figure 1-9. The contribution of marginal net liquid assets to mobility is large in the critical region, around the zero-net-liquid-assets threshold, where the slope becomes quite steep. Overall Table 1.6 and Figures 1-15 and 1-16 show that high LTV ratios, triggered by divorces and couple splits that shift the timing of purchase, as well as low-net-liquid-asset positions, are associated with subsequent lower total mobility and lower mobility across labor markets.

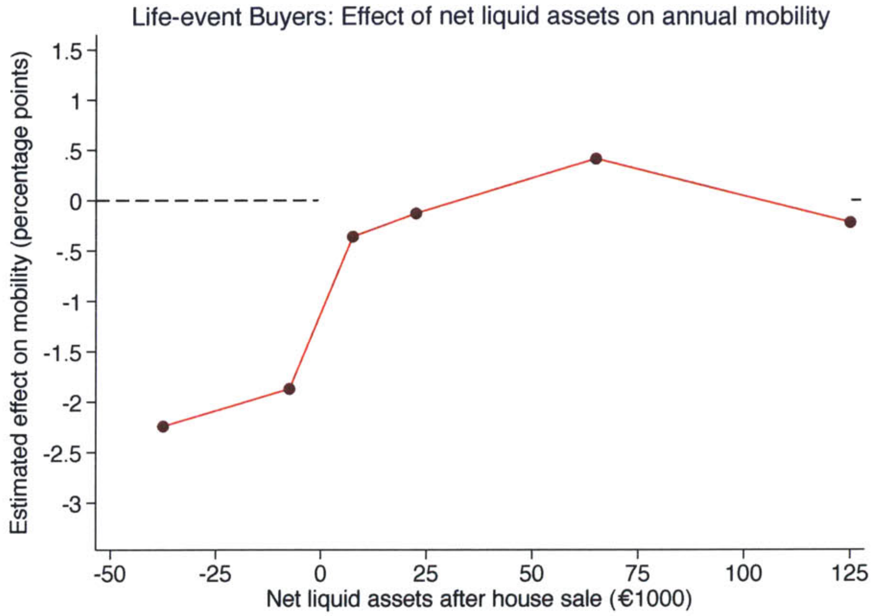
Figure 1-15: Estimated effect of Loan-To-Value ratio on total annual mobility rate in the sample of life-event buyers



Notes: This figure visualizes the 95% confidence intervals around the coefficients on LTV ratio categories $\mathbf{1}\left[l_k < LTV_{it} \leq h_k\right]$ from the following equation estimating the effects of LTV ratio categories on annual mobility indicators:

$y_{icrt} = \lambda_{tr} + \sum_k \delta_{1k}\mathbf{1}\left[l_k < LTV_{icrt} \leq h_k\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. The model is estimated from the sample of 113,539 life-event buyer-years in the 2007-2012 period with balance sheet data.

Figure 1-16: Estimated effect of net liquid assets on total annual mobility rate in sample of life-event buyers



Notes: This figure visualizes the 95% confidence intervals around the coefficients on "net liquid assets after house sale (NLAS)" categories $\mathbf{1}\left[l_k < NLAS_{it} \leq h_k\right]$ from the following equation estimating the effects of net liquid assets on annual mobility indicators $y_{icrt} = \lambda_{tr} + \sum_j \delta_{2j} \mathbf{1}\left[l_j < NLAS_{icrt} \leq h_j\right] + X_{it}^{'}\beta + \epsilon_{icrt}$. Net liquid assets after a house sale are defined as the sum of home equity and household financial asset holdings. The model is estimated from the sample of 113,539 life-event buyer-years in the 2007-2012 period with balance sheet data.

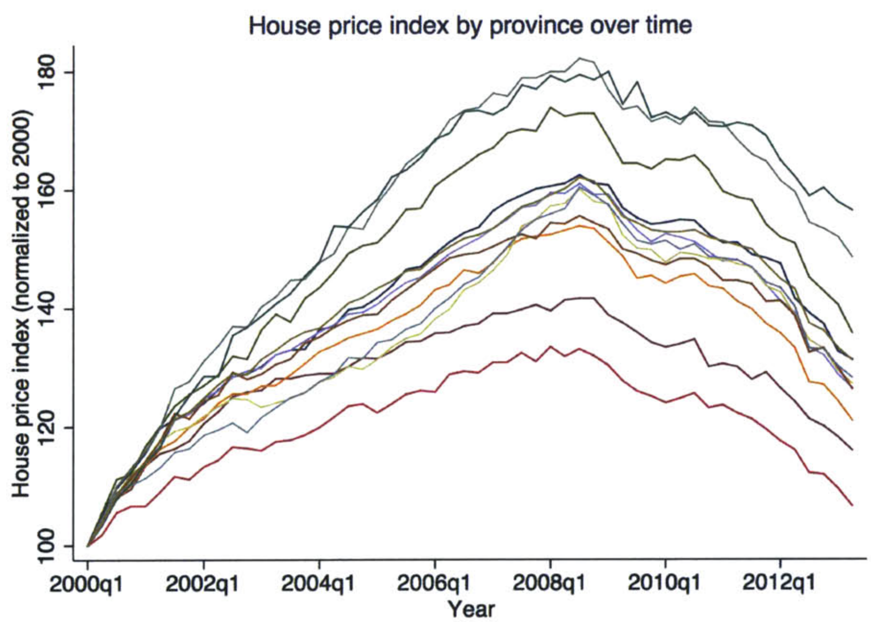
1.5.4 Estimates using regional variation in house price trajectories

I will now show the robustness of the findings to shutting down any variation across cohorts. The purpose of this is to assess the endogeneity of purchase dates as a source of potential contamination, which may affect the prior results. However, the analysis of life-event buyers and the stability of the following three factors suggest that these findings, based on variation across purchase cohorts, capture the housing lock: (i) mobility as a function of loan age year patterns from Figure 1-4 for the early 1996-2001 purchase year cohorts, that were not affected by the decline in house prices, (ii) buyer observables across cohorts from Table 1.2, and (iii) coefficients in Columns 2 and 3 of Table 1.3, which respectively exclude and include the household observables. To overcome any remaining concerns with variation in purchase dates, this section eliminates all variation across purchase cohorts in the model from equation (1.3) by including a full set of fixed effects for calendar year-purchase cohort interactions λ_{tc}. This specification exploits cross-regional variation in house price trajectories as well as the distribution of LTV ratios within a given purchase cohort-year. Figure 1-17 shows substantial variation in house price changes across the 12 provinces. For instance, the cumulative house price appreciation between the first quarter of 2000 and the third quarter of 2008 is approximately 2.5

times higher in the province with the highest growth, Groningen (in the North of the Netherlands), relative to the province with the lowest growth, Limburg (in the South of the Netherlands).

Table 1.7 reports the estimation of the model in equation (1.3), both for total mobility and mobility across local labor markets. All columns include a full set of time-purchase cohort interaction fixed effects to soak up any variation across purchase cohorts. Columns 1 and 3 do not include region fixed effects. The inclusion of region fixed effects in Columns 2 and 4 allows for the control of time-unvarying differences in average mobility rates across regions. Columns 1 and 2 confirm the pattern of lower mobility rates for higher LTV ratios, exploiting regional variation in home equity. Similarly, Columns 3 and 4 demonstrate the housing lock for mobility across local labor markets. The effects are similar but a bit smaller when region fixed effects are included. To conclude, Table 1.7 demonstrates the robustness of the housing lock finding to eliminating any variation across purchase cohorts.

Figure 1-17: Regional house prices



Notes: The provincial house prince indices are from Statisistics Netherlands (CBS).

1.6 Robustness checks

This section demonstrates the robustness of the evidence consistent with the housing lock along several dimensions. Table 1.8 estimates equation (1.1) for two subsamples to demonstrate the robustness of the housing lock to: (i) excluding Great Recession purchase year buyers, and (ii) the definition of household mobility. Columns 1 and 2 do not include the buyer-years, who started their ownership spell during the

2009-2012 recession period. The potential concern which might be associated with their inclusion is that the decision of homeownership and mortgages may be different during the Great Recession along unobservable variables, possibly correlated with future moving propensity. Nevertheless, the subsample of 1995-2008 buyers also features the housing lock pattern, as both total mobility and mobility across local labor markets decline monotonically in LTV ratios. This paper defines mobility as the mobility of the household head (as opposed to other household members). I now confirm the robustness of the housing lock to this definition of mobility. Columns 3 and 4 of Table 1.8 study the effects of LTV ratios on both total and inter labor market mobility in the sample of buyers who have been single for their full period of ownership. In the case of always-singles, household mobility is unambiguously defined as the mobility of the single individual. For the 12% of buyers who remain single during their home ownership, I even find somewhat larger housing lock effects than are evident in the full sample.

Table 1.9 estimates equation (1.1) to show that the housing lock results are robust to: (i) excluding Great Recession buyers from the sample of life event buyers, and (ii) including finer geographical control variables. The results in Columns 1 and 2 do not include the life event buyers, who started their ownership spell during the 2009-2012 period. They address the potential concern that life event decisions and/or decisions to purchase a home conditional on a life event were somehow different in the Great Recession. However, the robust housing lock pattern is also present in the sample of 1995-2008 life event buyers as mobility declines in LTV ratios. Columns 3 and 4 add finer geographical controls by including fixed effects for the municipality and fixed effects for the interaction of the calendar year and the smaller COROP region (instead of the province region in the main specification).[18] Columns 3 and 4 suggest that the housing lock results become larger when using these more granular spatial controls.

Table 1.10 estimates equation (1.1) to establish the robustness of the housing lock to: (i) the definition of local labor markets; (ii) the presence of mobility shocks specific to buyer-age categories, and (iii) the treatment of LTV ratio outliers. Column 1 estimates the model with an indicator for mobility across provinces as the dependent variable. While about two-thirds of the moves across local labor markets (so-called COROP areas) involve a move to a different province, one third of the moves across local labor markets occurs within the same province. The estimates for the effects of the LTV ratios on inter-province mobility in Column 1 of Table 1.10 are comparable in relative terms to the estimates for mobility across local labor markets in Table 1.3. These estimates corroborate the housing lock effects, now also for longer-distance moves across provinces. Column 2 of Table 1.10 includes fixed effects for the interaction between the calendar year and 5 buyer age category fixed effects. This model allows for temporary shocks to mobility for specific buyer-age categories. Young workers may be particularly vulnerable to negative labor market shocks in recessions, for instance if employers' lay-off decisions feature "last in and first out"- patterns. Nevertheless, Column 2 confirms the stability of the housing lock to such age-category shocks. Finally, Columns 3 and 4 of Table 1.10 present the estimation of the effects of LTV ratios on mobility when the extreme LTV ratio outliers below

[18] As of January 1st 2015, the Netherlands features 393 municipalities, 40 COROP areas and 12 provinces.

zero or above 150 are included. The housing lock estimates are relatively stable, when these outliers are included. Finally, in unreported regressions, I confirm the housing lock effect in a non-linear Probit model, which yields similar results to those of the linear probability models estimated in this paper.

1.7 Simulating Effects of Counterfactual House Price and Borrowing Trajectories on Mobility

This section uses the estimates of the effects of LTV ratios on mobility to simulate mobility under two different counterfactual trajectories of home prices as well as a counterfactual trajectory of mortgage borrowing. I simulate counterfactual mobility rates for 1995-2008 buyer cohorts in the estimation sample during the 2009-2012 period. These partial equilibrium simulations are not policy simulations. The scenarios for house price trajectories assume exogenous alternative house prices from 2009 to 2012 and keep the borrowing trajectory fixed.[19] The third scenario fixes house prices and assumes an exogenous alternative scenario for borrowing. Distributions of LTV ratios as well as mobility rates will be simulated under the three scenarios and will be compared with those in reality, the so-called baseline scenario. These simulations will generate two important insights. First, in recessions the effect of the housing lock on total owner-occupied mobility can be substantial. Second, given the highly non-linear effects of LTV ratios on mobility, small shocks to house prices or borrowing levels can have relatively large effects on aggregate mobility.

Counterfactual House Price Trajectories The parameter inputs for the various scenarios appear in the top panel of Table 1.11. In the baseline scenario, nominal house prices, which declined from the end of 2008 until mid 2013, declined by 16% in the simulation period 2009-2012. This decline corresponds to an average reduction of 4% per year. In scenario "Price growth as usual" 1, I assume that nominal house prices increased in 2009-2012 at their average historical annual rate of 8.5%, where the average is computed over the 1995-2007 period. In scenario "Halfway prices" 2, the trajectory of house prices in the 2009-2012 period is half way the decline of the baseline scenario and the increase in scenario 1. The "Halfway prices" scenario thus assumes that nominal house prices increased in 2009-2012 at 2.25% every year.

The methodology for the simulations consists of the following iterative steps. First, I apply the exogenous input parameters, namely, house prices in scenarios 1 and 2, to all the buyers, who live in their properties in 2009 at the beginning of the simulation period. Second, the exogenous inputs and the remaining micro-data then allow for computation of counterfactual LTV ratios at the end of 2009. Third, I then use the estimated effects of LTV ratios in the main specification of this study (i.e. Column 3 from Table 1.3) to simulate which buyers would have moved in 2009 under the alternative scenario. The lower LTV ratios under the

[19] This section thus ignores the arguably positive impact of house prices on refinancing. In reality, ABN AMRO data suggest that the the constant prepayment rate, where prepayment includes refinancing, curtailments and relocations, in prime Dutch mortgage loans in RMBS transactions dropped from around 12% in the 2004-2008 period to approximately 6% in 2009-2012.

counterfactual scenarios relative to the baseline scenario and the associated higher mobility cause the exit of some extra buyers in 2009. This different composition of the sample on January 1st, 2010 then affects the distribution of LTV ratios in 2010. In a fourth step, I again apply the exogenous parameters to the new micro-data sample in 2010 and compute counterfactual LTVs in 2010. I repeat this iterative "Price Shock-LTV-Mobility-Exit" procedure each year until the end of the sample period in 2012.

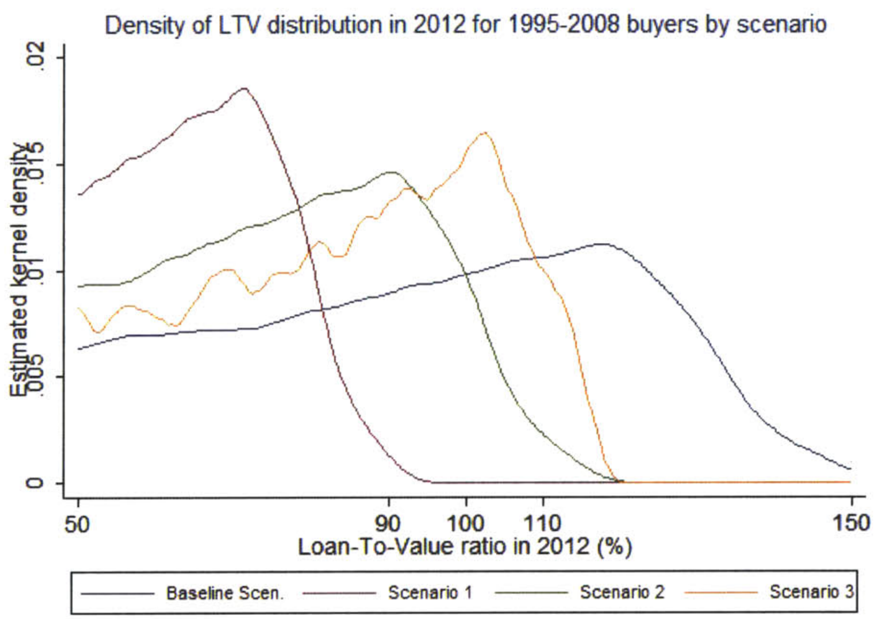
In the baseline scenario, a high fraction of buyers have LTV ratios above 100% and even above 110%, as shown in the blue density kernel of Figure 1-18. 14.2% of the buyers in the sample have moved during the 4 Great Recession years in the baseline scenario, as reported in the bottom panel of Table 1.11. Let us now turn to the "Price growth as usual" scenario 1. The red density in Figure 1-18 shows that the rapid run-up in prices in scenario 1 pushes the distribution of LTV ratios to the left. Here, almost no observation in the simulation sample, which consists of the 1995-2008 buyers, features LTV ratios in 2012 above 90%. Table 1.11 shows that the cumulative mobility of the simulation sample under this "Price growth as usual" scenario would have been 15.3%. Cumulative mobility would thus have been 1.1 percentage points (15.3%-14.2%) higher than in reality. Expressed in relative terms, this corresponds to a cumulative mobility rate that would have been approximately 7.5% higher in the "Price growth as usual" scenario 1. To gauge the quantitative importance of this mobility difference one can, for instance, perform an out-of-sample, back-of-the-envelope calculation of the number of involved individuals. About 10 million Dutch individuals live in an owner-occupied home. Therefore the comparison of the "Price growth as usual" scenario 1 to the baseline scenario, suggests that, *ceteribus paribus*, approximately 110,000 more individuals would have moved, if house prices had continued to increase at their historical average rate. One may also estimate the share of the decline in owner-occupied mobility that can be attributed to housing lock balance sheet effects. Owner mobility declined by 35% during the crisis relative to the pre-period. Dividing the decline of 7.5%, associated with the housing lock effects, by the total decline during the crisis period of 35%, yields a suggestive ratio of 22%. The 22% contribution of housing lock effects to the total decline in owner-occupied mobility is arguably reasonably large. Indeed, multiple other factors, such as higher uncertainty or fewer income opportunities, hamper mobility in recessions and have been absorbed by the time-region fixed effects in my model of the housing lock.[20] While these back-of-the-envelope calculations focus on the cumulative effect on mobility in 2009-2012, Table 1.11 also reports the impact on the mobility rate in 2012. In the "Price growth as usual" scenario 1, mobility in 2012 would have been 11.2% higher in relative terms than the baseline mobility. Intuitively, the effect of higher house price growth rates increases over time, as declining LTV ratios reflect the cumulative impact of the full house price trajectory.

The LTV distribution in 2012 for the "Halfway prices" scenario 2 is plotted in green in Figure 1-18. While the rate of price growth is only halfway between the baseline scenario and scenario 1, most of the buyers

[20] While the contribution of the housing lock to the decline in owner-occupied mobility is large, calculations of the potential impact on unemployment should take into account that 25% of the moves occur across labor markets (Kothari, Saporta-Eksten and Yu (2013)). However, in the absence of the housing bust, cross labor market mobility rates may have risen in the recession due to heterogeneous shocks, which increase incentives to migrate out of more depressed areas (Karahan and Rhee (2013)).

with LTV ratios above 100 or 110% in the baseline scenario have positive home equity under the "Halfway Prices" scenario. Table 1.11 reports a cumulative mobility rate of 14.9% in the "Halfway prices" scenario 2 in the 2009-2012 period. This corresponds to an impact on cumulative mobility of 5.1%, expressed in relative terms, relative to the baseline. While the rate of price growth in the "Halfway prices" scenario 2 is the average of the growth rate in scenario 1 and the growth rate in baseline scenario, the mobility rate of 14.9% in the "Halfway prices" scenario 2 is thus closer to the mobility rate of 15.3% in the "Price Growth as usual" scenario 1 than to the baseline 14.2% mobility. This non-linearity of mobility rates in house prices growth rates reflects the highly non-linear effects of LTV ratios on mobility estimated in this paper.

Figure 1-18: Density of LTV distributions under scenarios in 2012



Notes: This figure visualizes the estimated Epanechnikov kernel density of the distribution of LTV ratios in 2012 for the 1995-2008 buyers in the estimation sample. The baseline scenario corresponds to the observed data in reality. Scenario "Price growth as usual" 1 assumes house prices increase in 2009-2012 at their average historical annual rate of 8.5%. In scenario "Halfway prices" 2, nominal house prices increase in 2009-2012 at 2.25% annually. In scenario "Capped borrowing" 3, mortgages are capped at 95% of the purchase value of the house for all the 1995-2008 cohorts and house prices follow the baseline scenario.

Counterfactual Borrowing Trajectory In scenario "Capped borrowing" 3, borrowing cannot exceed 95% of the value of the house at purchase for all the 1995-2008 cohorts. This third scenario also assumes that house prices follow their baseline scenario trajectory, as they did in reality. In the "Capped borrowing" scenario, I also assume that the binding borrowing maxima are countercyclical; as they are relaxed in 2009-2012. In reality, the Netherlands introduced procyclical LTV at origination norms in 2011, at relatively high levels of 112%. This exercise assumes that the alternative borrowing trajectory in scenario "Capped borrowing" 3 has no effect on i) housing demand in the 1995-2008 period or ii) the trajectory of house prices.

For the "Capped borrowing" scenario 3, the associated LTV distribution in 2012 is shown in yellow in Figure 1-18. As a consequence of the hard maximum cap on borrowing at 95% of a house's value at origination, only the buyers who bought close to the peak have LTV ratios above 100 or 110%. The cumulative mobility in 2009-2012 for the simulation sample would have been 15.0% under the "Capped borrowing" scenario 3, as shown in the last column in Table 1.11. This corresponds to an impact on the cumulative mobility rate of 5.8% in relative terms. However, the last line in this Table shows that the impact on mobility in 2012 of house price scenarios 1 and 2 is larger than the impact of the "Capped borrowing" scenario 3. Over time, as house prices continue to decline and as the cumulative, negative house price shocks become larger, the "Capped borrowing" trajectory becomes relatively less useful in terms of "preventing moves lost because of the housing lock". One potential insight for the design of borrowing regulation may be the recognition of the volatility of house price processes, and to take into account, for instance, the likelihood of 1-sigma or 2-sigma house price change events. Further implications for macro-prudential policy (e.g. LTV ratio at origination caps) are beyond the scope of this study. Policy simulations of caps on LTV ratios would require the modeling and/or measurement of the impact of these policies on subsequent changes in housing demand, house prices, refinancing and aggregate demand. The simulations in this section are primarily developed to quantify the magnitude and non-linearity of the estimated coefficients and constitute at most a first step to understand the partial equilibrium consequences of such policies for household mobility.[21]

Overall, the simulations of the effects of counterfactual house price and borrowing trajectories on mobility have led to two insights. First, the effect of the housing lock during recessions on total owner-occupied mobility can be substantial and depends on the assumed counterfactual house price scenario. Second, given the highly non-linear effects of LTV ratios on mobility, relatively small shocks to house prices or borrowing levels can have large effects on aggregate mobility.

1.8 Conclusion

This paper investigated the impact of home equity and financial assets on household mobility in the Netherlands. My results suggest that a decline in home equity, particularly when the LTV ratio is near 100 percent, is associated with large and statistically significant reductions in household mobility both within and across local labor markets. The effects of falling home equity are substantially larger for households with low levels of financial assets than for those with substantial financial wealth. The simulations of counterfactual trajec-

[21] Several recent macro-prudential reforms emphasize countercylicality, as such reforms intend to dampen the business cycle. Those new macro-prudential tools often include norms or caps on LTV ratios at originations. Soft norms or hards caps have been or are being introduced in Hong Kong, Singapore, China, Norway, the UK, Israel, New Zealand and also the Netherlands. Policymakers have mentioned multiple potential costs and benefits, both *ex-ante* and *ex-post*. The *ex-post* benefits and intented consequences may, for instance, lead to more stable trajectories of credit growth and asset prices.

tories for house prices and borrowing levels suggest substantial, non-linear effects of house price shocks on the aggregate mobility rate among owner-occupiers.

The finding of substantial housing lock when house prices fall and home equity declines must be recognized as conditional on the housing and mortgage institutions in the Netherlands. One important feature of the Dutch market is the reliance on full recourse loans which eliminates the strategic default channel that may affect homeowners in the United States. The quantitative importance of the balance sheet channel that links house price fluctuations to mobility rates is likely to depend on country-specific institutions, such as the assumability of mortgage debt, downpayment requirements, the liquidity of the rental market, moving costs, and the availability of alternative borrowing opportunities, such as unsecured credit or loans from family and friends. More detailed balance sheet information for Dutch households could provide further information on this issue, and data and research from other nations could also help to calibrate both the balance sheet and strategic defaults channels.

One of the reasons "housing lock" has attracted attention is because it may be related to the functioning of the labor market and to the rate at which unemployed workers find new jobs. While this paper has shown that negative home equity can reduce the likelihood that homeowners leave their local labor market, it has not explored how house price fluctuations and variation in housing equity affect the rate at which homeowners find new jobs. The effects of housing lock on job finding rates, unemployment, the quality of job and housing matches and consumer spending are important questions for future research.

Tables

Table 1.1: Buyer summary statistics

	Mean	median	sd	N
1995-2012 panel of buyers				
Annual Mobility (%)	5.31	0	22.41	3,783,286
Annual Inter labor market mobility (%)	1.39	0	11.73	3,781,227
2007-2012 panel of buyers with balance sheet data				
Annual Mobility(%)	4.31	0	20.31	1,956,183
Annual Inter labor market mobility (%)	1.12	0	10.51	1,955,474
LTV ratio (%)	75	81	37	1,969,905
LTV ratio below 50 (%)	25	0	44	1,969,905
LTV ratio btwn 50-90 (%)	33	0	47	1,969,905
LTV ratio btwn 90-100 (%)	12	0	32	1,969,905
LTV ratio btwn 100-110 (%)	12	0	33	1,969,905
LTV ratio btwn 110-150 (%)	17	0	38	1,969,905
Negative home equity dummy (%)	30	0	46	1,969,905
Home equity (€1000)	74	41	123	1,969,905
Home equity if negative (€1000)	-29	-22	31	581,158
Zero mortgage balance dummy (%)	7	0	26	1,969,905
Financial assets (€1000)	77	17	563	1,969,663
Net liquid assets if house sale (€1,000)	151	74	593	1,969,663
Financial-Assets-To-Value ratio (%)	23	8	115	1,969,663
Financial-Assets-To-Value ratio below 15 (%)	68	1	47	1,969,663
Financial-Assets-To-Value ratio btwn 15-35 (%)	18	0	38	1,969,663
Financial-Assets-To-Value ratio above 35 (%)	15	0	34	1,969,663
Buyers in the year of the move into the property				
Age	36.86	34	11.88	574,337
Household size	2.36	2	1.19	574,337
Male	0.86	1	0.35	574,337
Native to country	0.85	0	0.35	574,337
Married	0.42	0	0.49	574,337
Kids dummy	0.35	0	0.48	574,337
Divorce in year dummy	0.031	0	0.173	548,076
Cohabiting couple split dummy	0.068	0	0.252	548,076

Notes: The top panel presents annual mobility and intermarket mobility indicators measured in every year where the buyer lives at a sampled purchased property on January 1st. The middle panel gives summary statistics for the 2007-2012 person-years. See Section 1.4 in the text for more details.

Table 1.2: Buyer summary statistics by cohort

Cohort	Age	Household Size	Male	Married	# Transactions
1995	36.00	2.44	0.89	0.51	26261
	(11.49)	(1.19)	(0.32)	(0.50)	
1996	36.11	2.44	0.89	0.50	31916
	(11.41)	(1.20)	(0.32)	(0.50)	
1997	36.10	2.42	0.89	0.48	33271
	(11.41)	(1.19)	(0.32)	(0.50)	
1998	36.09	2.42	0.89	0.47	34331
	(11.31)	(1.20)	(0.32)	(0.50)	
1999	36.27	2.41	0.88	0.46	36540
	(11.42)	(1.20)	(0.32)	(0.50)	
2000	36.38	2.38	0.88	0.44	34431
	(11.55)	(1.19)	(0.33)	(0.50)	
2001	36.68	2.39	0.87	0.43	36482
	(11.69)	(1.19)	(0.33)	(0.50)	
2002	36.67	2.38	0.87	0.41	38001
	(11.65)	(1.19)	(0.34)	(0.49)	
2003	36.86	2.37	0.86	0.41	36634
	(11.73)	(1.20)	(0.35)	(0.49)	
2004	37.20	2.33	0.85	0.40	37217
	(11.98)	(1.19)	(0.36)	(0.49)	
2005	37.53	2.33	0.84	0.39	39387
	(12.03)	(1.19)	(0.37)	(0.49)	
2006	37.76	2.34	0.84	0.38	40933
	(12.08)	(1.20)	(0.37)	(0.49)	
2007	38.02	2.31	0.84	0.38	38757
	(12.42)	(1.18)	(0.37)	(0.48)	
2008	37.59	2.32	0.84	0.37	36472
	(12.32)	(1.18)	(0.37)	(0.48))	
2009	36.25	2.21	0.82	0.33	25933
	(12.22)	(1.14)	(0.38)	(0.47)	
2010	36.78	2.22	0.82	0.33	24538
	(12.31)	(1.15)	(0.38)	(0.47)	
2011	37.65	2.25	0.82	0.35	23233
	(12.74)	(1.16)	(0.38)	(0.48)	

Notes: Age, household size, male and married are measured on December 31st of the year of the move into the property. See Section 1.4 in the text for more details.

