Essays on Housing Markets

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Claes Bäckman

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PhD School in Economics and Management
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"The PhD School in Economics and Management is an active national and international research environment at CBS for research degree students who deal with economics and management at business, industry and country level in a theoretical and empirical manner".

Preface

This Ph.D. thesis is the result of my time at the Department of Economics at Copenhagen Business School. Spending time at the Economics Department has been a privilege, and looking back upon my time here I realize how much I have learned and developed. The last three years have not only been about writing this dissertation, but also about learning how to organize, write, teach, present, and listen to new research. These are formative years, and I am very thankful that I spent this time together with all my colleagues at the Department of Economics.

I am especially grateful for the opportunity and the financial support provided by Copenhagen Business School. Special thanks goes to my supervisor Marcus Asplund for all his help, feedback and support. I would also like to thank Fane Groes, Søren Leth-Petersen and Ralf Wilkes for their thorough and helpful comments during my Closing Seminar, which improved my work tremendously. Thank you to my co-authors, Natalia Khorunzhina and Chandler Lutz for our joint work together, and for their support and guidance. Another special thanks goes to my fellow PhD colleagues, who made our office great.

Individually, there are many people I would like to thank: Lasse for always finding a topic to discuss, Tobin for always being helpful and for nights at Mikkeller, Pat for sharing xkcd jokes, Marie for music, Friedrich for heated discussions European politics, Julie for her tremendous work on the housing data, Alejandra and Oscar for their friendship. Additional thanks goes to Henrik, Vittorio, Philip, Federico, and all other colleagues in the Ph.D. office. You truly made the office great. There are many others I would like to thank for discussions, friendship, and laughter. I hope that I will have to opportunity to thank every one of you personally, but suffice to say for now that I am extremely thankful that I have such great friends. Finally, I want to thank my family, who are amazing in every way, and Olga, for always being there and for making everything immeasurably better.

Abstract

In Denmark and in many countries around the world, housing markets are of considerable importance for households and policy-makers alike. As the boom and bust in the US and Danish housing market so aptly demonstrated, disruptions in the housing market potentially have wide-ranging consequences for individual households and for the aggregate economy. Housing is important because we all have to live somewhere, but also because it serves as a considerable source of both wealth and debt. As such, housing market policy can not only create vast benefits for many, but can also have substantial negative impacts for all, and should therefore be a topic of major interest for economists and policy makers alike.

This Ph.D. thesis, entitled "Essays on Housing Markets", analyzes the Danish housing market during the 2000s, with a focus on how policy changes affected house prices and how changes in house prices affect households. While independent, each chapter in this thesis attempts to contribute to our understanding of how housing markets function, and has important lessons for policy-makers and economists around the world.

The first chapter, "Examining the Housing Boom in Denmark", provides an overview of the Danish housing and mortgage market and describes how house prices developed between 1998 and 2010. While the Danish boom closely resembles developments in the United States over the same period, many of the explanations for house price gains in the United States do not apply to Denmark. Of particular note is the fact that the Danish housing market has been highly praised for its design, which provides incentives for lenders to carefully assess borrowers, and works to transfer risk to investors who are capable of bearing it. This stands in sharp contrast to the United States, where declines in lending standards and increases in sub-prime borrowing are linked to house price gains.

Between 1998 and 2003 house price gains were relatively modest, with low dispersion between different areas in Denmark. This quiet period was following a period of substantial

volatility between 2004 and 2007. The highest price growth is observed in dense, urban areas with inelastic supply. During this boom period, fundamental determinants of house prices fail to explain why house prices went up by so much. Most of the price gains between 2004 and 2007 were erased in the down-turn that started in 2007, and house prices reverted back to their pre-boom level. There are important differences in when the decline started across municipalities, which present difficulties for theories that attribute the end of the boom to national factors.

In the second chapter, “Prime Borrowers and Financial Innovation in the Housing Boom and Bust”, written together with Chandler Lutz, we use a natural experiment to assess the impact on house prices of a new form of mortgages, interest-only loans. While many proposed explanations for the housing boom in the United States have focused on securitization and subprime lending as the leading cause, the housing boom in the United States also coincided with an dramatic increase in the use of alternative mortgage products. In this chapter we construct a model to show that changing amortization requirements, a common feature of alternative mortgage products, can lead to an increase in credit demand even absent changes in income. We test the model on the full population of Danish households, and find that the fraction of buyers who purchased housing increased following the introduction of interest-only mortgages. On the aggregate level the results indicate that the introduction of interest-only mortgages amplified the housing market cycle. Our results suggest that Denmark would have experienced an increase in house prices without interest-only loans, but that the boom-bust would have been significantly smaller in magnitude. Our results suggest that interest-only loans increased house prices by 35 percent over the counter-factual that also experienced a housing boom. These results cannot be explained by a shift in credit supply, or by fundamental increases in income growth.

The third chapter, entitled “Consumption and Housing Wealth: Theory and Evidence”, written together with Natalia Khorunzhina, estimates how house price changes affects the real economy. In an extensive empirical literature on both the aggregate and household level, changes in house prices have a large impact on consumption. This impact is attributed to three separate factors: a wealth effect, a collateral effect and a common factors hypothesis. However, the relative importance of these factors is difficult to disentangle. In this chapter, we use the full population of Danish households and an imputed measure of consumption to estimate the impact that changing house prices have on the real economy. Further, we examine whether the housing wealth effect is driven by a wealth or collateral effect, while controlling for the common factors hypothesis. Our results indicate that house prices have a large impact on consumption, and that the estimated effect is mainly driven by collateral borrowing. We find the largest effects during the Danish housing boom between 2003 and 2007, and we find that borrowing constrained households are the main drivers of the effect. The results are similar when we use an instrumental variable strategy, although the estimated coefficients are substantially larger in magnitude. Overall, our results suggest that collateral borrowing is the most important channel.

Sammanfattning (Abstract – Swedish)

Bostadsmarknaden är av stor betydelse för hushåll och beslutsfattare i Danmark och i andra länder runt om i världen. Den amerikanska bostadskraschen visade tydligt att problem på bostadsmarknaden kan leda till omfattande konsekvenser för enskilda hushåll och den samlade ekonomin. Vår bostadssituation är viktig inte bara för att vi alla behöver en plats att bo på, men också för att en stor del av vår förmögenhet och skuld är knuten till vår bostad. Förändringar på bostadsmarknaden kan således ha stor positiv och negativ inverkan för alla, och det är av stor vikt för både ekonomer och beslutsfattare att nå en bättre förståelse för hur bostadsmarknaden fungerar. Denna doktorsavhandling, med titeln "Essays on Housing Markets", analyserar den danska bostadsmarknaden under 2000-talet. Avhandlingen fokuserar på att beskriva och förklara den stora uppgång och nedgång i pris som Danmark upplevde under den här tiden, och på att analysera hur perioden påverkade enskilda hushålls situation. Alla tre kapitel är oberoende, men syftar till att öka förståelsen för hur husmarknader fungerar. Det första kapitlet, "Examining the Housing Boom in Denmark", ger en översikt över den danska bostads- och bolånemarknaden och beskriver hur huspriserna utvecklades mellan 1998 och 2010. Prisutvecklingen på den danska marknaden liknar utvecklingen på den amerikanska marknaden under samma period, men många av förklaringarna till den amerikanska bostadsboomen är inte tillämpbara i Danmark. Detta beror till stor del på att den danska bolånemarknadens design ger incitament till långivare att noggrant utvärdera låntagare och att inte ge ut lån till de som inte rimligen kan betala tillbaka, och att samtidigt arbeta för att överföra riskerna till investerare som är kapabla att bära dem. Till skillnad från USA så är minskning av kreditkvalitet inte en stor faktor i den danska bostadskraschen. Husprisökningen mellan 1998 och 2003 var relativt blygsam, med låg spridning mellan olika områden och utan större prissvingar. Den efterföljande perioden, mellan 2004 och 2007, kännetecknas av kraftiga prisökningar, där de största ökningarna

observeras i täta, urbana områden. Det är svårt att rationalisera de stora prisökningarna under den här perioden med enbart fundamentala förklaringsfaktorer. Priserna föll sedan med start år 2007, då mestadelen av den tidigare prisuppgången raderades. Nedgången skedde dock inte samtidigt i alla kommuner, vilket är svårt att förklara med teoretiska modeller som tillskriver slutet på en husprisboom till nationella faktorer.

I det andra kapitlet, "Prime Borrowers and Financial Innovation in the Housing Boom and Bust", skriven tillsammans med Chandler Lutz, använder vi ett naturligt experiment i Danmark för att bedöma effekterna av en ny bolåneform; amorteringsfria lån. Många föreslagna förklaringar till bostadsboomen i USA har fokuserat på ökad värdepapperisering eller rollen som mindre kreditvärdiga låntagare spelat, medan mindre fokus har lagts på den ökande populariteten av nya alternativa låneformer. I det här kapitlet analyserar vi effekten av nya låneformer genom att först konstruera en teoretisk modell för att visa att förändringar i amorteringar, ett vanligt inslag i alternativa låneformer, leder till en ökad efterfrågan på kredit även utan inkomstökningar. Vi finner empiriskt att införandet av amorteringsfria lån i Danmark ledde till en kraftig ökning i antalet transaktioner på bostadsmarknaden, vilket följdes av kraftiga prisökningar. Resultaten visar att införandet av amorteringsfria lån ledde till ökad volatilitet på den danska bostadsmarknaden. Specifikt visar vi att Danmark hade upplevt en bostadsboom även utan amorteringsfria lån, men att den hade varit betydligt mindre omfattande i storlek. Amorteringsfria lån ledde till att bostadspriserna ökade med 35 procent, vilket förklarar ungefär hälften av den totala ökningen mellan 2004 och 2007. Dessa resultat kan inte förklaras av en förändring i kreditutgivning eller genom grundläggande faktorer såsom inkomsttillväxt.

Det tredje kapitlet, "Consumption and Housing Wealth: Theory and Evidence", skrivet tillsammans med Natalia Khorunzhina, analyserar hur den danska bostadsmarknaden påverkade den danska ekonomin. Förändringar i huspriser har i omfattande empirisk litteratur visats ha stor inverkan på konsumtion. Denna inverkan tillskrivs tre separata hypoteser: en förmögenhetshypotes, en lånehypotes, och en hypotes om gemensamma faktorer som påverkar både huspriser och konsumtion. Dock är det svårt att mäta den relativa betydelsen av dessa tre hypoteser. I detta kapitel använder vi data för hela den danska befolkningen för att estimera effekten förändringar i huspriser har på konsumtion. Vidare undersöker vi om denna effekt drivs av en förmögenhets- eller en låneeffekt. Vi visar att den största uppmätta effekten av husprisförändringar skedde under den danska bostadsboomen mellan 2003 och 2007; att det främst är hushåll med hög belåningsgrad som reagerar på bostadsprisförändringar; och att effekten uteslutande drivs av en låneeffekt. Slutligen finner vi liknande resultat när vi använder en instrumental variabel-strategi.

Contents

Introduction

This Ph.D. thesis is composed of separate three chapters and a general conclusion. While all three chapters are independent and can be read as such, they each provide insight into housing market dynamics and its impact on the aggregate economy. The first chapter details the institutional context and background of the Danish housing market, and provides an overview of the developments between 1998 and 2010. In particular, the first chapter describes in detail how the Danish housing boom evolved over time and space, and finds that even a well-designed housing and mortgage market is prone to boom-bust episodes. The second chapter finds that the introduction of interest-only mortgages can explain a large fraction of the boom and subsequent bust. The third chapter analyzes the effect that this boom-bust cycle had on household consumption, and investigates whether house price changes affects consumption through a wealth effect or through increased borrowing.

All chapters in this dissertation attempt to improve our understanding of how housing markets by building upon existing research. Since the sharp rise in mortgage defaults in the United States in 2006 precipitated the financial crisis, both academics and policy makers have tried to understand how housing market booms and busts can lead occur, and how they propagate throughout the economy. As economists, the focus is on identifying the underlying causal factor, a task which is complicated in housing markets by the multitude of simultaneous explanations for a single fact – housing prices increased dramatically and then plunged down. For example, the cause of the U.S. housing boom has been attributed to declining interest rates Himmelberg et al. (2005); Mayer and Sinai (2009), mortgage credit expansion (Mian and Sufi, 2009), sub-prime lending (Coleman et al., 2008), optimistic house price expectations (Foote et al., 2012; Shiller, 2014) and other explanations discussed in Mayer (2011) and Glaeser and Nathanson (2015).

All three chapters focuses on the Danish housing market, a market that experienced a sizable boom and bust episode during the 2000s. The Danish housing market have several design features that prove instructive for understanding housing market dynamics elsewhere. For instance, the design of the mortgage system is set up to provide lenders with an incentive to carefully screen borrowers, and attempts to allocate capital to investors who are capable of bearing risk (Campbell, 2013). As I will argue, this removes many of the proposed explanations for the financial crisis in the United States, especially the concerns related to subprime borrowing and bad incentives within the mortgage industry. At the same time, full recourse mortgages lowers the value of strategic default on mortgage debt (Ghent and Kudlyak, 2011), which further limits the impact of strategic behavior on the part of borrowers, particularly in the form of speculation on rising house prices. Indeed, these two design features combine to remove many of the confounding factors present in any study of the US housing markets. The fact that we observe such a similar housing market dynamics in Denmark and the United States is instructive about the operating of housing markets, and suggests that housing markets may exhibit an inherently different type of volatility than other asset markets. Indeed, Glaeser and Nathanson (2015) note that while house prices exhibit the same pattern of excess volatility as other asset classes, it does so in a different way. While stock markets tend to have higher volatility than changes in fundamentals would suggest during almost all periods, housing markets are prone to episodes of substantial volatility, followed by quieter periods where prices do not deviate substantially from fundamentals. Studies of the Danish housing market, and indeed on markets in other countries, help us understand how these dynamics arise, and thereby help inform policy and regulation.

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Chapter 1 - Examining The Housing Boom in Denmark

Examining the Housing Boom in Denmark

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September 26, 2016

Abstract

I document several findings of a housing boom and bust cycle in the 2000s that is nearly equivalent in magnitude to the United States housing cycle, but where securitization and sub-prime lending were non-existent. Fundamental factors can explain a large fraction of the increase in prices for most of the period, but in 2006 and 2007 house prices increased in excess of what fundamentals would predict. The magnitude and timing of the boom and bust in Denmark during the 2000s varied across locations, where the largest and earliest price increases are found in urban areas.

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1 Introduction

Following the spectacular rise and fall of house prices in the 2000s in the United States, academics have primarily focused on explaining developments in the housing market in the United States. Despite the fact that housing booms were ubiquitous around the developed world in the 2000s, several of the proposed explanations are specific to the institutional setting in the United States. For instance, an expansion in sub-prime lending (Mian and Sufi, 2009; Coleman et al., 2008), implicit government guarantees, or increased securitization (Nadauld and Sherlund, 2013; Keys et al., 2010) are used to as explanations for the rapid house price gains in the United States, but cannot explain the appearance of housing booms and busts in other markets (Mayer, 2011).[1]

In this paper I examine the housing market cycle in Denmark between 1996 and 2010, a market which is designed to provide clear incentives for lenders to assess the quality of their borrowers, where sub-prime borrowing is non-existent, and where full recourse mortgages make default prohibitively costly (Campbell, 2013). Even so, housing market dynamics in Denmark and the United States during the 2000s share remarkable similarities. Figure 1 shows that real Danish house prices increased by 67 percent from 2000 to 2007 and subsequently declined by 31 percent. In comparison, real house prices in the United States increased by 89 percent from 2000 until 2006, before declining by 35 percent. The purpose of this paper is to document the Danish housing boom, and to answer two questions: 1) what is the shape of the Danish housing market cycle over time and space, and 2) can house price changes be explained by economic fundamentals such as interest rates or incomes?

To begin, I construct repeat-sales house price indices for Danish municipalities and document several facts about the Danish housing market.[2] The boom-bust pattern in Denmark is reminiscent of the pattern in the United States, where a period of relatively steady house price gains between 1996 and 2004 was followed by a boom period with dramatic house price gains between 2004 and 2007 (see Sinai, 2013, for similar evidence for the United States).

[1] Alternative explanations with more universal application include the global savings glut of Bernanke et al. (2007) or overly optimistic house price expectations Shiller (2006, 2015).

[2] A Danish municipality is approximately the size of a US county.

After the boom period, prices declined rapidly between 2007 and 2009, and as a result almost all of the gains between 2004 and 2007 were erased in the downturn. Overall, Danish housing returns exhibit the same pattern of short-run momentum (price increases in this year predicts price increases next year) and long-run mean reversion (price increases this year predicts price decreases in 3-5 years) as in the United States, although the estimated effect is smaller than in comparable studies for the United States (Head et al., 2014; Glaeser and Nathanson, 2015).

Additionally, there is considerable heterogeneity in the timing of both the peaks and the troughs across Danish municipalities, as several areas experienced peaks already in 2006, whereas others only peaked in 2008. Furthermore, house price growth returned to certain areas quickly, whereas others continued to decline. This presents a challenge to theories linking house prices to a national factor such as changing interest rates.