Table 1.3: Impacts of home equity on annual total and interlabor market mobility

	(1) Mobility	(2) Mobility	(3) Mobility	(4) Inter labor market mobility
$50 < LTV \leq 90$	-0.41	-0.27	-0.08	-0.02
	(0.04)	(0.07)	(0.06)	(0.03)
$90 < LTV \leq 100$	-0.59	-0.30	-0.24	-0.02
	(0.06)	(0.08)	(0.07)	(0.03)
$100 < LTV \leq 110$	-1.57	-1.02	-1.01	-0.20
	(0.06)	(0.08)	(0.08)	(0.04)
$LTV > 110$	-2.32	-1.22	-1.22	-0.29
	(0.05)	(0.06)	(0.06)	(0.03)
Person age category FE	Yes	Yes	Yes	Yes
Loan age FE	Yes	Yes	Yes	Yes
Other controls	No	No	Yes	Yes
Time · region FE	No	Yes	Yes	Yes
Observations	1,956,183	1,956,183	1,956,003	1,955,294
Mean of dep. var.	4.31	4.31	4.31	1.12

Notes: This table reports results from the estimation of linear probability models of annual mobility dummies. The models are estimated using the 2007-2012 panel. The dependent variable in Columns (1)-(3) is total annual mobility. The dependent variable in Column (4) is mobility across local labor markets. The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, 3 financial asset category fixed effects and indicators for male, native to the country, married and a change in familiy size. Standard errors in parentheses are clustered on region-years in Columns (2)-(4).

Table 1.4: Impacts of home equity on annual mobility: Balance sheet effects

	(1) Mobility	(2) Mobility	(3) Mobility	(4) Mobility
Sample: Financial-Assets-To-Value (%)	All	Above 35	15-35	Below 15
$50 < LTV \leq 90$	-0.15	0.29	0.46	-0.48
	(0.07)	(0.11)	(0.13)	(0.07)
$90 < LTV \leq 100$	-0.34	0.03	0.49	-0.67
	(0.08)	(0.20)	(0.19)	(0.09)
$100 < LTV \leq 110$	-1.11	-0.07	-0.41	-1.48
	(0.08)	(0.19)	(0.16)	(0.09)
$LTV > 110$	-1.36	-0.22	-0.67	-1.64
	(0.06)	(0.19)	(0.16)	(0.07)
Time · region FE	Yes	Yes	Yes	Yes
Financial assets FE	No	No	No	No
Controls	Yes	Yes	Yes	Yes
Observations	1,956,003	283,272	346,862	1,325,869
Mean of dep. var.	4.31	4.62	4.68	4.14

Notes: This table reports results from the estimation of linear probability models of annual total mobility indicators. The models are estimated using the 2007-2012 panel. Column (1) is estimated in the full sample of buyers. Columns (2)-(4) estimate the model in subsamples of observations grouped by the household Financial-Assets-To-Value ratio category in a given year. The ratio between financial assets and the value of the house is respectively above 35% in Column (2), between 15 and 35% in Column (3) and below 15% in Column (4). The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, and indicators for male, native to the country, married and a change in familiy size. The specification in this table does not include fixed effects for financial asset holdings categories. Standard errors in parentheses are clustered on region-years.

Table 1.5: Impacts of home equity on annual mobility across labor markets: Balance sheet effects

	(1) Inter lab. mkt. mob.	(2) Inter lab. mkt. mob.	(3) Inter lab. mkt. mob.	(4) Inter lab. mkt. mob.
Sample: Financial-Assets-To-Value (%)	All	Above 35	15-35	Below 15
$50 < LTV \leq 90$	-0.02	0.06	0.13	-0.10
	(0.03)	(0.05)	(0.06)	(0.03)
$90 < LTV \leq 100$	-0.02	0.07	0.21	-0.12
	(0.04)	(0.10)	(0.08)	(0.04)
$100 < LTV \leq 110$	-0.21	0.06	0.05	-0.31
	(0.04)	(0.08)	(0.06)	(0.05)
$LTV > 110$	-0.30	-0.04	-0.16	-0.37
	(0.03)	(0.10)	(0.07)	(0.04)
Time · region FE	Yes	Yes	Yes	Yes
Financial assets FE	No	No	No	No
Controls	Yes	Yes	Yes	Yes
Observations	1,955,380	283,180	346,735	1,325,379
Mean of dep. var.	1.12	1.13	1.10	1.12

Notes: This table reports results from the estimation of linear probability models of annual mobility across local labor markets indicators. The models are estimated using the 2007-2012 panel. Column (1) is estimated in the full sample of buyers. Columns (2)-(4) estimate the model in subsamples of observations grouped by the household Financial-Assets-To-Value ratio category in a given year. The ratio between financial assets and the value of the house is respectively above 35% in Column (2), between 15 and 35% in Column (3) and below 15% in Column (4). The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, and indicators for male, native to the country, married and a change in familiy size. The specification in this table does not include fixed effects for financial asset holdings categories. Standard errors in parentheses are clustered on region-years.

Table 1.6: Impacts of home equity on annual mobility: Life-event buyers

	(1) Mobility	(2) Mobility	(3) Inter labor market mobility	(4) Inter labor market mobility
$LTV > 100$		-1.27		-0.14
		(0.23)		(0.13)
$50 < LTV \leq 90$	0.34		0.23	
	(0.23)		(0.11)	
$90 < LTV \leq 100$	0.36		0.13	
	(0.38)		(0.18)	
$100 < LTV \leq 110$	-0.93		0.08	
	(0.34)		(0.20)	
$LTV > 110$	-1.09		-0.06	
	(0.25)		(0.15)	
Time · region FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	113,539	113,539	113,514	113,514
Mean of dep. var.	6.93	6.93	2.13	2.13

Notes: This table reports results from the estimation of linear probability models of annual mobility dummies. The dependent variable in Columns (1)-(2) is the total annual mobility. The depedent variable in Columns (3) and (4) is the annual mobility across different local labor markets. The models are estimated using the 2007-2012 panel. The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, 3 financial assets category fixed effects and indicators for male, native to the country, married and a change in familiy size. Standard errors in parentheses are clustered on region-years.

Table 1.7: Impacts of home equity on annual mobility: Regional variation

	(1) Mobility	(2) Mobility	(3) Inter labor market mobility	(4) Inter labor market mobility
$50 < LTV \leq 90$	-0.14	-0.14	-0.03	-0.03
	(0.13)	(0.14)	(0.04)	(0.04)
$90 < LTV \leq 100$	-0.27	-0.27	-0.04	-0.04
	(0.16)	(0.16)	(0.05)	(0.05)
$100 < LTV \leq 110$	-0.95	-0.92	-0.21	-0.19
	(0.20)	(0.20)	(0.06)	(0.06)
$LTV > 110$	-1.26	-1.21	-0.32	-0.29
	(0.20)	(0.21)	(0.05)	(0.06)
Time · cohort FE	Yes	Yes	Yes	Yes
Time · Region FE	No	No	No	No
Region FE	No	Yes	No	Yes
Controls	Yes	Yes	Yes	Yes
Observations	1,956,003	1,956,003	1,955,294	1,955,294
Mean of dep. var.	4.31	4.31	1.12	1.12

Notes: This table reports results from the estimation of linear probability models of annual mobility indicators. The dependent variable in Columns (1)-(2) is total mobility and the dependent variable in Columns (3)-(4) is inter labor market mobility. The models are estimated using the 2007-2012 panel. The controls are 5 person age category fixed effects, 5 household size category fixed effects, 3 financial assets category fixed effects and indicators for male, native to the country, married and a change in familiy size. Standard errors in parentheses are clustered on cohort-years.

Table 1.8: Impacts of home equity on annual mobility: Robustness

	(1) Mobility	(2) Inter labor market mobility	(3) Mobility	(4) Inter labor market mobility
$50 < LTV \leq 90$	0.08	0.03	-1.07	-0.12
	(0.05)	(0.03)	(0.13)	(0.05)
$90 < LTV \leq 100$	-0.07	0.03	-1.61	-0.27
	(0.07)	(0.03)	(0.18)	(0.07)
$100 < LTV \leq 110$	-0.75	-0.13	-2.12	-0.49
	(0.10)	(0.04)	(0.19)	(0.09)
$LTV > 110$	-0.86	-0.22	-2.26	-0.56
	(0.08)	(0.04)	(0.19)	(0.09)
Time · region FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Sample	1995-2008 buyers	1995-2008 buyers	Always-singles	Always-singles
Observations	1,816,985	1,816,301	235,085	235,041
Mean of dep. var.	4.48	1.15	2.65	0.72

Notes: This table reports results from the estimation of linear probability models of annual mobility indicator variables. The dependent variable in Columns (1) and (3) is the total annual mobility dummy. The dependent variable in Columns (2) and (4) is the annual mobility across different local labor markets. The models are estimated using the 2007-2012 panel. The sample in Columns (1)-(2) is restricted to buyers who started their ownership spell prior to 2009. The sample in Columns (3)-(4) is restricted to buyers who are single during every year of the ownership spell. The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, 3 financial assets category fixed effects and indicators for male, native to the country, married and a change in familiy size. Standard errors in parentheses are clustered on region-years.

Table 1.9: Impacts of home equity on annual mobility: Robustness

	(1) Mobility	(2) Mobility	(3) Inter labor market mobility
$50 < LTV \leq 90$	0.61	-0.12	-0.03
	(0.24)	(0.05)	(0.02)
$90 < LTV \leq 100$	0.63	-0.34	-0.05
	(0.39)	(0.07)	(0.03)
$100 < LTV \leq 110$	-0.55	-1.13	-0.23
	(0.37)	(0.07)	(0.04)
$LTV > 110$	-0.68	-1.36	-0.34
	(0.28)	(0.07)	(0.04)
Time · region FE	Yes	No	No
Time · small region FE	No	Yes	Yes
Municipality FE	No	Yes	Yes
Controls	Yes	Yes	Yes
Sample	1995-2008 life event buyers	Full	Full
Observations	102,579	1,956,003	1,955,294
Mean of dep. var.	7.28	4.31	1.12

Notes: This table reports results from the estimation of linear probability models of annual mobility dummies. The dependent variable in Columns (1)-(2) is the total annual mobility. The dependent variable in Column (3) is the annual mobility across different local labor markets. The models are estimated using the 2007-2012 panel. The sample in Column (1) is restricted to life event buyers who started their ownership spell prior to 2009. Columns (2) and (3) include municipality fixed effects and fixed effects for the interaction between COROP areas and calendar years. The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, 3 financial assets category fixed effects and indicators for male, native to the country, married and a change in familiy size. Standard errors in parentheses are clustered on region-years in Column (1) and COROP area-years in Columns (2) and (3).

Table 1.10: Impacts of home equity on annual mobility: Robustness

	(1)	(2)	(3)	(4)
	Inter province mobility	Mobility	Mobility	Inter labor market mobility
$50 < LTV \leq 90$	-0.06	-0.14	-0.06	-0.01
	(0.02)	(0.06)	(0.07)	(0.03)
$90 < LTV \leq 100$	-0.06	-0.35	-0.19	-0.02
	(0.03)	(0.07)	(0.07)	(0.03)
$100 < LTV \leq 110$	-0.19	-1.09	-0.94	-0.18
	(0.03)	(0.09)	(0.08)	(0.04)
$LTV > 110$	-0.25	-1.15	-0.96	-0.23
	(0.03)	(0.06)	(0.07)	(0.03)
Time · region FE	Yes	Yes	Yes	Yes
Time · person age category FE	No	Yes	No	No
Other controls	Yes	Yes	Yes	Yes
Sample	Full	Full	Non-trimmed	Non-trimmed
Observations	1,955,945	1,956,003	2,004,999	2,004,280
Mean of dep. var.	0.75	4.31	4.31	1.12

Notes: This table reports results from the estimation of linear probability models of annual mobility indicator variables. The dependent variable in Column (1) is the annual mobility across provinces. The dependent variable in Columns (2)-(3) is the total annual mobility. The dependent variable in Column (4) is the mobility across local labor markets. The models are estimated using the 2007-2012 panel in Columns (1)-(2). The models are estimated using the 2007-2012 panel, including the person-years with extreme LTV ratios below 0 or above 150 in Columns (3)-(4). The controls are loan age fixed effects, 5 person age category fixed effects, 5 household size category fixed effects, 3 financial assets category fixed effects and indicators for male, native to the country, married and a change in familiy size. The controls in Column (2) also include fixed effects for the interaction between the calendar year and 5 person age category fixed effects. Standard errors in parentheses are clustered on region-years.

Table 1.11: Mobility simulations for 1995-2008 purchase cohort buyers during Great Recession years 2009-2012

Type of scenario	Baseline	Scenario 1	Scenario 2	Scenario 3
	LTV inputs:			
Average annual house price changes 2009-2012 (%)	-4	8.5	2.25	-4
LTV at origination maximum (%)				95
	Mobility outputs:			
Cumulative mobility rate 2009-2012 (%)	14.2	15.3	14.9	15.0
Impact on cumulative mobility 2009-2012 vs. baseline (%)	0	7.5	5.1	5.8
Impact on mobility rate in 2012 vs. baseline (%)	0	11.2	9.4	5.2

Notes: This table simulates counterfactual mobility rates in three scenearios for LTV trajectories. The scenarios are applied to the 1995-2007 buyers in my sample for the calendar years 2009-2012. From the distribution of LTV ratios in the scenarios, I simulate counterfactualy mobility using the estimated effects of loan-to-value ratios on mobility using the point estimates in Column 3 of Table 1.3. See section 1.7 of the text for more details on the assumptions formulated in each of the three scenarios.

Chapter 2

Central Bank Liquidity Provision and Collateral Quality

with François Koulischer

2.1 Introduction

The collateral policy of central banks - or the types of assets central banks should require when lending to commercial banks - has traditionally been absent from discussions on monetary policy. The Bagehot (1873) assumption has been that central banks should lend only against high quality collateral.[0] In line with this principle, the Federal Reserve bought and sold only Treasuries in its open market operations over the last decades prior to 2007. During the same period more than half of the collateral pledged by banks to the European Central Bank (ECB) were liquid government bonds.

This changed dramatically during the 2007-2011 financial crisis which led to a paradigm shift. Not only did central banks expand the range of assets accepted as collateral, but they also adapted collateral requirements to changing market conditions. For example, when the market for asset-backed securities dried up in the United States and banks were unable to use them as collateral, the Fed provided credit to banks against these illiquid assets (see Table 2.1 and Appendix 3.7). In Europe, the ECB removed the rating thresholds for distressed government bonds which private lenders refused to accept as collateral. The policy of setting low collateral requirements in the face of falling quantities and qualities of bank collateral has been and still

[0] In Bagehot's words: "If it is known that the Bank of England is freely advancing on what in ordinary times is reckoned a good security – on what is then commonly pledged and easily convertible – the alarm of the solvent merchants and bankers will be stayed." — Bagehot (1873), p. 198.

is controversial on both sides of the Atlantic (Buiter 2008, De Grauwe 2012, Sinn 2014).[1]

The changes in the collateral policy of central banks raise two questions: (1) Should the central bank tailor its collateral policy to developments in financial markets and if so, how? (2) How does the collateral policy of the central bank interact with its interest rate policy?

The central contribution of this paper is to show how negative collateral shocks provide a novel justification for central bank collateral policy loosening when the traditional transmission mechanism of monetary policy is distorted.[2] A looser central bank collateral policy can reduce the spread between rates in the real economy and the policy rate and increase output.

In our model, a commercial bank refinances projects in the real economy by borrowing against collateral from the interbank market or the central bank. While collateral prevents the bank from shirking, it is costly to use as its value is lower for investors and the central bank than for the bank. We find that when the bank has plenty of high quality collateral, it borrows in the interbank market against low collateral requirements so that the collateral policy of the central bank has no impact on borrowing. However, when the amount or the quality of the available collateral falls below a threshold, the lack of collateral prevents borrowing. In this case, collateral policy can affect lending, and it is optimal for the central bank to relax its collateral requirements to avoid the credit crunch. Our model suggests that interest rate and collateral policy are complements: when the bank faces a collateral crunch, the return required by the bank from firms and households in the real economy increases without changes in the policy rate, set by the central bank. In these cases, a looser collateral policy can alleviate the negative impact of a lack of bank collateral and lower interest rates in the economy.

We develop our results in three steps. We first consider the situation where a commercial bank can only borrow from the interbank market to finance its project. We assume that the interbank market is fully competitive so that lenders in the interbank market earn zero profits in equilibrium. This corresponds to the Holmström and Tirole (2011) model of collateralized lending in the presence of moral hazard with the addition that the collateral is characterized by its quality. We define the quality of a collateral as the difference between the bank and the investors' value for the collateral.[3] This is an important consideration for thinking about collateral policy, where not only the quantity but also the quality of collateral matters.

This model helps us understand the interaction between the interest rate and collateral in addressing the moral hazard problem. From the perspective of investors, interest payments and collateral transfers are cash flows that pay in different states of the world (the interest rate is paid if the project succeeds while the collateral is seized if the project fails) but are otherwise substitutes: investors would be willing to trade

[1] In April 2009, the U.S. Congress required the Federal Reserve to reveal the names of the banks that received financial assistance as well as the collateral used in these transactions.

[2] In Acharya et al. (2012), imperfect competition provides the rationale for central bank lending. Our model allows to fully characterize the lending contract of the central bank.

[3] The difference in valuation is in the spirit of Geanakoplos (2010) and Simsek (2013) who model how differences in valuations affect lending. An alternative interpretation is the mechanism of Shleifer and Vishny (1992) through which liquidation values constrain the capacity to borrow.

off a higher interest rate for lower collateral transfer. However, interest payments and collateral transfers have different incentive properties for the commercial bank: a high interest rate reduces the profit from a successful investment, thereby making shirking more attractive. In contrast, a high collateral requirement makes shirking more costly as the commercial bank loses the collateral in case of default. The introduction of collateral quality - where the investors and the central bank have a different valuation for the collateral - adds a new trade-off. Because collateral has an extra cost (its transfer in case of default destroys value), in equilibrium the bank does not always pledge all the available collateral but minimizes its use. This allows us to define and explain the behavior of collateral requirements. When investment opportunities are attractive relative to the benefits of shirking, collateral requirements in the interbank market are low. When investment opportunities worsen, collateral requirements in the interbank market increase. The extra cost also explains the use of uncollateralized transactions in the interbank market prior to the 2007-2013 crisis, which other models cannot explain. Collateral quality also enables us to derive cross-sectional predictions regarding the equilibrium mix between interest rate and collateral requirements across collateral quality. We find that both interest rates and collateral requirements increase as the quality of collateral decreases, in line with empirical studies of collateralized lending (Gorton and Metrick, 2012)).

In the second step, we consider the case where the central bank is the only potential lender to the commercial bank (there are no investors anymore). This case illustrates how the solution to the moral hazard problem between the commercial bank and the lender (the central bank) changes with the objective function of the lender. In our model the central bank is concerned about total output but discounts expected losses heavily. This implies that, unlike interbank market investors, it can tolerate some losses if this increases the efficiency of the investment by the commercial bank. We find that, in contrast with the collateral requirements of the interbank market, the optimal central bank collateral policy sets low collateral requirements in the face of low quantities and qualities of bank collateral and high collateral requirements otherwise. We also find that the central bank should refuse to lend to banks that have too little high quality available collateral and are "too encumbered to save".

Finally, we consider the interbank market, the central bank and the commercial bank together in the third and last step of our analysis. We assume that both the central bank and investors make an exclusive loan offer to the commercial bank, which selects the most attractive loan. While the coexistence of the two types of lenders does not change the contracts offered by these lenders, it changes the source of the commercial bank's funding. We show that when the bank has a high level of quality collateral available, it borrows from the interbank market only. However when the amount or the quality of available collateral falls below a threshold, the commercial bank borrows from the central bank, which replicates the observed shift from interbank markets to the central bank during the 2007-2013 financial crisis.

We then use these results to revisit the optimal design of monetary policy. Several empirical papers (e.g. Kashyap and Stein, 2000; Jimenez et al., 2012) have shown that the transmission from the short term policy rate, set by the central bank, to the interest rate in the real economy varies with the banks' amount of available collateral (measured as the ratio of securities to assets or the equity level). Banks with less collateral available tighten credit more than other banks when the short term interest rate increases.[4] In our model, the short term interest rate corresponds to the return required from the bank, which we normalize to one (break-even). The interest rate in the real economy can be interpreted in our model as the marginal return required by the bank from its customers. In our model, the return required by the bank from its customers is higher than one in cases where the bank borrows with collateral because of the imperfect collateral quality. Consistent with the empirical evidence, the lower the collateral quality, the higher the wedge between the returns required by the bank and the investors. This wedge increases even further when the bank runs out of collateral, e.g. due to a fall in the value of its collateral. Our model implies that collateral policy facilitates the transmission of monetary policy by reducing the spread between the short-term interest rate (the return required from the bank) and the cost of funding of firms and households in the real economy (the return required by the bank from its customers).

While collateral policy loosening allows to repair the transmission of monetary policy in crises, it is ineffective for tightening during booms, when collateral is abundant. During booms, collateral requirements in the interbank market are low and banks prefer to borrow in the interbank market as collateral use is costly. This raises the question of moral hazard, or whether lenient collateral policy may lead to lower equilibrium collateral quality. Our model suggests that one way to address this problem where banks have an incentive to hold too little collateral is to require banks to keep sufficient levels of quality collateral during booms, as with the Basel III Liquidity Coverage Ratio (LCR) requirements.

Section 2.2 sets up our model of commercial and central bank collateralized lending. Sections 2.3 and 2.4 consider collateralized lending by the interbank market and the central bank, respectively. In section 2.5 we consider the case where both the central bank and the interbank market can fund the commercial bank and we revisit the optimal design of monetary policy. Section 2.6 considers the Basel III Liquidity Coverage Ratio (LCR) requirements as potential solution to the incentive issues associated to loose collateral policy. Section 2.7 concludes.

[4]For an empirical assessment of the importance of the bank lending channel, see Peek and Rosengren (1997) and Khwaja and Mian (2008). The impact of collateral on funding costs and investment are respectively documented in Benmelech and Bergman (2011) and in Chaney et al (2012).

Table 2.1: Changes in ECB and Fed collateral policy (2007-2013)

Date		ECB	Federal Reserve
Oct	2007		Term-Auction Facility: Provided up to $500 bn against residential mortgages (25%), asset-backed securities (ABS) (17%) or commercial loans (15%).
Mar	2008		Term Securities Lending Facility and Primary Dealer Credit Facility: primary dealers can exchange (mainly) mortgage backed securities against Treasuries.
Oct	2008	Credit threshold is lowered to BBB- from A- (except for ABS). Bonds traded on certain non-regulated markets become eligible.	Commercial Paper Funding Facility and Money Market Investor Funding Facility: provide liquidity against asset-backed commercial paper
Nov	2008	Foreign-currency denominated assets become eligible (until January 2011).	Term Asset-Backed Securities Loan Facility: provide loans against newly issued ABSs.
May	2010	Suspension of minimum rating threshold of Greek government debt	
Mar	2011	Suspension of minimum rating threshold of Irish government debt	
Jul	2011	Suspension of minimum rating threshold of Portuguese government debt	
Feb	2012	Additional credit claims (e.g. consumer loans, credit card loans) become eligible	
Jul	2013	Broader ABS eligibility criteria	

Sources: ECB and Federal Reserve

2.2 Setup

The model features a representative commercial bank (from now on called "bank") that needs liquidity to refinance loans, investors in the interbank market with excess cash and the central bank.[5] The interbank

[5]The interbank market literature considers both shocks to assets, such as in our model, but also shocks to liabilities as drivers of liquidity needs. See Rochet and Tirole (1996) for asset shocks or Bhattacharya and Gale (1987) and Diamond and

market and the central bank are potential lenders and compete in offering collateralized loan contracts.

Bank. A bank with balance sheet of size 1 has extended long term loans to its customers and faces a negative liquidity shock as these loans need refinancing. The bank also owns collateral of quality v that pays 1 with probability θ (and is thus worth θ). The quantity of collateral available θ is common knowledge. The loans (worth $1-\theta$) cannot be used as collateral and are worth zero if they are not refinanced and have to be liquidated.[6]

To refinance its loans, the bank may obtain an amount of funding q by borrowing from the interbank market or the central bank.[7] The bank however faces moral hazard when reinvesting: if it properly manages the reinvestment of its loan q, it earns $R(q)$ with probability p and zero with probability $1-p$. The probability of success p and the monitoring effort are unobservable to outsiders, and the bank can mismanage its investment and get a private benefit $A+Bq$, where $A, B > 0$, in which case the project fails ($p=0$). The return function $R(\cdot)$ is increasing and concave $R'(q) > 0$, $R''(q) < 0$ and satisfies the Inada conditions $\lim_{q\to 0} R'(q) = \infty$, $\lim_{q\to\infty} R'(q) = 0$.

A loan contract specifies a loan size q, a gross interest rate r and a gross haircut $h \geq 0$, which implies an interest payment of rq and a total value of collateral pledged of hq.[8] The collateral is seized if the project fails and the bank is unable to reimburse the loan.

To ensure that the bank properly manages its investment, the payoff of proper management must exceed the payoff from shirking

$$p(R(q) - rq) - (1-p)hq \geq A + Bq - hq.$$

This incentive compatibility (IC) constraint can be simplified to

$$pR(q) - prq + phq \geq A + Bq. \tag{IC}$$

The interest rate has negative incentive properties as it makes the IC harder to satisfy. The haircut has positive incentive properties since it decreases the payoff of the bank in case of default and makes the IC easier to satisfy.

Any feasible contract must also ensure that the bank has enough collateral to pledge. This is the collateral capacity (CC) constraint

$$hq \leq \theta. \tag{CC}$$

Dybvig (1983) for liability shocks.

6In contrast with Simsek (2013) and Weymuller (2013), the investment opportunity is unpledgeable as the bank invests in real economy projects. In practice this excludes the potential issuance of ABS or covered bonds.

7We focus on the case of collateralized lending and assume that the bank cannot sell its collateral. For models of fire-sales in interbank lending see Acharya et al. (2012) and Bindseil (2013).

8The formulation $h \geq 0$ allows for collateralized and uncollateralized loans, where the latter have $h = 0$.

Interbank Market. The private funding market, which can be thought of as the interbank or money market, is perfectly competitive as in Gale and Hellwig (1985) and in Holmström and Tirole (1997). Investors fund any contract that yields a non-negative profit. Investors receive a cash payment rq if the project succeeds. If the project fails, investors seize the collateral worth hq to the bank and hqv to investors. The term v captures the quality of the collateral. It is close to 1 for liquid assets like high grade government bonds for which investors and the bank have a similar value for the collateral. When $v < 1$, collateral has a smaller value to the investors than to the bank.[9]

Any equilibrium contract in the interbank market (q, r, h) must ensure that the market clears, i.e. that investors make zero profits

$$prq + (1 - p)\, hqv - q = 0. \qquad \text{(Market clearing)}$$

Central bank. The central bank has two goals: to maximize output and to minimize losses.[10] The central bank is concerned about losses as it increases political pressure and ultimately reduces its ability to pursue its core mission of output and price stability. This objective also corresponds to the way central bankers typically define their mission in practice, and is in line with observed monetary policy (Clouse et al, 2003; Friedman and Schwartz, 2008; Judd and Rudebusch, 1998; Krugman, 1998; Sargent and Wallace, 1981; Stella, 2005).

Let (q, r, h) be the collateralized loan contract taken by the bank. The expected profit of the bank is given by

$$\Pi_b = p\,(R\,(q) - rq) - (1 - p)\, hq.$$

When the central bank and the interbank market compete to offer a loan, we assume exclusive loans, i.e. the bank cannot borrow from both lenders. We set $\lambda = 1$ to indicate that the bank borrows from the interbank market and $\lambda = 0$ if the bank borrows from the central bank. If the bank borrows from the interbank market, the expected profit of interbank investors and the central bank (respectively Π_p and Π_{cb}) is the sum of interest payments and collateral payments minus the lent amount

$$\Pi_p, \Pi_{cb} \equiv prq + (1 - p)\, hqv - q.$$

Output is given by

$$\Pi_b + \lambda \Pi_p + (1 - \lambda)\, \Pi_{cb} = pR\,(q) - q - (1 - v)\,(1 - p)\, hq.$$

[9]The wedge $1 - v$ could capture that the bank is the first-best user of the collateral, as in Shleifer and Vishny (1992) or Kiyotaki and Moore (1997). Alternatively, the bank may hold optimistic beliefs about the collateral value as in Geanakoplos (2010) and Simsek (2013)

[10]Stabilizing output at its potential may also stabilize inflation (Goodfriend and King, 1997).

Interest payments cancel out from the expression of output, as they represent simple transfers from borrowers to lenders. In contrast, collateral transfers hurt output as collateral is transferred to second-best users with probability $1-p$. As a result, output is given by the expected value of the investment minus the losses, due to the inefficient allocation of collateral in case of default.

To capture the sensitivity of the central bank to losses, we assume that the central bank puts a weight on its expected losses. This yields the final objective function for the central bank

$$\text{Output} + \omega \min \{0, \Pi_{cb}\}.$$

The central bank sets the utilitarian welfare function as objective when $\omega = 0$. Finally, we capture the highly non-linear sensitivity of central banks to losses (Stella, 1997) by assuming a maximum amount of losses that the central bank can support, Π_{cb}^{loss}:

$$\Pi_{cb} \geq \Pi_{cb}^{loss}.$$

First-best Benchmark. Before solving the full model, let us consider the first-best case where there is no moral hazard so that the IC can be ignored. In a perfectly competitive funding market, the equilibrium contract maximizes:

$$\max_{r,h,q} \pi = p\left(R\left(q\right) - rq\right) - \left(1-p\right) hq \tag{2.1}$$

such that the expected payoff to investors is zero and that the bank has sufficient collateral:

$$\begin{aligned} prq + (1-p)\, hqv - q &= 0. \\ hq &\leq \theta. \end{aligned} \tag{2.2}$$

The first-best contract is uncollateralized ($h = 0$) as using collateral of imperfect quality $v < 1$ is costly.

Lemma 1. *(First-best) In the first best, all positive NPV projects are undertaken. The loan level q^* solves $R'(q^*) = \frac{1}{p}$, the haircut h is zero and the interest rate is $r = \frac{1}{p}$.*

Proof. Appendix 3.7.

2.3 Interbank Market Lending

This section considers the situation where the bank can only borrow in the interbank market. We explain the conditions under which the bank borrows using collateral and then discuss properties of the uncollateralized and collateralized borrowing equilibrium.

Collateralized or uncollateralized borrowing? For a given loan amount, there are two ways to reimburse the loan: through interest payments or with a transfer of collateral. From the perspective of interbank investors, interest payments and collateral transfers are cash flows that pay in different states of the world (the interest rate is paid if the project succeeds, the collateral is seized if the project fails) but are otherwise substitutes: the investor would be willing to trade off a higher interest rate for lower collateral. However, interest payments and collateral transfers have different incentive properties for the commercial bank: a high interest rate reduces the profit from a successful investment, thereby making shirking more attractive.

When the returns from undertaking the project (the investment prospects $R(\cdot)$ and p) are high relative to the private benefits from shirking, pledging collateral is unnecessary. We formalize this claim using the threshold loan size q^{ec} that solves $R'(q^{ec}) = \frac{1}{p} + \frac{(1-p)(1-v)B}{p}$.

Proposition 1. *[Shift to collateral] The equilibrium contract is uncollateralized when investment prospects $R(\cdot)$ and p are high ($h = 0$ if $pR(q^{ec}) - q^{ec} \geq A + Bq^{ec}$). The bank shifts from uncollateralized to collateralized borrowing when investment prospects fall ($h > 0$ else).*

Proof. Appendix 3.7.

For future reference, we define the condition

$$C_1 \equiv pR(q^{ec}) - q^{ec} < A + Bq^{ec}. \tag{C1}$$

which corresponds to the case where the bank uses collateral and $\overline{C_1}$ to refer to the other case.

The condition for using collateral is intuitive: when investment prospects are high relative to the private benefits, the moral hazard problem becomes irrelevant as the bank has a high reward if the project succeeds. The uniqueness of the uncollateralized lending contract is arguably less straightforward. The uniqueness is driven by imperfect collateral quality $v < 1$, which imposes an extra cost in case of default so that the bank prefers to borrow without collateral if this is incentive compatible. When $v = 1$ as in Holmström and Tirole (2011) , the model yields a continuum of equilibria when $\overline{C_1}$ holds, as investors and the bank are indifferent between cash or collateral transfers whenever the contract satisfies the incentive compatibility constraint.[11] The imperfect collateral quality explains the use of uncollateralized transactions in the interbank market, which moral hazard models without collateral quality cannot account for.

In Europe, the volume of uncollateralized lending more than halved from 2007 to the height of the sovereign debt crisis in 2010 while the volume of collateralized lending increased by 3%.[12] This shift to collateral is consistent with Proposition 1: as investment opportunities deteriorate and private benefits from shirking increase, interbank lenders require more collateral.[13]

[11] This suggests a mechanism reminiscent of the Modigliani-Miller theorem where the amount of collateral does not matter when $v = 1$ as long as the bank is properly incentivized (see Appendix 3.7).

[12] Sources: International Capital Markets Association (ICMA) and European Central Bank (2012) report "Changes in bank financing patterns".

[13] Private benefits may increase in a downturn as firms in distress that do not bear the losses in case of failure shift risks

Uncollateralized borrowing. The uncollateralized lending contract is similar to the first-best contract: the interest rate is $r = 1/p$ and there are no collateral requirements ($h = 0$). The loan size q is equal to the first-best loan size when the investment prospects p and $R(\cdot)$ are large relative to the private benefits from shirking (A and B) (i.e. when $pR(q^*) - q^* > A + Bq^*$). When this condition does not hold, the IC constraint binds and the loan size is lower than the first-best. In order to keep the bank incentivized, the equilibrium contract reduces the investment so that the average return increases.

Proposition 2. *[Uncollateralized Efficiency] The loan size q is higher when the bank borrows uncollateralized than when it uses collateral ($q > q^{ec}$ if $\overline{C_1}$ holds). The uncollateralized interest rate and haircut are the same as in the first-best and the loan size is at the first-best level if $pR(q^*) - q^* > A + Bq^*$ else it solves $A + (1 + B)q - pR(q) = 0$.*

Proof. Appendix 3.7.

We emphasize two features of the uncollateralized equilibrium. First, the quantity and quality of available collateral θ and v do not affect investment or interest rate levels as collateral is not used in equilibrium. Therefore banks may borrow extensively in good times even when they have virtually no collateral available. This leaves those banks exposed to the "shifts to collateralized borrowing" from proposition 2.3, which may explain why banks like Northern Rock in the United Kingdom could rely extensively on interbank borrowing before 2007 but were severely hit by a lack of collateral after August 2007.

A second feature is that the loan size q is higher when the bank borrows without collateral as imperfect collateral quality increases the funding cost of the bank. Therefore the bank reduces investment when using collateral to ensure that the marginal cost remains equal to the marginal return on investment.

Collateralized borrowing. When investment prospects worsen or when private benefits from shirking increase, the equilibrium shifts to collateralized borrowing. Depending on the amount of collateral available and its quality, the bank finds itself in one of three regimes: the enough collateral regime, the collateral crunch or the liquidity dry-up. Each regime corresponds to a specific set of binding constraints. While the initial problem has four constraints (IC, CC, $h \geq 0$ and market clearing), two results reduce the number of cases to consider. First, the haircut constraint ($h \geq 0$) and the CC ($hq \leq \theta$) cannot both bind at the same time. Second, the IC must bind when the bank pledges collateral ($h > 0$) as to minimize the cost associated to the collateral transfer. This leaves us with four cases to consider. The two cases where $h = 0$ binds are the uncollateralized lending regimes discussed above (where the IC binds or slacks). When the bank uses collateral, the IC always binds and the two cases are when the CC is slack (enough collateral) or binds (collateral crunch). When the problem does not have a nonnegative solution, there is a liquidity dry-up.

A key determinant of the collateralized equilibrium is the collateral quality factor

(Landier et al., 2011).

$$f = p\theta + (1-p)\,\theta v. \qquad \text{(Quality factor)}$$

This factor f corresponds to the expected social value of a quantity of collateral θ with quality v when it is pledged as collateral: with probability p the project succeeds and the asset keeps its value of θ to the bank and with probability $1-p$ the asset is transferred to the lender who values it at θv. Two thresholds for the collateral quality factor are relevant to distinguish the several regimes. The first one is $\underline{f}_1^I = A + (1+B)\,q^{ec} - pR\,(q^{ec})$ and the second threshold $\underline{f}_2^I$ is the lowest f for which $pR\,(q) + f - q = A + Bq$ has a real and nonnegative solution in q.

Proposition 3.

(Enough Collateral) If $f \geq \underline{f}_1^I$ and C_1, the loan size is $q^{ec} < q^*$, the interest rate is $r = \frac{1-(1-p)hv}{p}$ and the haircut is $h = \frac{A+(1+B)q-pR(q)}{q[(1-p)v+p]}$.

(Collateral crunch) If $\underline{f}_2^I < f < \underline{f}_1^I$ and C_1, the loan size $q < q^{ec}$ solves $pR\,(q) + f - q = A + Bq$, the haircut is $h = \theta/q$ and the interest rate is $r = \frac{1-(1-p)hv}{p}$.

(Liquidity dry-up) If $f \leq \underline{f}_2^I$ and C_1, there is a liquidity dry-up ($q = 0$).

Proof. Appendix 3.7.

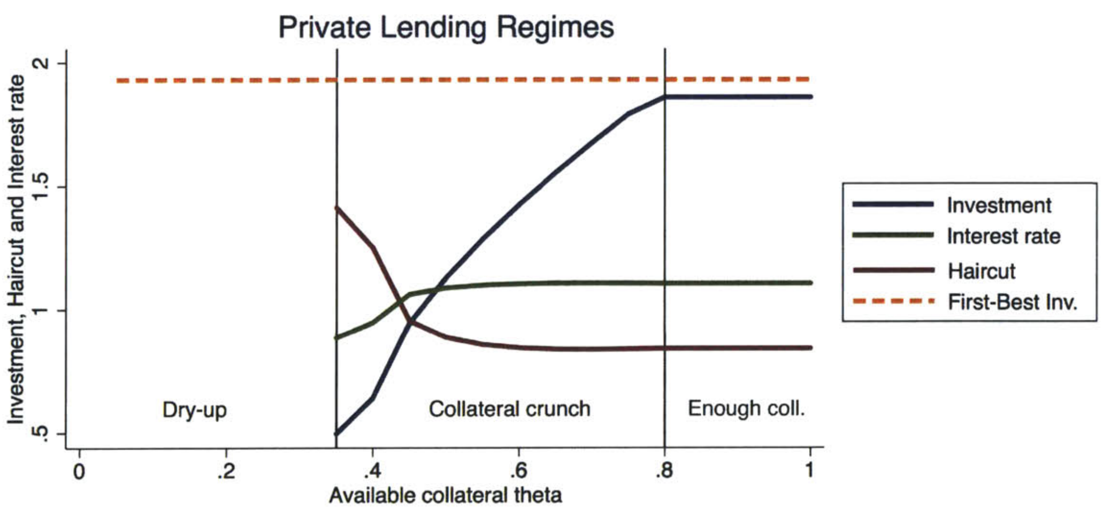


Figure 2-1: Interbank market collateralized lending regimes

This Figure plots the haircut, interest rate and loan size in the three regimes of interbank lending (dry-up, collateral crunch and enough collateral) as a function of the amount of available collateral θ. The parameters are $A = 0.9$, $B = 0.45$, $v = 0.9$, $p = 0.7$ and the function of investment opportunities is $R\,(q) = 2\sqrt{q}$.

Figure 2-1 illustrates the various collateralized regimes as a function of the amount of available collateral θ for a constant collateral quality v. When the bank has enough collateral, it pledges the amount necessary to satisfy the IC which always binds while the CC is slack. The lending level is lower than that of the first-best as using collateral is costly: with probability $1-p$ the collateral is transferred to investors who only value each unit of the collateral at $v<1$. The Collateral Crunch regime corresponds to the case where the CC binds: the bank pledges all its available collateral. However, this is insufficient to secure funding at the "enough collateral" level. In this case investment is determined by the amount of available collateral. Finally when the collateral quality factor f falls below $\underline{f}_2^I$, the bank runs out of collateral and liquidity dries up.

We now discuss the major comparative statics of the contract terms from proposition 2.3 and match those with the stylized facts of collateralized lending.

Proposition 4. *[Irrelevant collateral quantity] The amount of collateral available is irrelevant for contract terms when the bank has enough collateral (If* C_1 *and* $f>\underline{f}_1^I \rightarrow \frac{\partial q}{\partial \theta}=\frac{\partial r}{\partial \theta}=\frac{\partial h}{\partial \theta}=0$*). In this regime the loan size falls when collateral quality falls (If* $f>\underline{f}_1^I \rightarrow \frac{\partial q}{\partial v}=\frac{\partial q^{ec}}{\partial v}>0$*).*

When the bank has enough collateral the loan size, the haircut and the interest rate are independent of the amount of available collateral θ. This differs from models as Shleifer and Vishny (1992) or Holmström and Tirole (2011), where the quantity of collateral determines borrowing levels. However collateral quality does influence the loan size even when the bank has enough collateral. The imperfect quality explains why the collateralized loan size (which solves $R'(q)=\frac{1}{p}+\frac{(1-p)(1-v)B}{p}>\frac{1}{p}$) is lower than the first best loan size (given by $R'(q)=1/p$).

Proposition 5. *[Haircut spikes] When the bank has relatively little collateral available, haircuts spike in response to a negative shock to collateral quality (If* C_1 *and* $\underline{f}_2^I<f<\underline{f}_1^I \rightarrow \frac{\partial h}{\partial v}<0$*).*

Proof. Appendix 3.7.

The predicted negative relationship between collateral quality v and haircuts h is consistent with patterns in the time series (Gorton and Metrick, 2012) and the cross-section. The average haircut levels for loans extended by Fidelity money market funds from 2004 to 2011 by asset class are respectively 3.0% for commercial paper, 3.2% for Treasures, 3.7% for mortgage loan obligations, 4.9% for corporate debt and 10.7% for other assets.[14] The lowest haircuts are for Treasuries and commercial paper, arguably the most liquid of the series.

One counterintuitive prediction of our model is that the interest rate falls when banks have little collateral available while interest rates increased during the crisis. This contrast is driven by the moral hazard friction we use: low interest rates reduce the incentives to shirk.[15]

One interesting and arguably more realistic prediction concerns the relative order in which the contract terms (q,r,h) respond to negative shocks to the quantity (or quality) of collateral. As visualized in the collateral

[14] Data are from the SEC N-MFP July 2004- August 2011 quarterly filings and include 6 money market funds (MMF). Fidelity is the second largest MMF manager with a 10% market share (Weymuller, 2013).

[15] In practice, other frictions such as adverse selection on collateral availability θ may explain why interest rates rise when collateral availability drops (for a model where θ is unobservable, see Tirole, 2012)

crunch zone of Figure 2-1, the adjustment to a negative shock to collateral quantity first mainly operates through the loan size q and then later through the haircut h and the interest rate r. The loan size q adjusts first as losses associated to downsizing are initially only second-order, whereas increasing the haircut h leads immediately to first-order losses associated to the liquidity wedge $1 - v$. By focusing on the most valuable projects, the higher average return improves bank incentives. However, as more and more valuable projects are canceled, fixing incentives through downsizing only becomes too costly. Higher haircuts as well as lower interest rates then kick in as a second channel of adjustment.

Proposition 6. *[Liquid first] When the bank pledges collateral, it is more profitable to use high quality collateral (If C_1 and $f > \underline{f}_2^I \rightarrow \frac{\partial \Pi_b}{\partial v} > 0$).*

Proof. Appendix 3.7.

The liquidity wedge $1 - v > 0$ implies that borrowers have an incentive to use first the most liquid, high quality collateral. Table 2.2 illustrates the predominance of liquid collateral in repo contracts for Fidelity money market fund repos. Treasuries, arguably the most liquid securities, account for more than half of the collateral used, followed by corporate debt. To control for differences in collateral holdings across asset classes, we include the outstanding amounts of securities from the Flow of Funds statistics in column 2. The ratio between assets used as collateral and total outstanding assets in column 3 provides a measure of the propensity to pledge specific asset types relative to Treasuries. All other asset classes have a much lower propensity to be pledged as collateral. International Capital Market Association (ICMA) data suggest a similar pattern for Europe: government bonds (with a high liquidity v and therefore a high quality f) account for 41 % of the collateral used in European private repos while corporate bonds and equity follow at 19.1% and 14.7% respectively.

Table 2.2: Collateral types used by Fidelity money market funds (2004-2011)

	Collateral value ($ bn)	Assets outstanding($ bn)	Propensity to Pledge
Treasuries	29.0	4,945.5	100.0
Corporate debt	10.5	7,799.4	23.0
Mortgage loan obligations	7.1	6,330.3	19.1
Equities	6.8	15,979.3	7.3
Other	3.5	-	-

This Table shows the total value of collateral used by Fidelity money market funds in repos. Data are from the July 2004-August 2011 SEC N-MFP quarterly filings. To compare the amounts used with availability, we include total assets outstanding in the economy using the Flow of Funds data Q4 2013 (see Appendix 3.7).

2.4 Central Bank Lending

We now consider the case where the central bank is the only source of funding, for instance because it uses its regulatory authority to impose a compulsory scheme.[16] The central bank has the bargaining power and maximizes output while minimizing its own expected losses. Its objective function is

$$W_{cb} = \text{Output} + \omega \text{ Losses}.$$

Plugging in the expressions for output and central bank losses, the central bank solves

$$\max_{r,q,h} W_{cb} = pR(q) - q - (1-p)\,hq\,(1-v) + \omega\,(prq + (1-p)\,hqv - q)\,1_{[\Pi_{cb}\leq 0]}$$

under the constraints that the bank is incentivized not to shirk, but to make non-negative profits and ensure sufficient collateral, and that the central bank's profit is higher than its maximum loss, Π_{CB}^{loss}:

$$\begin{aligned} pR(q) - prq + phq &\geq A + Bq \\ p\,[R(q) - rq] - (1-p)\,hq &\geq 0 \\ hq &\leq \theta \\ prq + (1-p)\,hqv &\geq \Pi_{CB}^{loss} \end{aligned}$$

When the profit of the central bank $\Pi_{cb} = prq + (1-p)\,hqv - q$ is positive, the objective function becomes:

$$W_{cb} = pR(q) - q - (1-p)\,qh\,(1-v)\,.$$

For a given loan size q and neglecting the constraints, the central bank prefers low haircuts. When the profit of the central bank is negative, the objective function is:

$$W_{cb} = pR(q) - q\,(1+\omega) - (1-p)\,qh\,(1 - v\,(1+\omega)) + \omega prq.$$

The central bank has now an ambiguous attitude towards collateral. On the one hand, all else equal, higher haircuts lower its losses. On the other hand, haircuts increase the output loss from the liquidity wedge. The net effect depends on the weight given to losses ω. We focus on the most interesting case where ω *is* sufficiently high and exceeds a threshold, $\omega > \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$. Appendix 3.7 covers the case where $\omega < \underline{\omega}$. We also focus on collateralized lending as the uncollateralized contract is identical to the one in the interbank market.

[16] One could also interpret the lending public authority as the Treasury. The central bank is however the most natural interpretation given its objective function, the impact of collateral policy on monetary policy transmission and the large share of central banks in public bank lending.

The solution depends on several thresholds for the quality factor $f = p\theta + (1-p)\,\theta v$. The thresholds $\underline{f}_1^{CB}$ and $\underline{f}_2^{CB}$ equal

$$\underline{f}_i^{CB} = A + (B+1)\,q - pR\,(q)\,,$$

where q is the loan size for respectively the equilibrium $f > \underline{f}_1^{CB}$ for $i = 1$ and the loan size of the equilibrium $\underline{f}_1^{CB} > f > \underline{f}_2^{CB}$ for $i = 2$. The collateral threshold $\underline{f}_3^{CB}$ is

$$\underline{f}_3^{CB} = \Pi_{CB}^{loss} + q - pR\,(q) + A + Bq,$$

where q is the loan size for the equilibrium $f > \underline{f}_3^{CB}$. The collateral threshold $\underline{f}_4^{CB}$ is the lowest f for which

$$pR\,(q) + f - A - Bq - \Pi_{CB}^{loss} - q = 0 \tag{2.3}$$

has a solution.

Proposition 7. *(Private Contract) If $\underline{f}_2^{CB} < f$ the central bank offers the same loan contracts as the interbank market does.*

(Lending Floor) If $\underline{f}_3^{CB} < f < \underline{f}_2^{CB}$ the loan size solves $R'\,(q) = \frac{1+\omega(1+B)}{p(1+\omega)}$, the haircut is $h = \theta/q$ and the interest rate is $prq = pR\,(q) + p\theta - A - Bq$.

(Loss Limit) If $\underline{f}_4^{CB} < f < \underline{f}_3^{CB}$ the central bank makes the maximum losses allowed Π_{CB}^{loss}. The loan size solves (2.3), the haircut is $h = \theta/q$ and the interest rate is $r = \frac{\Pi_{CB}^{loss}+q-(1-p)\theta v}{pq}$.

(Too encumbered to save) If $f < \underline{f}_4^{CB}$ the bank is unfunded ($q = 0$).

Proof. Appendix 3.7.

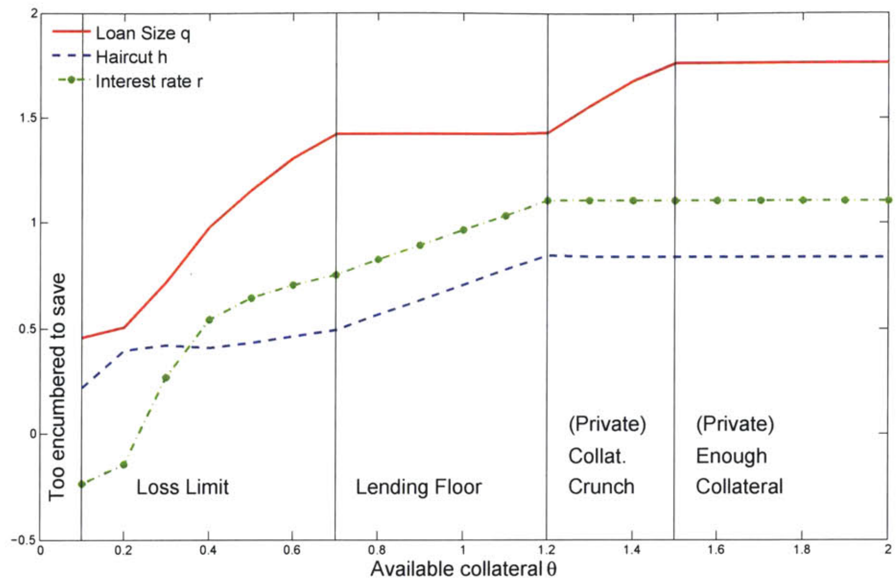


Figure 2-2: Central bank lending regimes

This Figure plots the haircut, interest rate and loan size in the five regimes of central bank lending as a function of the quantity of collateral θ. The parameters are those from Figure 2-1 and $\Pi_{CB}^{loss} = -0.25$, $\omega = 0.2$.

Figure 2-2 illustrates the different regimes in the central bank only case. Contract terms in the "enough collateral" case and the collateral crunch are identical for the central bank and for the interbank market. In the collateral crunch case, borrowing is cut when the amount of available collateral θ drops and the central bank breaks even.

Proposition 8. *[Haircuts and Collateral Quality] When the amount of available collateral reaches an intermediate level, central bank liquidity provision does not depend on collateral quality ($\partial q/\partial v = 0$ if C_1 and $\underline{f}_3^{CB} < f < \underline{f}_2^{CB}$).*

Proof. Appendix 3.7.

When the collateral quality factor falls below $\underline{f}_2^{CB}$ and $\underline{f}_3^{CB} < f < \underline{f}_2^{CB}$, the cost to the economy in terms of lost output becomes larger than the welfare cost of central bank losses. The central bank then becomes ready to incur losses in the third regime, the so called lending floor. In this regime, the central bank keeps the lending level constant. As lending is constant and as the CC binds, haircuts decrease when the amount or the quality of the available collateral drops. This matches a key stylized fact: central banks accepted collateral of lower quality during the recent crisis. The Fed for instance significantly broadened the range of collateral eligible to obtain credit whereas it only buys and sells Treasuries to selected counterparties in normal times. Figure 2-3 shows the total value of collateral pledged to the Fed in the Term Auction Facility (TAF), Primary Dealer Credit Facility (PDCF) and the Term Securities Lending Facility (TSLF) repo operations. In contrast with private markets (Table 2.2), the use of Treasuries was limited and banks mostly pledged agency-guaranteed MBS, ABS and corporate bonds. The European Central Bank (ECB) also broadened the range of collateral eligible for repos. It lowered its minimum quality threshold from A- to BBB- after the Lehman bankruptcy. In our model, this implies that assets with a gross haircut of $h = \infty$ subsequently became eligible, with finite h. Figure 2-4 shows that the collateral pool of the ECB became less liquid as the share of government bonds decreased while the share of ABS, uncovered bank bonds and non-marketable assets increased.

While the Great Recession provides the most recent and arguably most salient illustration of the principle of accepting lower quality collateral in the lending floor regime, collateral policy was also loosened in earlier periods where collateral values dropped such as the 1907 bankers' panic and the Great Depression. Gorton and Metrick (2013) describe the willingness to transform bankers' collateral into currency as one of the primary motives to create the Federal Reserve System in 1930. Richardson and Troost (2006) explain how collateral eligiblity requirements at the Federal Reserve Bank of Atlanta were relaxed in February 1932.

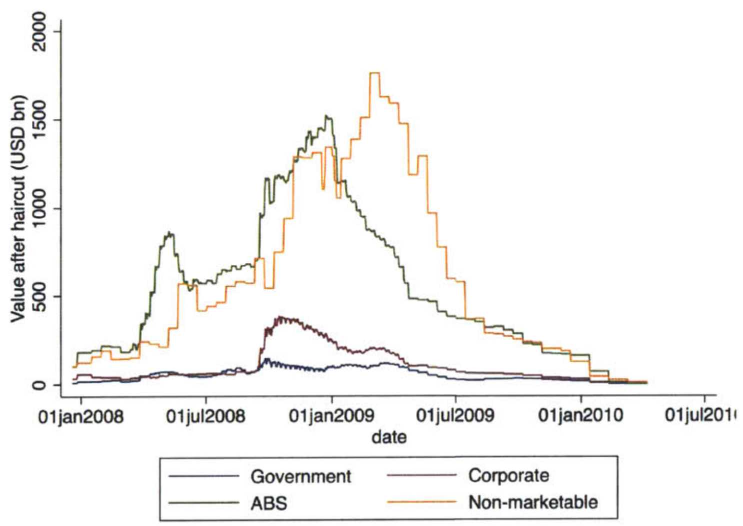


Figure 2-3: Value of collateral pledged to the Federal Reserve

This Figure includes values after haircut from Term Auction Facility, Primary Dealer Credit Facility and Term Securities Lending Facility operations. *Treasury*: Debt issued by the Treasury and GSEs. *Muni*: Securities issued by state and local governments. *Corporate*: Unsecured securities issued by corporations. *ABS* includes agency and non-ageny mortgage-backed securites (MBS), collateralized mortgage obligations (CMO) and securities collateralized by assets other than first-lien mortgages.

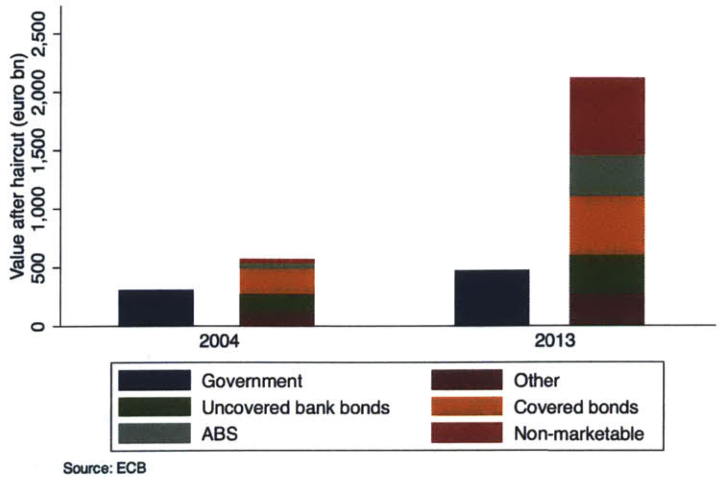


Figure 2-4: Value of collateral pledged to the ECB

This Figure plots the total value of collateral pledged to the ECB by asset type in 2004 and 2013. The values are net values after subtraction of the haircut (Source: ECB).

Proposition 9. *[Too encumbered to save] The central bank refuses some types of collateral (If $f < \underline{f}_4^{CB}$, $q = 0$).*

Proof. Appendix 3.7.

The central bank stops providing liquidity to the bank if the amount or the quality of bank collateral falls too much, i.e. when $f < \underline{f}_4^{CB}$. In this case, the bank is too encumbered to save: the subsidy required to support bank investment generates losses sufficiently large to undermine the credibility of the central bank. This matches another stylized fact of central bank collateral policy: central banks refused some types of collateral. While sovereign bonds remained eligible throughout the Euro crisis (except for Greek government bonds, which were temporarily ineligible during the restructuring of Greek sovereign debt), several assets issued by private issuers became ineligible because of rating downgrades. For instance, the downgrade of Irish government bonds on 2 February by S&P from A- to BBB+ was followed by downgrades of Irish banks and assets. These downgrades brought the rating of these assets below the ECB minimum rating threshold. A comparison of the lists of eligible assets published by the ECB at the beginning of February 2011 and at the beginning of April 2011 suggests that 77 assets (roughly 10% of assets issued in Ireland and eligible to the ECB) were rendered ineligible.