There is considerable spatial variation in both the absolute level and the growth rate of house prices across Denmark in both boom and non-boom periods.[3] The largest price increases during the boom occurred in municipalities where population density was high, housing supply was constrained, and the average square meter price was high. Price growth was especially high in dense urban area such as Copenhagen.[4]

The question is whether the dramatic house price increased during the boom and the difference in timing across municipalities can be explained by fundamental factor. While the evidence from the United States suggest that the time series of house prices are difficult to explain without resorting to non-fundamental explanations (house price expectations for example), it is worthwhile to examine Denmark through the same lens, especially considering the differences in institutional design. I examine whether house price growth can be explained by lower interest rates or rising incomes, following the methodology developed in Poterba (1984).[5] The results show that a majority of the increase in house prices prior

[3] See Glaeser and Nathanson (2015); Cotter et al. (2014); Ferreira and Gyourko (2012) for evidence for the United States.

[4] Spatial patterns in house price developments are well documented in the literature. Geographical differences in income (Ferreira and Gyourko, 2011), housing supply (Saiz, 2010; Mian and Sufi, 2009) or credit (Favara and Imbs, 2015) can lead to differential house price growth across locations.

[5] See also Himmelberg et al. (2005) and Mayer and Sinai (2009).

to 2006 can be rationalized by lower interest rates and high incomes. In 2006 however, house prices continued their ascent even as interest rates started rising. Importantly, the fraction of income going to interest payments for new buyers increased over this period. Within the user-cost model, this behavior can be explained by buyers anticipating higher capital gains on their housing investment, which would compensate for the higher interest payments. This is essentially an explanation based on higher house price expectations. It is certainly possible that buyers in 2006 and 2007 expected continued high returns on housing investments, especially if expectations are extrapolative (Case et al., 2012; Piazzesi and Schneider, 2009). As there is no long-running survey on household expectations in Denmark over this time-period, it is difficult to test whether expectations are extrapolative. However, if expectations are indeed extrapolative, then increasing prices in the early stages of the boom lead to higher expectations and thus higher prices later in the boom. There is evidence for momentum in the Danish housing boom, especially during the boom years. As house price growth continues even as interest rates increase in early 2006, it is plausible that expectations played a role in the Danish housing boom.

Importantly, the evidence does not suggest that the boom started because of high house price expectations, as the correlation between house price growth in the pre-boom (1996 to 2004) and boom period (2004-2007) is low.[6] The conclusion of this paper is that housing boom and bust episodes can occur even in well-designed mortgage markets. This observation suggests that we should consider what factors are similar across Denmark and the United States, and that we need further research on what common factors create the dynamics so frequently observe in housing markets across the developed world.

The paper is organized as follows. Section 2 provides an overview of the Danish housing and mortgage markets, section 3 provides a theoretical framework, section 4 details the data and the methodology for estimating a repeat sales price index. Section 5 documents the shape and determinants of the Danish housing market cycle in the 2000, section 6 examines whether fundamentals can explain house price gains, and section 7 concludes.

[6] See also Dam et al. (2011) and Rangvid et al. (2013) for Denmark.

2 Housing and Mortgage Finance in Denmark

Mortgage Market Design

The Danish mortgage system traces its roots back to 1795, when a large fire burned down a quarter of Copenhagen. In order to provide credit for the rebuilding of the city, lenders provided loans secured by properties, funded by issuing bonds to investors (Andersen et al., 2014). Today there are 7 mortgage credit banks which operate independently subject to regulatory oversight. There is no government-sponsored entity that intervenes directly in the mortgage market.[7]

There is no sub-prime lending in Denmark, and there is no continuous credit scoring system. Credit is granted on the condition that the borrower is able to afford a 30-year mortgage, even in the face of increasing interest rates (Ministry of Economic and Business Affairs, 2007). The mortgage banks are required to assess the value of the underlying property and the credit worthiness of the borrowers, and are strictly prohibited from granting a mortgage in excess of 80 percent of the assessed value. Moreover, mortgage banks are legally required to retain all credit risk associated with their lending. The retention of credit risk ensures that the mortgage banks have an incentive to carefully monitor the borrower's financial situation, thus reducing potential concerns over insufficient or reduced monitoring as the driver of boom-bust patterns (Campbell, 2013). During the boom and bust, there are limited concerns over fraudulent income statements, increased securitization or lower lending standards.[8]

Mortgage banks sell the proceeds from loans to investor in the form of mortgage bonds. All individual bonds sold to investors are matched exactly to an underlying mortgage provided to borrowers. In the case of a default, the mortgage bank is legally obliged to replace any defaulting mortgage in the pool backing the bond. The bond holders therefore face no credit risk (provided the issuing lender remains solvent), but instead assume interest rate-

[7]See Campbell (2013), Association of Danish Mortgage Credit Banks (2009) and Danske Bank Markets (2013) for a detailed description of the Danish mortgage system.

[8]For studies on these issues from the United States, see Mian and Sufi (2015) for fraudulent income statements, Keys et al. (2010) and Nadauld and Sherlund (2013) on securitization, and Mian and Sufi (2009) for lower lending standards and expansion of credit to low-quality borrowers.

and pre-payment risk. In over 200 years of operation, no mortgage bond has ever defaulted (Andersen et al., 2014); every single mortgage bond has been repaid in full to investors. As Campbell (2013) notes, the system is set up to give incentives to lenders to monitor borrowers by requiring them to retain credit risk, while transferring interest-rate risk to investors capable of bearing it. Instead of collapsing when the housing market declined, the Danish mortgage market continued operating well and has received considerable praise for its performance in recent years (e.g. Campbell, 2013; International Monetary Fund, 2011).

For borrowers, the Danish mortgage design shares several similarities with the United States. Historically mortgages in both Denmark and the United States consisted of fixed-interest, 30-year contracts with fee-free repayment, where mortgage interest is tax-deductible. Borrowers in Denmark can finance up to 80 percent of any house price purchase using low interest mortgage credit, and a further 15 percent with higher-interest bank debt. The interest rate on mortgage debt is entirely decided by the investors into mortgage bonds, and not by the issuing bank. Mortgage interest is tax deductible, but at a rate that has decreased from 73 percent in 1987 to approximately 50 percent in 1993, to 46 percent between 1993 and 1998, and to 33 percent in 2001. The maximum contract term is 30 years, and borrowers can choose between fixed and variable interest loans. Variable interest loans were introduced in 1996, and deferred amortization mortgages were introduced in October 2003. Deferred amortization mortgages allow the household to postpone repayments of principal for up to 10 years, while retaining the requirement that the mortgage has to be repaid within the 30-year contract. Borrowers are at all times legally allowed to refinance their mortgage to take advantage of lower interest rates, regardless of their current income or the value of their property. Since 1992 borrowers are allowed to extract housing equity using mortgage loans.[9]

Finally, mortgage debt in Denmark is full-recourse. If a borrower defaults, the mortgage bank can trigger a forced sale of the property, where any residual claim is converted into a

[9]See Backman and Lutz (2016) for more detail on the introduction of IO mortgages, Leth-Petersen (2010) and Browning et al. (2013) for an analysis of the 1992 mortgage reform, and Andersen et al. (2014) for an analysis of borrower refinancing decisions.

private claim against the borrower. If the borrower has an outstanding balance after a sale, any residual debt is converted into higher-interest, unsecured bank debt. Mortgage default in Denmark is therefore very costly. This implies that assuming mortgage debt to finance house purchases is riskier than in the United States, as the strategic default option is simply not available. Full recourse mortgages contributed to the far fewer problems with default and foreclosures than in the United States, even though house prices declined by similar amounts (Campbell, 2013). Mortgage arrears as a share of total repayments peaked at 0.6 percent in 2009, whereas non-performing loans to total loans peaked at close to 6 percent in the United States. Palmer (2014) finds that nearly 70 percent of sub-prime defaults were due to losses on home equity, and that strategic defaults were a contributing factor to the decline in U.S. house prices. Campbell et al. (2011) finds that forced sales and foreclosures had a negative impact on house prices in the United States. Such negative externalities are likely not as important in Denmark due to the lower number of defaults and forced repossessions.

Housing

Home-ownership is prevalent in Denmark, and like in the United States, housing represents the largest item on the balance sheet for most households (Campbell and Cocco, 2007). Approximately 60 percent of households were home-owners during at least one year between 1996 and 2010, and with a conservative valuation, housing wealth made up an average of 45 percent of total gross wealth.[10]

Nearly all properties are subject to a residency requirement (bopælspligt), where the property has to be occupied by either the owner or a renter chosen by the owner. Additionally, a renter receives occupation rights after two years of renting, after which the owner is not allowed to take possession of his property again without the explicit consent of the renter.

There are several types of housing in Denmark. The first is the *owner-occupied* housing,

[10]The share of home-owners is 52 percent on average from 1996 to 2010. The conservative valuation comes from the annual tax assessment of property values from Danish Tax and Customs Administration, SKAT. This number underestimates the importance of housing wealth in the population, and the wealth share if housing was estimated at market values is higher.

in the form of apartment (condominiums) and single- and multi-family houses. The market for these properties is liquid, and purchases can be financed by mortgage debt. The second type is *cooperative* housing, which is an indirect form of ownership. Households can buy a share of a cooperative, thereby acquiring the right to reside in a housing unit owned by the cooperative. Since the cooperative owns the unit and reserves the right to use the property as collateral, the purchase cannot be financed by mortgage debt, and is instead financed by higher interest bank debt. The square meter price for cooperative housing is subject to a price ceiling set by the cooperative itself. The third type is *rental*, which may be price controlled. Finally, social housing is provided by non-profit housing associations and made up 20 percent of the housing stock in 2006 (Erlandsen et al., 2006).

Owner-occupied housing is subject to a property-value tax (ejendomsværdiskat) and land-value tax (grundskyld). Prior to 1998 the property-value tax was calculated based on an estimated value contingent on property characteristics, which then became a part of the household's capital income and was taxed accordingly. From 1998 to 2002, the property tax was calculated as a percentage of the property value based on an annual assessment. The property-value tax was frozen in nominal terms in 2002, and afterwards it is calculated as 1 percent of the 2002 tax valuation for values up to a threshold of 3,040,000 DKK (408.000 EUR), and 3 percent of the value above this threshold. The land value is based on an assessment conducted by Danish Tax and Customs Administration ($SKAT$). The tax is set by the local municipality and is limited to be between 0.16 and 0.34 percent of land values. Property owners are not subject to a capital gains tax, provided that they have occupied the property with the purpose of permanent residence at some time during ownership. Temporary occupation does not qualify a household for a tax exemption, but the owner does not need to live in the property at the time of the sale.

3 Theoretical Framework

In real estate economics the benchmark "user-cost" model provides the foundation for understanding house price changes (Poterba, 1984). In the model a single price for housing, paid by all owners, is derived from an inter-temporal no-arbitrage condition. The value of housing today equals the net benefit of owning today, plus the discounted property value tomorrow: $P_t = B_t + \frac{E(P_{t+1})}{1+r}$. Using recursive substitution, the fundamental value for housing can be written as:

$$P = E\left(\sum_{j=0}^{\infty}(1+r)^{-j}B_{t+j}\right), \tag{1}$$

where B_t is the *net* benefit of owning after costs, and $1/(1+r)$ is a discount factor.[11] House prices thus reflect the sum of discounted net benefit of owning. House price changes must come from changes in the fundamental value B_t, where any change in prices is due to either changing gross benefits, R_t, or due to changes in the annual cost of ownership, the user-cost u_t. While R_t is unobserved, it is occasionally approximated by the market rent for housing, i.e. the rental cost. The user cost can be written as:

$$u_t = P_t(\omega_t + (1 - \tau_t^m)r_t^m + \delta_t + \gamma_t - g_{t+1}). \tag{2}$$

This equation reflects costs and offsetting benefits of owning. The first term is the one-year property tax, ω_t. The second term is the annual mortgage cost $P_t(1 - \tau_t^m)r_t^m$, calculated as the mortgage rate r_t^m after mortgage deductions τ_t^m. The third term δ_t reflects maintenance costs and capital depreciation, and the fourth term γ_t is a risk premium to compensate home-owners for a higher risk of owning versus renting. The final term is expected growth in house prices g_{t+1}. The sum of these terms gives the annual cost of ownership.

In equilibrium the annual cost of ownership is equal to the annual cost for renting the same property. A change in the annual cost of ownership have to be compensated by changing house prices, or equivalently, an increase in gross benefits must be accompanied by an increase in house prices to maintain the equilibrium. Consider the below equation:

$$R_t = P_t u_t, \tag{3}$$

where R_t is the annual rental cost, and u_t is the user cost of housing (the annual cost of

[11] The above expression imposes a transversality condition to rule out non-fundamental factors.

housing per unit of property value). Changes in the price of housing P_t derive from changes in either the rental value R_t, or through changes in the user cost u_t. This implies that changes in the interest rate or changes in the gross value give rise to empirically predictable changes in house prices.

The above model addresses the demand side of housing. However, the spatial and time-series patters in housing are difficult to explain in a rational user-cost model (Wheaton, 1999). Interest rates, for example, are set on a national level, which means that rationalizing differences across locations is difficult. Glaeser et al. (2008) postulate that a shock can interact with housing supply to produce differential rates of growth in prices. The time it takes for supply to expand and re-establish equilibrium prices leads to a period where prices are above their fundamental level. The more inelastic housing supply is, the longer the adjustment takes. Saiz (2010) shows that housing supply is a strong predictor of both the level and growth rate of house prices. Hetserogeneity in housing supply helps to explain differential increases in prices across locations, and why house prices tend to display short-term momentum and long-run mean reversion.

4 Data

All property transactions in Denmark are listed in the Danish Gazette (*Statstidende*) as a part of the judicial process of transferring ownership, and I use this data to construct house price indices for each Danish municipalities. The register contains data on the sale price, the percentage sold, the date of purchase, the date ownership is assumed, the municipality where the property is located, and an identification number for each property. To ensure that property characteristics are unchanged between transactions, I obtain year-over-year property characteristics through the Housing Register (*Bygnings- og Boligregister, BBR*). The Housing Register covers all properties and is continuously updated by municipalities with new information, in particular from planning permissions.[12] The register contains data

[12]Planning permissions is required e.g. for larger renovations, for merging two apartments, for additions to a house, or for any renovation that involves changes the plumbing.

on whether the property is a single-family house or apartment, interior size, basement size, the number of bathrooms and kitchens, and construction year. I match each property to its owner to identify buyers and sellers.

I further collect demographics and financial information from the official Danish Civil Registration System (*CPR Registreret*). I collect demographic data including date of birth, marital history (marriages, divorces, and widowhoods) and date of death. This data includes a unique identification of all individuals across time, which I use to identify within family-trades and trades due to divorce or death.[13]

In addition, I collect financial information from SKAT. This information is supplied to SKAT through third-party reporting, which ensures that the information is comprehensive and accurate. I collect data on disposable income, wealth, mortgage debt, and mortgage interest payments. Disposable income is defined as the sum of income after taxes, interest payments, rental value of owned properties, alimony payments and repaid social benefits. Mortgage debt is the market value of each individual's mortgage bond, which by design is slightly larger than the actual mortgage size (see Andersen et al., 2014, for more details). I define owners as individuals with positive registered housing wealth, and conversely renters as individuals without registered housing wealth.[14] All individuals are aggregated into households using a unique family-identifier.

I use administrative data on interest payments for mortgage and bank debt to calculate an actual housing burden ratio as interest payments divided by income. I calculate buyer income as the weighted average of all individuals who purchase the property, where the weights is the percentage that they purchase. Further, I calculate leverage as buyer mortgage divided by the sales price.

Finally, I construct several municipality level variables. Housing supply is calculated as the square meter size of all registered properties per municipality, divided by the square meter size of the municipality. Population density is the number of households divided by

[13]Property ownership can be transferred within a family (to grandparents, parents or children) at a minimum price equal to the latest public valuation minus 15%.

[14]The owner of cooperative housing are not considered as owner in this definition, as the value of cooperative housing is not available in the data.

municipality size in square meters. I define a measure of income inequality as the income of households in the 90th percentile divided by the income of households in the 50th percentile.

4.1 A Repeat-Sales Index

It is difficult to characterize a "typical" house. Houses are distinct, where size, location, type of property and property quality can vary substantially between different areas and across time. This presents a problem for measuring changes in house prices over time, as variation over time in traded property characteristics can introduce bias into the estimation of a house price index.[15] Furthermore, observed transactions are infrequent, as most properties are only traded on single occasions. Several approaches have been suggested to address these issues, where perhaps the most prominent approach is the repeat-sales price methodology first introduced by Bailey et al. (1963), and later refined by Case and Shiller (1987, 1989). The repeat-sales methodology attempts to circumvent the problem of heterogeneous properties by comparing the price of the same property across time. In the repeat-sales procedure the data requirements are minimal and it is not necessary to specify functional form for the estimation.

Formally, following Harding et al. (2007), consider the equations for the price of a property at time t and $t + \tau$:

$$P_t = e^{\gamma_t} f(X_t; \beta_t), \tag{4a}$$

and

$$P_{t+\tau} = e^{\gamma_{t+\tau}} f(X_{t+\tau}; \beta_{t+\tau}), \tag{4b}$$

where $f(X_t; \beta_t)$ is an unknown function of the period-specific characteristics of the property (X) and their shadow price (β). The characteristics in X include both area- and property-specific characteristics. The terms γ_t and $\gamma_{t+\tau}$ are time varying factors that are specific to the housing market in which the property is located.

[15] A municipality reform in 2006 provides further difficulty in Denmark. There is no disaggregated, high-frequency index available for the full time period.

Suppose now that X and β remain constant over time. Substituting 4a into 4b gives:

$$P_{t+\tau} = e^{\gamma_{t+\tau}-\gamma_t} P_t. \tag{5}$$

After taking logs and rearranging, I get that the difference in prices between time t and $t+\tau$ is:

$$\log \frac{P_{t+\tau}}{P_t} = \gamma_{t+\tau} - \gamma_t \tag{6}$$

Under the assumption that X and β are time-invariant, $f(X_t;\beta_t)$ drops out of the model, and it is not necessary to specify its functional form. The percentage change in quality adjusted prices is measured as the difference between $\gamma_{t+\tau}$ and γ_t.

4.2 Estimation

Estimation of a repeat-sales index requires several methodological choices. I use transactions data for single-family houses and owner-occupied apartments from 1994 to 2010, a total of 539,452 transactions. I follow convention in the literature and exclude non arm-length transactions, transactions with short holding period, outliers in sales prices and outliers in house price growth, as they may not be representative of market prices.[16] Specifically, I exclude trades between family members, sales due to divorce and death, sales-pair with a holding period of less than 2 quarters, sales where the property is transacted multiple times per year, and the top and bottom 1 percent of sales price and price growth.[17] Table 8 in the appendix shows the details of the sample selection.

The equation of interest is equation (6), and its sample equivalent:

$$\log \frac{P_{t+\tau,i}}{P_{t,i}} = \sum_{t=1}^{\tau_i} \gamma_t D_{t,i} + \omega_{t,i} \qquad \text{for all properties } i = 1, \ldots, n \tag{7}$$

where $\omega_{t,i}$ is an error term, and $D_{t,i}$ equals -1, 0 or 1 depending on whether the property in

[16] Non arm-length transactions are typically not sold at market prices, and a short holding period may be because professional house buyers renovate the property with the intention to re-sell it at a higher price. Additionally, a distressed sale may occur due to job loss or divorce.

[17] It is not possible to identify buyers and sellers if the property is transacted more than once a year.

period t is traded for the first time, not traded, or traded for the second time, respectively. The time dimension is quarterly. Under the assumption that $\omega_{t,i}$ has zero mean and constant variance, equation (7) can be estimated with OLS, and the exponentiated coefficient of γ_t is interpreted as the quality-adjusted price index.[18] Case and Shiller (1987) suggest that observations with a long time between sales should be given less weight in the estimation as the error term is likely related to the length of time between transactions. I use the following method to down-weight observations. First, I estimate equation (6) by OLS to obtain the vector of regression residuals. Second, I run a regression of the squared residuals on a constant term and the time interval between sales. Third, I re-estimate equation (6) where each observation is weighted by the square root of the fitted value for the second step.[19]

The main disadvantage of the repeat-sales methodology is that it discards a large fraction of all observations, as only properties traded twice or more are included (Gatzlaff and Haurin, 1997; Clapp et al., 1991; Jiang et al., 2015). In other words, while the methodology avoids a specification-bias, it may introduce a sample selection bias, as properties traded repeatedly may not be representative of the entire market. Table 1 provide summary statistics on observed characteristics for single transactions and repeat sale transactions, and t-test for the difference between single and repeat sales.[20] There are 539,452 properties transacted two times or more during the sample period, and 267,318 transactions where the property was sold only once. The average square meter price for single-sale (repeat-sales) transactions is 9,018 DKK (9,686 DKK), the average size is 127 (109) square meters and the average property age is 51 (56) years. There is a statistically significant difference between single- and repeat-sales for all three categories.

Even with these differences however, the repeat-sales index remains the most appropriate methodology to use for this study. To see why, consider the alternative estimation methods.

[18] For more details and a practical guide to different house price indexes, see Balk et al. (2013).

[19] A robustness check confirms that the results are similar if do not down-weight observation based on time between sales.

[20] The equivalent table when the sample is split between single-family houses and owner-occupied apartments can be found in table 9 and 10 in the Appendix.

One alternative is the *hedonic house price* methodology, which uses a bundle of property characteristics and their associated prices to derive a price index. This methodology requires a correctly specified functional forms for each characteristic, an inherently difficult proposition. Shiller (2008) argues that a repeat sales index is the "only way to go", as there are too many different permutations of hedonic data that could possibly allow the researcher to chose their own results. Another alternative is the *appraisal-based* methodology, which uses data from appraisals (normally tax appraisals) to calculate an index. Tax values are generally available for all properties, which makes this methodology attractive. Indeed, the official property index available from Denmark Statistics is constructed with the appraisal-based method. However, the appraisal-based index relies on having a good assessment of property values. High quality on-site value assessments in Denmark was conducted annually by SKAT prior to 2002. After the freeze of nominal property tax values in 2002 the appraisal is no longer conducted on-site, and housing values are instead estimated from a model of housing transactions. This likely lowers the quality of the appraisal, and therefore limits the attractiveness of the index. Appendix C compares the estimated repeat-sales indices with the official Denmark Statistics property indices, and find a strong level of correspondence between the two different approaches prior to 2002, but also finds that there are increasing differences between the two methodologies after the on-site assessment was abolished in 2002.

Due to the dependency on quality of assessments and to the inherent difficulty in specifying a functional form for a hedonic index, I chose to construct a repeat-sales index. With the repeat-sales index, there is no dependence on assessments, and there is no specification bias. As the repeat-sales methodology is prominently used in the United States, this also enables an easier comparison to US house price indices.

5 Results

This section describes the Danish housing market from 1996 to 2010, with a focus on house price developments on a municipal level. There is considerable variation across locations in both the timing and the amplitude of house price growth. In fact, the geographical clustering, the difference in timing and the difference in amplitude during this period are reminiscent of what Sinai (2013) and Abel and Deitz (2010) document for the US housing market between 1980 and 2010. Further, Danish house prices display the type of short-run momentum and long-run mean reversion that Glaeser et al. (2014) and Head et al. (2014) document for the United States.

5.1 House Price Growth Over Time

The Danish housing market between 1996 and 2010 is characterized by three distinct phases, which I will refer to as the *pre-boom*, the *boom* and the *bust* period. Figure 2 plots the distribution of annual house price growth over time. Within each year-quarter observation there are 93 municipalities, where the dots indicate the median house price growth in the period and the black box indicates the 25th and 75 percentiles. In the pre-boom period the median annual growth rate was 6 percent, consistent with growing real incomes, lower interest rates and low unemployment rates (Dam et al., 2011). During the *boom period* between 2004 and 2007 the median growth rate was 11 percent, and house price volatility was substantially higher. The peak median growth rate was over 20 percent per year, a rate at which house prices would double in approximately 4 years. Third, during the *bust period* from 2007 to 2009, the median price growth was negative 6.4 percent. During this time most of the gains from the boom period were erased, and at the end of this period prices had returned to their pre-boom level. The over-arching pattern of a relatively stable period followed by periods of substantial volatility and subsequent reversion in price growth is also found in the United States (Glaeser and Nathanson, 2015; Sinai, 2013).

However, even within booms and busts, there are differences in timing. Figure 3 shows that municipality-specific peaks in house prices occurred over a 2-and-a-half-year period, and that a large fraction of the peaks took place prior to the outbreak of the financial crisis in 2008. The date at which price declines stopped and prices started growing again (the through) also differs across municipalities. In certain municipalities house prices rebounded quickly and started growing again already in early 2009, but other municipalities had not seen the end of price declines in 2010.[21] The differences in peaks present a challenge for theoretical models that attribute the end of the boom to national factors. For example, it seems unlikely that reverberation from the onset of the financial crisis can explain that the peak in certain areas of Denmark occurred in 2006, or that increasing interest rates in 2006 can explain that the decline in prices started in 2008.

Figure 4 shows how the three periods are related by plotting changes in house prices in the pre-boom period against changes in house price in the boom period in a), and price changes in the boom against price changes from the peak to the trough in b). Somewhat surprisingly, and in contrast to the evidence from US housing markets presented in Glaeser and Nathanson (2015), the correlation between pre-boom and boom house price growth is low, and several areas that experienced substantial increase in prices in the boom period experienced low growth in the pre-boom period. The substantial mean reversion observed in b) is familiar from studies of the United States' housing market.

House price dynamics over time are well documented for the United States. Two empirical regularities that regularly appear in studies of the United States' housing market are long-run mean reversion and short-term momentum (Glaeser et al., 2014; Glaeser and Nathanson, 2015). If housing markets are efficient and house prices follow a random walk, the coefficient on past house prices should be zero. I investigate whether Danish house prices exhibit the same patterns in table 3, which shows the result when log price growth is regressed on lagged price growth. And indeed, the observed pattern is similar in Denmark and the US. Price growth displays serial correlation at high frequencies and mean revert at longer frequencies.[22] The estimated coefficients on the 1-year lag of 0.18 shows evidence of short-run momentum, although it is substantially lower than the estimated coefficients of 0.6 in Glaeser et al. (2014) and 0.75 in Head et al. (2014). The negative coefficient on the

[21] House price peaks and troughs are more concentrated in time in Denmark than in the United States. There are several areas in the United States with a peak in house prices in 2000 or 2001, although a majority of peaks occurred between 2005 and 2007 (Sinai, 2013; Ferreira and Gyourko, 2012).

[22] The regression equation is: $\Delta r_{k,t} = \Delta P_{k,t-j} + \kappa_k + \epsilon_{k,t}$ for $j = 1, 2, 3, 5$, where $\Delta P_{k,t}$ is the log j-th difference in the repeat sales index in year t for municipality k, and κ_k are municipality dummies.

3-year lag implies that house prices mean-revert, which is consistent with the evidence in previously mentioned studies. The one-year serial correlation is difficult to reconcile with rational models of housing market, as fundamental factors such as interest rates or rental prices do not display high enough variation over time to justify the strong movements of house prices over time (Glaeser and Nathanson, 2015).[23]

The serial correlation is not uniform across municipalities. Glaeser et al. (2008) show how elastic supply mitigates housing bubbles by allowing a quicker supply response. If supply is elastic and can be added quickly, then house prices should reflect construction cost. If supply is inelastic however, prices may increase for a longer period of time before new construction brings prices back down. The implication of this is that there should be less momentum in more elastic areas. Panel B reports the results when the one-year lag of house price changes is interacted with 4 groups of housing supply, where the 1st group is low (unconstrained) housing supply, and the 4th group is the most constrained supply. The coefficient on one-year lagged changes in prices is negative in municipalities with low housing supply, and is positive and significant in areas with constrained supply. These result indicate that supply is an important determinant of house price dynamics.

Finally, the degree of serial correlation differs across time. Panel C shows the coefficients where the one-year lag in house price growth is interacted with year dummies. Figure 5 plots the coefficients and the associated confidence intervals. The coefficients are the highest during the boom years of 2005 and 2006, and during the downturn of 2008 and 2009. This pattern is also observed in the U.S. housing market during the same time period (compare figure 5 with figure 11.4 in Glaeser and Nathanson, 2015).

5.2 Geographic Distribution

How is house price growth distributed geographically? Figure 6 plots the growth in house prices for each municipality in Denmark for different periods. Panel (a) plots the increase

[23]It is possible to rationalize the observed empirical patterns in alternative models of the housing market. The positive coefficients can be due to costly learning, where households learn about the state of the housing market from prices, or due to search and matching as in Head et al. (2014).

from 1998Q1 up to 2004Q1 (pre-boom period); panel (b) plots the increase in prices from 2004Q1 to the municipality-specific peaks; and panel (c) plots the decrease in prices from the peak to trough. Note that values in panel (c) denote decreases in prices. The largest price increases in the pre-boom period occurred in the eastern regions of Denmark (specifically in the area around Copenhagen), while smallest price changes occurred in western Denmark, where house prices declined in some municipalities and growth was generally low. During the boom, prices increased substantially in all local markets – the average increase was 54 percent from 2003Q3 to the peak in house prices. The largest price increases are again found in the area around Copenhagen, on the east coast of Denmark. In contrast to the pre-boom period however, the largest increases were not concentrated only in eastern Denmark. Two other high growth areas of the boom are located around the cities of Odense and Aarhus, the second and third largest cities in Denmark; areas that were not among the fastest growing municipalities prior to 2003. During the bust, all municipalities experienced substantial decreases in prices – the smallest decrease was 14 percent from peak to trough, and the average decrease was 31 percent. Price declines were concentrated in areas that previously experienced substantial price growth, in particular the area around Copenhagen.

Table 4 presents evidence on differences in observable characteristics between municipalities. Specifically, I present results for municipality characteristics from 2002, before the boom occurred. All municipalities are divided into four groups based on price appreciation during the boom in columns (1)-(4), and the last column shows the results of a t-test of differences between the first and fourth column. Between 2004Q1 and the peak prices appreciated by 40 percent on average for the 23 municipalities with the lowest appreciation in column 1, and by 71 percent for the municipalities with the largest appreciation in column 4. Note that even the group of municipalities with the lowest appreciation rate experienced a substantial increase in prices during the housing boom. However, most of these gains were reversed during the boom. For the municipalities with the largest appreciation (column 4), a 69% increase followed by a 39% decline meant that house prices increased by just 3% between 2004 and the trough. Average income, the average income of renters below the age of 35 (young renters), population density and income inequality (as measured by the ratio of the 90th income percentile and the 50th income percentile for each municipality, the P90/P50 ratio) were all significantly larger in high-growth areas compared to low-growth areas. The boom was larger in magnitude in municipalities with a higher initial price level, higher levels of income, higher levels of inequality, and in municipalities with more constrained housing and higher population density. Taken together, this suggests that the boom was mainly a city phenomenon, and that consistent with the theory of Glaeser et al. (2008), house price growth was higher in areas with less elastic housing supply, only to decline more when prices adjusted.

Table 5 presents the results of a regression of municipality-level growth in house prices during the boom separately on several variables measured in 2002. Price increases during the boom is positively and significantly correlated with higher levels of income, whether measured by the average income, income for renters below the age of 35, or buyer income. The P90 / P50 ratio, a measure of income inequality, is also positively correlated with house price appreciation, showing that more unequal municipalities experienced a larger increase in prices. Neither the unemployment rate nor the population size in 2002 are significantly related to house price growth. Moreover, non-income related variables such as housing supply, the pre-boom increase, the square meter price, and population density are all positively correlated with house price appreciation. The square meter price and density explain 39 and 30 percent of the variation in house price growth across municipalities respectively, and buyer income explains 20 percent.

Table 6 further characterizes where the boom occurred. Column (1) shows the result when price increases during the boom are regressed on all the above variables related to income and labor markets in 2002. While the signs remain positive for income and the P90 / P50 ratio, none of the income variables are significant. The level of unemployment in 2002 is the only significant variable. Column (2) shows that municipalities with higher initial house prices experienced higher house price growth during the boom. This positive correlation remains in column (3), where all variables are included. In addition to the square meter price, column (3) shows that log population and pre-boom house price growth are negatively correlated with boom growth. Overall, the results suggest that about half of the variation in house prices can be explained by observed characteristics of municipalities.

6 Explaining the Boom

There are two facts that require explanation. The first is the spatial differences across municipalities in the size of the boom. Section 5 already covered differences across municipalities in terms of housing supply, and other explanations related to levels. This section will extend this analysis to cover changes in variables, such as income, that may explain the differential pattern observed across municipalities. If income changes are substantially higher in Copenhagen for example, this explain why house prices expanded more rapidly in Copenhagen than in other areas.

The second fact that require explanation is the size of the boom itself. I will focus on three potential explanations: an increase in income as a proxy for increasing benefits of housing, a decrease in interest rates to measure the reduced gross cost of housing, and the potential role of expectations in explaining the Danish housing boom.[24] These explanations are motivated by the user-cost model described in section 3.

Income Growth and Differences Across Municipalities

It is difficult to rationalize differences across municipalities within the user-cost model, as the factors that cause house prices to fluctuate generally do not vary on the national level. Mortgage rates are set nationally and can therefore not explain differences across municipalities. While the previous results suggest that differences in housing supply and density can help explain differential increases in prices, an alternative explanation is that the benefit of living in certain locations are higher. For example, living in Copenhagen is

[24] An alternative method for evaluating the benefits of housing is to use rental values as a measure of the annual benefit of owning, and to calculate a price-to-rent ratio. First, owned and rented properties may differ significantly, as Glaeser and Gyourko (2009) finds. Second, at least a portion of the rental market is price-controlled, and another part of the housing market is subsidized. This violates the assumptions of the user-cost model, which assumes that the rental housing market is free and efficient. Third, there is no municipality-level data on rental prices available in Denmark. Comparing house prices to rent in Denmark is therefore of limited value.

more expensive, which could be because amenities are higher or because incomes are higher. While amenities are difficult to measure, we can examine whether high growth areas also had higher income growth, which thereby could explain differences in house price growth.