2.5 Central Bank and Interbank Market

We now consider the case where both the central bank and the interbank market are a potential funding source for the bank as the collateralized lending scheme offered by the central bank is now voluntary rather than compulsory. The bank first chooses a funding source (the interbank market or the central bank as we assume exclusive loans) and then obtains funds as in sections 2.3 and 2.4. If the bank chooses to go to the central bank, it must accept the conditions set forth by the central bank. If it goes on the private market, it must offer private investors on the interbank market a contract that yields them nonnegative profits, i.e. there is perfect competition among investors as in section 2.3.

The bank thus chooses the contract that yields the highest profit. This simplifies the problem and rules out competition between the central bank and investors.[17] The contracts offered by the central bank and the interbank market are the same as those in respectively sections 2.3 and 2.4.

Lemma 2. *The equilibrium collateralized loan contracts offered by the interbank market and the central bank are the same as those offered when each lender is the only possible source of funding for the bank (propositions 3 and 7 respectively).*

Proof. Appendix 3.7.

If we assume that the probability of success of the project is marginally higher in case of private funding, i.e. $p_{cb} = p - \epsilon$ for $\epsilon \to 0+$, we have:

Proposition 10. *(Source, level and structure of bank funding)*

If $f \geq \underline{f}_2^{CB}$*, the bank is financed by the interbank market through a loan contract identical to the contract offered in proposition 3.*

If $f < \underline{f}_2^{CB}$*, the bank is funded by the central bank and the equilibrium contract corresponds to the contract of proposition 7.*

Proof. Appendix 3.7.

Proposition 10 matches the stylized fact that the volume of collateralized loans provided by central banks spiked during the 2007-2013 financial crisis. Major central banks used repos or simarly asset swaps when the quality and quantity of bank collateral fell. Figure 2-5 illustrates this using equity levels of banks as a proxy for available collateral θ. The Figure plots the the total amount of collateralized lending by the ECB, the BoE and the Fed together with an index of bank stocks. Low levels of bank equity tend to coincide with high amounts of central bank repos, especially for the Fed and the BoE.

[17] See Tirole (2012) for a model where the offer of the public investor interacts with the private market and Bernheim and Whinston (1986) for a seminal common agency model.

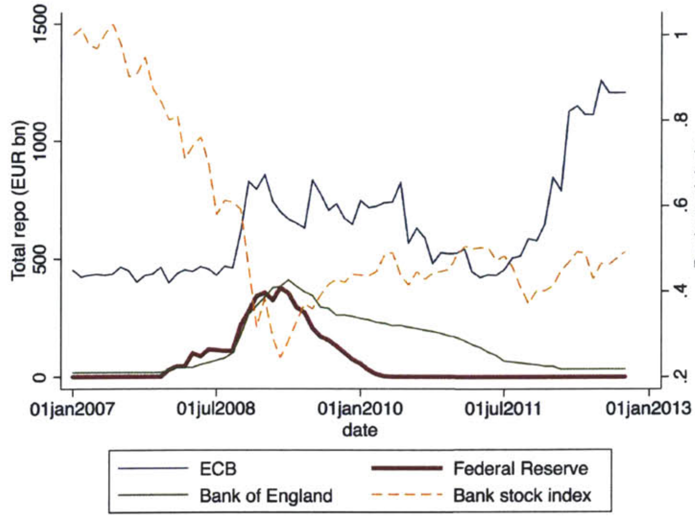


Figure 2-5: Repo outstanding for the ECB, the Fed and the BoE and US bank stock index

This Figure shows the total amount of repos lent by the ECB, the Fed and BoE in billions of Euros (USD and GBP are converted using the average exchange rate from 1 January 2007 to 1 January 2013, or \$1.31 and £0.82 respectively against €. The ECB data includes both the main (1 week) and long-term (3 months or higher) refinancing operations. The Fed data includes the Term Auction Facility, Primary Dealer Credit Facility and Term Securities Lending Facility operations. The BoE data includes the term repo operations and the special lending scheme. The bank stock index is the Dow Jones Financials index, normalized to 1 on January 2007.

The swing of bank funding from the interbank market to the central bank in proposition 10 in case of negative shocks to the availability of collateral θ, its liquidity v or solvency p (lowering the expected social value of collateral f below $\underline{f}_2^{CB}$), is an important fact that our model matches. The assumptions driving this result deserve a further discussion.

In normal times (when $f \geq \underline{f}_2^{CB}$), the bank borrows from the interbank market since its probability of success when investing is marginally higher than with the central bank , i.e. $p_{cb} = p - \epsilon$ for $\epsilon \to 0+$. This marginal edge of interbank market investors captures in a reduced form way the efficiency gains from private market intermediation. Investment management firms may for example be better equipped to anticipate returns on projects and help the bank through direct advice to select the best performing projects. These tasks are typically not considered to be core missions of central banks.

In bad times (when $f < \underline{f}_2^{CB}$), the central bank funds the bank since it internalizes the profits made by the bank and is therefore willing to incur a loss if this allows positive NPV projects to be financed. If one wants to relax the assumption that the central bank is willing to take a loss, our model suggests a potential other interesting channel through wich the role for central bank intervention may arise. In practice, the central bank may be less concerned about liquidity risk in bad times than interbank market investors. It may have a longer horizon and hold assets until maturity whereas private lenders may have to liquidate the collateral at fire-sale prices (like money market funds). If the central bank has an advantage over private lenders in bad times, the losses in our model may capture liquidity risk relative to the market but do not necessarily translate into long term losses for the central bank.

The default of Lehman Brothers is a case in point. In September 2008, several subsidiaries defaulted on their loans to the ECB for a total of €8.5bn. A rapid sale of the collateral would at the time have resulted in fire-sale discounts. In 2007, the Eurosystem made provisions of €5.6bn to cover the Lehman losses. These provisions have been reduced to €0.3bn in result of the sale on February 2013 for a total amount of €7.4bn.

Revisiting optimal monetary policy. We now take a step back and interpret our results in the framework of optimal monetary policy. The traditional view of monetary policy is that the central bank influences short-term interest rates or the monetary base which in turn influences rates in the financial markets and ultimately the availability of credit for firms and households (Bernanke and Blinder, 1992). Several empirical studies have shed light on the frictions in this transmission process. For example, Kashyap and Stein (2000) show that the effect of monetary policy on lending is stronger for banks with less liquid balance sheets, measured by the ratio of securities to assets. Jimenez et al. (2012) similarly conclude that higher short-term interest rates particularly reduce the supply of credit by banks with low capital.

Our paper provides a micro-foundation for the finding that the transmission of traditional monetary policy depends on the quality of bank collateral. Moreover, our paper suggests the use of collateral policy as an alternative to broken transmission mechanisms. The policy rate set by the central bank in its traditional policy can be interpreted in our model as the return required from the bank by the investors, which is normalized to one in our baseline model (break-even). The policy rate could correspond to the interest rate of the central bank in its deposit facility, where investors may lend to the central bank without risk. One might thus extend our model by assuming that the interbank market investors require a return equal to the gross policy rate r_p . Therefore, the bank borrows on the interbank market from investors at an interest rate equal to $\frac{1-(1-p)hv}{p}$ in our baseline model, which corresponds to $\frac{r_p-(1-p)hv}{p}$ in the extended model where we introduce the policy rate r_p .

At the other end of the spectrum, the key monetary policy variable for the central bank is the marginal return $pR'(q)$. This is the return required by the bank from its customers wishing to refinance a loan. When the bank borrows without collateral, the marginal return $pR'(q)$ is equal to r_p, e.g. there is a perfect transmission of monetary policy to the real economy. When the bank shifts to collateralized funding, a spread appears between the policy rate and the return that the bank requires from its customers. This spread is due to the cost of using collateral whose value is different for the bank than for investors. The spread increases as the quality of collateral falls, which typically occurs in downturns when assets are downgraded.

Proposition 11. *For a given policy rate r_p, negative shocks to the amount or to the quality of bank collateral may reduce the amount of credit in the economy and increase interest rates in the real economy, e.g. the* *required return by the bank from its customers ($\partial\left(pR'\left(q\right)\right)/\partial\theta \leq 0$, $\partial\left(pR'\left(q\right)\right)/\partial v \leq 0$).*

Proof. Appendix 3.7.

We show that if banks have too little collateral available, they may suffer from a collateral crunch. The amount of credit allocated to the economy depends on the amount of available bank collateral, and is more disconnected from investment opportunities in the real economy. By relaxing its collateral policy, the central bank can reduce the spread between the policy rate and the funding cost in the real economy. At the zero lower bound ($r_p = 1$), reducing the spread becomes the only option available to central bankers wishing to bring down interest rates in the real economy. As an alternative to the broken transmission of traditional monetary policy, collateral policy in our model can reduce this spread and increase welfare at the cost of imposing losses on the central bank.

2.6 Liquidity Coverage Ratio

Our paper demonstrates the potential of collateral policy relaxation to increase welfare by reducing the spread between the policy rate and returns in the real economy. However, we have abstracted from the incentive issues triggered by collateral policy loosening as both the amount of available collateral θ and the quality v are exogenous. In reality, lenient collateral policy may reduce equilibrium values of collateral, as banks do not internalize the full consequences of disposing of low quality collateral they would face in the absence of intervention.

Let us endogenize the quantity of collateral. The amount of collateral θ is determined from an initial, chosen amount $\bar{\theta}$ subject to an unobservable shock ϵ affecting its value. The realized collateral is then worth $\theta = \bar{\theta} + \epsilon$. The initial amount $\bar{\theta}$ is unobservable, chosen by the bank and comes at an increasing and convex cost $c\left(\bar{\theta}\right)$. $c\left(\bar{\theta}\right)$ can be the cost of holding liquid assets with lower yields or the cost of asset due diligence.

Proposition 12. *The intervention of the central bank lowers the average level of collateral chosen by the bank $\bar{\theta}$. The less the central bank cares about its losses, the more banks reduce average collateral holdings ($\partial\bar{\theta}/\partial\omega \geq 0$).*

Proof. Appendix 3.7.

Proposition 12 shows that the intervention of the central bank lowers the incentives of banks to hold liquid collateral. This may lead to lower collateral holdings in the long run and increase the frequency of episodes during which the central bank has to perform its role as "lender of last resort" by lowering its collateral requirements.

How to tackle the negative incentive properties of a lenient collateral policy in periods when the quality and/or quantity of bank collateral are low? Our model suggests that tightening collateral policy in periods when the quality and/or quantity of bank collateral are high is not a panacea, as banks switch to private market funding precisely at these moments. However, "Liquidity Coverage Ratio" (LCR) rules that require banks to hold an adequate stock of available High-Quality Liquid Assets (HQLA) can complement flexible collateral policy more effectively, as they mitigate the associated moral hazard problem.

The introduction of LCR rules would have both costs and benefits. The benefit is that banks would hold more collateral to avoid penalties for non-LCR compliance, when collateral values are endogenous. In turn, higher quantities and qualities of bank collateral would reduce the need to appeal to the balance sheet capacity of central banks and reduce central bank losses as well as the associated welfare costs. On the cost side, LCR rules could immobilize assets that would otherwise be used more efficiently. For a bank with available collateral θ, that faces a liquidity coverage requirement of K, the "new" collateral available to obtain short-term funds, would be $\theta - K$. Since these assets cannot be used for funding purposes, they are equivalent to encumbered assets. The rest of the model would hold as such, with $\theta - K$ being the new level of available collateral.

The LCR requirements may prove particularly useful in normal times, in the uncollateralized lending equilibrium. In this case, LCR rules might counterbalance the temptation of some commercial banks to reduce their amount of high quality collateral, as it does not affect their access to funding. However, changes in the environment may create a swing to collateralized lending, with a potential credit crunch for banks that have too little or low quality collateral. Our model shows that in time of financial distress, LCR requirements may worsen a credit crunch. In this case, it may be desirable to relax the requirements and use the asset buffer.

The idea that the LCR requirements $K(s)$ should depend on the state of the economy s is included in the January 2013 regulations proposed by the Basel III Committee. The LCR rules prescribe the availability of a stock of HQLA assets that can be converted into cash easily and immediately in private markets to meet its liquidity needs for a 30 calendar day liquidity stress scenario (Noked, 2013). HQLA include government bonds and corporate debt rated above BBB-.

2.7 Conclusion

During the 2007-2013 financial crisis, many central banks loosened their lending policies by lending more to commercial banks, against lower quality collateral, than in more normal times. This paper characterizes efficient collateral policies of central banks. In our model, a bank borrows from the interbank market or the central bank to fund projects in the economy. Providing collateral has favorable incentive effects, but it is costly to transfer collateral to lenders who have a lower value for the collateral because of imperfect collateral quality.

When the bank borrows from the interbank market, we find that it uses no collateral when return prospects in the economy are high relative to moral hazard concerns. The equilibrium however shifts to collateralized borrowing in downturns. In this case, both the quality and the quantity of bank collateral determine the loan size. We show that the lack of collateral or a fall in the quality of bank collateral can trigger a credit crunch and increase the spread between the policy rate and interest rates in the real economy. It may then be optimal for the central bank to relax its collateral policy and lend more for a given quantity of collateral in order to lower interest rates in the economy closer to the policy rate.

The policy of low collateral requirements in turbulent times may lower incentives of banks to hold enough high quality collateral. Collateral policy is ineffective in good times to influence bank borrowing as interbank collateral requirements are low and banks borrow from the private markets. Our model suggests that introducing minimum collateral availability requirements may help attenuate this "soft collateral budget constraint". The concept of minimum collateral availability requirements is part of the Basel III reform which includes Liquidity Coverage Ratio (LCR) rules coming into force in the coming years.

Our study suggests several avenues for future research. First, one may build on our stylized facts to empirically identify the role of collateral in the transmission of monetary policy. One could also use our extension on the choice of collateral in a dynamic setting to pin down optimal collateral availability requirements for banks over the business cycle.

Chapter 3

The Effects of Macroprudential and Fiscal Policy on Mortgage Debt: Evidence from the Netherlands

3.1 Introduction

High levels of mortgage debt have been at the center of the recent financial and economic crisis. To prevent those mortgage debt build-ups, economists and policymakers have suggested tighter monetary policy (Borio and Lowe (2002)), macroprudential rules (Brunnermeier, Crockett, Goodhart, Persaud and Shin (2009)) and changes in housing-related tax policies (Bowles and Simpson (2010), Hilber and Turner (2014), Mian and Sufi (2014)). In contrast to monetary policy, macroprudential policies, or the non-interest rate tools to deal with problems arising from the behavior of asset prices (Fischer (2014a)), can be targeted at mortgage markets. Macroprudential mortgage policies include (i) Loan-To-Value (LTV) and Loan-To-Income (LTI) limits, (ii) increasing capital requirements and provisioning on (risky) mortgage loans[0], and (iii) limiting the share of housing financing packages indexed to the policy rate. While housing-related tax policies are typically not considered to be macroprudential policies, they may also affect mortgage demand. Such housing-related fiscal policies include the repeal or restriction of the Mortgage Interest Deduction (MID) to safer loans (e.g. amortizing loans, shared responsibility mortgages, ...) as well as higher property or housing transaction taxes. But how do potential mortgage borrowers respond to loan limits and tighter interest deductions? Despite the potential importance of this question for households and financial stability, policymakers "do

[0] Capital adequacy risk weights rise in the LTV ratio of mortgage loans in Ireland, Norway, Spain, Estonia, Peru, Brazil, Turkey, Malaysia and Thailand. The problem with housing sector-oriented capital requirements is the loss of effectiveness when banks hold capital well above the regulatory minmum, which often happens during real estate booms (IMF(2013)).

not have good empirical estimates of the effectiveness of these measures" (Fischer (2014b)). In the words of Bernanke (2015), "The macroprudential approach remains unproven".

This paper exploits several policy changes in the Netherlands, the country with the world's largest residential mortgage-to-GDP ratio, to study the effects of LTV limits, PTI limits and the mortgage interest deduction on mortgage demand. I study the effect of those reforms on mortgage transaction volume, mortgage leverage ratios and other mortgage risk characteristics at origination using novel administrative mortgage offer data.

This paper uncovers four findings. First, as intended, regulatory loan limits can reduce mortgage leverage ratios. This response on the intensive margin is detected from significant bunching behavior at the LTV- and PTI limits as well as from sharp changes in the distribution of leverage ratios precisely at the policy start dates.[1] The decline in LTV ratios in response to LTV limits is particularly important at the right-tail of the LTV distribution for young and arguably borrowing-constrained households. Second, the large declines in mortgage volume on the policy start dates, which are more pronounced for young households, demonstrate important borrower responses on the extensive margin. At this point, it is difficult to tell whether these drops are purely short-run shifts or also include a permanent reduction in access to homeownership for liquidity-constrained households. As households substantially retime their mortgage- and house purchase decisions, policymakers may want to implement macroprudential and fiscal housing policies rapidly after their announcement. Third, the repeal of the MID for non-amortizing mortgages decimates the market for non-amortizing mortgages. This conclusion relies on a difference-in-difference strategy exploiting the grandfathering of the pre-reform MID rules for refinanced mortgages. The non-amortizing mortgage market has been historically the single largest market in the Netherlands until the reform. Therefore, this finding highlights how tax design can shape mortgage markets, which are characterized by substantial cross-country differences (Badarinza, Campbell and Ramadorai (2014)), which in turn influence the monetary policy transmission mechansim. Fourth, both the loan limits and the MID reform are associated with changes in non-targeted mortgage characteristics. On the one hand, lower PTI norms and the subsequent decline in PTI ratios reduce income risk (Campbell and Cocco (2003)), or the risk that mortgage payments become high relative to income, exhaust savings, reduce consumption and potentially induce default. On the other hand, the PTI tightening is also associated with a substantial rise in the fraction of mortgages that have very short periods during which the interest rate is fixed. This second effect on the endogenous choice of the mortgage type raises income risk, as required nominal mortgage payments fluctuate with the interest rate, which now has become more variable. This unintended risk-shifting pattern may thus partially substitute for the intended positive consequences associated to lower LTI ratios. The net effect of the PTI reform on income risk and subsequent household outcomes is therefore ambiguous. However, the unintended consequences of mortgage reforms could also complement the intended consequences. The introduction of the MID reform, which boosts amortization, is associated with a significant decline in principal amounts at origination. Both

[1] For work on bunching in public finance see Saez (2010) and Einav, Finkelstein and Schrimpf (2013) or in mortgage markets De Fusco (2013).

the decline in loan size at origination as well as the rise in amortization contribute to lower mortgage debt levels. By highlighting the response of loan sizes to changes in the MID reform, this study also confirms that neglecting behavioral responses to reducing the MID could lead to overstating the revenue gains asscociated to the reform (Poterba and Sinai (2011)).

Review of international presence and literature on mortgage leverage limits. Multiple countries have introduced caps on residential mortgages to slow down the growth of credit, house prices and to protect customers and the finanical system against negative consequences associated to high leverage (e.g. higher default rates, lower consumption, lower household mobility). Hong Kong was the first region to introduce limits on LTV ratios in 1991. By 2013, 24 countries have regulated limits on LTV ratios. Among those 24 countries, 14 countries also have DTI ratios and 12 adopted LTV ratios over the period 2010-2013 (IMF (2013)). Advanced economies having adopted those policies include Canada (80% LTV- and DTI limits in 2008), Finland (LTV limit in 2010), Israel (LTV limit in 2012), Norway (LTV- and LTI limits in 2010) and Sweden (LTV limits in 2010). In some places such as Estonia and Hong Kong, the LTV limits are time- and state varying (Brunnermeier et al. (2009)). In the US Dodd Frank legislation, Qualified Residential Mortgages, which are exempt from risk retention requirements, must have a total DTI ratio that does not exceed 43%. LTI limits can also be introduced at the bank-level as in the UK where not more than 15% on the mortgages can have a LTI ratio above 4.5. A few studies have investigated the empirical effects of mortgage leverage limits. Igan and Kang (2011), the only study to my knowledge which uses micro-data, uses variation in LTV- and DTI limits across Korean regions and find that LTV and DTI limits are associated with a decline in house prices and transaction activity. Wong, Fong, Li and Choi (2011) present evidence from a 13 country panel that LTV limits are associated with a lower incidence of mortgage defaults for a given fall in house prices. Ahuja and Nabar (2011) find that LTV caps may slow down house price growth while LTV and DIT limits slow property lending growth.

3.2 Description of reforms

PTI limits. Limits on mortgage Payment-To-Income (PTI) ratios have been introduced in the Netherlands on January 1st 2007 and have been substantially tightened twice since then, namely in January 2011 and in January 2013.[2] Since 2007 the Code of Conduct for Mortgage Loans (CCM) limits mortgage payments as a function of income using National Budget Institute (NBI) criteria (SEO (2011)). Mortgages below the CCM limit are so-called comply mortgages whereas so-called explain mortgages above the limit have to be documented and justified by the lender, as the Authority of Financial Markets (AFM) uses the CCM as its regulatory framework. If the AFM assesses and communicates that a lender violates the PTI rules, this can lead to fines and hurt the lender's reputation.

[2]Some lenders as well as the public mortage insurance agency NHG have used internal PTI or LTI norms prior to 2007.

The maximum PTI ratio is set by the NBI based on the analysis of housing- and non-housing survey consumption patterns by household income category. In particular, the housing percentage is the maximum share of income that can be used for mortgage payments such that other basic consumption needs in a two person household without children can be satisfied. The maximum mortgage payment is converted into a maximum loan using the standard Payment-To-Loan (PTL) formula for a 30-year fixed-rate (FRM) annuitizing mortgage, regardless of the actual mortgage type and maturity. The interest rate in this calculation is the regulatory interest rate if the fixed interest rate period is shorter than 10 years and if the effective rate is also lower than the regulatory rate. The regulatory rate is set every quarter by the Agency of Mortgage Finances (the Contactorgaan Hypothecaire Financiën).[3] Empirically, the maximum PTI ratio in a given year increases in income and the relevant interest rate. The PTI norm rises in income (see Figure 3-1) as non-housing expenses do not increase in a proportional way with income and as the personal income marginal tax rate (MTR), at which the Mortgage Interest Deduction (MID) is deducted, increases in gross income. The PTI norm also depends positively on interest rates as a higher fraction of housing expenditures can be deducted if the interest rate rises (see Appendix Figure A3.1).

The first substantial tightening of the PTI regulation occurred on January 1st 2011. On April 21st 2010 the Minister of Finance announced two important policy changes by supporting the reforms recommended by the regulator AFM. First, the maximum PTI ratios are reduced, in particular for lower incomes (see Figure 3-1). Second, from a qualitative point of view, it becomes more difficult for lenders to justify explain mortgages as five restrictive exception categories are now formulated. The PTI limits have been substantially tightened a second time on January 1st 2013 (see Appendix Figure A3.2).

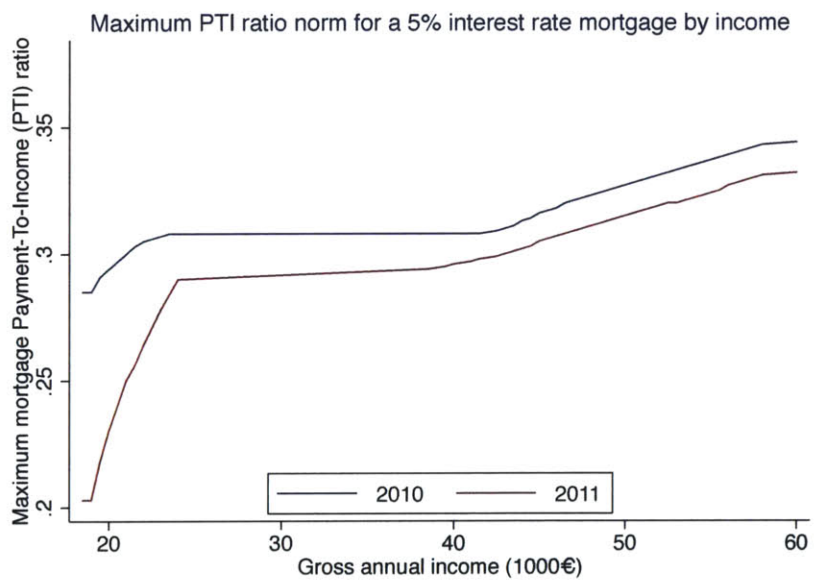
LTV limits. A legal maximum LTV limit was introduced in the Netherlands on August 1st 2011. The introduction of the LTV limit was announced on the 21st of March 2011 by the Minister of Finance and this was confirmed and clarified on April 11th 2011.[4] The maximum LTV was set at 106%. LTV ratios at origination around 100 or even above 106% were quite usual then. The loan proceeds can finance the entire purchase price of the house, the transaction costs of about 10% or home improvements. The subsequent reductions in LTV limits after the introduction in 2011 have been very gradual. Declines by one percentage point per year have been implemented on January 1st of 2013 (from 106% to 105%), 2014 (from 105% to 104%) and 2015 (from 104% to 103%). The maximum loan limit will continue its gradual decline until it is reduced to 100% in 2018. As it is the case for the PTI limits, banks' compliance with the legal LTV limit is monitored by the AFM regulator.

[3]The regulatory rate has been equal to 5.6% in the first half of 2009, 5.8% from 2009 Q3 until 2010 Q2, 5.4% in 2010 Q3, 4.9% in 2010 Q4, 5.2% in 2011 Q1, 5.8% in 2011 Q2, 5.7% in 2011 Q3, 5.2% in 2011 Q4, 5.6% in the first half of 2012, 5.4% in the second half of 2012, 5.3% in the first half of 2013 and 5% since then.

[4]The 2011 law also requires households with a LTV above 100% to repay the part above 100% in 7 years. Some lenders and the public mortgage insured NHG have used internal LTV norms prior to the 2011 law.

MID reform. On April 26th of 2012, the Dutch government announced new rules for the Mortgage Interest Deduction (MID) in the context of its Stability Program. New mortgages have to be paid back in at least 30 years and at least through annuities to be eligible for mortgage interest deduction since January 1st 2013. This so-called structural reform is estimated to save €5.4 billion per year or 0.9% of GDP. In principle, existing Dutch mortgages can be refinanced or used in case of a move. In practice, mortgage roll-overs to a different property are rare and quasi absent for underwater loans (Struyven (2015)). To avoid a tax lock-in and its potential negative effects on residential mobility, the old MID rules are grandfathered for existing, refinanced loans. Existing refinanced mortgages can thus still be non-amortizing after January 1st 2013. However, in case of refinancing, the part of the loan that rises above the balance prior to refinancing cannot benefit from the old MID rules.

Figure 3-1: Maximum mortage Payment-To-Income (PTI) ratios on 5% interest rate mortgages in 2010 and 2011



Notes: The historical PTI norm data are from NBI.

3.3 Data

Network of Mortgage Data (HDN) data. This paper uses data on mortage offer requests from the Network of Mortgage Data, or Hypotheken Data Netwerk (HDN). The Network of Mortgage Data is a platform created by Dutch mortgage lenders to request and receive mortgage offers (Boumeester (2012)). The platform is also used to share appraisals, insurance policies associated to the mortgage contracts, status updates, file pieces and portfolio status updates. Lenders and mortgage advisors use the Network of Mortgage Data primarily to transfer mortgage information but also increasingly to inform targeted marketing and funding decisions. The typical Dutch borrower first chooses a mortgage he/she is interested in and then requests an offer from one or more lenders with the help of a mortgage advisor.[5] Second, the lender sends an offer within a few days to the borrower who can sign until the offer date. Finally, after the signing the borrower has a certain period (often 2 months) to sign the mortgage certificate at the notary. A mortgage offer request offer does not necessarily lead to a mortgage offer which does not necessarily result into an extension of credit. The HDN data do not indicate whether a mortgage offer leads to an ultimate provision of credit.

The HDN database covers new and refinanced mortgage offer requests from September 2009 to December 2014. Aproximately 35 mortgage lenders including all the large lenders except for Rabobank use HDN. The share of HDN requests in the total number of Dutch mortgage offer requests has risen slowly and steadily from approximately 55% in September 2009 to approximately 70% in December 2014. When a combination mortgage contracts exists of multiple loans (e.g. a non-amortizing loan and a non-amortizing loan with an associated savings account), then loan-level information, such as the loan size, the interest rate and the interest rate type is available for each loan.