I use three different samples when calculating changes in average income; the full sample, only buyers and only young renters. A large fraction of buyers is below 35 years of age, and the income growth for these young households may be relatively more important than the average income in the municipality. Young income growth also proxies for future incomes. Furthermore, Gyourko et al. (2013) show that in some "superstar" cities an increasing number of high-income households crowd out low-income households, leading to high house price appreciation rates. Figure 7 plots the ratio of buyer income to average income for 4 groups based on house price growth during the boom. In municipalities with the highest price growth, the ratio is around 1.35, meaning that the income of buyers is 35 percent higher than the average incomes. In the group with the lowest growth , the ratio is slightly below 1.3. Except for an increase between 2003 and 2004 for the third group, the ratios remain stable over time prior to 2006.

Table 7 investigates differences in income growth rates between high and low growth areas for all households, for buyers and for young households. All incomes increased between 2002 and 2006. However, the largest increased are observed in the lowest growth areas, not the highest growth area. The same pattern is observed for buyer income, which increased by approximately 6 percent for the municipalities in columns (1) - (3), but only 4.40 percent in column (4). For households below the age of 35, there was no statistically significant difference in income growth across municipality. It is therefore difficult to explain the spatial differences in house price growth through income changes alone – the low growth areas in column (1) actually experienced higher income growth.

The Decline in Costs and the Magnitude of the Boom

As the user-cost model predicts, declining costs for ownership lead to a predictable increase in house prices. As depreciation rates and tax rates are relatively stable over time, the major driver of price changes in the user cost model is mortgage interest rates.[25] I therefore focus

[25] Dam et al. (2011) report that the tax freeze was accompanied by an increase in the land-value tax, and

on declines in interest rates as the main change in costs of ownership and as the main cause of rising house prices. In figure 8 the long mortgage rate declines from 5.65% in 2003 to a low of 4.17% in 2005. Interest rates were generally going down over the period, but started rising again in the end of 2005. As an illustration of the effect of the decline in mortgage rate, consider taking out a mortgage of 1,000,000 DKK in the beginning of 2004 when the long term mortgage rate was 5.65 percent.[26] The total interest cost of the mortgage over the 30-year contract is 1,078,049 DKK. When the long-term bond rate declined to a low of 4.17 percent in 2005, a household could increase their borrowing by 43 percent and pay the same total amount over the loan contract.[27] This implies an elasticity of borrowing to interest rates of 29.

The elasticity implied in the above exposition is higher than the econometrically estimated elasticity in the literature. Dam et al. (2011) estimate a model for the Danish housing market and find an elasticity of -15, whereas Himmelberg et al. (2005) estimate an elasticity of -20. In Glaeser et al. (2012), the elasticity ranges from -19 for a naive case where households expect interest rates to remain at the lower level, to -7 in a more comprehensive model where households anticipate mean-reversion in interest rates. As borrowers can fix interest rates in Denmark for 30 years, expected mean-reversion in interest rates may be less important than in countries with variable interest rates. Using this range of estimates, the approximately 1.5 percentage point decline in the long bond rate increased house prices by between 10.5 percent and 30 percentage point between 2003 and 2005. Given that price growth were much higher than this during the boom, especially in high growth areas where the average increase was 65 percent, it is not sufficient to explain the price movements in all municipalities. However, declines in interest rates can explain most of the increases in house prices in low growth areas, where house prices increased by 35 percent. Importantly, note that interest rates increase in late 2005 as house prices continued their ascent. The decline

that the net effect on house prices was negligible.

[26]Himmelberg et al. (2005) recommends using a long-term interest rate, as the expected future interest-rate may be higher than the short-term rate.

[27]When calculating the cost of the contract, I assume an annuity contract where the sum of interest and amortization payments are the same across years, and that the loan is repaid over 30 years.

in house prices began at a much later stage than the increase in interest rates, suggesting that there was another factor that caused the house price to grow in 2006 and 2007.

The data suggests that incomes went up and interest rates went down. To combine these two observations I plot the distribution of interest payments to income (the housing burden) in figure 9, where each line indicates a separate year. The distribution of interest payments to income is almost identical in 2004 and 2005, but shifts to the left in 2006 and 2007. This can be seen more clearly in figure 10, where I plot the average housing burden per quarter in the lowest and highest house price growth groups defined earlier. There was a sharp increase in the housing burden starting in 2006; households were willing to accept a higher interest share as a percentage of income in 2006 and 2007, compared to 2004. Within a user-cost model, the explanation for the willingness of households to accept higher interest payments is normally taken as expectation of capital gains. Higher house price expectations compensate owners for the higher interest payments. Several papers have made the claim that unreasonably high expectations of capital gains were to blame for housing crisis in the United States (Shiller, 2015; Foote et al., 2012; Case et al., 2012), a claim also made in Denmark (Rangvid et al., 2013; Dam et al., 2011). Case et al. (2012) find that new home-owners expected large increases in prices, and that these expectations peaked at the height of the boom. Piazzesi and Schneider (2009) find similar evidence. As there is no long-running survey on expectations in Denmark, this proposition is difficult to test. The data is consistent with such an explanation, as households were willing to pay more for housing relative to income in 2006 and 2007.

Finally, a note on an implicit assumption of the user cost model. As interest rates go down, the user-cost model predicts that house prices go up, which generates large increases in wealth for owners. The increase in wealth can be used to finance the down-payment for the next housing purchases (Ortalo-Magne and Rady, 2006). The usual assumption in the empirical application of the user-cost model is that housing purchases are fully leveraged (**?**).g.][]himmelberg2005assessing. In contrast to this assumption, figure 11 shows that the distribution of buyer leverage for each year between 2004 and 2007 shifts towards the left, showing that leverage is reduced as the boom progresses. The annual cost of housing was therefore not changing by as much as can be inferred from simply observing mortgage rates. This also suggests that the implied risk of a house price fall is lower than what is commonly assumed, as a lower leverage provides an larger buffer against declines in house prices. Indeed, for households concerned with the possibility of a bubble in housing market, a higher equity buffer may be desirable as an insurance policy. Moreover, a higher percentage of equity corresponds to a lower degree of debt, which naturally translates into lower interest-payments and thus makes housing more affordable.

7 Conclusions

This paper has documented several facts about the Danish housing boom. Overall, there are striking similarities between the Danish and the US housing boom, especially given the differences in institutional design. The boom was most prominent in the area surrounding the capital region of Copenhagen, where prices increased very rapidly between 2004 and 2006. These municipalities, where house prices deviated substantially from fundamentals, are characterized by high average incomes, constrained housing supply and high population density. However, the boom was not concentrated to a subset of municipalities. All municipalities experienced substantial increases in prices between 2004 to 2007. The fact that prices increased substantially across all municipalities is suggestive of a national shock affecting all municipalities in 2004. The heterogeneous growth in prices between municipalities and the pattern of structural breaks in house prices suggest that this shock interacted with local area characteristics to produce differentially sized booms.

It is difficult to explain the increase in prices that occurred over this period using fundamental factors only. Neither interest rates nor heterogeneous income growth can fully explain the large fluctuations in house prices observed across Denmark, nor can they explain the differing start and end dates of the boom. Indeed, interest rates declined only until mid 2005, only to increase again afterwards. Even as interest rates started increasing in late 2005, house prices continued rising. There is some suggestive evidence that expectations of capital gains were important in the later stages of the Danish housing boom, as the later stage of the boom cannot be explained by reductions in costs. However, as this is a residual explanation, some caution is required with this interpretation of the Danish housing boom.

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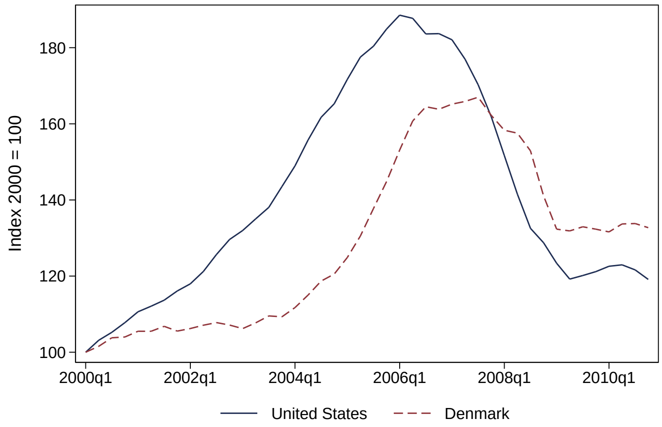
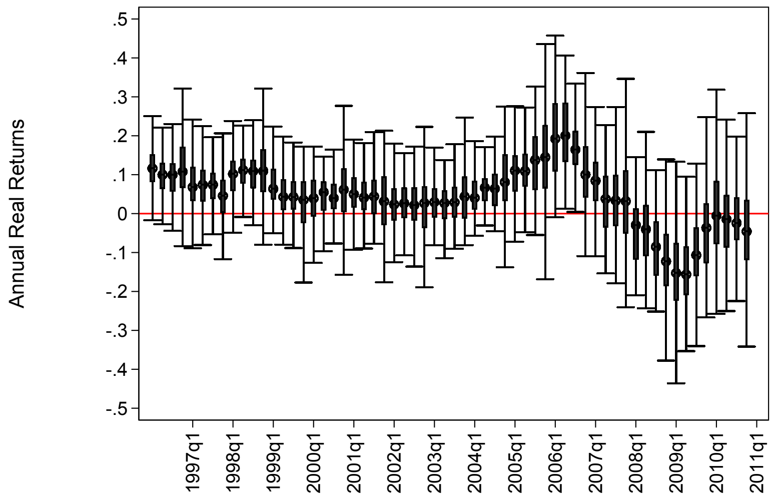
8 Figures

Figure 1:
House Prices in the United States and Denmark (2000Q1=100)



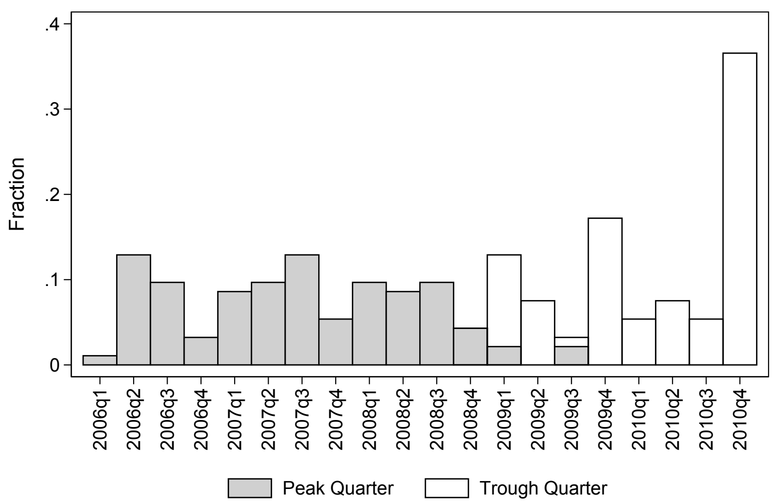
Source: United States: S&P/Case-Shiller 10-City Composite Home Price Index©, Index Jan 2000=100, Quarterly, Seasonally Adjusted. Deflated by the Consumer Price index.

Figure 2: Distribution of Annual House Price Growth



Notes: Figure plots the distribution of year-over-year house price growth across municipalities. The black dot shows the median and the black box ranges from the 25th to the 75th percentile.

Figure 3: Peaks And Troughs in House Prices

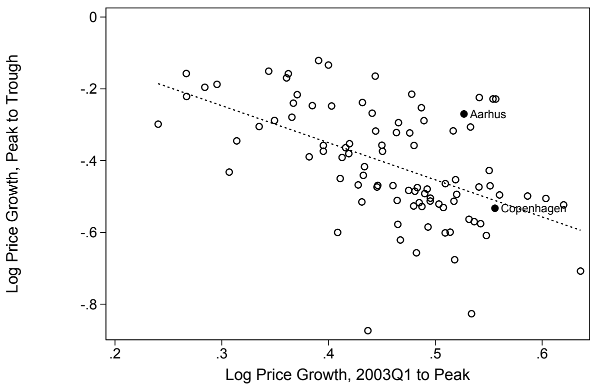


Notes: Figure plots the fraction of municipalities with a peak/trough in house prices in a given quarter. Peaks are defined as the highest value for the municipality house price index before 2010.

Figure 4: Momentum and Mean Reversion

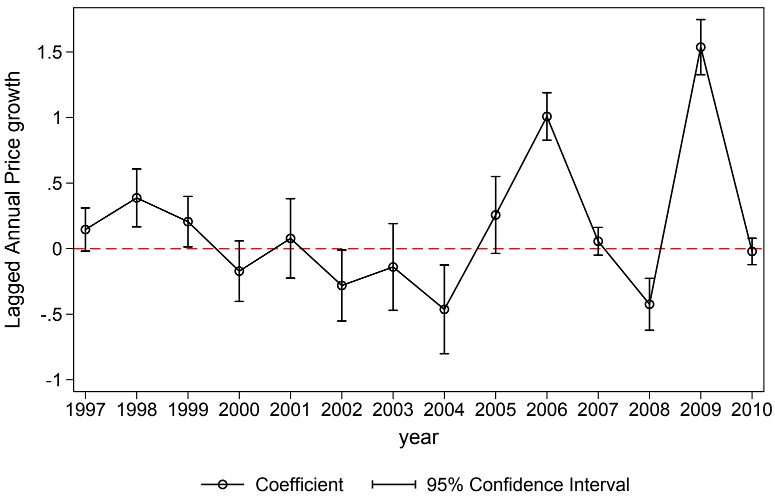
a) Pre-Boom versus Boom

b) Boom versus Bust



Notes: Percentage increase in house prices for each municipality over the specified period. Pre-boom period occur between 1998Q2 to 2003Q3. Boom period occur between 2003Q3 and the municipality-specific peak in house prices. Bust period begin at the peak in house prices and end in the municipality-specific trough.

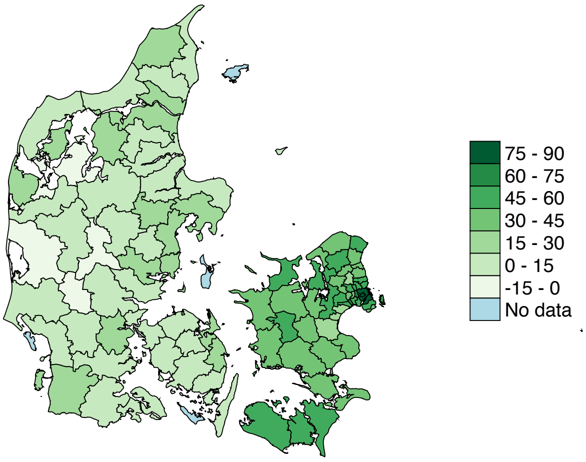
Figure 5: Coefficient on annual price growth on lag of annual price growth



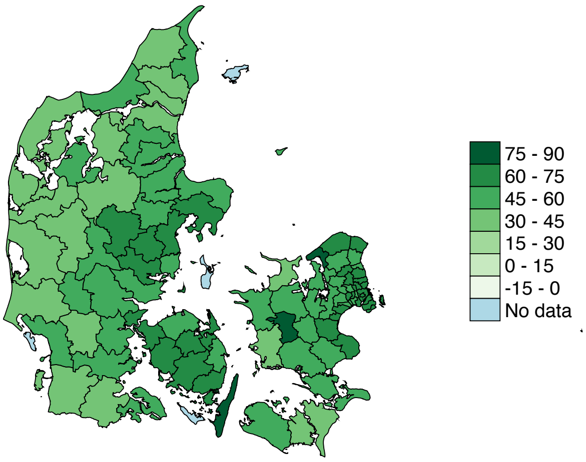
Notes: Dependent variable is the first quarter year-over-year price change. Figure plots the coefficients and a 95 % confidence interval from a regression of annual price growth on lagged annual price growth interacted with dummies for years and municipality fixed effects. Coefficients available in table form in Table 3.