Sample, variable definitions and summary statistics. The sample consists of the 840,125 HDN mortgage request offers from September 2009 until December 2014. I will now define and describe the summary statistics for the main variables in Table 3.1. The variable total income is equal to the sum of the annual gross income of the different individuals that co-sign the mortgage offer request. As Dutch individuals in a household almost always co-sign, the total income is thus in practice very often equal to household income. The mean income is €56,603 while the median and the percentile 90 of total income are respectively equal to €48,571 and €92,016. The mean HDN income is thus comparable to the mean Dutch household income, which was equal to €55,600 in 2009. The average borrower age is 39.6 years with the percentile 25 of borrowers being quite young and aged 29. The borrower age is missing for 18.8% of the observations. The available house value variable corresponds to the hypothetical foreclosure value of the home at the time of the mortage offer request. According to an HDN data expert, the ratio between the foreclosure value of the home and the market value of the home is almost always equal to 90% (and sometimes equal to 89%). Given some important outliers in the foreclosure value, I winsorize the foreclosure value at 1%. The mean house value is equal to €212,483 whereas the median equals €185,400. The loan size, which is winsorized at 1%, has a mean of €198,981. The interest rate, which is also winsorized at 1%, is on average equal to 4.26%.

[5]When multiple offer requests for a given client at a given point in time are sent to multiple potential lenders, these offer requests can unfortunately not be matched in the HDN data.

Table 3.1: Summary Statistics of HDN mortgage offers

	N	mean	sd	min	p25	p50	p75	p90	max
Total income	833,038	56,603	51,349	0.00	35,054	48,571	67,087	92,016	9,999,999
Borrower age	681,889	39.55	12.34	17.00	29.00	38.00	48.00	57.00	99.00
House value (foreclosure)	811,644	212,483	116,52	0.00	141,810	185,400	247,500	350,000	722,500
Loan size	840,085	198,981	106,967	15,000	135,000	182,000	244,821	320,000	644,200
Interest rate	808,282	4.26	0.77	2.35	3.75	4.30	4.80	5.20	5.90
Months with fixed rate	837,520	120.71	67.05	0.00	120.00	120.00	120.00	240	999.00
Combination contract	837,520	0.54	0.50	0.00	0.00	1.00	1.00	1.00	1.00
Refinanced mortgage	689,583	0.15	0.35	0.00	0.00	0.00	0.00	1.00	1.00
Public insurance	840,125	0.63	0.48	0.00	0.00	1.00	1.00	1.00	1.00
Loan-To-Value	796,148	87.16	29.62	0.00	73.82	99.95	108.00	112.00	150.00
Loan-To-Income	825,044	3.86	1.47	0.26	3.09	4.07	4.73	5.33	8.49
Maximum loan size	801,438	283,360	177,116	18,848	163,119	232,568	353,041	511,889	1,018,121
Non-amortizing	639,514	0.42	0.49	0.00	0.00	0.00	1.00	1.00	1.00

Notes: The house value, loan size, interest rate, Loan-To-Income ratio and maximum loan size are winsorized at 1%. The Loan-To-Value ratio is the ratio between the loan size and the market value of the home (which is computed as the foreclosure value of the home divided by 0.9). The LTV is defined as missing when it exceeds 150%.

The vast majority of Dutch mortgages has an interest which is fixed for a couple of years until the interest rate becomes floating and tied to the ECB policy rate. Therefore, a critical variable to describe the mortgage type is the number of months for which the interest rate is fixed. The number of months with a fixed rate is typically equal to 120 but quite regularly also smaller (e.g. 60 months) and sometimes larger (e.g. 240 months). 54% of the requested contracts are so-called combination contracts consisting of more than one loan, which generally feature different amortization types. 15% of the offers correspond to refinancings. Almost 2/3 of the requested loans are covered by the public mortgage insurance NHG. The Loan-To-Value (LTV) is the ratio between the loan size and the market value of the home, where the market value is the foreclosure value divided by 0.9. The LTV ratio variable may feature some measurement error, as house prices in the denominator may be measured with some imprecision. The LTV is defined as missing when it exceeds 150%. The median LTV is almost equal to 100% while the average is substantially lower and equals 87%. 10 percent of the observations have a LTV above 112%. The Loan-To-Income (LTI) ratio is the ratio between the loan size and the total income and is winsorized at 1%. The mean LTI is equal to 3.93 whereas the median equals 4.07. Using total income, the Payment-To-Income (PTI) norms and the standard Payment-To-Loan (PTL) formula, I compute the maximum loan size, that a given household can obtain at the time of the mortgage request.[6] The PTI norm-based maximum loan size is on average equal

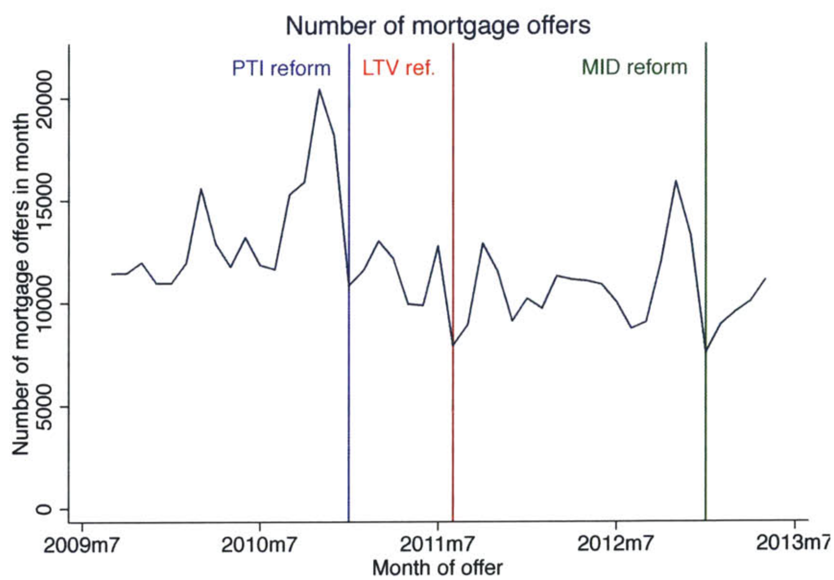
[6]The maximum loan size L_{max} depends on total income Y^t, the regulatory maximum mortgage PTI ratio

to €283,360. I define a mortgage contract as non-amortizing when the amortization type is equal to non-amortizing (31.9% of the observations). The non-amortizing dummy is equal to zero for contracts with an "annuities" amortization type or equal to "savings account mortgage" (12.0% of the observations) and defined as missing when the amortization type variable is equal to "other or unknown", which corresponds to 23.6% of the observations. The non-amortizing dummy has an average value of 0.42.

3.4 Effects of LTV Limits

Effects on mortgage volume (extensive margin). The LTV limit of 106% is introduced on August 1st 2011. As shown in Figure 3-2, the aggregate monthly volume of HDN mortgages declines from approximately 13,000 in July 2011 prior to the introduction date of the LTV limit, which is plotted vertically in red, to 8,000 in August 2011. This decline by more than 30% suggests potentially important borrower responses on the extensive margin. Given the nature of the variation, it is however difficult to tell whether these drops are purely short-run shifts (Goolsbee (2000)) or also permanent reductions in access to homeownership for liquidity-constrained households. Figure 3-2 suggests even larger volume responses to the PTI reform in January 2011 (in blue) and to the MID reform in January 2013 (in green).

Figure 3-2: Number of mortgage offers over time



Notes: The vertical lines indicate respectively the months of the tightening of the PTI parameters (blue), the introduction of the LTV limit (red) and the MID tax reform (green).

$PTI^{max}(Y^1, Y^2, r, r_{reg})$, and the PTL formula: $L_{max} = Y^t \cdot \frac{PTI^{max}}{PTL}$. For households with more than 1 earner, PTI^{max} is based on the highest income Y^1 plus a third of the second highest income Y^2.

The coincident timing of the troughs with the reform start dates and of the peaks with the month just prior to the reform start dates, may be confounded by other aggregate time-related factors, such as time trends, seasonality effects or unobserved temporary non-policy related shifters of mortgage demand. To control for trends and seasonality factors and test for the statistical significance of the changes in volume around the various reform start dates, I aggregate the micro-data at the 2 digit zipcode-month level. I estimate the effects of the PTI, LTV and MID reform months on the log volume of monthly zipcode-level HDN mortgage offers in Table 3.2. For simplicity, I assume an identical effect in the 2 months before the reform as well an identical effect in the 2 months after the reform. The log-linear specification in column (1) of Table 3.2 includes year fixed effects and zipcode fixed effects to exploit time-series variation across months within a zipcode and within a year. The specification in Column (2) of Table 3.2 includes year of the month fixed effects (e.g. a January FE, a February FE, ...) to control for seasonality effects in mortgage demand and a linear trend to control for the important upward trend in volume since the start of the recovery in February 2013. For each of the three reforms and across the two Columns, we see a positive, significant and substantial positive difference between the pre-dummies relative to the post-dummies. Housholds borrow significantly more directly preceeding than directly following the reforms that restrict mortgage demand.

The coefficient on the PTI_pre-variable in both Columns (1) and (2) is positive, large, significant and equal to approximately 38%. The magnitude of 0.38 suggests that the two months prior to the PTI loan limit reform, namely November and December of 2011, are associated with a $100 \cdot (e^{0.38} - 1)\% \simeq 100 \cdot (1.46 - 1)\% = 46\%$ rise in the predicted number of zip-code level mortgage requests. Moving to the volume effects of the LTV loan limits, the coefficients on the LTV_post-dummy in both Columns are negative and significant. The magnitude of the coefficient of -0.3038 in Column (1) suggests that the months just after the LTV loan limit introduction, namely August and September of 2011, are associated with a decline in the predicted number of offers by a factor of $e^{-0.27} \simeq 0.73$, or equivalently a 27% drop. While the coefficient on the LTV_post-dummy shrinks in (absolute value) when moving from Column (1) to Column (2), its value remains large and significant.

The MID reform in January 2013 features the largest gap between the pre- and post-coefficients. The coefficient of -0.44 on the dummy MID_post indicates that the two months of January and February 2013 are associated with a 35% decline in volume. Unreported regressions with separate coefficients for each month in a 6 months-window around the three reforms show that the volume typically peaks the most 1 or 2 months before the start and drops the most during the first month of the new regime. The coincident timing of the volume peaks with the month just prior to the reform start dates and the volume regression results that households substantially retime their mortgage- and house purchase decisions. While policymakers implemented those macroprudential and fiscal housing policies to avoid large or risky (i.e. non-amortizing loans) loans, their annoucement has induced a temporary rise in the behavior the policymakers precisely want to prevent. Just as in the case of tax investment tax credits aimed at stimulating investment, where the annoucement can lead to a temporary freeze in investment, policymakers may want to implement macroprudential and fiscal housing policies rapidly after their announcement.

Table 3.2: Effects of PTI-, LTV- and MID reforms on volume of mortgage offers

	(1) Mortgage offer volume (logs)	(2) Mortgage offer volume (logs)
PTI_pre	0.39***	0.37***
	(0.02)	(0.02)
PTI_post	-0.02	0.11***
	(0.02)	(0.02)
LTV_pre	-0.03	0.02
	(0.02)	(0.02)
LTV_post	-0.31***	-0.17***
	(0.02)	(0.02)
MID_pre	0.32***	0.30***
	(0.02)	(0.02)
MID_post	-0.44***	-0.00
	(0.02)	(0.01)
Constant	6.26***	6.10***
	(0.03)	(0.03)
Zipcode FE	Yes	Yes
Year FE	Yes	Yes
Year of Month FE	No	Yes
Linear Trend	No	Yes
N	5760	5760
adj. R^2	0.90	0.94

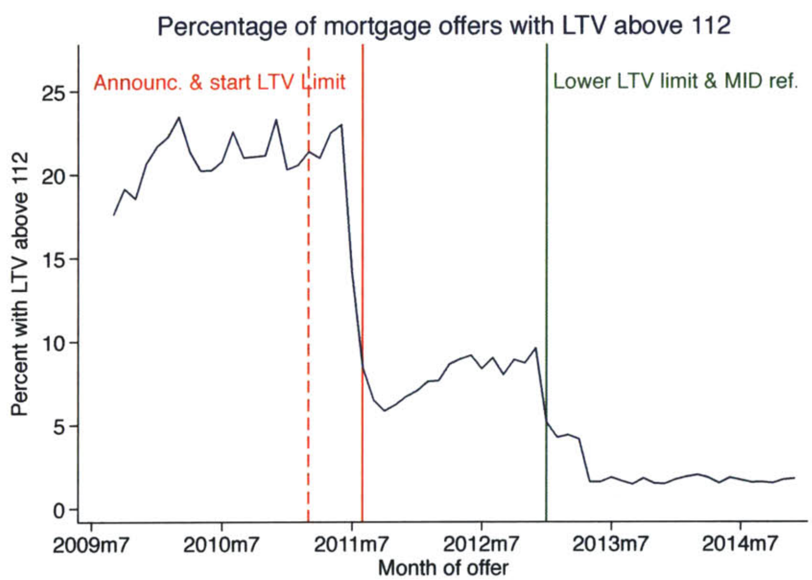
Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The unit of observation in this regression is a zipcode-month. There are 90 2-digit zipcodes. Column (2) adds year of the month FEs (e.g. January, February, ...) and a linear trend for the recovery in volume, which starts in February 2013. The variables "PTI_pre/PTI_post" are equal to one for mortgages offered 2 months prior to/after the PTI reform in January 2011.The variables "LTV_pre/LTV_post" are equal to one for mortgages offered 2 months prior to/after the LTV reform in August 2011. The variables "MID_pre/MID_post" are equal to one for mortgages offered 2 months prior to/after the MID reform in January 2013.

Effects on leverage ratios (intensive margin). After having detected responses on the extensive margin, I now examine whether the regulatory LTV limits also reduce LTV ratios on the intensive margin. As the LTV limits intend to prevent borrowers from taking mortgage offers with very high LTV ratios, I will now study the evolution over time of the fraction of mortgages with a LTV above 112 in Figure 3-3. Figure 3-3 shows a large decline in the share of mortgages with a LTV ratio above 112. This fraction drops from almost a quarter just prior to the LTV loan limit introduction to 5 to 10% immediately at the introduction of the loan limit. After the introduction of the loan limit, the fraction of mortgages with a LTV above 112 recovers a little bit from 6 to 10% but remains much lower than the average fraction prior to new policy. Interestingly, the two reforms on January 2013, namely the reduction of the LTV loan limit by one percentage point and the restriction of the MID to non-amortizing mortgages, also appear to be associated with a further reduction in the fraction of very high above 112 LTV mortgages, which have practically disappeared since 2013.

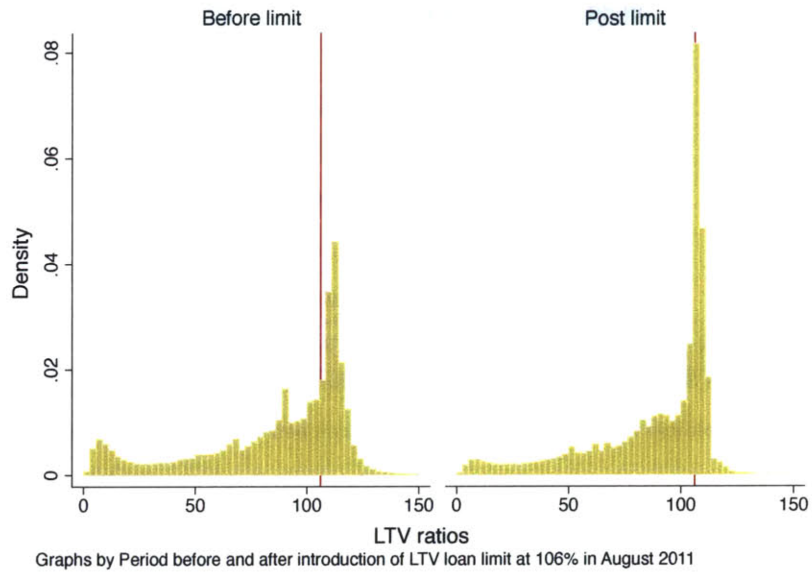
Figure 3-3: Percentage of mortgage offer requests with LTV above 112



Notes: The vertical dotted red line indicates the month of the announcement of the LTV limit. The vertical solid red line indicates the month of the introduction of the LTV limit. The vertical green line indicates the month of the further reduction of the LTV limit by one percentage point. This month is also the month where the MID reform is introduced.

The very rapid decline in the fraction of high LTV mortgages in Figure 3-3, precisely when the loan limit is introduced, suggests important effects of the loan limit. Nevertheless, Figure 3-3 summarizes the full distribution of LTV ratios each month in only one number. It is therefore important to also study the whole distribution and in particular changes in the mass of loans in the full region around the loan limit at 106%. Figure 3-4 shows the histogram of LTV ratios before and after the introduction of the LTV limit. After the introduction of the loan limit, the right-tail of the distribution becomes more concentrated. A large fraction of the borrowers now "bunches" precisely at the 106% loan limit while the fraction of borrowers to the right of the loan limit decreases significantly. The amount of bunching at the loan limit is important despite the potential attenuation of this effect through measurement error in LTV ratios, as houses prices in the denominator may be measured with some imprecision. Ideally, I would solve for the potential measurement error problem by using instrumental variables, which are unfortunately not available.

Figure 3-4: Distribution of LTV ratios before and after introduction of LTV limit in August 2011



Notes: The Loan-To-Value ratio is the ratio betweeen the loan size and the market value of the home (which is computed as the foreclosure value of the home divided by 0.9).

While both the timing of the change in the LTV distribution as well as the location of bunching are very much consistent with causal effects of the loan limits, we have until now mostly relied on time-series variation. But in the cross-section, do loan limits affect the borrowing-constrained borrowers most? What are the distributional effects of the loan limits? Table 3.3 shows that net worth and financial assets for the median Dutch household increase rapidly in age. For households with household heads of age 25 to 30, the median values of net worth and financial assets in 2011 are respectively equal to €1,000 and €5,000. The data thus show that person age is therefore a reasonable proxy for the potential importance of liquidity- and borrowing constraints.

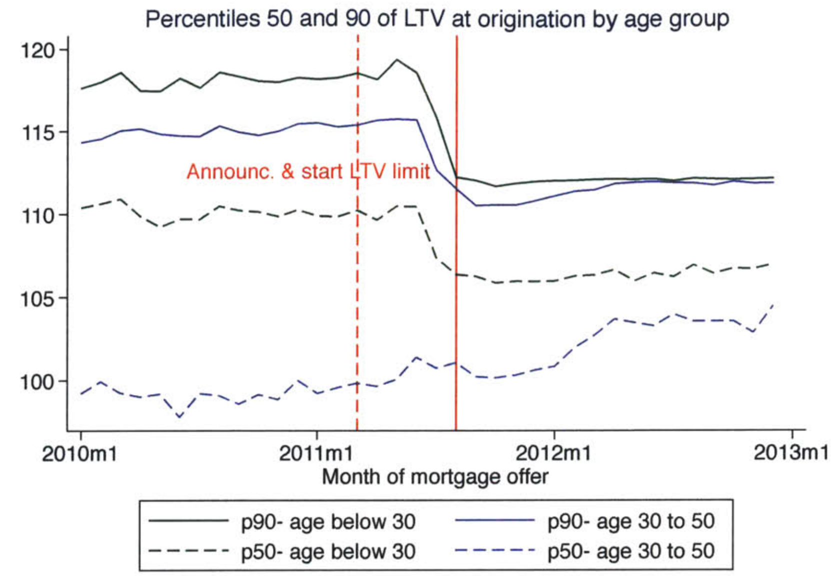
Table 3.3: Distribution of household net worth and financial assets in 2011 by age for Dutch population (in €1,000)

Age household head	Net worth		Financial assets	
	Mean	Median	Mean	Median
25-30	14	1	15	5
30-35	31	2	26	8
35-40	71	9	45	11
40-45	125	32	68	14
45-50	169	59	85	16
50-55	203	84	96	19
55-60	234	110	106	22
60-65	265	133	118	24
All ages-population	162	30	79	16

Notes: The data are from CBS Statistics Netherlands Statline. Financial assets are the sum of amounts on checkings- ands savings accounts, bond holdings and equity holdings. Wealth components are measured on January 1st of 2011.

I now plot the evolution over time of a few percentiles of the LTV distribution for the very young borrowers of age below 30 and the medium age group of borrowers af ages 30 to 50 in Figure 3-5 as well as Appendix Figure A3.4. The figures for the two age categories reveal three facts. First, for the most-borrowing constrained borrowers of age below 30, the distribution of LTV ratios is pressed inwards precisely at the loan limit introduction date for mortgages for the top-50% of LTV ratios. For borrowers of age 30 to 50, the distribution of LTV ratios is pressed inwards for the top 25% of loans precisely at the LTV introduction date. Finally, unreported figures for borrowers of age above 50 show that the distribution of LTV ratios is quite stable. Overall, the graphical evidence suggests that the decline in LTV ratios associated to LTV limits is particularly important at the right-tail of the LTV distribution for the young borrowing-constrained households.

Figure 3-5: Distribution of LTV ratios before and after introduction of LTV limit in August 2011



Notes: The red vertical shaded and solid lines indicate respectively the months of the announcement and the introduction of the LTV limit. The Loan-To-Value ratio is the ratio betweeen the loan size and the market value of the home (which is computed as the foreclosure value of the home divided by 0.9).

To control for potential changes in the composition of borrowers, I will now verify the robustness of the visual results from Figures 3-5 and Appendix Figure A3.4 with quantile regressions. Table 3.4 estimates the effect of the LTV loan limit on the percentiles 25, 50, 75 and 90 of the LVT ratio distribution for 3 borrower age categories in the 3 months after the introduction of the LTV limit relative to the 3 months prior to its introduction.[7] The quantile regression estimates largely feature a double monotonicity pattern consistent with the hypothesis that the negative effect of the LTV loan limit on LTV ratios is more important for younger and more constrained borrowers. For the borrowers below age 30, the effect on the percentile 25 of the LTV distribution is modest and equals -1.63 percentage points. This effect becomes more important and equals -3.18 percentage points for the median, -4.48 percentage points for the percentile 75 and rises to -6.06 percentage points for the 90th percentile. For borrowers of age 30 to 50, the changes in the LTV quantiles are also monotone as they become more negative (i.e. larger in absolute value) for the higher percentiles. This same monotonicity pattern across quantiles is also featured for the above age 50 borrowers, except for the median in this age category. Consistent with the hypothesis that younger households are more constrained and more affected by the LTV loan limits than the older households, the estimates of the effects for the percentiles 75 and 90 in Table 3.4 are monotonic in age as the point estimates in a given column/percentile become more negative when the borrower age declines.

[7]The estimates may also partially capture the effects of the stamp duty reduction from 6 to 2% in July 1st 2011. It is however not clear why this stamp duty reduction would almost only affect the higher percentiles of the LTV distribution.

Table 3.4: Quantile regression coefficients for the effect of the introduction of LTV caps on LTV ratios of mortgage offers for three categories of borrower age

		Desc.Stats		Quantile regr. estimates				OLS estimates
Age	Obs.	Mean	SD	0.25	0.50	0.75	0.90	
Below 30	12,753	102.4	17.6	-1.63	-3.18	-4.48	-6.06	-1.92
				(0.42)	(0.18)	(0.13)	(0.21)	(0.31)
30-50	31,804	89.9	28.5	0.26	-1.73	-2.37	-4.18	-0.53
				(0.48)	(0.29)	(0.13)	(0.13)	(0.31)
Above 50	11,348	64.6	32.8	-0.29	-2.50	-0.60	-2.28	-0.79
				(1.10)	(0.87)	(0.77)	(0.70)	(0.59)

Notes: The table reports quantile regression estimates of the effect of the introduction of the LTV cap in August 2011 on LTV ratios, with OLS estimates shown at the right for comparison. The effect is assumed to be constant in the 3 months after the introduction of the cap. The sample includes mortgage offers in the 3 months prior to the introduction of the LTV cap and mortgage offers in the 3 months after the cap for which the LTV ratio and control variables are non-missing. The sample size and the mean and standard deviation of LTV ratios are shown at the left. Standard errors are reported in parentheses. All models control for borrower age category fixed effects, 10 income category fixed effects and 90 zipcode fixed effects.

3.5 Effects of PTI limits

Effects on mortgage volume (extensive margin). The PTI norms are substantially tightened for the first time on January 1st 2011. Figure 3-2 shows that the monthly number of mortgage offers declines from approximately 20,000 in November-December 2010 just before the PTI reform to 11,000 in January-February 2011 immediately after the reform. The timing of this 45% decline perfectly coincides with the PTI reform. Table 3.2 already demonstrated the statistical significance of the decline in mortgage volume after the PTI reform, also when one controls for trends and seasonality effects. It is again however difficult to decompose this large decline in volume into a temporary and a permanent component. Consistent with the theoretical prediction according to which young borrowing-constrained households should be more affected by the PTI reform, the mortgage volume does decline more for young borrowers after the PTI tightening relative to older borrowers. Table 3.5 reports results from the regression of the log of mortgage volumes in zipcode-borrower age category-month cells. The estimates of the coefficient on ypti_post, the interaction of the post-PTI month dummy and the age below 35 dummy, are negative, large and significant across the two specifications in Columns (1) and (2).[8] Appendix Table A3.1 finds similar larger volume declines for young borrowers

[8] These regressions restrict the effects to be identical in respectively the 3 months prior to the PTI reform as well as the 3 subsequent months. Unreported regressions with separate coefficients for each month in a 6 months window around the reform show that the young borrower volume peaks 1 month before the PTI tigthening and drops the most during the first month of the new regime.

relative to older borrowers in response to the 2nd PTI reform in January 2013.[9]

Table 3.5: Effects of PTI reforms on volume of mortgage offers: Zipcode-age group cell analysis

	(1) Mortgage offer volume (logs)	(2) Mortgage offer volume (logs)
pti_pre	0.37***	0.25***
	(0.02)	(0.02)
pti_post	0.10***	0.25***
	(0.02)	(0.02)
ypti_pre	0.04	0.04
	(0.03)	(0.03)
ypti_post	-0.16***	-0.16***
	(0.03)	(0.03)
Age_below35	-0.48***	-0.48***
	(0.02)	(0.02)
Constant	5.79***	5.54***
	(0.03)	(0.03)
Zipcode FE	Yes	Yes
Year FE	Yes	Yes
Year· Age_below35 FE	Yes	Yes
Year of Month FE	No	Yes
Linear Trend	No	Yes
N	10080	10080
adj. R^2	0.852	0.890

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

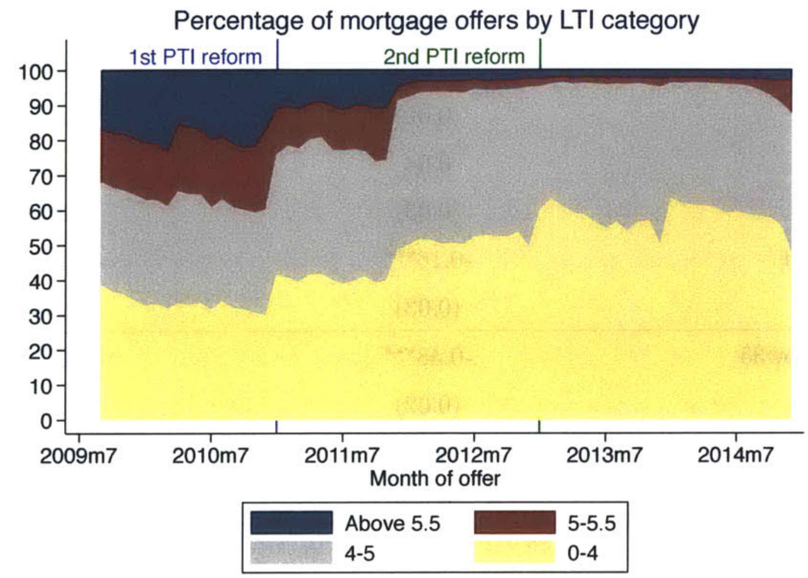
Notes: The unit of observation in this regression is a zipcode-month-age group. There are 90 2-digit zipcodes and 2 age categories (below age 35 and equal to or above age 35). Column (2) adds year of the month FEs (e.g. January, February, ...) and a linear trend for the recovery in volume, which starts in February 2013. The variables "pti_pre/pti_post" are equal to one for mortgages offered 1 or 2 months prior to/after the PTI tightening in January 2011. The variables "yPTI_pre/yPTI_post" are equal to one for mortgages offered 1 or 2 months prior to/after the the PTI tightening in January 2011 to young borrowers of age below 35.

Effects of leverage ratios (intensive margin). The mortgage volume did decline in response to the PTI reform. Now the question is whether measures of mortgage debt also declined relative to income for

[9]This finding may be confounded by the MID reform and the reduction in the maximum LTV ratio from 106% to 105% on the same day.

those who did still borrow. Figure 3-6 shows important declines in the fraction of high LTI loans both when PTI norms are tightened for the first time in January 2011 as well as at the second time in January 2013. By January 2013, as very few loans with a LTI above 5 are left, is it the lower 0-to-4-LTI category that rises by 11 percentage points from 49 to 60%.