Figure 6: Spatial Distribution of House Price Growth

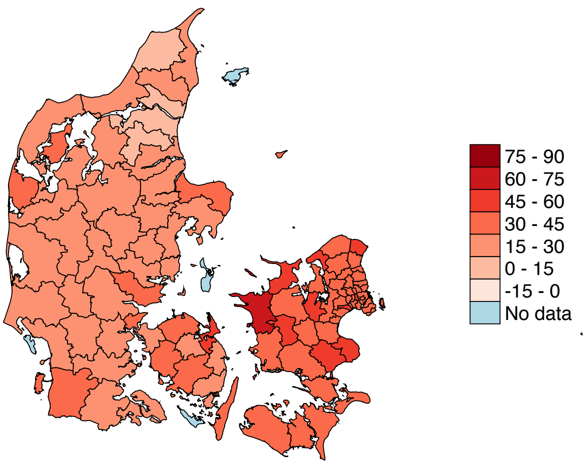
(a) Increase in Prices during Pre-boom Period



(b) Increase in Prices during Boom Period

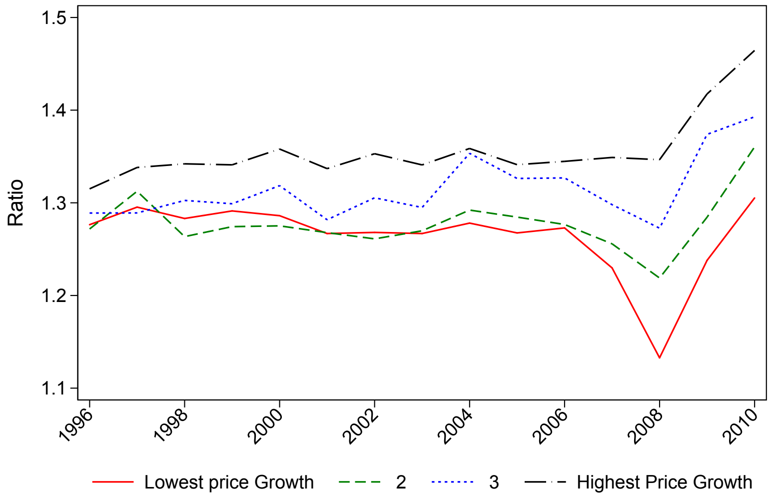


(c) Decrease in Prices During Bust Period



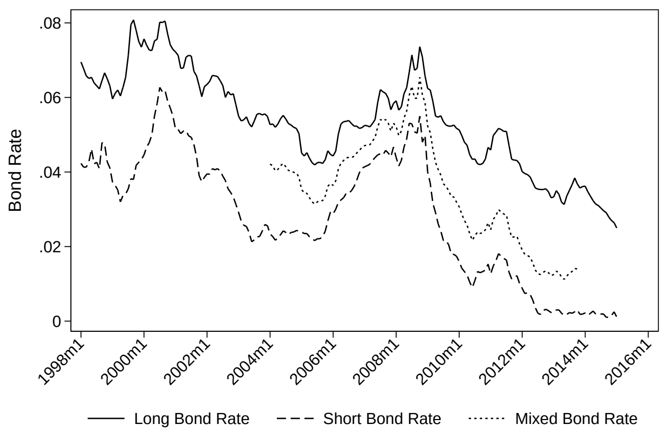
Notes: Percentage increase in house prices for each municipality over the specified period. Pre-boom period occur between 1998Q2 to 2003Q3. Boom period occur between 2003Q3 and the municipality-specific peak in house prices. Bust period begin at the peak in house prices and end in the municipality-specific trough.

Figure 7: Ratio of Buyer Income to Average Income



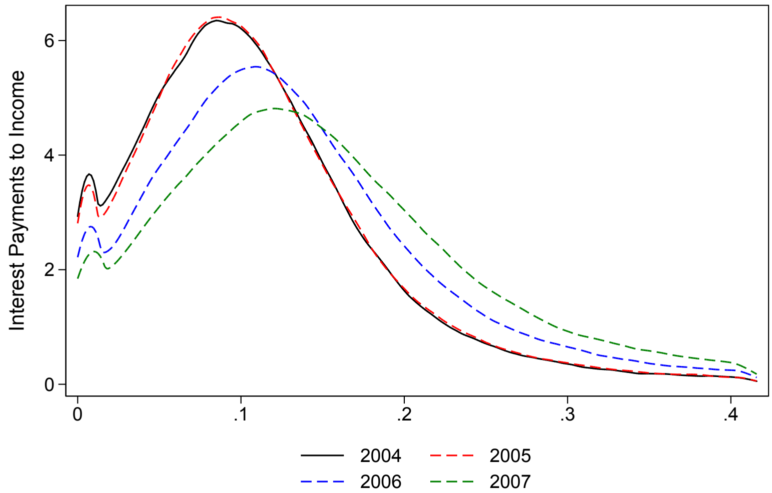
Notes: AS

Figure 8: Mortgage Interest Rate



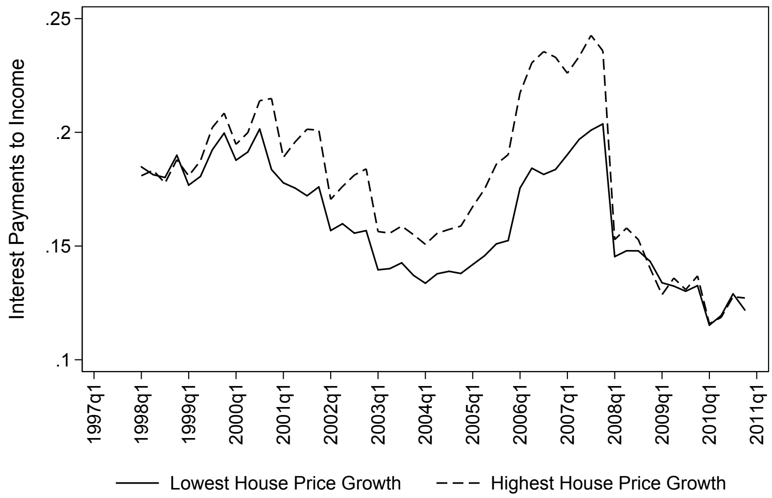
Notes: Short and long term mortgage bond rate in DKK. Source: The Association of Danish Mortgage Banks and author's calculation.

Figure 9: Distribution of Housing Burden



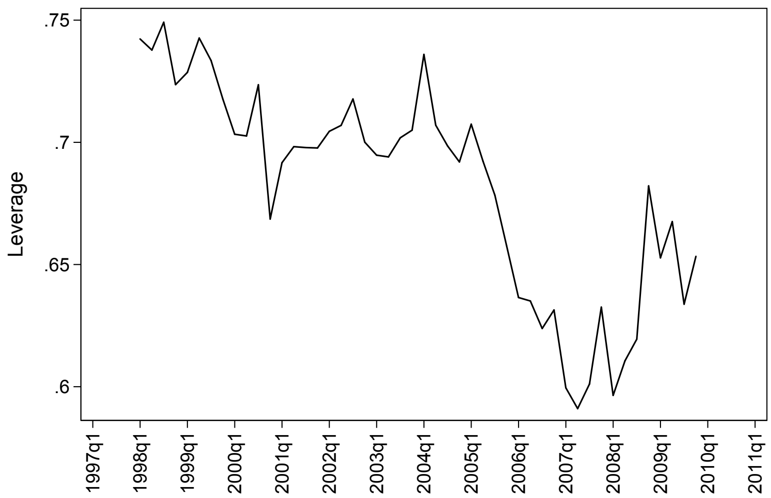
Notes: The sum of interest payment on mortgage debt and bank debt, divided by disposable income, in year t for households who purchased households in year $t-1$.

Figure 10: Housing Burden over Time



Notes: The average housing burden over time, calculated as the sum of interest payment on mortgage debt and bank debt, divided by income, in year t for households who purchased households in year $t-1$. Lowest House Price growth (Highest House Price Growth) is the average housing burden for households in the group of municipalities that experienced the lowest (highest) increases in house prices over the boom period.

Figure 11: Buyer Leverage



Notes: Seasonally adjusted average leverage for buyers in each quarter.

9 Tables

Table 1:
Single and Repeat Sales

	(1) Single Sale	(2) Repeat Sale	(3) T-test
Square Meter Price	9,018	9,686	-668***
	(5,935)	(5,872)	[-48]
Square Meters Size	127	109	18***
	(43)	(50)	[169]
Property Age	51	56	-6***
	(37)	(37)	[-64]
N	267,318	539,452	806,770

Notes: Summary statistics for all property transactions from 1994 to 2010. The corresponding statistics for owner-occupied apartments and single-family houses are available in Table 9 and 10 respectively. Single Sale in Column 1 are transactions where the property is transacted a single time, and repeat sale in Column 2 where a property is transacted two or more times. Column 3 provides T-tests for the difference in means. Size (M^2) is the square meter residential property size. Price (M^2) is calculated as the observed transactions price divided by the square meter size of the property. Property Age is the age of the building. Standard deviations in parenthesis, and t-statistics in brackets.

Table 2:
Single and Repeat Sales Over Time

	Panel A: Single Sale			Panel B: Repeat Sale		
	Price (M^2)	Size (M^2)	Age	Price (M^2)	Size (M^2)	Age
1994	6,039	126	44	5,877	112	49
1995	6,308	123	46	6,083	109	50
1996	6,928	123	48	6,779	108	52
1997	7,214	124	48	7,170	106	53
1998	7,943	124	51	7,982	106	55
1999	8,209	125	52	8,610	105	55
2000	8,609	127	52	9,065	107	56
2001	8,860	127	52	9,626	107	57
2002	8,901	129	51	9,880	107	56
2003	9,080	129	52	10,141	108	57
2004	9,733	130	52	11,072	109	58
2005	10,528	130	54	12,276	109	60
2006	11,642	131	55	13,330	111	62
2007	12,442	128	54	13,518	111	61
2008	11,668	128	54	12,566	112	61
2009	11,003	126	52	11,801	112	61
2010	11,411	127	52	12,251	112	61
N	267,318	267,318	267,318	539,452	539,452	539,452

Notes: Summary statistics for all property transactions from 1994 to 2010. Panel A show statistics for properties transacted a single time, and Panel B show statistics for properties transacted a mulitple times. Size (M^2) is the square meter residential property size. Price (M^2) is calculated as the observed transactions price divided by the square meter size of the property. Property Age is the age of the building.

Table 3:
Serial Correlation in Prices

	Coefficient	SE	R-Squared	Obs
Panel A: Different Lags				
$\Delta P_{i,t-1}$	.18	.03	.03	1302
$\Delta P_{i,t-2}$	-.1	.04	.01	1209
$\Delta P_{i,t-3}$	-.63	.04	.17	1116
$\Delta P_{i,t-5}$	-.01	.07	0	930
Panel B: Housing Supply - One Year Lags				
$\Delta P_{i,t-1}$ X Housing Supply = 1	-.16	.06	.02	322
$\Delta P_{i,t-1}$ X Housing Supply = 2	.16	.06	.02	294
$\Delta P_{i,t-1}$ X Housing Supply = 3	.35	.05	.12	350
$\Delta P_{i,t-1}$ X Housing Supply = 4	.26	.05	.07	336
Panel C: Year by Year Regressions				
$\Delta P_{i,t-1}$ X 1997	.15	.08	.26	1302
$\Delta P_{i,t-1}$ X 1998	.39	.11	.26	1302
$\Delta P_{i,t-1}$ X 1999	.21	.1	.26	1302
$\Delta P_{i,t-1}$ X 2000	-.17	.12	.26	1302
$\Delta P_{i,t-1}$ X 2001	.08	.15	.26	1302
$\Delta P_{i,t-1}$ X 2002	-.28	.14	.26	1302
$\Delta P_{i,t-1}$ X 2003	-.14	.17	.26	1302
$\Delta P_{i,t-1}$ X 2004	-.46	.17	.26	1302
$\Delta P_{i,t-1}$ X 2005	.26	.15	.26	1302
$\Delta P_{i,t-1}$ X 2006	1.01	.09	.26	1302
$\Delta P_{i,t-1}$ X 2007	.06	.05	.26	1302
$\Delta P_{i,t-1}$ X 2008	-.42	.1	.26	1302
$\Delta P_{i,t-1}$ X 2009	1.54	.11	.26	1302
$\Delta P_{i,t-1}$ X 2010	-.02	.05	.26	1302

Notes: Dependent variable is annual change in house prices.

Table 4:
Summary Statistics

	Lowest	2	3	Highest	(Highest)-(Lowest)
Annualized Pre-Boom Price Growth	2	4	5	5	3***
	(1)	(3)	(2)	(3)	[4]
Annualized Boom Price Growth	5	7	10	10	5***
	(1)	(1)	(1)	(2)	[13]
Annualized Bust Price Growth	-13	-16	-16	-19	-7**
	(12)	(10)	(8)	(8)	[-2]
Boom Price Growth	35	47	57	65	31***
	(7)	(3)	(2)	(4)	[17]
Bust Price Growth	-23	-31	-37	-39	-16***
	(8)	(10)	(8)	(9)	[-7]
Panel A: Summary Statistics for 2002					
Square Meter Prices	6,131	7,840	11,088	11,650	5,519***
	(1,652)	(2,836)	(3,224)	(3,786)	[7]
Income	312,071	335,551	359,894	350,255	38,184***
	(11,622)	(50,928)	(53,060)	(57,193)	[3]
Income, Young Renters	404,581	425,092	459,201	456,297	51,716***
	(18,461)	(59,635)	(58,632)	(55,659)	[4]
Number of Households	27,868	22,617	24,877	37,419	9,551
	(17,703)	(13,455)	(29,161)	(60,429)	[1]
Population Density	82	196	571	1,369	1,287**
	(69)	(301)	(699)	(2,314)	[3]
Apartments	0.18	0.13	0.23	0.25	0.06
	(0.18)	(0.18)	(0.32)	(0.28)	[0.91]
Pct. Owners	0.63	0.64	0.57	0.54	-0.09***
	(0.07)	(0.07)	(0.13)	(0.13)	[-3.03]
Housing Supply	0.01	0.05	0.18	0.30	0.29***
	(0.01)	(0.12)	(0.27)	(0.38)	[3.72]
Mortgage Rate	0.07	0.07	0.07	0.07	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	[0.67]
Employment Ratio	0.96	0.97	0.97	0.97	0.00
	(0.01)	(0.01)	(0.01)	(0.01)	[1.24]
P90 / P50 Ratio	2.12	2.12	2.18	2.26	0.15***
	(0.07)	(0.15)	(0.23)	(0.24)	[2.91]

Notes: Summary statistics for four groups municipalities. Groups are based on house price growth between 2003Q3 and the municipality-specific peak in house prices. List of municipalities and groups are provided in Table 11. All variables are averages for municipalities. Five municipalities were excluded due to an insufficient number of transactions. The last column provides a T-test of the difference in means between Lowest and Highest. Standard deviations in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level respectively.

Table 5:
Univariate Regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log Income	0.218***									
	(0.0617)									
Log Income, Young Renters		0.296***								
		(0.0684)								
Log Buyer Income			0.250***							
			(0.0518)							
P90 / P50 Ratio				0.106**						
				(0.0447)						
Unemployment					0.00617					
					(0.00744)					
Log Population						-0.00539				
						(0.0147)				
Log Square Meter Price							0.131***			
							(0.0173)			
Housing Supply								0.112***		
								(0.0311)		
Log Density									0.0350***	
									(0.00556)	
Pre-Boom Price Growth										0.00154***
										(0.000423)
Observations	93	93	93	93	93	93	93	93	93	93
R^2	.12	.17	.2	.059	.0075	.0015	.39	.13	.3	.13

Notes: The table reports coefficient estimates from regressing boom-period increase in house prices (2003Q3 until the peak) on income and other determinants of house prices. All independent variables are averages for municipalities. Δ_{0206} indicates the percentage change between 2002 and 2006. Five municipalities were excluded due to an insufficient number of house transactions. Standard errors in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level respectively.

Table 6:
Multivariate Regressions

	(1)	(2)	(3)
Log Income	0.11		-0.13
	(0.190)		(0.189)
Log Income, Young Renters	0.21		-0.15
	(0.205)		(0.200)
Log Buyer Income	0.10		0.019
	(0.136)		(0.134)
P90 / P50 Ratio	0.013		0.024
	(0.053)		(0.053)
Unemployment	0.029***		0.0073
	(0.009)		(0.010)
Log Population		-0.011	-0.034**
		(0.012)	(0.015)
Log Square Meter Price		0.11**	0.24***
		(0.043)	(0.065)
Housing Supply		-0.070	-0.074
		(0.059)	(0.066)
Log Density		0.024	0.0078
		(0.019)	(0.020)
Pre-Boom Price Growth		-0.00058	-0.0013**
		(0.001)	(0.001)
Observations	93	93	93
R^2	.31	.42	.48

Notes: The table reports coefficient estimates from regressing boom-period increase in house prices (2004Q1 until the peak) on income and other determinants of house prices. All independent variables are averages for municipalities. Δ_{0206} indicates the percentage change between 2002 and 2006. Five municipalities were excluded due to an insufficient number of house transactions. Standard errors in parentheses. T-statistics in square brackets. ***, **, and * indicate significance at the 1%, 5% and 10% level respectively.

Table 7:
Changes in Fundamentals

	Lowest	2	3	Highest	(Highest)-(Lowest)
Changes Between 2002 and 2006					
Δ_{0206} Income	5.57	5.05	4.55	4.68	-0.89**
	(0.82)	(1.38)	(1.91)	(1.20)	[-2.98]
Δ_{0206} Buyer Income	6.04	6.53	6.34	4.40	-1.64
	(3.86)	(3.51)	(4.20)	(5.36)	[-1.21]
Δ_{0206} Young Income	3.90	3.72	3.37	3.50	-0.40
	(1.69)	(3.74)	(3.39)	(2.38)	[-0.67]
Changes Between 2006 and 2009					
Δ_{0206} Income	-0.43	0.07	0.64	0.91	1.34**
	(1.28)	(1.44)	(1.36)	(1.43)	[3.38]
Δ_{0206} Young Income	0.12	0.23	1.46	1.95	1.82*
	(2.39)	(2.71)	(2.95)	(3.38)	[2.14]
Δ_{0206} Buyer Income	-3.14	0.64	3.43	5.76	8.90**
	(6.79)	(4.48)	(9.30)	(10.47)	[3.47]

Notes: Summary statistics for four groups municipalities. Groups are based on house price growth between 2003Q3 and the municipality-specific peak in house prices. List of municipalities and groups are provided in Table 11. All variables are averages for municipalities. Five municipalities were excluded due to an insufficient number of transactions. The last column provides a T-test of the difference in means between Lowest and Highest. Standard deviations in parentheses. T-statistics in square brackets.
***, **, and * indicate significance at the 1%, 5% and 10% level respectively.

A Appendix: Figures

B Appendix: Tables

Table 8:
Sample Selection

	Dropped	Remaining
All Observations		
Inital	.	1,312,909
Single Sales	475,853	837,056
Non Arms Length	178,551	658,505
Summer Houses	78,098	580,407
Outliers in Prices	33,883	546,524
Not 100% sold	7,104	539,420
Repeat Sales Pairs		
Repeat Sales Pairs	.	263,733
Sales less than 6 months apart	3,044	260,689
Outliers in Price Changes	4,014	256,675
Final Sample		256,675

Table 9:
Apartments – Single and Repeat Sales

	(1) Single Sale	(2) Repeat Sale	(3) T-test
Square Meter Price	12,519	12,450	69
	(9,533)	(6,860)	[1]
Square Meters Size	79	71	8***
	(32)	(25)	[37]
Property Age	57	64	-7***
	(38)	(34)	[-28]
N	25,847	163,178	189,025

Notes: Summary statistics for apartment sales from 1994 to 2010. Single Sale in Column 1 are transactions where the property is transacted a single time, and repeat sale in Column 2 where a property is transacted two or more times. Column 3 provides T-tests for the difference in means. Size (M^2) is the square meter residential property size. Price (M^2) is calculated as the observed transactions price divided by the square meter size of the property. Property Age is the age of the building. Standard deviations in parenthesis, and t-statistics in brackets.

Table 10:
Single Family Houses – Single and Repeat Sales

	(1) Single Sale	(2) Repeat Sale	(3) T-test
Square Meter Price	8,643	8,487	155***
	(5,274)	(4,928)	[12]
Square Meters Size	132	125	7***
	(41)	(50)	[62]
Property Age	50	53	-3***
	(36)	(38)	[-32]
N	241,471	376,274	617,745

Notes: Summary statistics for all single-family housing transactions from 1994 to 2010. Single Sale in Column 1 are transactions where the property is transacted a single time, and repeat sale in Column 2 where a property is transacted two or more times. Column 3 provides T-tests for the difference in means. Size (M^2) is the square meter residential property size. Price (M^2) is calculated as the observed transactions price divided by the square meter size of the property. Property Age is the age of the building. Standard deviations in parenthesis, and t-statistics in brackets.

Table 11:
Municipalities in each Price Growth Group

Lowest	2	3	Highest
Odsherred	Brøndby	Ballerup	København
Slagelse	Høje-Taastrup	Dragør	Frederiksberg
Guldborgsund	Ishøj	Gladsaxe	Gentofte
Tønder	Vallensbœk	Glostrup	Albertslund
Varde	Fredensborg	Herlev	Hvidovre
Vejen	Frederikssund	Rødovre	Lyngby-Taarbœk
Aabenraa	Holbœk	Tårnby	Furesø
Herning	Ringsted	Hillerød	Allerød
Holstebro	Lejre	Hørsholm	Helsingør
Lemvig	Lolland	Egedal	Rudersdal
Struer	Nœstved	Køge	Greve
Ikast-Brande	Nyborg	Roskilde	Halsnœs
Ringkøbing-Skjern	Nordfyns	Faxe	Solrød
Morsø	Haderslev	Kalundborg	Gribskov
Thisted	Billund	Vordingborg	Stevns
Viborg	Sønderborg	Fredericia	Sorø
Brønderslev	Esbjerg	Syddjurs	Middelfart
Vesthimmerlands	Kolding	Norddjurs	Assens
Rebild	Vejle	Odder	Faaborg-Midtfyn
Mariagerfjord	Favrskov	Randers	Kerteminde
Jammerbugt	Hedensted	Silkeborg	Odense
Aalborg	Skive	Skanderborg	Svendborg
Hjørring	Frederikshavn	Aarhus	Langeland
			Horsens

Notes: Groups are based on house price growth between 2003Q3 and a municipality specific peak in house prices.

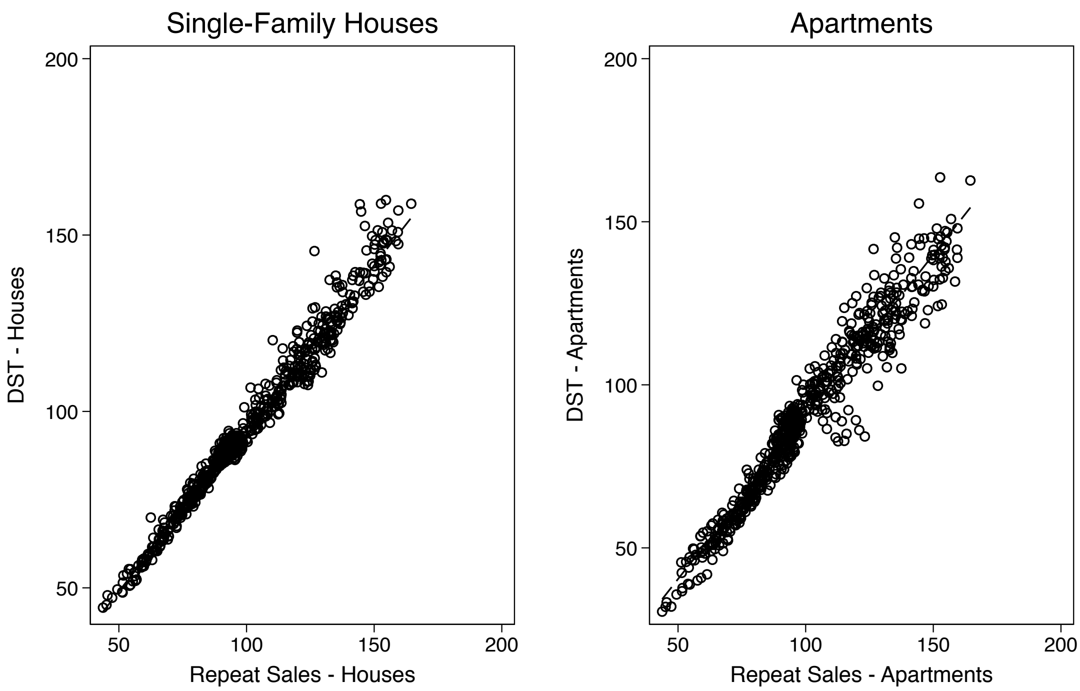
C Appendix: Comparison of House Price Indices

This section compares the repeat sales price index with the official property index provided by Denmark Statistics (DST). The DST index is constructed using appraisal-based methods, using the official property tax valuation as the appraised value.

DST provides quarterly indices over the sample period on a regional level, not on the municipality level. To enable a comparison, I therefore estimate regional-level quarterly indices. Both indices are adjusted for inflation.

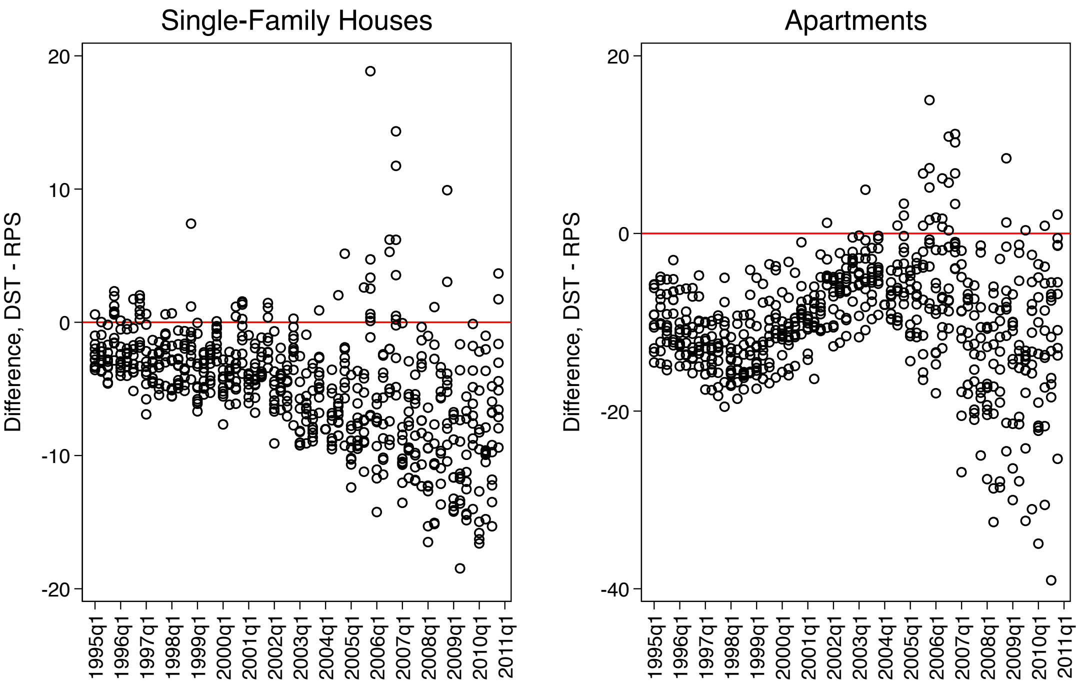
Figure 12 plots the values of the DST indices against the Repeat-Sales indices.

Figure 12:
House Price Index Comparison



Notes: House price indices from Denmark Statistics (DST) on the Y-axis, and repeat-sales price indices on the x-axis.

Figure 13:
Differences in House Price Indices over Time



Notes: First difference of Denmark Statistics and the repeat-sales indices.

Chapter 2 - Prime Borrowers and Financial Innovation in the Housing Boom and Bust

Prime Borrowers and Financial Innovation in the Housing Boom and Bust*

Claes Bäckman† and Chandler Lutz†

September 29, 2016

Abstract

We use the introduction of interest-only (IO) mortgages in Denmark as a natural experiment to assess the impact of alternative mortgage products on house prices during the 2000s. We construct a model to show that lower amortization payments lead to an increase in credit demand by allowing for better consumption smoothing, even absent any shift in credit supply. In support of the model, we find that the introduction of interest-only mortgages was followed by a large increase in the number of buyers, even as credit quality remained constant. On the aggregate level the results indicate that interest-only mortgages amplified the boom-bust pattern in housing: house prices increased an additional 35 percent during the boom due to IO loans, and subsequently reverse during the bust. These effects, which cannot be explained by changes in lending standards or shifts in credit supply, are magnified in local housing markets with higher *ex-ante* house price expectations. Together, the findings document the consequences of introducing IO loans on the micro- and macro level, and illustrates how new mortgage products can have large impacts even in the absence of a shift in credit supply.

JEL Classification: G01, R21, R31, E30, G21 R30

Keywords: Interest Only Mortgages, Housing Boom and Bust; Housing Affordability; Mortgage Lending; Synthetic Control

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1 Introduction

The 2000s global housing boom coincided with the permeation of alternative mortgage products that imploded into the worst economic downturn since the Great Depression. Many of these products aimed at improving affordability for households through reduced amortization payments, a valuable feature for households that wish to align their life-cycle consumption to their long-term income expectations (Cocco, 2013). During the same period, credit supply expanded rapidly following advances in securitization and increased sub-prime lending (Mian & Sufi, 2009). Explanations for the global housing boom have focused largely on credit supply and low quality borrowers using the United States as a case study, and have put limited attention on the role of alternative mortgage products and prime borrowers. In this paper, we use the introduction of a specific form of alternative mortgage products, interest-only (IO) loans, to Denmark to answer two key questions: (1) how are households affected by the introduction of new mortgage products; and (2) what is the aggregate effect on house prices?

Denmark provides the ideal laboratory for such an analysis, because interest-only mortgages were introduced into the highly regulated and conservative Danish mortgage market through a rapidly implemented law change in 2003. The political aim was to improve flexibility in mortgage financing for temporarily cash-constrained households. But as we will show, interest-only loans are valuable to a large fraction of the population, as amortization payments are often not trivial. Figure 1 shows that the first year mortgage payments can be reduced substantially with an IO loan. Indeed, for the average buyer in Copenhagen just before the legalization, amortization payments were as high as 11 percent of annual disposable income. As Figure 2 shows, the legalization of IO loans led to a large increase in the number of housing transactions and an upwards spike in house prices. In the course of the housing boom that followed between 2004 and 2007, aggregate house prices increased by 62 percent. In comparison, the US S&P/Case-Shiller 20-City Composite Home Price Index increased by 37 percent over the same time period.

To begin, we construct a three-period model with wealthy hand-to-mouth households (Kaplan *et al.* , 2014). The model formalizes the intuition in Cocco (2013), who shows empirically that households with high expected income growth are more likely to choose an alternative mortgage product. In the model, a reduction in amortization payments raise the attractiveness of investing in an illiquid asset (housing), because the increase in liquidity can be used to smooth consumption across periods. As the purchase of the illiquid asset is financed through debt, the model clearly shows that reducing amortizations causes an increase in *credit demand*, even absent any fundamental shifts in income.[1] To test the model, we estimate the probability of buying a property using the detailed micro-level data on the full population of Danish households. Our results show that the fraction of households who purchase a house following the reform increase, even after including a comprehensive set of controls, and that households with higher income growth had a larger increase in the probability of buying. These empirical estimates are congruent with our theoretical framework, and thus suggest that housing demand increasing following the law change. Additionally, we use IO loan penetration data to show that IO loans were more prominent in areas with higher pre-treatment house price growth, and in municipalities with higher average income growth, in line with our theoretical predictions. These municipalities also experienced larger increases in house prices during the boom.

We continue to estimate the aggregate impact of introducing interest-only mortgages with the Synthetic Control Methodology (SCM) and several cross-country panel datasets. Our results indicate that the introduction of IO loans amplified the boom-bust pattern in Danish housing markets. Specifically, the introduction of IO loans during the 2000s caused Danish house prices (at the national level) to increase 35 percent relative to a carefully chosen control group of housing markets that also experienced a boom but for whom IO loans were not available. This increase accounts for 60 percent of house price growth between 2003Q4 and 2006Q4. In contrast, during the bust (2007Q1 - 2010Q1), Danish house prices fell 23 percent more than a counter-factual that also

[1] Andersen *et al.* (2012) show that Danish households with interest-only mortgages tend to take out a larger loan.

experienced a housing bust. We also examine the effects of the policy innovation on the cross-section of Danish cities.[2] These results imply that the consequences of the IO loan policy are heterogeneous and vary based on local housing supply and house price expectations at the time of the reform. If supply is unconstrained new supply should quickly lead prices to revert downwards. In inelastically supplied areas, such supply responses may be slower, and thus house prices may stay above some fundamental level for longer (Glaeser *et al.* , 2008). Consistent with this, the cross-sectional effect varies based on local housing supply, and we find that the effect of the reform is mainly concentrated in inelastically supplied areas.