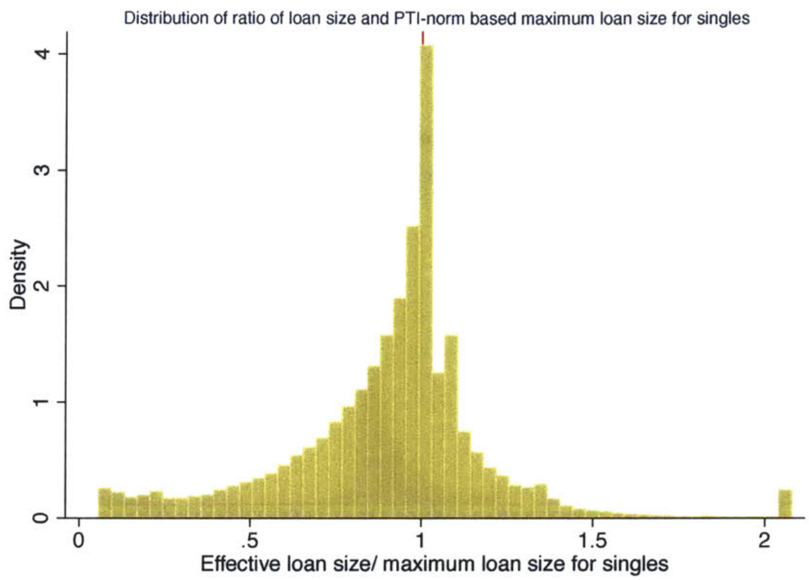
Figure 3-6: Percentage of mortgage requests by LTI category



Notes: The vertical solid lines indicate the months of the tightening of the PTI norms in respectively January 2011 (blue) and January 2013 (green).

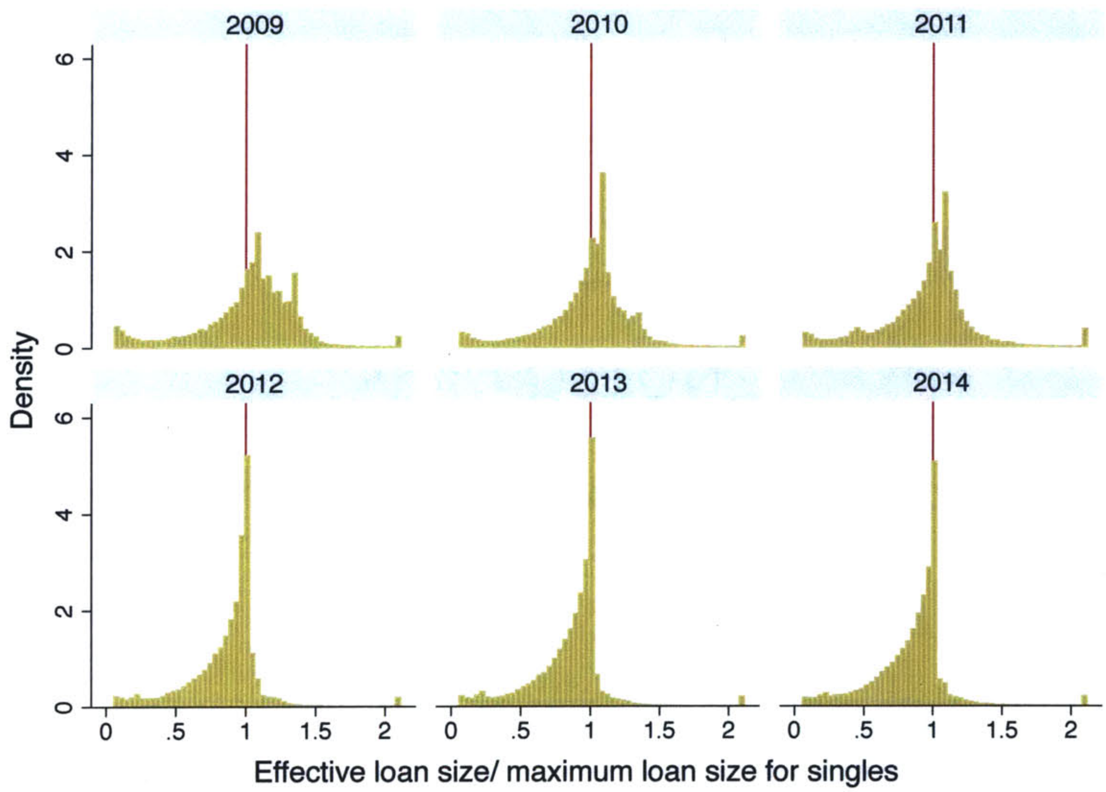
While the timing of the declines in high LTI ratios coincides with the PTI reform dates, it still may be possible that these changes capture secular declines in LTI ratios rather than the causal effect of the PTI norms. I therefore test if a abnormally high fraction of households obtains loans, whose size corresponds exactly to the maximum permitted by the PTI-norm. To study borrowing bunching behavior and changes in response to the PTI reforms, I compute the maximum loan sizes induced by the PTI norms for all the mortgage offers based on total borrower income, the relevant interest rate (loan rate or regulatory rate) as well as the PTI norm prevalent at the date of the mortgage offer. Figure 3-7 shows the histogram of the ratio between the effective loan size relative to the maximum loan size for single borrowers. As the peak of the distribution of the ratio exactly corresponds to 100% where borrowers max out their loan size, this histogram suggests an important amount of bunching at the PTI norm based maximum loan size. The measured amount of bunching is larger for singles, arguably given the better measurement of individual income using total income for singles, which determines the PTI norm, relative to non-singles (see Appendix Figure A3.3). Bunching at the PTI norm-based maximum loan size and compliance with the PTI norms have risen substantially over time since 2011 (see Figure 3-8). The fact that the high peak in the histograms remains exactly at 100%, even when PTI norms are substantially reduced such as in January 2013, suggests negative, causal effects of the PTI norm on equilibrium LTI- and PTI ratios at the intensive margin. It is remarkable that even in the later years of higher compliance, namely 2013-2014, approximately 10% of the mortgages has a loan size more than 2% higher than the maximum loan size.

Figure 3-7: Distribution of effective and maximum loan offer sizes for singles



Notes: The maximum loan size is calculated using household income, the historical PTI norm data from NBI and the standard 30 year FRM PTL formula.

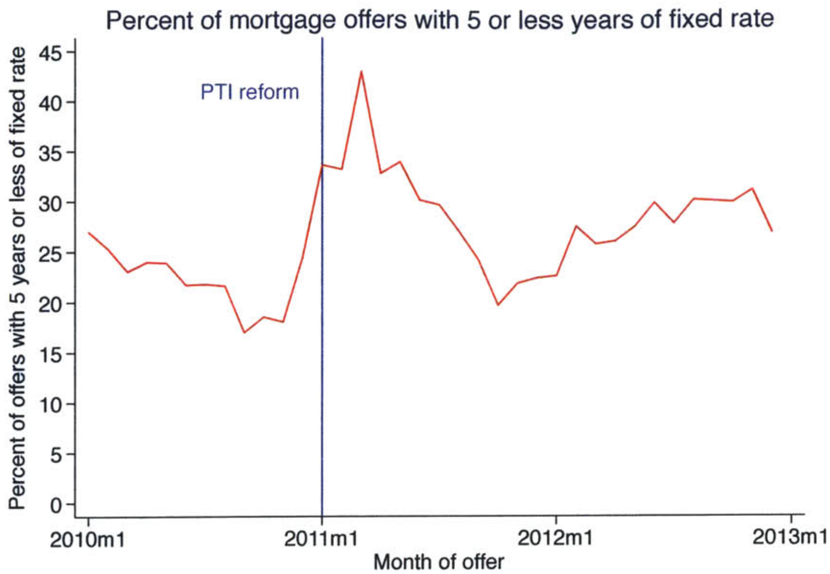
Figure 3-8: Distribution of effective and maximum loan offer sizes for singles in 2009-2014 by year



Notes: The maximum loan size is calculated using household income, the historical PTI norm data from NBI and the standard 30 year FRM PTL formula.

Effects on other mortgage features: risk shifting. The PTI reform thus arguably led to both a decline in mortgage volume as well as lower PTI ratios. But is the PTI reform also associated with changes in non-targeted mortgage characteristics? Figure 3-9 shows that the share of mortgages with a fixed rate period below 5 years increases from 18% in November 2010 to approximately 43% in March 2011.

Figure 3-9: Evolution of the fraction of mortgages with a short period of fixed interest rates



Notes: The vertical solid line indicates the month of the tightening of the PTI norm in January 2011.

The rise in adjustable-rate mortgages (ARM) when PTI norms are tightened is consistent with the Campbell and Cocco (2003) model where households choose between adjustable-rate (ARM) and fixed-rate (FRM) mortgages. In this life-cycle model with borrowing constraints, uncertain income, inflation and real rates, the benefit of ARM mortgages is the stability of real ARM payments in periods of low inflation. The low wealth risk benefit of ARM mortgages comes at the expense of higher income risk or cash-flow risk. The income or cash-flow risk refers to the situation where ARM payments will rise suddenly, exhaust savings, force cutbacks in consumption and potentially lead to defaults.[10] As the income or cash-flow risk of ARM mortgages is low for households with low mortgage payments relative to their income, i.e. low PTI ratios, the Campbell and Cocco (2003) model predicts that exogenous reductions in PTI ratios could cause households to switch from FRM mortgages to ARM mortgages.

But what is the statistical relationship between LTI norms and the choice of mortgage type? In addition to the time-series variation in LTI ratios triggered by the PTI reform, one can also study the cross-sectional relationship between LTI ratios and mortgage type. The cross-section also suggests that low LTI offers are much more likely to have short period of fixed rates (or quasi ARM) as the fraction of offers with 5 or less years of fixed rates for the bottom third LTI loans, the middle third LTI loans and top third LTI loans are respectively equal to 32.3%, 20.1% and 15.9%. The regressions in Table 3.6 investigate the risk-shifting patterns consistent with the Campbell and Cocco (2003) model. The coefficient of interest here is the elasticity of the mortgage type, measured by an indicator variable for the number of years with a

[10]A second cost of ARMs relative to FRMs is the real interest rate risk, or the risk that real interest rates will rise for borrowers.

fixed rate below or equal to 5, with respect to the PTI/LTI ratio at origination. Columns (1)-(3) study the cross-sectional relationship between the mortgage type and LTI ratios using the full micro-sample of mortgage offers. The specification of the regression of the indicator variable for a fixed-rate period equal to or smaller than 5 years on the LTI ratio includes month fixed effects to exploit purely cross-sectional variation. To interprete the magnitude of the negative and significant coefficient of -0.05 on the LTI ratio, it is helpful to report that only 23% of the mortgages has a fixed-rate period equal to or smaller than 5 years. As the LTI ratio has a standard deviation of 1.47, a decrease in the LTI ratio by one standard deviation is associated with a 35% ($35\% = \frac{-0.05 \cdot 1.47}{0.23}$) increase in the propensity for mortgages to be quasi-ARM. Column (2) includes borrower age category- and zipcode fixed effects and also finds a negative relationship between the LTI ratio and the quasi-ARM nature of mortgages. Column (3) finds that this relationship is monotone and non-linear in LTI ratios.

Columns (4)-(5) of Table 3.6 exploit solely the time-series variation in average LTI ratios in a given zipcode-month associated to the "natural experiment" of tightening the PTI caps in January 2011. Here I restrict the analysis to the 3 months prior to the tigthening of the PTI caps and the 3 months after the tightening of the PTI caps. The dependent variable in columns (4)-(5) is the fraction of mortgage offers in a zipcode-month that has a number of years with a fixed rate smaller than or equal to 5. Column (4) finds that a decline in the average LTI ratio by one percentage point is associated with a rise in the share of quasi-ARM loans by 17 percentage points. Column (5) exploits only variation within zipcodes and finds an even larger coefficient on the average LTI ratio, which now suggests that a decline in the average LTI ratio by one percentage point is associated with a rise in the share of quasi-ARM loans by 23 percentage points.

Taking stock, the net effect of the PTI reform on income risk is thus ambiguous given the risk-shifting pattern. On the one hand, PTI ratios at origination decline, which lowers income risk. On the other hand, the endogenous switch to ARM-like mortgages increases the potential variability in interest payments, in particular if future interest rates will rise, which increases income risk. While the risk-shifting patterns are definitely interesting, more research is needed on at least two fronts. First, the mechanism through which lower PTI at origination-driven income risk leads to higher mortgage type-driven income risk merits further investigation. Are interest rates on ARM loans with very high PTI ratios prohibitively expensive given potential important interaction effects of the PTI and mortgage type in default behavior? Do lenders only extend loans if the "total income risk" does not exceed a certain threshold? Second, what is the net effect of the PTI reform on future household outcomes, including consumption volatility and default decisions, in particular in response to potential rises in interest rates?

Table 3.6: Risk-shifting effects of changes in LTI ratios on the number of years for which the interest rate is fixed

	(1) Less than 5 yrs	(2) Less than 5 yrs	(3) Less than 5 yrs	(4) Less than 5 yrs	(5) Less than 5 yrs
Sample period	September 2009-December 2014			October 2010-March 2011	
Unit of observation	Mortgage offer			Zipcode-Month	
LTI	-0.05***	-0.04***			
	(0.00)	(0.00)			
LTI_btwn_4_and_5			-0.07***		
			(0.00		
LTI_above_5			-0.08***		
			(0.00)		
Avg_LTI_in_zip_month				-0.17***	-0.23***
				(0.01)	(0.01)
Constant	0.58***	0.49***	0.39***	0.98***	1.45***
	(0.00)	(0.01)	(0.01)	(0.06)	(0.07)
Month FEs	Yes	Yes	Yes	No	No
Zipcode FEs	No	Yes	Yes	No	Yes
Borrower age category FEs	No	Yes	Yes	No	No
N	822572	604816	604816	540	540
adj. R^2	0.07	0.11	0.10	0.22	0.50

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The table reports the estimates of changes in LTI ratios on the fraction of mortgages that have a fixed-rate period below 5 years ("mortgage type"). Columns (1)-(3) study the cross-sectional relationship between the mortgage type and LTI ratios using the full micro-sample of mortgage offers. Columns (4)-(5) exploit the time-series variation in average LTI ratios in a zipcode-month associated to the tightening of LTI caps in January 2011. The sample in Columns (4)-(5) consists of the 540 (=90 zipcodes/month*6 months) zipcode-months for the 3 months prior to the tigthening of the LTI caps and the 3 months after the tightening of the LTI caps. The dependent variable in Columns (1)-(3) is an indicator for whether the number of years with a fixed rate for a mortgage offer is smaller than or equal to 5. The dependent variable in columns (4)-(5) is the fraction of mortgage offers in a zipcode-month that has a number of years with a fixed rate smaller than or equal to 5. The default LTI category in column (3) is an LTI below 4.

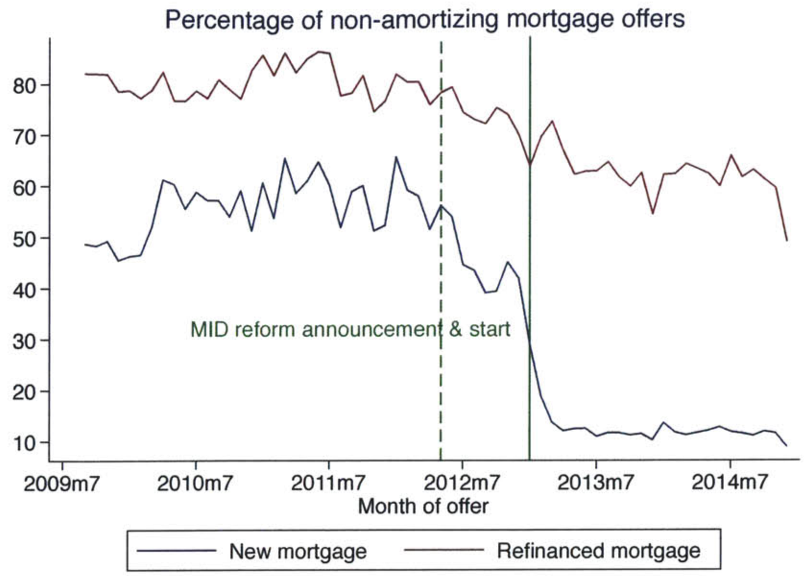
3.6 Effects of the Mortgage Interest Deduction Reform

Effects on amortization choice. Since January 1st 2013 only amortizing mortgages benefit from the MID. To analyze the effects of the policy on amortization choice, it is helpful to discuss the trade-offs involved in choosing whether to amortize. Prior to the reform, choosing a non-amortizing mortgage offer is associated with at least two benefits and three costs. In terms of benefits, the non-amortizing loan permits avoiding amortization payments in the near future, which is particularly valuable for impatient or constrained households that want to front-load consumption relative to their income streams.[11] Second, for a given orgination amount, tax rate and interest rate, the MID is larger for non-amortizing loans, and especially for high personal marginal income tax rate (MTR) borrowers. In terms of costs, the non-amortizing loan borrower (i) builds up wealth by having higher home equity, (ii) pays larger interest payments (holding again the origination amount and interest rate constant), and (iii) may face a higher interest rate (holding income, the LTV ratio and borrower risk type constant) reflecting the higher risk for the lender of selling the home at a price below the outstanding loan.

The MID reform for new mortgage offers does not affect the 1st current consumption benefit neither the 3 main costs of the non-amortizing loans but turns the second tax benefit, i.e. higher deductions for non-amortizing loans prior to the reform, into a cost as the MID is now zero for the non-amortizing loans and therefore smaller than the MID of the amortizing loan. Given the grandfathering of existing loans, the reform should not affect the relative attractiveness of non-amortizing vs. amortizing loans for refinancing. In addition, the change in relative value of the deduction and therefore in the net benefit of new non-amortizing loans vs. new amortizing loans, is proportionate to the personal income marginal tax rate.

[11] This benefit of non-amortizing loans is similar to the benefit of high LTV mortgages in models of demand for leverage such as Kermani (2012) and Bokhari, Tourous and Wheaton (2013).

Figure 3-10: Effect of MID reform on the percentage of non-amortizing mortgage offers



Note: The vertical solid line indicates the month of the MID reform in January 2012 and the dotted line is the month of the announcement of the reform.

This simple conceptual framework thus allows to formulate two testable predictions. First, the decline in the fraction of non-amortizing loans should be larger for the "treated" new mortgages than for the "control" grandfathered refinanced mortgages. This prediction is clearly present in the raw time-series amortization patterns shown in Figure 3-10. The percentage of non-amortizing loans collapses from approximately 50% prior to the MID reform to 10% for new loans. This decimation contrasts with the relative stability of the market share of non-amortizing loans for refinanced loans. Table 3.7 reports the results of a Difference-In-Difference regression of an indicator variable for non-amortizing loans on a new mortgage indicator, which corresponds to the treatment dummy, as well as the interaction of the new mortgage indicator and a dummy for the post-MID reform period. The specification in column (1) also includes month fixed effects. Consistent with the first prediction, the coefficient on the new mortgage·post MID reform-term is negative, large and significant. The important decline of the fraction of non-amortizing treated new loans relative to the control refinanced loans is also robust to including a rich series of control variables in Column (2), including borrower age category fixed effects, household income decile fixed effects and zipcode fixed effects.

The second prediction from the conceptual framework exploits differences in marginal tax rates. The decline in the fraction of non-amortizing loans should be larger for the "more intensively treated" new mortgages of households subject to the top personal marginal income tax rate than for the "less intensively treated" new mortgages of households not subject to the highest personal income MTR. This second prediction is tested in Columns (3) and (4). Consistent with the second prediction, the coefficient on the New mortgage·post MID reform·top MTR -term is negative, large and significant in Columns (3) and (4).

Table 3.7: Effects of the MID reform on the amortization type of mortgages

	(1) Non-amortizing	(2) Non-amortizing	(3) Non-amortizing	(4) Non-amortizing
	Difference-in-Difference (DD)		DDD	
New mortgage	-0.26***	-0.14***	-0.31***	-0.17***
	(0.00)	(0.00)	(0.00)	(0.00)
New mortgage·post MID reform	-0.24***	-0.16***	-0.20***	-0.12***
	(0.00)	(0.00)	(0.01)	(0.01)
Top marginal tax rate			0.02***	-0.05***
			(0.01)	(0.01)
New mortgage·post MID reform·top MTR			-0.12***	-0.12***
			(0.01)	(0.01)
Post MID reform·top MTR			0.03***	0.04***
			(0.01)	(0.01)
New mortgage·top MTR			0.14***	0.09***
			(0.00)	(0.01)
Constant	0.76***	0.54***	0.76***	0.56***
	(0.01)	(0.01)	(0.01)	(0.01)
Controls	No	Yes	No	Yes
N	510274	359891	359891	359891
adj. R^2	0.26	0.38	0.25	0.38

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The dependent variable in all columns is an indicator for whether the offered mortgage is non-amortizing. All columns include month fixed effects. The controls in column (2) and (4) are 10 borrower age category fixed effects, 10 household income deciles and 90 zipcode fixed effects. The top marginal tax rate indicator equals one when the household income on the mortgage offer falls into the highest 52% marginal personal income tax rate bracket in the year of the mortgage offer.

Effects on loan size. In addition to the targeted effect on amortization choices, the MID reform may affect other mortgage features. How does the MID reform alter loan sizes and mortgage leverage ratios? In principle, the effect of the MID reform on loan sizes and leverage ratios is theoretically potentially ambiguous as there are 2 potential channels with opposite effects. On the one hand, according to the *payment-to-income risk* channel, loan sizes may drop. For a given PTI and a given interest rate, the shift to amortization could be associated to higher PTL ratios and therefore smaller loans as amortizations increase total mortgage payments. On the other hand, according to the *foreclosure loss risk* channel, the lender may associate the shift to amortization with lower foreclosure loss risk, shift risk forward and therefore allow for higher leverage/LTV ratios at origination.[12] The regressions in Table 3.8 investigate the effect of the MID reform on loan sizes and leverage ratios. The DiD specifications in all 6 Columns again exploit variation in treatment between the new mortgages and the refinanced grandfathered mortgages in a DiD strategy. Column (2), which includes controls, reports that the MID reform is associated with a decline in the loan size by €8,487, which corresponds to more than 4% of the average loan size. Columns (3) and (4) find large reductions in the LTI ratio associated to the MID reform. The coefficient on the New mortgage·post MID reform- term in Column (4) suggests that the MID reform is associated with a decline in the LTI ratio by 24 basis points. Finally, the positive effect on the LTV ratio in Column (5), which may be consistent with the foreclosure risk channel, becomes negative once one includes controls in Column (6). Overall, the results suggest that amortization is associated with smaller loan sizes, lower LTI ratios and probably also lower LTV ratios. These findings suggest that the effects of amortization are rather consistent with the payment-to-income risk channel than with the foreclosure risk channel. The very low incidence of foreclosures in the Netherlands may explain why the payment-to-income risk channel dominates the foreclosure risk channel.

Table 3.8: Effects of the MID reform on loan size

	(1)	(2)	(3)	(4)	(5)	(6)
	Loan size	Loan size	LTI	LTI	LTV	LTV
New mortgage	-1541***	4347***	0.39***	0.06***	15.17***	7.45***
	(434)	(338)	(0.01)	(0.01)	(0.11)	(0.10)
New mortgage·post MID reform	-3546***	-8487***	-0.11***	-0.24***	2.81***	-1.44***
	(890)	(666)	(0.01)	(0.01)	(0.22)	(0.19)
Constant	2.067e+05***	1.595e+05***	4.01***	5.66***	75.98***	83.47***
	(1148)	(1067)	(0.02)	(0.02)	(0.29)	(0.31)
Controls	No	Yes	No	Yes	No	Yes
N	513793	513793	507976	507976	508948	508948
adj. R^2	0.01	0.45	0.08	0.31	0.06	0.30

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The dependent variables in columns (1)-(2), (3)-(4) and (5)-(6) are respectively the loan size, the Loan-To-Income ratio and the Loan-To-Value ratio. The LTI and loansize variables are winsorized at 1% and the LTV is defined as missing if it is not in the 0-150 range. All columns include month fixed effects. The controls in column (2), (4) and (6) are 10 borrower age category fixed effects, 10 household income deciles and 90 zipcode fixed effects.

[12] The second channel is also consistent with the cross-sectional relationship where non-amortizing loans are more prevalent among low LTV and older borrowers.

3.7 Conclusion

This paper has studied the effects of LTV limits, PTI limits and the mortgage interest deduction on mortgage demand exploiting a series of policy changes in the Netherlands. As intended, regulatory loan limits can reduce mortgage leverage ratios and they also induce bunching at the loan limits. Loan limits and restrictions of the mortgage interest deduction also trigger large declines in mortgage volumes. The responses on the intensive and extensive margin are larger for young and arguably borrowing-constrained households. The repeal of the MID for non-amortizing mortgages decimates the large market for non-amortizing mortgages, which highlights how tax design can shape mortgage markets. Both loan limits and the MID reform are associated with changes in non-targeted mortgage characteristics. The PTI tightening is associated with a substantial rise in the fraction of mortgages that have very short periods during which the interest rate is fixed. This unintended risk-shifting pattern to quasi- adjustable-rate mortgages (ARM) may increase income risk. On the other hand, the introduction of the MID reform, which boosts amortization, is also associated with a significant decline in principal amounts at origination.

Overall, this paper highlights four potential insights for policy. First, loan limits can have important distributional effects as they mostly affect the young and borrowing-constrained households. Second, while housing-related tax policies are usually not thought of as macroprudential, they have the potential to transform mortgage markets. Third, as households substantially retime their mortgage- and house purchase decisions, policymakers may want to implement macroprudential and fiscal housing policies rapidly after their announcement. Fourth, to quantify the effect of macroprudential and fiscal policies aiming to reduce mortgage debt on total risk-taking and mortgage debt, it is important to take into account the unintended potential consequences of those measures.

This paper also outlines three promising avenues for future research. First, it will be important to decompose the large declines in mortgage volume around the reform dates into short-run shifts and permanent reductions in access to homeownership. Second, and relatedly, the effects of the loan limits and the MID on house prices deserve further investigation. Finally, the net effect of loan limits on subsequent household responses to negative shocks (e.g. consumption, defaults, mobility) constitutes an important line of future inquiry.

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Appendices for Chapter 1

Data Appendix on Construction of Sample of Buyers

I construct the 1995-2012 buyers in three steps. First, I randomly select 25% of the transactions of existing owner-occupied homes in 1995-2011. Second, I identify the unique household head among the persons moving into the selected property. Third, I build a panel following these identified buyers over the period 1995-2012. I now detail each of these three steps as well as the number of remaining observations after each step shown in Figure A1.1.

Random selection 25% of transactions in 1995-2011. I make use of the universe of 3,057,528 transactions of the existing owner-occupied dwellings file with transaction dates during the period 1995-2011. This file has as identifiers an address and a month of home purchase. I drop 35,242 transactions for which the address variable is missing and keep 3,022,286 transactions. I drop 32,066 transactions for which there is more than 1 transaction in a given quarter for a given address and keep 2,990,220 transactions. Given memory constraints, I then randomly select 25% of the purchases to obtain 747,554 purchase transactions.

Identifying unique household heads among persons moving in into sampled properties. To identify the unique household head from the persons moving into a selected property, I first consider all the individuals moving in during the same quarter at a given address. I use the universe of individual address spells with coverage January 1995-December 2012, which has as identifiers an address, an encrypted social security number, a spell start date and a spell end date. There are 35,642,414 individual address spells starting after January 1st 1995[13]. I drop 1,198,597 individual address spells with more than 10 persons moving in[14] and obtain 34,443,817 individual address spells. I consider all the address spells on a given address starting in a given quarter and regroup them. The 34,443,817 individual address spells correspond to 21,467,505 household address spells.

I then merge the 747,554 purchase transactions with the 21,467,505 reshaped household address spells using the addresses and quarter of purchase of spell start as keys. 398,826 transactions (=53.35% of the transactions) are matched to a spell that starts in the same quarter as the purchase date. 185,575 (=24.82%) of the transactions are matched to a spell that starts in the quarter after purchase. Finally, 46,546 (=6.23%) of the transactions are matched to a spell that starts two quarters after the purchase. Hence, I match 630,947 of the 747,554 purchase transactions (=84.40%).[15]

To identify the household heads for the selected transactions, I use the head of household identifier dummy on December 31st of the transaction year from household structure spells that I will match to transactions. The head of household dummy is created by Statistics Netherlands with a time-consistent and intuitive rule.

[13] I drop the 15,415,895 left-censored spells starting exactly on January 1st, 1995; the database starts on January 1st 1995.

[14] The main goal is to avoid those who moved into institutional addresses (e.g. senior citizen housing, nursing homes).

[15] For the remaining 116,607 non-matched transactions, I observe the variable "Is the buyer a current renter" (which has always been measured since 1998 and never before) for 85,732 transactions. 27,276 of those 85,732 non-matched transactions are bought by current renters (17,028 are sales by public housing corporations).