Why did house prices increase so dramatically following the reform? The evidence is consistent with a *credit demand shift* following the reform. As our model shows, introducing interest-only loans can actually lead to an increase in credit demand, even absent any changes in income. Interest-only mortgage does not preclude the household from saving in a different asset, and the increased liquidity could be used to increase consumption, pay down higher-interest debt or to save in alternative asset. Danish interest-only loans, combined with an institutional framework that allows for home-equity withdrawal and provides all borrowers legal right to refinance to take advantage of lower interest rates regardless of housing equity, resembles the optimal contract derived in Piskorski & Tchistyi (2010). Piskorski and Tchistyi show that an option ARM (Adjustable Rate Mortgage) contract with an attached credit line, is an Pareto improvement over a traditional 30-year mortgage for both borrowers and lenders. Our evidence is not consistent with a *credit supply shift*. While mortgage debt did increase following the reform, this was a movement along the credit supply curve, not a shift of the curve itself. We base this assertion on several facts. First, the fraction of income spent on interest payments is *lower* in 2004 and 2005 compared to the year prior to the reform. Additionally, there is no change in the income, wealth or age distribution of buyers, and the percentage of mortgage debt for the lowest quintile of income is stable across time. If anything, the income distribution shifts to the right (towards

[2]Spatial patterns in housing markets are well established. See Sinai (2013) and Ferreira & Gyourko (2012).

higher income) during the housing boom. There is also no decrease in borrower quality and no shift in credit supply towards low-quality borrowers in the data. Second, non-performing loans, forced sales of homes and default rates all remained low throughout downturn in 2008, and are an order of magnitude lower than corresponding rates in the United States, even though the rise and fall in house prices was similar in Denmark and the United States. Third, these facts match official government reports on bank lending activity and statements from the mortgage banks, which affirm that borrowers were evaluated on their ability to afford payments on a standard 30-year mortgage. If lending standards were unchanged following the reform, the increase in mortgage debt is not caused by a new group of households that were earlier denied credit. Moreover, it is also not likely that households purchased homes with IO mortgages with the intent of defaulting if prices declined.[3] Full recourse mortgage debt removes the option to default if the value of mortgage debt exceeds housing values. If a home-owner defaults the bank can force a sale of the property and convert any residual debt into higher-interest bank debt.

This paper contributes to an important literature that aims to determine the origins of the recent housing boom and its subsequent collapse. Mian & Sufi (2009) contend that an outward shift in the supply of credit to low quality borrowers was an important determinant of the recent boom.[4] In contrast, Adelino *et al.* (2016) argue that there was no outward shift in credit, and that the housing boom was a demand-side phenomenon.[5] Our work extends this literature in the following ways. First, we show financial innovation, in the form of new mortgage products, can cause an increase in the demand for credit, and that this increase in demand can have large effects on house prices. This yields an additional mechanism than the one emphasized in Adelino *et al.* (2016). Adelino et al attribute the boom to high house price expectations, home-buyers who bought into expected increases in prices.[6] On top of this, our theoretical and empirical results show that IO loans provide an additional mechanism that affects

[3] See Barlevy & Fisher (2011).

[4] See also Favara & Imbs (2015) and Garmaise (2013).

[5] See alsoGerardi *et al.* (2010) and Ferreira & Gyourko (2015).

[6] See Brueckner *et al.* (2016) on house price expectations and subprime borrowing.

house prices.

Second, we show that this increase in demand occurs throughout the income distribution, consistent with recent research that has emphasized the importance of prime borrowers in the housing boom (Adelino *et al.* , 2016; Ferreira & Gyourko, 2015). The implication of the results is that financial innovation is of primary importance for understanding the housing boom, but that the effect of financial innovation is not necessarily limited to low-quality borrowers. As we show, financial innovation in the form of new mortgages are attractive for all borrowers, and financial innovation does not necessarily have to target worse quality borrowers to have an effect on house prices. The increased availability of IO loans in the US, triggered by financial innovation and shifts in credit supply, thus likely increased housing demand even among prime borrowers.

Overall, our results provide new insights into the origins of the housing boom and show how financial innovation and credit demand, even if they are directed towards prime borrowers, can amplify price swings. The findings may thus warrant a re-examination of the role of financial innovation for prime borrowers in the genesis of the US and global housing crisis.

2 Theoretical Framework

Here, we analyze the effects of amortization payments within two models. First, we treat the required amortization share as a policy parameter and thus exogenous in a two-asset model. Then, we consider a simpler one-asset model where the share paid into amortization is endogenous to determine optimal amortization payments in terms of model parameters. These two models allow us to concisely describe the role of amortization payments in a policy framework, and what factors affect households' choice of amortization payments. Generally, this class of models builds on two-asset models including those of Kaplan *et al.* (2014) and Kaplan & Violante (2014).

2.1 Model 1: The Amortization Share is Policy Parameter

Consider a household that lives for periods $t = 0, 1, 2$, consumes only during periods $t = 1, 2$, and makes a portfolio allocation decision during period $t = 0$. In period $t = 0$, the household allocates its initial endowment, ω, between a liquid (safe) asset, m_1, that matures in period 1 and an illiquid asset, a, that matures in period $t = 2$. The liquid asset is available again for purchase in period $t = 1$ and matures in period $t = 2$ (m_2). The household consumes all available funds in period 2 and cannot die with negative financial wealth.

As we want to study the role of amortization payments, we make the assumption that $a > \omega$. Thus, the household can purchase the illiquid asset with a down-payment equal to $a \cdot d$, where d is the down-payment percentage and hence the household takes out a loan to purchase the illiquid asset. The amortization share is s. The one-period gross return on liquid asset is normalized to 1, the one-period gross return for the loan used to purchase the illiquid asset is r, and the two-period return on the illiquid asset is R. For simplicity, we assume that there is no discounting and no uncertainty and that $1 < r^2 \leq R$. We also assume that the household can only borrow by purchasing the illiquid asset, so that $m_1 \geq 0$ and $m_2 \geq 0$. Finally, the household earns labor income y_1 and y_2 in periods $t = 1$ and $t = 2$ respectively.

Utility in consumption in period $t = 0$ is given by

$$v_0 = \max u(c_1) + u(c_2) \tag{1}$$

where $u(\cdot)$ is twice continuously differentiable with $u' > 0$ and $u'' < 0$.

The resource constraint in period $t = 0$ is

$$ad + m_1 = \omega \tag{2}$$

and the budget constraints for periods $t = 1$ and $t = 2$ are

$$c_1 + m_2 + \underbrace{(r-1)(1-d)a}_{\text{interest}} + \underbrace{s(1-d)a}_{\text{principal}} = y_1 + m_1 \tag{3}$$

and

$$c_2 + \underbrace{r(1-s)(1-d)a}_{\text{interest plus principal}} = y_2 + m_2 + Ra \tag{4}$$

In period $t = 1$, the household has potential expenditures consisting of consumption, the liquid asset that will mature in period $t = 2$, interest on the debt used to purchase the illiquid asset, and any principal repayments. Income stems from the labor market and the liquid asset purchased in period $t = 0$. During period $t = 2$, the household has to pay off any remaining principal plus interest, but get income from labor as well as the liquid and illiquid assets.

In period $t = 0$ the household solves the following optimization problem:

$$\max_{m_1,a} u(c_1) + u(c_2)$$

$$\text{s.t.}$$

$$c_1 + m_2 + (r-1)(1-d)a + s(1-d)a = y_1 + m_1$$

$$c_2 + r(1-s)(1-d)a = y_2 + m_2 + Ra$$

$$a \geq 0, m_1 \geq 0$$

Taking the first order condition (FOC) of the households problem at $t = 0$ with respect to a, the FOC at $t = 1$ with respect to m_2, and combining equations yields the following "long-run" Euler equation:

$$u'(c_1) \geq \bar{R}u'(c_2) \tag{5}$$

where

$$\bar{R} = \left[\frac{R - r(1-s)(1-d)}{d + (1-d)(r-1+s)}\right] \tag{6}$$

The numerator of $\bar{R}$ is the net period 2 return on the illiquid asset and the denominator is the portion of the illiquid asset that the household has paid for by the end of period 1 (down-payment percentage + interest + amortization share). Note that $\bar{R}$ is increasing in s. For a household optimizing at $t = 0$, equation 5 states that $\bar{R}$ is the price of consuming at $t = 1$ rather than $t = 2$. Thus a decrease in the required share to be paid into amortization will lower the price of consumption at period $t = 1$ relative to $t = 2$, given that the household owns the illiquid asset. Intuitively, a decrease in s lowers the period 2 net return (numerator of $\bar{R}$) while decreasing period 1 amortization payments, allowing the household to better consumption smooth the income increase created by illiquid asset across periods 1 and 2.

Using the FOC with respect to m_2 from the optimization problem at $t = 1$ and the fact that $c_1 \leq c_2$ when $u'(c_1) \geq u'(c_2)$ yields

$$m_2 = \max\left\{\frac{y_1 + \omega - y_2 - a[2d - 1 + s(1 + r)(1 - d) + R]}{2}, 0\right\} \tag{7}$$

Here, an increase in s leads to a reduction in m_2 as the household pays more in amortization. For simplicity, we assume that $u(c)$ has a constant elasticity of substitution utility with elasticity parameter σ. If m_2 is equal to zero (a Hand-to-Mouth (HtM) household (Kaplan *et al.* , 2014)), the household will purchase the asset ($a > 0$) when

$$R > \left(\frac{y_2}{y_1 + \omega}\right)^{1/\sigma} [d + (1 - d)(r - 1 + s)] + r(1 - s)(1 - d) \tag{8}$$

Further, the right hand side of equation 8 is increasing in s if

$$\left(\frac{y_2}{y_1 + \omega}\right)^{1/\sigma} > r \tag{9}$$

In other words, for HtM households, a decrease in the required share paid into amortization increases the probability of illiquid asset purchase as long as income growth, augmented by the inverse of intertemporal elasticity of substitution, is larger than the mortgage rate. Intuitively, congruent with Cocco (2013), HtM households are more likely to purchase the illiquid asset as s drops since lower levels of s allow households to smooth consumption while still owning the illiquid asset. This was also the Danish Government's rationale for the law change.

For non-HtM households ($m_2 > 0$), equation 9 becomes

$$\left(\frac{y_2 + y_1 + \omega}{y_1 + \omega - y_2}\right)^{1/\sigma} > r$$

Here, for reasonable parameter values, and non-zero y_2, a decrease in s will increase the probability that a non-HtM household purchases the illiquid asset, because a decline in s lowers $\bar{R}$, and aids the household smoothing the gains of the illiquid asset over its lifetime.

2.2 Model 2: The Amortization Share is Endogenous

Next, we augment the above model and let s be a choice variable at $t = 1$. For simplicity, we eliminate the liquid asset. Taking the FOC of the household's period 1 maximization problem with respect to s yields

$$s \geq \frac{y_1 - ry_2 - arR + a(1-d)(r^2-1)}{(1-d)(r^2-1)} \tag{10}$$

The following testable predictions are immediately clear: (1) s is increasing in $(y_1 - ry_2)$, so higher second period income growth, given the interest rate, will reduce the share that the household pays into amortization; and (2) s is decreasing in R and thus a higher return on the illiquid asset will induce the household to make lower amortization payments. The model also predicts that s is decreasing in r, but the mortgage rate in our data unfortunately does not vary over the cross-section.

3 Housing and Mortgage Markets

The following section describe the housing market and mortgage system in Denmark and the sample countries. See Campbell (2013) for more information about mortgage market design, and Bäckman (2016) for more information about the Danish housing market.

3.1 Mortgage Finance in Denmark

The mortgage finance system in Denmark is highly rated internationally (Campbell, 2013). Similar to the United States, Danish mortgages have historically consisted of a long-term fixed rate mortgage without pre-payment penalties. Households can finance up to 80 percent of home purchases using mortgage loans with a legally mandated maximum maturity of 30 years, and can fund an additional 15 percent using higher interest bank debt. Denmark does not have a continuous credit-score system and there are no requirements on positive equity for refinancing. There are no pre-payment penalties, and households are legally allowed to refinance their mortgage loans to take advantage of lower interest-rates, provided the principal balance is not increased.

Mortgage credit in Denmark is extended to borrowers through specialized lenders called mortgage credit banks (henceforth mortgage banks), who act as intermediaries between borrowers and investors. These institutions face strict underwriting criteria that require them to assess the credit worthiness of all borrowers upon granting a mortgage, and they are prohibited from offering new products without regulatory and legal approval, which has limited the number of mortgage products available for households. Mortgage banks are required to assess both the value of the underlying property and the borrowers ability to afford mortgage payments (International Monetary Fund, 2011). After extending credit to borrowers, the proceeds from the loans are sold to investors in the form of mortgage bonds. The interest rate for borrowers is therefore set by the market for mortgage bonds. The mortgage banks is legally mandated to hold the mortgage bond on their balance sheet throughout the loan period, thereby retaining any credit risk. If a borrower defaults, the mortgage bank is required to replace the defaulting mortgage by one with similar characteristics. Mortgage bonds therefore face no credit risk, provided the issuing lender remains solvent, and the investors in mortgage bonds instead assume interest rate- and pre-payment risk. In over 200 years of operation, no mortgage bond has ever defaulted (Andersen *et al.* , 2014).

If a borrower defaults, the mortgage bank can trigger a forced sale of the underlying asset. Any residual claim is converted into an unsecured personal claim, where the interest rate is higher than the mortgage rate. In legal parlance, mortgage loans in Denmark are full recourse. This feature of the Danish mortgage system makes default unattractive for borrowers (see Ghent & Kudlyak, 2011, for evidence on recourse laws and default from the United States) and default rates remained low throughout the boom and the bust. As we describe in more detail later, mortgage arrears peaked at 0.6 percent of outstanding amounts, and forced home sales remained low throughout the housing bust. Compare this to the United States, where mortgage default peaked above 10 percent. Further, personal bankruptcy in Denmark is difficult and does not necessarily reduce the debt burden.

In total, the mortgage system provide 1) originators with strong incentives to monitor borrowers during the underwriting process (Campbell, 2013); 2) strong incentives for the borrower to carefully assess the state of both their future income and the state of the housing market, and to not over-extend themselves; and 3) a low risk environment for investors in mortgage bonds. The design of the system combine to remove concerns over moral hazard in lending, excessive points and fees, low documentation loans, and limited monitoring of new borrowers during the Danish housing boom.

3.2 Mortgage Reform in 2003

Following a rapidly implemented law change, mortgage banks were allowed to offer a new type of mortgage product on October 1st, 2003. The law was introduced to the Danish parliament on March 12, 2003, and passed on June 4, 2003 with a large majority voting in favor of the proposal. The law change allowed mortgage banks to offer a form of interest-only loans, *deferred amortization* mortgages, where principal repayments could be postponed for up to 10 years, even though the full amount still had to be repaid over the 30-year contract.[7] The intention of the government was to

[7]The law technically allows the *mortgage* to have a ten-year interest-only period. Amortization payments can potentially be deferred forever by rolling over into a new mortgage contract after ten years, provided that the house value does not decrease. Danish media reported on this aspect of the

increase the flexibility of mortgage financing, thereby increasing affordability for cash-constrained households, such as students, young adults and households on temporary leave from the labor market. The expectation was that IO loans would be used as a temporary niche solution. Indeed, the government expected that penetration would be low, and that the reform would have no long-term impact on house prices.[8] IO mortgages were only granted to households who could afford a standard 30-year fixed interest mortgage (Ministry of Economic and Business Affairs, 2007). Prior to 2007, the interest rates and the fees collected by the mortgage credit institutions did not differ between mortgage products. Further, households understood the consequences of IO loans: In a 2011 survey of households with IO mortgages, 89 percent reported that they were "very well informed" or "well informed" on the implications of choosing IO mortgages (Association of Danish Mortgage Banks, 2011).

Even though an IO loan is considerably more expensive in total, the first year costs can be substantially reduced. Figure 1 plots the first-year cost for a 1 million DKK fixed-rate mortgage with (solid line) and without (dashed line) amortization payments. On October 2003, total payments could be reduced by approximately 13,000 DKK ($2,000 USD) per year. For the average house buyer in Copenhagen during 2003, the difference in annual payments for a fixed rate mortgage amounts to 7 percent of annual disposable income, or 11 percent of annual income when comparing payments for a variable interest-rate mortgage.[9]

IO loans rapidly became a popular choice across all types of households. Figure 3 plots the outstanding mortgage amounts by loan type. Prior to the reform, nearly all mortgages were fixed interest with amortization payments, but this rapidly changed

new loans. See e.g. Politiken (2003).

[8]The law proposal includes a rationale the reform, along with the expected effects. The material is available in Danish at `https://www.retsinformation.dk/Forms/R0710.aspx?id=91430`.

[9]Calculations are based on an annuity schedule, where the total monthly cost is constant across the loan period. The reduction in monthly payments would higher with a straight amortization schedule. The average sales price in Copenhagen was 1.3 million DKK, the average disposable income for buyers was 204,575 DKK per year, and the average difference in payments from the introduction of IO loans to the end of 2003 for a 1 million DKK mortgage was 13,000 DKK for a fixed rate mortgage and 22,000 DKK for a variable interest mortgage. Assuming a down-payment of 20 percent, the savings as a percentage of disposable income is 13,000*1.3*0.8 / 204,575 = 6.7% for a fixed rate mortgage and 22,000*1.3*0.8 / 204,575 = 11.1% for a variable rate mortgage.

once IO mortgages were introduced. One year after the reform, 15 percent of all *outstanding mortgages* were IO loans. This number increased to 30 percent in 2005 and to 50 percent in 2010. Mortgage lending expanded rapidly following the reform, increasing by nearly 50 percent between 2003Q3 and 2007Q1. Nearly all of this growth is attributable to IO loans. Finally, figure 4 plots the geographical distribution of interest-only mortgages across Danish municipalities in 2012. Interest-only loans are concentrated in the Copenhagen area, in Northern Zealand and in the area around Aarhus.