If there is a couple in the household, then the male member of the couple is the head of household. If the couple is of the same gender, then it is the oldest person. The head of single-parent household heads is the parent. In an "other household", the head is the oldest male, 15 years or older- and if this is missing- the oldest woman, 15 years or older. In multiple-generation households (e.g. non-married pair with daughter and mother), then the partner in the couple rule dominates the parent rule in a single-parent family and in the case of two (via child-parent related) pairs, the head is chosen as the youngest pair.

To select the head of household from the persons who moved in an address, I list all the individuals moving into the sampled transactions, and I consider 1,441,087 person moving-in years corresponding to the 630,947 transactions. The 1,441,087 person moving-in years correspond to 1,364,733 distinct persons. Focusing on persons who have only 1 transaction per year per address in our 630,947 transactions, I drop 4,445 person-years and get 1,436,642 moving in person years, which corresponds to 1,362,594 distinct persons and 629,174 transactions. To identify the head in the year of the move, I then build a annual panel of household structures of persons moving in. I therefore merge the universe of 138,238,794 household spells with the list of 1,362,594 transacting distinct persons using the SSN. Household spells have as a unit of observation a SSN, a family-structure-spell start date, a family-structure-spell end date and a household number. 21 persons cannot be matched and I find 13,244,303 individual household structure spells for the 1,362,573 matched distinct persons. Because of insufficient disk space constraints, I drop the 1,576 household spells (0.01% of 13,244,303 spells) with more than 150 household spells to keep 13,242,727 spells.I then match the moving in person-years and person-years from the household structure panel. From the 1,436,642 moving in person years (629,174 transactions), I can match 1,436,459 person years (629,137 transactions) to their household structure in December of the year of the transaction. I then restrict myself to the 1,434,705 moving in person years (628,349 transactions) where there is only 1 selected move in that year for that person at that address. I then drop transactions for which the move starts in 2012, as I cannot observe subsequent mobility out of purchase dwellings in 2013 and later as of yet. I thus drop 6,750 moving in person years for which the moving in date occurs in 2012 (0.47%), and I obtain 1,427,955 moving in person-years (625,315 transactions). I then match transactions and heads.

From the 625,315 transactions, I can match 577,815 transactions (=92.40%) to exactly 1 household head (as defined by SN) using the panel of household structures of persons moving in. However, 5.06% of the transactions have no household head and 2.20% of the transactions are associated to starting address spells for 2 household heads. To keep things simple and non arbitrary, I keep the 577,815 transactions associated to starting address spells with exactly one household head (which corresponds to 1,332,388 moving in person years). The 577,815 transactions- that we can match to the start of the address spell of a unique household head correspond to 552,168 distinct persons. 527,407 (95.52%) persons occur once, 23,912 persons twice (4.33%), 812 persons three times (0.15%) and 37 persons four times (0.01%). I then use the universe of 2012 time-unvarying personal characteristics file GBAPERSOONTAB and merge it with the list of 577,815 selected and matched buying heads of households using the SSN as key.

Building a 1995-2012 panel for selected buyers To know the address before and after the purchase, we build a panel of December addresses for the 552,168 distinct persons retaining the 2,175,981 address spells of the 552,168 distinct persons. I reshape the 2,175,981 address spells into 552,168 lines where we put the 1 to 40 addresses of a given person on 1 line. I then reshape the file to create 18 December addresses for the 552,168 distinct persons which corresponds to 9,939,024 person-years (=18*552,168). I then merge the 9,939,024 person-years and the list of 552,168 distinct persons using as key, the SSN and the year (where the year is the year in which the address spell associated to the transaction began). Finally, I implement two minor transaction sample restrictions using the panel of addresses. First, before defining mobility, I drop 378 person years- which corresponds to 45 transactions- if the same person buys the same address more than once to keep 9,938,646 person years (552,147 persons) and 577,770 transactions. Second, for 3,433 out of the 577,770 transactions, the January address after the move in is already different from the address where the buyer moved in. I focus on the remaining 99.44% or 574,337 transactions.

Appendix Figures

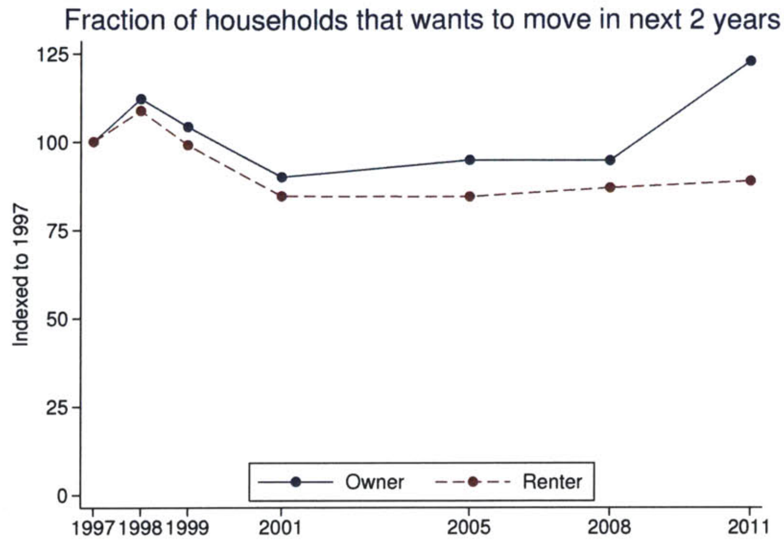


Figure A1.1: Mobility intentions of owners and renters over time

Notes: The data are from the WBO 1998, 1999, 2000 and WoON 2002, 2006, 2009 and 2012 surveys. WoON (WoonOnderzoek Nederland) is a repeated cross-sectional nationally representative survey of about 70,000 individuals about their housing situations which was known as WBO (WoningBehoefteOnderzoek) until 2000.

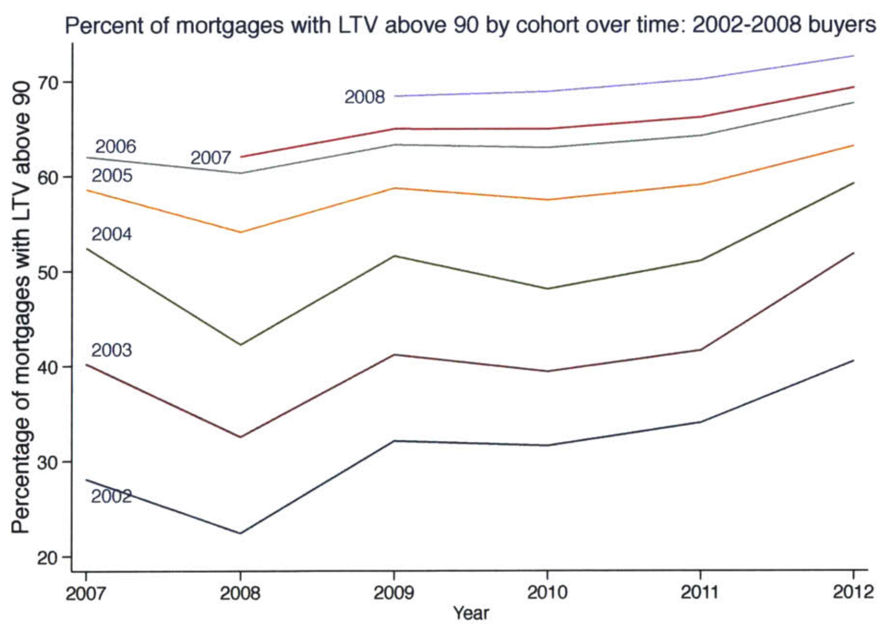


Figure A1.2: Percentage of mortgages with LTV above 90 by cohort over time

Notes: The percentage of mortgages with a LTV ratio above 90 is based on CBS household balance sheet, transaction price and regional house price index data. See section 4 of the text for more details.

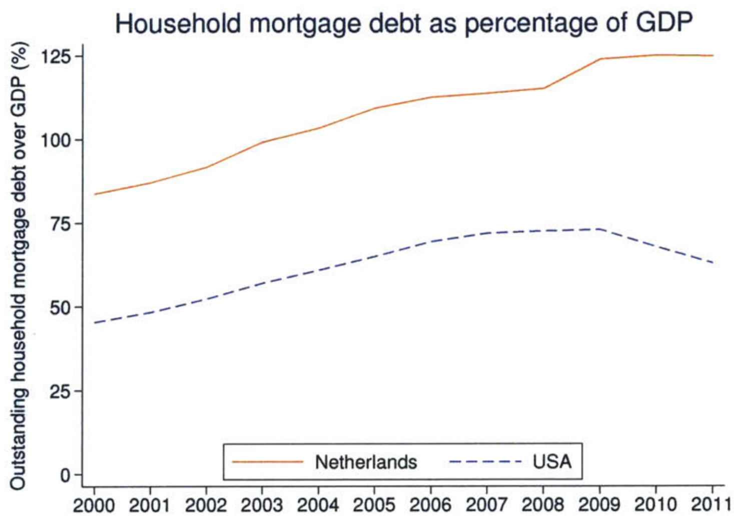


Figure A1.3: Household debt to GDP ratio for the US and the Netherlands

Notes: The sources are Statline Statistics Netherlands and Federal Reserve Bank of St. Louis Economic Data.

Figure A1.4: Construction of panel of buying heads of existing homes

Notes: The figure provides visual support for the explanation of the construction of the sample of buyers of transacted existing homes and the associated panel of buyer-years. See section 4 of the text for more details.

Appendix Tables

Table A1.1: Description of selection of transactions

Criterion	Deleted observations	Remaining observations
Initial transaction data 1995-2011		3,057,528
Missing address	35,242	3,022,286
More than one transaction at address per quarter	32,066	2,990,220
Random 25% selection	2,242,666	747,554
No match to start address spell of person moving in	116,607	630,947
More than one transaction per person per year at address	1,773	629,174
No match to household spell	37	629,137
More than one move per person at a given address in a year	825	628,349
Move after 2011 (we cannot measure subsequent mobility in 2013)	3,034	625,315
Match to exactly one household head	47,500	577,815
More than one purchase of given address by given household head	45	577,770
No match of transaction address to January address of next year	3,433	574,337
Selected transactions matched to head of household		**574,337**

Notes: This table summarizes the number of deleted and remaining observations at each step of the construction of the sample of buyers. See Appendix 3.7 of the text for more details.

Table A1.2: Life events and moves into owner-occupied homes by calendar year

Calendar year	# Life Events	# Moves into owned homes	Share of life events individuals moving into owned homes (%)
2003	17,021	62,807	37.1
2004	17,380	62,742	38.0
2005	17,344	66,365	40.4
2006	16,853	68,117	40.5
2007	16,087	64,188	40.9
2008	15,742	60,628	39.5
2009	14,078	45,969	37.8
2010	13,661	42,742	36.4
2011	12,669	39,908	35.7

Notes: Columns 1 and 2 in this Table count the number of life events and the number of moves into owned homes in the full sample of 549,066 buyers for the calendar years 2003-2011. The move into an owned home can but does not have to be a move into a sampled purchased existing home. Conditional on going through a life event, the percentage of person-years that moves into an owned home, is shown in Column 3 of this Table. The table starts in 2003 as the homeownership indicator variable is available since 2003, and ends in 2011, the last year for which life events can be defined.

Appendices for Chapter 2

Institutional Appendix: Collateral frameworks at the ECB, the BoE and the Fed

This section provides a brief introduction to the European Central Bank's, the Bank of England's and the Federal Reserve's liquidity provision from 2002 to 2013. From 2002 to 2007, the main objective of central banks' liquidity provision was to influence the price of short term loans in money markets by changing the supply of liquidity. Although the goal remained unchanged from 2007 to 2013, Central Banks had to significantly adapt their operational frameworks because of the financial turmoil.

European Central Bank

The ECB used two types of repo operations from 2002 to 2007. The main refinancing operations (MRO) have a maturity of one week and are sold through weekly auctions.[16] The long term refinancing operations (LTRO) have a maturity of three months and are also sold through weekly auctions. The total liquidity allocated by the ECB fluctuated around EUR 500 billion depending on the market liquidity needs. Approximately 2/3 of this amount was allocated through the MROs.

The range of collateral accepted for these operations has always been relatively broad, partly due to the concatenation of national central banks' collateral frameworks at the time of introduction of the euro. The general rules on collateral eligibility are set by the ECB's Governing Council. National Central Banks then implement these rules on a daily basis. Eligible assets include several types of bonds (corporate bonds, government bonds, uncovered bank bonds, covered bonds). Before 2008, these bonds had to have a credit-rating above or equal to A. This rating must be attributed by recognized Eurosystem credit assessment institutions. Assets without a rating may also benefit from an internal rating from the National Central Bank. Collateral is marked to market on a daily basis and non-marketable assets are priced and rated by National Central Banks.[17]

The repo operations remained the ECB's main tool during the financial crisis from 2007 to 2013. The repo operations were however modified in several key dimensions. First, the ECB started to sell repos with maturities of six months, one year and up to three years. The ECB also allocated repos in foreign currencies: US dollar, Swiss Franc, British pounds and Japanese yen. These operations where mostly wound down by the end of 2009, although the dollar operations restarted in May 2010. Third, the ECB dropped its auction allocation procedure and adopted a full allotment procedure whereby all banks could take up as much liquidity as needed at a fixed interest rate. Last but not least, the ECB broadened the criteria for collateral eligibility. These changes are summarized in Table 2.1.

[16] See Cassola et al. (2013) for an analysis of these auctions.

[17] Cheun et al. (2009) compare the collateral frameworks of the ECB, the Fed and the Bank of England from 2007 to 2009. Cassola and Koulischer (2014) provide an analysis of collateral pledged to the ECB from 2009 to 2011.

Federal Reserve

From 2002 to 2007 the Fed used open market operations to control the liquidity available in money markets. By buying or selling high-quality assets (Treasuries), the Federal Reserve provides or withdraws liquidity from the system in order to keep the Fed funds rate in line with the policy rate. These operations are restricted to a limited number of counterparties: the primary dealers.

Repurchase agreements or similar contracts like asset swaps were at the heart of the Fed's most important facilities during the crisis. These facilities include the Term Auction Facility (TAF) which allocated loans with a maturity of one week to three months.[18] The TAF amounts allocated topped USD 500 billion around May 2009. Other repo facilities included the Term Securities Lending Facility (TSLF)[19], whereby the Fed loaned Treasuries to primary dealers against less liquid collateral. Finally, the Primary Dealer Credit Facility (PDCF) is similar to the TAF: it allocated repos to primary dealers. The PDCF amount lent reached USD 150 billion in October 2008.

The range of collateral accepted at these operations is broader than the type of securities accepted from 2002 to 2007. As shown in section 2.4, ABS were the most widely used collateral type.

Bank of England

The Bank of England also uses repos to implement its monetary policy. In 2006 the BOE changed its reserve requirements system so that banks would only have to meet their requirements over a medium period, instead of having to meet the requirement every day. The bank offered reserves for a maturity of 3, 6, 9 and 12 months. The total stock of long-term operations was around GBP 15 billion.

As a response to the financial crisis, the Bank also extended its collateral framework in the Fall of 2008 to include CMBS and corporate debt as well as RMBS and covered bonds. The Bank increased the size of its operations during the crisis to GBP 180 billion in November 2008, up from around GBP 20 billion a year before.[20]

In order to avoid moral hazard, the Bank charged a higher interest rate on repos using "extended" collateral. The spread with the rates on the repos with high-quality collateral was fixed. In February 2010, the bank introduced the product mix auction. Described by ?, this auction allocates loans with “narrow” and “broad” collateral at different interest rates. These interests rates are set during the auction and vary with the banks' bids and the BOE's allocation policy.

[18] The Term Auction Facility has been analyzed, among others, by Benmelech (2012), Armantier et al. (2008, 2014).

[19] See Fleming et al. (2009) for an analysis of the design and effect of the TSLF.

[20] The website of the Bank of England provides a detailed description of the evolution of the operational framework over time, available at http://www.bankofengland.co.uk/markets/Pages/sterlingoperations/timeline/timeline.aspx (last retrieved on 4 July 2014).

Flow of Funds data

Collateralizable assets for financial and nonfinancial sectors

The estimates of the shares of pledgeable assets in balance sheets for the financial and nonfinancial business sector are based on the US Flow of Funds Matrix for 2013 data in Table A2.1 and the assumption that the only pledgeable assets in the Flow of Funds nomenclature are checkable deposits and currency, time and savings deposits, money market fund shares, Fed funds and security repurchase agreements, Treasury Securities, Agency- and GSE-backed securities, Municipal Securities, Corporate and foreign bonds, Corporate Equities and Mutual Fund Shares.

Breakdown of available collateral

Table A2.2 presents the match between the Flow of Funds asset breakdown and the Money Market SEC N-MFP forms that is used in table 2.2.

Proof of First-Best Lending Contract (Lemma 1)

Proof. The use of collateral is costly since in case of transfer, the value of the collateral is lower for interbank lenders than for the central bank (as $v < 1$).

Plug prq from (2.2) in (2.1):

$$\max_{h,q} \pi = pR(q) - (1-p)\,hq\,(1-v) - q.$$

This function is decreasing in h, so the optimal haircut is $h = 0$. The FOC yields $pR'(q^*) = 1$ and the interest rate is $r = 1/p$.

Equilibrium private lending (proof of propositions 1-4)

We first prove that when $pR(q^{ec}) - q^{ec} > A + Bq^{ec}$, uncollateralized lending is optimal (proposition 1). We then characterize uncollateralized lending (proposition 2) and collateralized lending (proposition 3), when $pR(q^{ec}) - q^{ec} < A + Bq^{ec}$.

The general problem solved by the bank is to maximize profits

$$\max_{r,h,q} \pi = p\left[R(q) - rq\right] - (1-p)\,hq \tag{1}$$

such that it is incentivized not to shirk, it has enough collateral, investors participate in the collateralized lending contract and haircuts are non-negative

$$\begin{aligned} pR(q) - prq + phq &\geq A + Bq \\ hq &\leq \theta \\ prq + (1-p)\,hqv - q &= 0 \\ h &\geq 0 \end{aligned}$$

<u>**Uncollateralized Lending (Proposition 1)**</u> The maximum profit of the bank is the solution to the unconstrained problem (plugging the market clearing equation in the objective function):

$$\max_{r,h,q} \pi = pR(q) + (1-p)\,hqv - q - (1-p)\,hq. \tag{2}$$

This function is monotone and decreasing in h so at the first best the constraint $h = 0$ is always binding and the investment level is q^*. Another regime exists if $h = 0$ and the IC binds. In this case the investment level q solves:

$$pR(q) - (B+1)\,q - A = 0.$$

(combining the IC with the market clearing constraint). The interest rate remains such that the investor breaks even, $r = 1/p$.

The first-best uncollateralized regime occurs if $pR(q^*) - q^* \geq A + Bq^*$ while the constrained uncollateralized regime occurs if $pR(q^*) - q^* < A + Bq^*$ and $q > q^{ec}$, where q^{ec} is the investment in the "enough collateral" regime.

<u>**Collateralized**</u> The constrained collateralized regime occurs because using collateral is costly (as shown in (2)). In the constrained uncollateralized case, it is optimal to reduce the investment level to satisfy the IC instead of pledging collateral. At one point, however, this becomes too costly and the bank uses collateral. The proof of the collateralized contract uses the following result:

Lemma 3. *If $pR(q^*) - prq^* < A + Bq^*$, the bank's IC must bind.*

Proof. If $pR(q^*) - prq^* < A + Bq^*$, the IC is violated with an uncollateralized loan $h = 0$ if $q = q^*$. Suppose that the optimal contract, indexed 0, has $h > 0$ and the IC is slack. Reduce the value of collateral pledged hq by ϵ and increase the interest payment rq by $\epsilon v\frac{(1-p)}{p}$. This new contract ensures that the market clearing condition (investors' IR) is respected and offers the bank a higher profit π_1:

$$\begin{aligned}\pi_1 &= p\left[R(q) - rq - \epsilon v\frac{(1-p)}{p}\right] - (1-p)[hq - \epsilon] \\ &= \pi_0 + \epsilon(1-v)(1-p) > 0\end{aligned}$$

so by contradiction the initial contract cannot be optimal.

The proof of proposition 3 is:

Proof. **Enough Collateral:** Consider the case $f \geq \underline{f}_1$ (where $f = \theta p + \theta(1-p)v$). Suppose, then verify, that the CC is slack. By lemma 3, the bank's IC binds. The problem is:

$$\max_{r,h,q} \pi = p[R(q) - rq] - (1-p)hq$$

such that:

$$pR(q) - prq + phq = A + Bq, \tag{3}$$

$$prq + (1-p)hqv - q = 0.$$

The two constraints give the following expression for the total collateral pledged:

$$hq = \frac{A + (1+B)q - pR(q)}{(1-p)v + p}, \tag{4}$$

Plugging this in the IC (3):

$$prq = pR(q) + \frac{p}{(1-p)v+p}[A + (1+B)q - pR(q)] - A - Bq, \tag{5}$$

Substitute prq and hq in the maximization problem:

$$\max_q \pi = pR(q) - \left[pR(q) + \frac{p}{(1-p)v+p}[A + (1+B)q - pR(q)] - A - Bq\right] - (1-p)\frac{A + (1+B)q - pR(q)}{(1-p)v+p} \tag{6}$$

The FOC yields:

$$-(1-p)(1-v)B + pR'(q) - 1 = 0$$

so the investment level q^{ec} in the "enough collateral" case is given by

$$pR'(q^{ec}) = 1 + (1-p)(1-v)B.$$

so the loan size is below first best, and this effect is magnified with low p and low v. The interest rate is given by:

$$prq = pR(q) + \frac{p}{(1-p)v+p}[A + (1+B)q - pR(q)] - A - Bq,$$

this simplifies to:

$$prq = \frac{(1-p)vpR(q) - (A+Bq)(1-p)v + pq}{(1-p)v+p}$$

Again:

$$prq = \frac{(1-p)v(pR(q) - A - Bq) + pq}{(1-p)v+p}$$

and the haircut is given by (4).

Finally we verify that the CC is slack because

$$\theta > \underline{\theta}_1 = \frac{A + (1+B)q - pR(q)}{(1-p)v+p}$$

since $f > \underline{f}_1$.

Collateral crunch

In the collateral crunch case, the CC binds because the available collateral is insufficient to ensure that the bank does not shirk with a loan level as in the "enough collateral" regime.

The bank maximizes profits

$$\max_{r,h,q} \pi = p[R(q) - rq] - (1-p)hq$$

such that

$$R(q) - rq + hq = \frac{A+Bq}{p}, \tag{7}$$

$$hq = \theta \tag{8}$$

$$prq + (1-p)hqv - q = 0. \tag{9}$$

The equilibrium is determined by the constraints. Plug the CC (8) in the IC (7) and market clearing (9) and sum the 2 constraints:

$$pR(q) + p\theta + (1-p)\theta v - q = A + Bq.$$

The loan level q solves this equation. The haircut is $h = \theta/q$ and the interest rate is determined by

$$r = \frac{q - (1-p)\,\theta v}{pq}.$$

Dry-up

A liquidity dry-up occurs when the profits generated by the project and the available collateral become insufficient to protect the investor from moral hazard for any given loan level.

The loan level q in the collateral crunch solves

$$pR(q) + f - q = A + Bq. \tag{10}$$

A dry-up may occur in two cases: (1) the loan size q that solves equation (10) is negative and (2) the equation does not have a real solution in q. The first case can be ruled out since we know that when $q = 0$ the function is positive. To see this, rewrite (10) as

$$G(q) + K = 0. \tag{11}$$

where $G(q) = pR(q) - (B+1)\,q$ and $K = f - A$.[21] The function $G(\cdot)$ crosses the $y = 0$ axis twice, at $q = 0$ and at $q > 0$. The relevant solution for our case is the right-hand solution, i.e. the highest q that solves this equation. Let $\hat{q} = \arg\max(G(q))$. We know that $\hat{q} > 0$ because $G(\cdot)$ is concave. In equation (11) we add a constant K to the function $G(q)$. For all K, the solution to (11) cannot be lower than $\hat{q}$, which is positive. Hence we may rule out case 1 where $q < 0$.

However for low values of θ (case 2), this equation may not have a solution. In fact when

$$\arg\max_{q}\{pR(q) + f - q - A - Bq\} = 0 \tag{12}$$

for any value of f lower than the $\underline{f}_2$ that solves equation(12), there are no solution to the investment equation (10).

Comparative statics of haircuts in private markets (proof of proposition 5)

This section formalizes the comparative statics of the haircut h in the collateral crunch case with respect to the asset's quality v.

[21] Note that $G(\cdot)$ is a typical concave function, which crosses $(0,0)$, has $\lim_{q\to\infty} G = -\infty$ and has $G'(0) = \infty$.

Proof of comparative statics of v *Proof.* We need to show that the haircut decreases in v in the collateral crunch regime. Remember that in this regime the haircut is set as $h = \theta/q$ and q solves

$$pR(q) + (p + (1-p)v)\theta - q = A + Bq, \tag{13}$$

so q unambiguously increases in v. To see this, note that (13) may be rewritten as

$$G(q) + K = 0. \tag{14}$$

where $G(q) = pR(q) - (B+1)q$ and $K = (p + (1-p)v)\theta - A$.[22] We are interested in the highest q that solves this equation. Since it increases when K increases and since K increases in v, then the loan size increases in v. This implies that the haircut $h = \theta/q$ decreases in v.

Perfect quality and irrelevance of haircuts

This section shows that multiple equilibria arise when collateral is perfectly liquid, $v = 1$.

Proposition 13. *Suppose that contract (q_0, r_0, h_0) is an "enough collateral" equilibrium for $v < 1$, and such that $v = 1-\epsilon$ where $\epsilon \to 0$. Let $\alpha = 1 - h_0(1-p)$. Then any contract $\left(q_0, \frac{\gamma}{p}, \frac{(1-\gamma)}{(1-p)}\right)$ where $\gamma \in \left[1 - \frac{(1-p)\theta}{q_0}, \alpha\right]$ is also an equilibrium when $v = 1$.*

Proof. The proof relies on the Karush-Kuhn-Tucker conditions of the maximization problem, which define a space of contracts that satisfy the constraints while providing a same profit to the bank. In the "enough collateral" regime, the CC is slack. Hence collateral requirements can be increased and interest rates reduced -while keeping the IR binding- until the CC binds. The CC is slack as long as $\frac{(1-\gamma)}{(1-p)} q_0 \leq \theta$. This condition is respected if $1 - \frac{(1-p)\theta}{q_0} < \gamma$. Lower haircuts but higher interest rate payments than in the initial contract are not possible as the IC would then be violated. This is why $\gamma < \alpha$.

Liquid first (Proof of proposition 6)

Proof. We must show that if C_1 holds (i.e. the bank uses collateral, $pR(q^{ec}) - q^{ec} < A + Bq^{ec}$) and $f > \underline{f}_2^I$ (i.e. the bank is not in the dry-up regime) then $\frac{\partial \Pi_b}{\partial v} > 0$. Lending in the "enough collateral" regime is given by $R'(q^{ec}) = \frac{1}{p} + \frac{(1-p)(1-v)B}{p}$, so q^{ec} is increasing in v. Lending in the collateral crunch regime solves $pR(q) + f - q = A + Bq$. Since f increases with v, the loan amount q also increases with v.

[22] $G(\cdot)$ is a typical concave function, which crosses $(0,0)$, has $\lim_{q\to\infty} G = -\infty$ and has $G'(0) = \infty$.

Optimal central bank lending

There are two cases to consider for the central bank's optimal lending contract. The first one is when the central bank's losses have a large weight in its objective function relative to output: $\omega > \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$. This is the case that we consider in the paper and the proof is in subsection 3.7. The second case (when $\omega < \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$) is developed in subsection 3.7. In this case the central bank's focus on output relative to losses is so important that the central bank always makes the maximum losses in order to support output.

Optimal central bank lending with large weight on losses (proof of proposition 7)

Proof. The proof of the central bank's optimal repo contract relies on lemma 4 which shows that for a given loan size, the central bank prefers to make zero profits instead of making a loss even if this entails a higher collateral requirement and thus a higher cost of liquidity wedge. We use collateral amount thresholds $\underline{\theta}_1, \underline{\theta}_2, \ldots$ which can be translated into quality factor thresholds $\underline{f}_1, \underline{f}_2, \ldots$.

Lemma 4. *If the central bank can capture bank surplus to avoid a loss by increasing haircuts, it should do it.*

Suppose that the CC is such that a break-even contract is attainable without violating the CC. Suppose that the optimal contract is (q, r, h) such that the central bank makes losses, i.e. $\Pi_{CB}^{loss} < \Pi_{CB} < 0$. The IR is slack (else total output would be negative)

Consider a contract $(r + \epsilon, q, h + \epsilon)$. The constraints: (i) the IC is still satisfied; (ii) the IR tightens but if the central bank still makes losses, it is still slack; (iii) the CC is still satisfied (by assumption); (iv) the CB's profit is higher (but still negative). The impact on welfare is:

$$\Delta W_{CB} = q\epsilon \left[\omega \left[p + (1-p)\, v\right] - (1-p)\,(1-v)\right].$$

This is positive since $\omega > \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$, so the initial contract wasn't optimal. It is therefore optimal for the central bank to increase the haircut and the interest rate until $\Pi_{CB} = 0$.

General proof. The proof proceeds in 5 steps. First, we show that if profit is negative and CC is slack (i.e. $\theta \geq \underline{\theta}_1^{CB}$), then the central bank always increases the haircut and the interest rate to the point where it makes zero profit. Second, if $\underline{\theta}_2^{CB} \leq \theta \leq \underline{\theta}_1^{CB}$, then it is optimal to keep the CC binding and reduce loan size. Third, if $\underline{\theta}_3^{CB} \leq \theta \leq \underline{\theta}_2^{CB}$, then the central bank keeps the CC and IC binding but maintains a constant loan size and starts making losses - until it hits the maximum loss constraint Π_{CB}^{loss}. Fourth, we show how for $\underline{\theta}_4^{CB} \leq \theta \leq \underline{\theta}_3^{CB}$ the central bank reduces the loan size while keeping losses constant at π_{CB}^{loss}. Fifth, when $\theta \leq \underline{\theta}_4^{CB}$ the central bank stops lending altogether: the bank is "too encumbered to save".

Part 1: Central bank's enough collateral case

The problem with positive profits is:

$$\max_{r,q,h} W_{cb} = pR(q) - q - (1-p)\,qh\,(1-v)\,,$$

s.t.

$$R(q) - rq + hq \geq \frac{A+Bq}{p}$$

$$p\left[R(q) - rq\right] - (1-p)\,hq \geq 0$$

$$hq \leq \theta$$

$$\Pi_{CB} \geq 0$$

All else equal, welfare W_{cb} decreases in haircut so the central bank chooses the lowest haircuts given the constraints. Interest rates are similarly lowered to keep the bank incentivized, and they are lowered until the central bank loss constraint $\pi_{CB} \geq 0$ binds. This implies that the IC binds. Indeed, suppose that the IC is slack, then you can increase r, lower h and increase the objective function.

The proof of this part is then similar to that of proposition 14, with $\Pi_{CB}^{loss} = 0$.

Part 2: Collateral crunch regime

The central bank solves

$$\max_{r,q,h} W_{cb} = pR(q) - q - (1-p)\,qh\,(1-v)\,,$$

such that

$$R(q) - rq + hq = \frac{A+Bq}{p}$$

$$prq + (1-p)\,hqv - q = 0$$

$$hq = \theta$$

The constraints determine the equilibrium: see proof of proposition 14, with $\Pi_{CB}^{loss} = 0$. The optimal loan size solves

$$pR(q) + p\theta + (1-p)\,\theta v - q - A - Bq = 0. \qquad (15)$$

The haircut is determined by $hq = \theta$ and the interest rate is determined by $prq = q - (1-p)\,\theta v$.

Part 3: Lending floor regime

The central bank now makes negative profits because $\theta \leq \underline{\theta}_2^{CB}$ so equation (15) does not have a real solution. The problem is:

$$\max_{r,q,h} W_{cb} = pR(q) - q\left[1+\omega\right] - (1-p)\,qh\,(1 - v\,(1+\omega)) + \omega prq,$$

such that

$$pR(q) - prq + phq = A + Bq$$

$$hq = \theta$$

Plug CC and the IC constraint in the objective function:

$$\max_{q} W_{cb} = pR(q) - q[1+\omega] - (1-p)\theta(1 - v(1+\omega))...$$

$$... + \omega(pR(q) + p\theta - A - Bq),$$

The FOC gives:

$$R'(q) = \frac{1+\omega(1+B)}{p(1+\omega)} \tag{16}$$

The haircut is given by $hq = \theta$ and the interest rate by $prq = pR(q) + phq - A - Bq$.

Lastly, the threshold $\underline{\theta}_3$ is the pledgeable asset level θ at which the central bank's maximum loss constraint binds:

$$prq + (1-p)\theta v - q = \Pi_{CB}^{loss}$$

where q is given by (16), i.e.

$$\underline{\theta}_3 = \frac{\Pi_{CB}^{loss} + q - prq}{(1-p)v_\theta}.$$

Part 4: Loss limit regime

The problem is:

$$\max_{r,q,h} W_{cb} = pR(q) - q[1 + \omega(1-p) + \omega] - (1-p)qh(1 - v(1+\omega)) + \omega prq,$$

s.t.

$$pR(q) - pRq + phq = A + Bq$$

$$prq + (1-p)hqv - q = \Pi_{CB}^{loss}$$

$$hq = \theta$$

The three constraints in 3 unknowns determine the equilibrium. A few computations yield (see proof of proposition 3.7, with $\pi_{CB}^{loss} = 0$ for more details) the following equation for the loan size:

$$pR(q) + p\theta + (1-p)\theta v - q - A - Bq - \Pi_{CB}^{loss} = 0. \tag{17}$$

The haircut is determined by $hq = \theta$ and the interest rate is determined by

$$prq = q + \Pi_{CB}^{loss} - (1-p)\,\theta v.$$

Part 5 - Too encumbered to save

If (17) does not have a real and nonnegative a solution, the bank is unfunded. Thus $\underline{\theta}_4^{CB}$ is the lowest θ for which (17) has a real and nonnegative solution.

Optimal central bank lending with low weight on losses

The case where the central bank is focused on output is driven by the central bank's desire to avoid costs of inefficient collateral transfer. The central bank provides haircut subsidies to the bank and makes maximum losses Π_{CB}^{loss}. When the bank has little collateral available, i.e. θ is below $\underline{\theta}_L$, the CC is binding: central bank subsidies are insufficient to avoid shirking and the central bank thus reduces lending to keep the bank incentivized.

Proposition 14. *If the central bank is focused on output ($\omega < \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$), we have:*

If the central bank is focused on output relative to losses (i.e. $\omega < \underline{\omega} = \frac{(1-p)(1-v)}{v(1-p)+p}$), then the policy depends on the amount of collateral available:

(Minimal inefficient collateral transfer) If $\theta > \underline{\theta}_L$, then the level of bank borrowing solves

$$R'(q) = \frac{(1+\omega)\left((1-p)\,v + p\right) + (B+1)\,(1-p)\,(1-v)}{p}$$

The haircut and interest rates are given by $h = \frac{\Pi_{CB}^{loss} + A + Bq - pR(q) + q}{q[(1-p)v+p]}$ and $prq = \Pi_{CB}^{loss} - (1-p)\,hqv + q$. The IC binds, the CC and IR are slack and the central bank's profit is $\pi_{CB}^{loss} < 0$. The collateral quality threshold $\underline{\theta}_L$ is given by:

$$\underline{\theta}_L = \frac{A + Bq + q + \Pi_{CB}^{loss} - pR(q)}{p\,(1-v) + v}.$$

(Collateral crunch) If $\theta < \underline{\theta}_L$, the level of borrowing q solves

$$pR(q) + (1-p)\,\theta v + p\theta - A - Bq - \pi_{CB}^{loss} - q = 0,$$

the interest rate is $r = \frac{\Pi_{CB}^{loss} - (1-p)\theta v}{pq}$ while the haircut is $h = \theta / q$.

Proof. The proof proceeds in two steps. First, we prove the minimal inefficient collateral transfer regime by showing that it is optimal for the central bank that weights profits (whether negative or positive) by ω to make losses in order to reduce the collateral requirement and the inefficient collateral transfer. We consider a slightly enlarged objective function for the central bank where not only losses are taken into account for welfare but also the profits. We show that in this case it is optimal for the central bank to make losses. We then show that when the central bank only weights losses (i.e. negative profits) by ω_L, then its welfare with nonnegative profits must be lower (because if not the previous contract was always attainable). Thus it is the optimal to make losses.

Second, we show that when $\theta < \underline{\theta}_L$ the losses required to support the minimal inefficient collateral transfer loan size would impose a loss on the central bank larger than π_{CB}^{loss}. The central bank therefore reduces the loan size: this is the collateral crunch regime.

Minimal inefficient collateral transfer regime

(1) Suppose the central bank accounts for profits with weight ω, whether profits are negative or positive. The problem is

$$\max_{r,q,h} W_{cb} = pR(q) - q[1+\omega] - (1-p)qh(1-v_\theta(1+\omega)) + \omega prq,$$

s.t.

$$R(q) - rq + hq \geq \frac{A+Bq}{p}$$

$$p[R(q) - rq] - (1-p)hq \geq 0$$

$$hq \leq \theta.$$

$$\Pi_{CB} \geq \Pi_{CB}^{loss}$$

In this case it is always optimal for the central bank to make losses π_{CB}^{loss} and to reduce collateral requirements until the IC binds. Let us start with a contract (r, q, h) such that the IC binds and the bank's profit is positive (i.e. IR is slack), and such that the central bank's profit is between zero and π_{CB}^{loss}, i.e. $\pi_{CB}^{loss} < \pi_{CB} < 0$. Consider a contract $(r-\epsilon, q, h-\epsilon)$. The constraints: (i) the IC is still satisfied; (ii) the IR is relaxed; (iii) the CC is relaxed; (iv) the CB's profit is lower (but still higher than π_{CB}^{loss}). The impact on welfare is:

$$\Delta W_{CB} = q\epsilon[(1-p)(1-v_\theta(1+\omega)) - \omega p]$$

This is positive since $\omega < \underline{\omega} = \frac{(1-p)(1-v_\theta)}{v_\theta(1-p)+p}$. The reasoning may be iterated until $\Pi_{CB} = \Pi_{CB}^{loss}$.

(2) This proves that the allocation where the central bank makes zero profit and has lowest haircuts possible has higher welfare (where positive and negative profits are weighted by ω) than when the central bank makes positive profit with a same quantity. Now consider the welfare function where only negative profits are weighted by ω, non-negative profits are weighted by zero. For any allocation with nonnegative profits, welfare must be higher in the case where profits are weighted than when they are not. To see this, suppose a contract is optimal when (nonnegative) profits are not weighted. Take the same contract when they are

weighted. Then welfare must be higher since profits are nonnegative. Thus welfare must be at least higher when profit is weighted by $\omega > 0$ and the CB makes nonnegative profits.

(3) These two statements imply that, for any q, the optimal interest rate and haircut policy is the one where haircuts are lowest given that the central bank makes losses Π_{CB}^{loss} and the IC binds.

The problem is

$$\max_{r,q,h} W_{cb} = pR(q) - q[1+\omega] - (1-p)\,qh\,(1 - v(1+\omega)) + \omega prq,$$

s.t. the bank's IC and the central bank's maximum loss constraint bind:

$$pR(q) - prq + phq = A + Bq$$

$$prq + (1-p)\,hqv - q = \Pi_{CB}^{loss}$$

Sum the 2 constraints:

$$pR(q) + (1-p)\,hqv + phq - q = \Pi_{CB}^{loss} + A + Bq$$

this gives the haircut

$$hq = \frac{\Pi_{CB}^{loss} + A + Bq - pR(q) + q}{(1-p)\,v + p} \tag{18}$$

The interest rate is

$$prq = \Pi_{CB}^{loss} - (1-p)\,v\frac{\Pi_{CB}^{loss} + A + Bq - pR(q) + q}{(1-p)\,v + p} + q \tag{19}$$

Plug this in the welfare function:

$$\max_{r,q,h} W_{cb} = pR(q) - q[1+\omega]\ldots$$

$$\ldots - (1-p)(1 - v(1+\omega))\left(\frac{\Pi_{CB}^{loss} + A + Bq - pR(q)}{(1-p)\,v + p}\right)\ldots$$

$$\ldots + \omega\left(\pi_{CB}^{loss} - (1-p)\,v\frac{\Pi_{CB}^{loss} + A + Bq - pR(q)}{(1-p)\,v + p}\right)$$

and take the FOC. The equilibrium contract is therefore:

$$R'(q) = \frac{(1+\omega_L)((1-p)\,v_\theta + p) + B(1-p)(1-v_\theta)}{p}.$$

The haircut is given by (18) and the interest rate is given by (19). The latter can be simplified to:

$$prq = \frac{p\Pi_{CB}^{loss} - (1-p)\,v\,(A - pR(q)) + q\,[p - (1-p)\,vB]}{(1-p)\,v + p}.$$

<u>Collateral crunch regime</u>

If $\theta \leq hq = \frac{\Pi_{CB}^{loss} + A + Bq - pR(q) + q}{(1-p)v_\theta + p} = \underline{\theta}_L$, the enough collateral contract is not implementable because it violates the CC. In this case the problem is to maximize welfare given that the CC and IC bind and the CB makes losses π_{CB}^{loss}.

The problem is

$$\max_{r,q,h} W_{cb} = pR(q) - q[1+\omega] - (1-p)qh(1-v(1+\omega)) + \omega prq,$$

s.t.

$$pR(q) - prq + phq = A + Bq$$

$$prq + (1-p)hqv - q = \Pi_{CB}^{loss}$$

$$hq = \theta. \tag{20}$$

The constraints determine the optimal contract:

$$pR(q) - prq + p\theta = A + Bq$$

$$prq + (1-p)\theta v - q = \Pi_{CB}^{loss}$$

Sum the 2 equations. The loan level q solves:

$$pR(q) + p\theta + (1-p)\theta v - q - A - Bq - \Pi_{CB}^{loss} = 0.$$

The haircut is determined by (20) and the interest rate is determined by:

$$prq = \Pi_{CB}^{loss} - (1-p)\theta v + q.$$

Haircut and collateral quality (Proof of proposition 8)

Proof. We must show that $\partial q/\partial v = 0$ if C_1 (the bank uses collateral) and $\underline{f}_3^{CB} < f < \underline{f}_2^{CB}$ (the bank is in the "lending floor regime"). This is direct from proposition 2.4, since the loan size solves $R'(q) = \frac{1+\omega(1+B)}{p(1+\omega)}$ and does not depend on v.

Contracts with both interbank and central bank lending (proof of lemma 2)

Proof. This result is derived from the structure of the game: once banks choose a funding source, the game proceeds as in sections 2.3 and 2.4 (with either the interbank market or the central bank as single source of funding). Thus any equilibrium contract in the subgames with a single lender must also be an equilibrium with the pre-stage game, else players would deviate when in the subgame.

Central bank and the interbank market (proof of proposition 10)

Proof. In our model, the bank compares its profit with the central bank and with the interbank market given its available collateral θ.

Suppose $\underline{f}_2^{CB} < f$. In this case the funding level q is the same with the central bank and with the interbank market and is given by:

$$R'(q) = \frac{1 + (1-p)(1-v)B}{p}.$$

If we assume that the probability of success is slightly lower for the central bank than for the investors, i.e. $p_{cb} = p - \epsilon$ for $\epsilon \to 0$, the quantity lent when borrowing from the central bank will be lower than that of the private market. The bank thus has a higher surplus in the private market than at the central bank when $\underline{f}_2^{CB} < f$.

If $f < \underline{f}_2^{CB}$, the central bank is willing to make losses to support investment while the investor still requires to break even. Hence the bank's profits are higher at the central bank.

Policy rate and real economy rate (proof of proposition 11)

Proof. The economy rate is a decreasing function of the amount lent q. As shown in propositions 3 and 7, the amount lent is always weakly decreasing in the available collateral θ, so the economy rate is always weakly decreasing in θ.

Negative incentive properties of central bank lending (proof of proposition 12)

In the extension, the bank chooses a collateral amount $\bar{\theta}$ which is subject to a shock ϵ drawn from a probability distribution $F(\cdot)$ (independent of $\bar{\theta}$), so that the available collateral $\theta = \bar{\theta} + \epsilon$ (this corresponds to the collateral amount used in sections 2.2 to 2.5). To focus on the choice of $\bar{\theta}$ made by the bank, it is useful to summarize the profit of the bank for a given collateral amount θ in various cases. First, we let $\pi_p(\theta)$ be the profit of the bank when it only borrows from the private interbank market (the equilibrium considered in section 2.3). Second, we let $\pi(\theta)$ be the profit when both funding sources are available (section 2.5). Finally, we let $\Delta\pi_{cb} = \pi(\theta) - \pi_p(\theta)$ be the difference between the two, or the "subsidy" of the central bank (since the bank always earns higher or equal profit when it has the choice of funding source, i.e. $\Delta\pi_{cb} \geq 0$).

The proof of proposition 12 uses the following lemma:

Lemma 5. *The subsidy of the central bank $\Delta\pi_{cb} = \pi(\theta) - \pi_p(\theta)$ weakly decreases with θ ($\partial\Delta\pi_{cb}/\partial\theta \leq 0$).*

Proof. For $f > \underline{f}_2^{CB}$ the bank borrows from the interbank market so $\Delta\pi_{cb} = 0$. If $\underline{f}_3^{CB} < f < \underline{f}_2^{CB}$, the amount lent by the central bank stays constant with θ whereas the amount lent in the interbank market only falls with θ, so $\Delta\pi_{cb}$ falls with θ. When $f < \underline{f}_3^{CB}$, the central bank makes the maximum losses Π_{cb}^{loss} and appart from that behaves as a private interbank lender, reducing investment to keep the bank incentivized. This is equivalent to providing Π_{cb}^{loss} worth of collateral to the bank. Intuitively, receiving extra collateral has more value to the bank when it has little collateral available (i.e. the marginal benefit of the bank from receiving an additional unit of collateral weakly increases with θ), so that the total value of the subsidy $\Delta\pi_{cb}$ decreases with θ in that range.

We now prove Proposition 12:

*Proof.*When borrowing only from the interbank market (section 2.3), the bank chooses $\bar{\theta}_p$ so that the marginal expected revenue from an additional $\bar{\theta}$ is equal to the marginal cost:

$$\frac{\partial E\left(\pi_p\left(\bar{\theta}_p\right)\right)}{\partial\bar{\theta}} = \frac{\partial c\left(\bar{\theta}_p\right)}{\partial\bar{\theta}}.$$

When the bank has the choice of funding source (section 2.5), and since $\pi(\theta) = \pi_p(\theta) + \Delta\pi_{cb}$, the level $\bar{\theta}_{cb}$ chosen by the bank solves :

$$\frac{\partial E\left(\pi\left(\bar{\theta}_{cb}\right)\right)}{\partial\bar{\theta}} = \frac{\partial E\left(\pi_p\left(\bar{\theta}_{cb}\right)\right)}{\partial\bar{\theta}} + \frac{\partial E\left(\Delta\pi_{cb}\right)}{\partial\bar{\theta}} = \frac{\partial c\left(\bar{\theta}_{cb}\right)}{\partial\bar{\theta}}.$$

By Lemma 5, we have that $\frac{\partial E(\Delta\pi_{cb})}{\partial\bar{\theta}} \leq 0$ so that, all else equal, the marginal profit of an additional unit of collateral $\bar{\theta}$ is always lower when the central bank lends. Since the marginal cost function is increasing (i.e. $c(\cdot)$ is convex), the optimal $\bar{\theta}_{cb}$ chosen by the bank is lower than in the "interbank market only" case, $\bar{\theta}_{cb} \leq \bar{\theta}_p$. This effect further increases when ω (the weight given to losses in the central bank's objective function) decreases, since the central bank subsidy increases when the weight on losses decreases.

Appendix Tables

Table A2.1: Share of pledgeable assets in balance sheets for nonfinancial and financial sector

	Nonfinancial business	Domestic Financial Sector
Total liabilities and equity	51,008	81,799
Total pledgeable assets:	*2,955*	*36,358*
Checkable dep. and currency	1,019	380
Time and savings deposits	1,037	706
Money market fund shares	536	739
Fed. Funds and security RPs	9	1,030
Treasury securities	102	4,946
Agency- and GSE-backed sec.	7	6,330
Municipal securities	33	1,943
Corporate and fgn. bonds	0	799
Corporate equities	0	15,979
Mutual fund shares	212	3,506
Pledgeable assets/balance sheet	**5.8%**	**44.4%**

This table is based on the Flow of Funds Matrix for 2013- All Sectors- Assets and Liabilities (Z.1, March 6, 2014). All amounts are in billions of dollars.

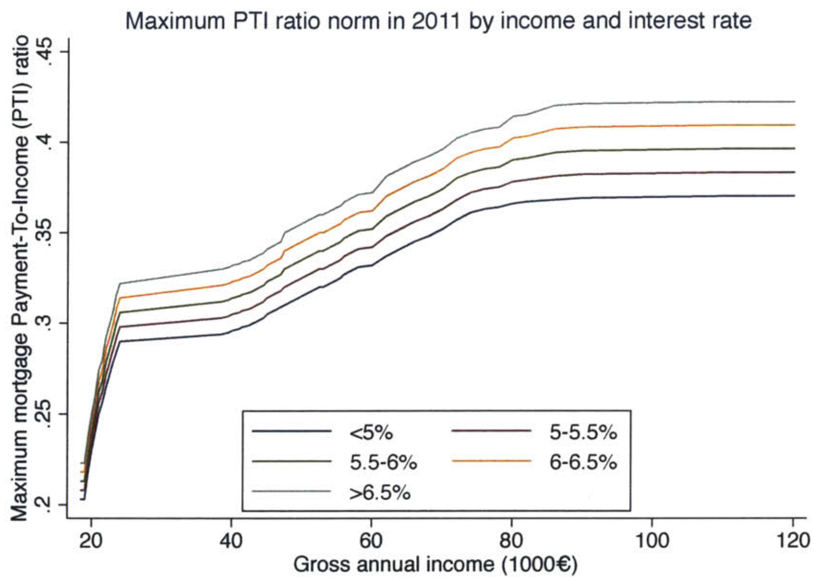
Table A2.2: Matching of money market collateral types and Flow of Funds item

N-MFP Filing Collateral Type	Flow of Funds item #	Flow of Funds Name
Treasuries	15	Treasury securities
Corporate debt	18	Corporate and fgn. bonds
Mortgage loan obligations	16	Agency- and GSE-backed sec.
Equities	23	Corporate equities
Other		-
Commercial paper	14	Open market paper
Municipals	17	Municipal securities

Appendices for Chapter 3

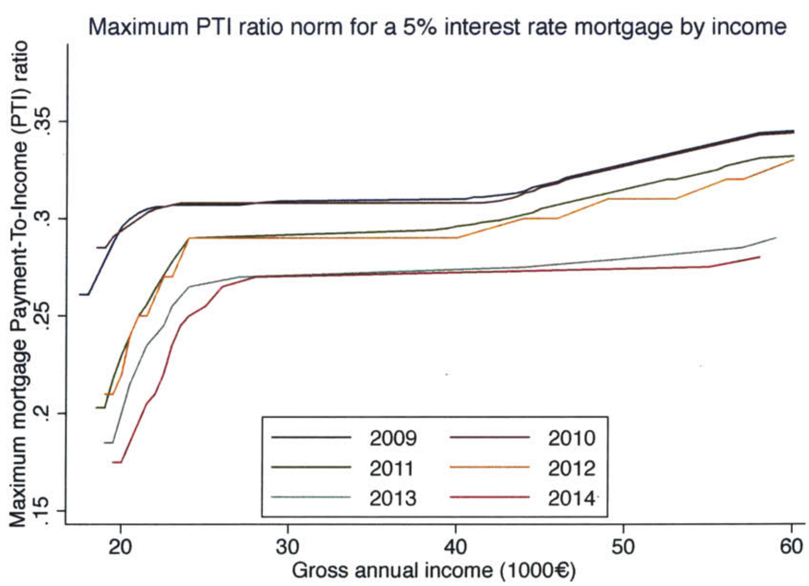
Appendix Figures

Figure A3.1: Maximum mortage Payment-To-Income (PTI) ratio norms as a function of income and interest rate in 2011



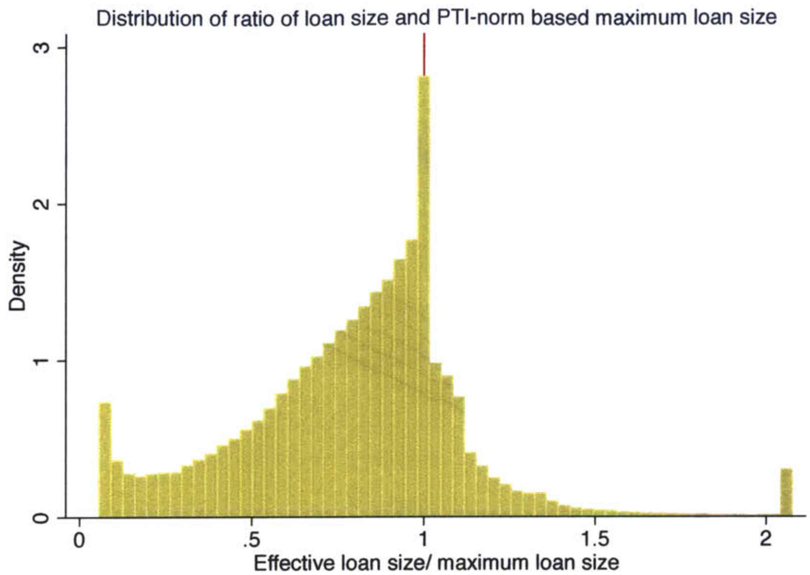
Notes: The historical PTI norm data are from NBI.

Figure A3.2: Maximum mortage Payment-To-Income (PTI) ratio norms on Dutch residential mortgages of 5% from 2009 until 2014



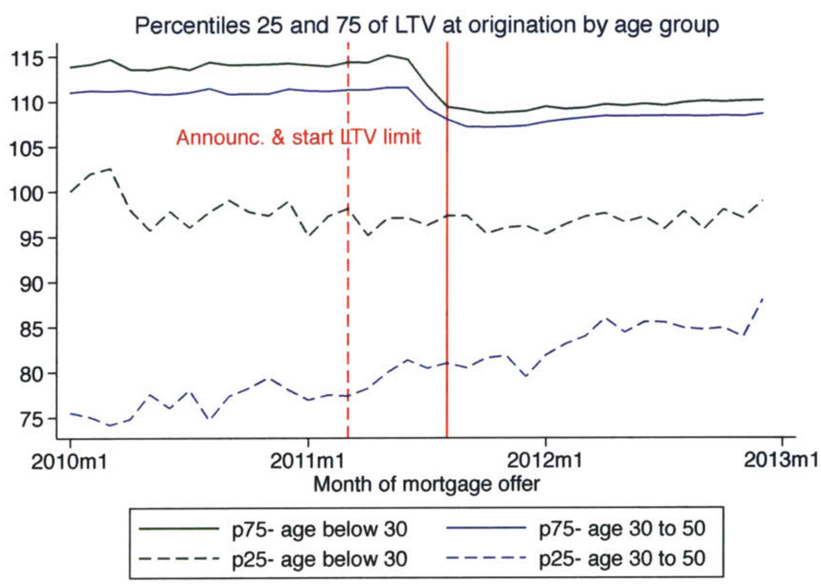
Notes: The historical PTI norm data are from NBI.

Figure A3.3: Distribution of effective and maximum loan offer sizes



Notes: The maximum loan size is calculated using household income, the historical PTI norm data from NBI and the standard 30 year FRM PTL formula.

Figure A3.4: Distribution of LTV ratios before and after introduction of LTV limit in August 2011



Notes: The red vertical shaded and solid lines indicate respectively the months of the announcement and the introduction of the LTV limit. The Loan-To-Value ratio is the ratio betweeen the loan size and the market value of the home (which is computed as the foreclosure value of the home divided by 0.9).

Appendix Tables

Table A3.1: Effects of 2nd PTI tightening in January 2013 on volume of mortgage offers: Zipcode-age group cell analysis

	(1)	(2)
	Mortgage offer volume (logs)	Mortgage offer volume (logs)
pti_pre	0.2997***	0.1725***
	(0.0232)	(0.0226)
pti_post	-0.3036***	0.1163***
	(0.0232)	(0.0257)
ypti_pre	0.0396	0.0396
	(0.0328)	(0.0295)
ypti_post	-0.3762***	-0.3762***
	(0.0328)	(0.0295)
Age_below35	-0.4802***	-0.4802***
	(0.0211)	(0.0191)
Constant	5.7932***	5.5840***
	(0.0306)	(0.0299)
Zipcode FE	Yes	Yes
Year FE	Yes	Yes
Year· Age_below35 FE	Yes	Yes
Year of Month FE	No	Yes
Linear Trend	No	Yes
N	10080	10080
adj. R^2	0.863	0.889

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Notes: The unit of observation in this regression is a zipcode-month-age group. There are 90 2-digit zipcodes and 2 age categories (below age 35 and equal to or above age 35). Column (2) adds year of the month FEs (e.g. January, February, ...) and a linear trend for the recovery in volume, which starts in February 2013. The variables "pti_pre/pti_post" are equal to one for mortgages offered 1 or 2 months prior to/after the PTI tightening in January 2011. The variables "yPTI_pre/yPTI_post" are equal to one for mortgages offered 1 or 2 months prior to/after the the PTI tightening in January 2013 to young borrowers of age below 35.