3.3 A Comparison of Mortgage Markets

This section documents key institutional characteristics of mortgage markets, such as predominant loan types and usual length of mortgage contracts. Table 9 in appendix D summarizes key characteristics of mortgage markets for Canada, Denmark, Finland, Italy, Spain and the United States.

There is considerable heterogeneity in mortgage market design across countries, reflecting cultural differences and the institutional setting of the banking sector (Campbell, 2013).[10] The typical loan term varies from 15 years in Italy and Spain, to 30 years in Denmark and the United States. Fixed interest mortgages are available in Canada, Denmark, Italy, and the United States, whereas variable interest loans are available in Canada, Denmark, Finland, Spain and the United States. Fixed interest loans are the predominant loan type in Denmark, Canada, Italy and the United States. The loan-to-value (LTV) ratio can exceed 80 percent in Canada, Denmark, Spain and the US. For all these countries except Spain, any mortgage with an LTV of over 80 percent incurs additional costs.[11] Next, all countries except Canada allow mortgage interest deductions, and all countries in the sample have full recourse mortgages expect the United States. Denmark, Canada and Finland allows for equity withdrawal.

[10] For a more detailed overview, see e.g. ECB (2003); Campbell (2013); International Monetary Fund (2011); Scanlon *et al.* (2008).

[11] In Denmark, a households can borrow an additional 15 percent using higher interest bank loans. In the US and Canada mortgages with an LTV over 80 percent are subject to mortgage insurance (Crawford *et al.* , 2013).

We report whether IO mortgages were available in the sample country. IO mortgages were legal and prevalent the United States over our sample period. In all other countries, IO mortgages were either not available or were accompanied by a repayment vehicle. In countries where IO loans are accompanied by a repayment vehicle there are no amortization requirements per se, but households are legally required to save in another savings vehicle for the purpose of repaying the mortgage debt at maturity. Hence, we consider such countries as non-IO counties. In Finland, IO mortgages have to be accompanied by a repayment vehicle where households save in some other asset, such as stocks or bonds, making them relatively conservative in nature. Additionally, Finish IO mortgages accounted for less than 3 percent of outstanding mortgages in 2005. Italian IO mortgages similarly have to be accompanied by an investment vehicle. Spain legalized IO mortgages in April 2006, but as Scanlon *et al.* (2008) report only a few Spanish banks offered these mortgages in 2008. IO mortgages have never been formally allowed in Canada. These non-IO countries constitute our control group. Last, as noted above, IO loans were introduced to Denmark in 2003.

House price growth was high for all countries between 1998Q1 and 2002Q4. Denmark's increase of 32 percent is very close to the observed increase in Canada, Finland and Italy. In figure 15 in appendix E, we plot the growth in private credit flows, 10-year government bond yields, mortgage rates, and house prices for our Canada, Denmark, Finland, Italy, and Spain.[12] The figure indicates that (1) private credit did not disproportionately flow more to Denmark than to any other country; (2) mortgage and interest rates were highly correlated across countries prior to the housing bust; and (3) house price growth was similar across countries between 1998 and 2003.[13] As private credit flows did not disproportionately flow to Denmark, and as interest and mortgage rates were similar across our sample, we can abstract from international changes in credit supply as a potential explanation for our Synthetic Control results below in section 6.2. To clarify, we do not believe that there is a reason that something

[12]Mortgage rates over our sample were only available for Canada and Denmark.

[13]The notable exception is Spain which experienced large private credit flows and large house price increases.

akin to the global savings glut hypothesis of Bernanke (2007) would affect Denmark dis-proportionally to the other countries in the sample.

Finally, as local Canadian housing markets will serve as our control group in our city-level analysis, we provide a detailed comparison between the Canadian and Danish labor and housing markets. Although Denmark is often compared to the United States (Campbell, 2013; Andersen *et al.* , 2014), the Danish housing market may more closely resemble that of Canada. Neither Denmark nor Canada experienced a deterioration of lending standards during the 2000s housing boom. In Canada, only 30 percent of mortgages are securitized and these securities are explicitly guaranteed by the government owned Canada Housing and Mortgage Corporation (Kiff, 2009). Similarly, Danish mortgage banks retain the credit risk associated with mortgage bonds and hence Danish mortgage bonds also carry little default risk.

The Danish labor market is characterized by a generous safety net, combined with active labor market policies (Andersen, 2012). While the safety net in Canada are less generous than in Denmark, it is certainly more prominent than in the United States. Furthermore, GDP per capita, the labor force participation rate, and trade as a percentage of GDP are all closely aligned in Denmark and Canada, along with health expenditure per capita as a percentage of GDP.

In total, recourse laws, the social security net and the conservative nature of the Canadian and Danish housing finance systems makes Canadian cities an apt control group in our assessment of the introduction of IO loans to Denmark in 2003.[14]

4 Data

We first collect high-quality micro-data from Statistics Denmark on the full population of households. Our dataset covers property transactions as well as detailed demographic and economic information on the universe of all Danish households from

[14] Also note that Canada pursued a number of pro-cyclical housing market policies during the 2000s and countercyclical policies after 2008. None of these polices are related to IO loans, but will make our results more conservative in nature if they had any impact on the Canadian housing market. See Krznar & Morsink (2014) and Kiff (2009) for more details.

1994 to 2010. We match data on property transactions to each household using ownership registers. Individual- and household-level variables include household level demographic information, along with financial information such as financial wealth and household income. Unfortunately there is no loan-level data that would allow us to identify interest-only loans from standard mortgages. For a more detailed description of the data and the sources, see Bäckman (2016).

Second, we assemble a dataset of international and city-level variable to estimate the impact on the aggregate level. We consider data at both the quarterly and monthly periodicities. Our aim is to estimate the impact of IO loans in Denmark where the donor pool of potential control units consists of countries where IO loans were not available. Unfortunately, IO loans were pervasive across many European countries and the United States, limiting the number of potential control units. The donor pool of potential control units consists of countries where IO loans were not available. Our set of non-IO loan countries includes Canada, Finland, Italy, and Spain. For each country, our data include house prices from the BIS, GDP per capita, durable consumption per capita, and the growth in private credit flows to the non-financial sector. All variables are in real terms.[15] House prices capture dynamics in the housing market, GDP per capita and durable consumption per capita capture national-level economic activity, and the growth in credit flows measures changes in credit. These data range from 1998Q1 to 2012Q1. In addition to these time series, we calculate time-varying housing market return volatility from a fitted GARCH(1,1) model and the pre-treatment period (1998Q1 - 2002Q4) house price growth. Appendix C contains a complete list of all variables, their sources, different permutations of the data, and the associated number of potential Synthetic Control units.

We also build a city-level dataset where we compare Danish and Canadian cities, as Canada is the only non-IO country where housing data is available across cities.[16]

[15]GDP per capita is aggregate real, seasonally adjusted GDP divided by total population; and real, seasonally-adjusted durable consumption data are transformed into Euros per capita. Currency conversion data date back to 1998 when Euro-area countries fixed their currencies. The currency data are from Eurostat.

[16]We use house price data for the following Danish regions: CopenhagenCity, CopenhagenSur-

The data available at the city-level include house prices, fitted time-varying housing return volatility estimated from a GARCH(1,1) model, the pre-treatment house price growth, population in 2001, median income in 2001, and the unemployment rate in 2001.[17] Canadian house price indices are available from both Statistics Canada and from Teranet. The house price data from Statistics Canada are based on new home construction and are available for 21 cities; while those from Teranet are repeat-sales indices estimated in a fashion similar to the Case-Shiller indices in the US and cover 11 cities.[18] These indices are constructed to ensure comparability – we closely follow the Teranet methodology when we construct Danish repeat-sales indices.[19] In our main results, we exclude Canadian cities that experienced a resource boom during the sample period from the donor pool.[20] The inclusion of Canadian resource cities does not qualitatively affect our results.

We subtract all pre-treatment macro predictor variables (unemployment rate, median income, and population density) by their country-level means and divide by their country-level standard deviations. Subtracting each macro predictor variable by its country-level mean is akin to including country fixed effects in panel models and thus allows us to account for unobserved heterogeneity, such as institutional or labor market differences, across countries. Further, dividing each predictor variable by its standard deviation creates a unit-less measure for easy comparison across countries. In our main results below, we report our findings for the "standardized" (Std) macro data. A robustness check confirms that our findings are similar when we use the unadjusted macro data.

roundings, EasternJutland, EasternZealand, Fyn, NorthernJutland, NorthernZealand, SouthernJutland, WesternJutland, WestSouthZealand.

[17]Income, population, unemployment data are from Statistics Canada and Statistics Denmark, respectively.

[18]Teranet cities include Calgary, Edmonton, Halifax, Hamilton, Montreal, Ottawa-Gatineau, Quebec City, Toronto, Vancouver, Victoria, Victoria, and Winnipeg. See `http://www.housepriceindex.ca/default.aspx`.

[19]Our results are also robust to the use of the HPIs available from Statistics Canada and an alternate set of HPIs provided by Statistics Denmark.

[20]The cities in our sample that experienced a resource boom include Calgary, Edmonton, Regina, Saskatoon, and Winnipeg. See International Monetary Fund (2010).

5 Econometric Methodology

To estimate the impact of IO mortgages on housing markets during the recent boom, we use the Synthetic Control Method (SCM) of Abadie & Gardeazabal (2003) and Abadie *et al.* (2010). The SCM implements a data-driven procedure for comparative case-studies that allows us to estimate the causal impact of a policy intervention occurring at the aggregate level. Overall, the advantages of the SCM are manifold.[21] Specifically, Abadie *et al.* (2010) show that the SCM generalizes the fixed effects (difference-in-differences) estimator as the unobserved unit-specific heterogeneity can vary over time.

Hence, the SCM is well-suited to evaluate the effects of the introduction of IO mortgages. We construct a Synthetic Control unit from a convex combination of available control units that best represents the most relevant characteristics of the treated unit during the period prior to the policy intervention. Then in the wake of the policy, the so-called post-policy intervention period, the path of the Synthetic Control unit represents the counter-factual situation of the treated unit in absence of the policy change. The causal impact of the policy is thus calculated by comparing the treated unit to its Synthetic counterpart.

Inferential techniques within the SCM can be carried out through placebo studies. A placebo study iteratively assigns the treatment to all other units of the donor pool.[22] Then we compare the causal impact of the treatment in this placebo experiment, the placebo effect, to the causal impact for the unit where the intervention occurred. Iteratively applying the treatment to random members of the control group and retaining the subsequent placebo effects is comparable to a permutation test where a test statistic is calculated under random permutations of the treatment and control group. The magnitude and rarity of the treatment effect can then be assessed relative to the set

[21] See Abadie *et al.* (2010) and Billmeier & Nannicini (2013) for more details.

[22] Placebo studies can also be carried out by assigning the treatment to a random point in time. In the results below, we follow the literature and assign the treatment to the control units. Assigning the treatment to other time periods also supports the causal interpretation of our results.

of estimated placebo effects. We apply the treatment to all members of the control group and this will yield our so-called permutation test.[23] The permutation test will then be used for inference.

6 Results

In this section, we examine how the Danish housing market changed following the reform, and how the characteristics of Danish home-buyers changed following the reform. We start by showing that there was an increase in the number of transactions following the reform, and show among which groups transactions increased the most.

6.1 Results – Micro-Level Effects

We use data on the full population of Danish households to investigate how the housing market was affected by the introduction of interest-only mortgages. Table 1 estimates a linear probability model of the probability of buying, where the dependent variable is a dummy equal to one if the household purchases a property, and zero otherwise. The sample consists of the full population of households in 2002 and 2004; the year prior to and the first full year following the introduction of IO loans. The variable of interest is Post Reform, a dummy equal to one in year 2004 and zero otherwise, and interactions between Post Reform and various other variables. All columns include household and municipality-specific controls and region dummies.

Overall, table 1 shows that there was an increase in the probability of buying in 2004 compared to 2002, even after including several household- and municipality-level control variables. Column 1 shows that the increase between 2002 and 2004 in the probability of buying was positive and significant. Columns 2-5 interacts the Post Reform dummy with select variables to provide evidence on which groups had the largest increase in the probability of buying. Column 2 interacts Post Reform with a dummy equal to one for households living in municipalities that later experienced a

[23] As in Abadie *et al.* (2010, 2011) we will discard any placebo studies where the mean squared prediction error during the pre-intervention period between treated unit and its synthetic control in the placebo experiment is more than five times larger than that for the observed experiment.

boom.[24] The positive coefficient on the interaction between boom and Post Reform shows that the increase in demand following the reform was larger in municipalities that later experienced a boom. A similar pattern is observed in column 3, which shows that areas with more inelastic housing supply experienced a larger increase in the probability of buying. In line with the predictions from the model, the coefficients on income growth between year t and $t-1$ and between year $t+1$ and t (column 4 and 5) are positive and significant. Furthermore, column 6 shows that the effect of income growth was not driven by HtM households.

To investigate the prediction from the model that IO loan use is related to future income growth, we use data on reported IO loan penetration for Danish municipalities made available in a Danish newspaper article from 2012 (Politiken, 2012). Note that this is the only cross-sectional data on IO loans that is publicly available, but as the IO loan term in Denmark is ten years the data should include a large number of IO loans originated just after the policy date. The data was provided to the newspaper by one of the mortgage credit bank (Realkredit Danmark), and covers their customer base. Recall from Figure 4 that IO loans are widely used in the Copenhagen region and on Zealand, with IO loan penetration reaching over 60 percent in some areas. These figures are consistent with those from the London or California housing markets and indicate that IO loans were popular with a large portion of buyers in boom markets. Further, figure 5 shows the scatter plot of the IO loan penetration versus pre-treatment house price growth in (a), and the IO penetration versus income growth for buyers in (b) across Danish municipalities. The corresponding regression estimates are in table 2.[25] The penetration is higher in areas with higher income growth, and increase with higher pre-treatment house price growth. A 1 percentage point increase in income growth increases the IO loan penetration by 1.22 percentage points. Using lagged house price growth as a proxy for house price growth expectations, as in Glaeser & Nathanson (2015), Brueckner *et al.* (2012), DellAriccia *et al.* (2012), and Case *et al.* (2012), we

[24]The municipalities in question are those surrounding Copenhagen, Aarhus and Odense.

[25]We only include 93 municipalities in the regression, due to missing data on house prices and a low number of inhabitants.

find that the penetration of IO loans is significantly larger in housing markets with higher pre-treatment house price growth expectations. The R^2 for this regression is 0.245, indicating that pre-treatment house price growth expectations explain a sizable portion of the variation in IO loan penetration in 2012. Note that the results in table 2 are consistent with the results in table 1. These findings are particularly noteworthy given the long time lag between the variables and are consistent with the prediction from the model that high income growth and higher expected returns on the illiquid asset increases the value of using an IO loan.

6.2 Results – Aggregate Level

In the following sections, we employ the SCM using international and city-level data to estimate the impact of IO loans during the 2000s housing boom. To start, data at the highest level of aggregation, the country-level, are used to assess the impact of IO loans during the 2000s boom and its aftermath within the SCM framework. In the international sample Denmark is the treated unit, and the donor pool consists of all other countries. Similarly, for the city-level results Danish regions are the treated unit, and the donor pool consists of Canadian cities. As noted above, we only include non-IO countries in the donor pool.

We begin by estimating the impact of the policy in Denmark and then we conduct placebo experiments where we iteratively apply the treatment to members of the donor pool in a permutation test. The pre-treatment period used to implement the SCM algorithm ranges from 1998Q1 to 2002Q4 as the policy was announced in 2003Q1. The implementation date for the policy was 2003Q4.

Table 3 shows the contribution of each unit in the donor pool to the Synthetic Control (for brevity, only countries with positive weight are listed), table 4 shows the average pre-treatment predictor values for Denmark, its Synthetic Control, and the sample average, and table 5 shows the estimated effects and the root mean-squared forecast error (RMSFE).

Overall, we believe that the Synthetic Control provide a good match for both Denmark and for the Danish cities. To begin, we estimate the effect with country-level data. The treated unit is Denmark, the outcome variable is the BIS house price index, and as we can see in table 3, Finland receives all of the weight, while Canada, Italy, and Spain receive no weight. The results in the top panel of table 4 indicate that Denmark is nearly identical to its Synthetic Control for the key pre-treatment predictor variables, house prices and pre-treatment house price growth. The pre-treatment house price growth, for example, is 31.65 percent for Denmark and 29.88 percent for the Synthetic Control. Moreover, the Synthetic Control Unit represents a much closer match to Denmark relative to the sample average for most of the other housing and macro variables including GARCH(1,1) volatility, GDP per capita, and private credit flows. To further highlight the closeness of the Synthetic match, we print the root mean-squared forecast error (RMSFE) of the Synthetic Control relative to Denmark for house prices over the pre-treatment period in panel 1 of table 5. The RMSFE over the whole pre-treatment period is 15.98 and thus the average RMSFE per quarter is just 0.799. In comparison, the quarterly standard deviation of Danish house prices over the pre-treatment period is 9.73; implying that the average RMSFE per quarter is less than one-tenth of the quarterly pre-treatment standard deviation. Altogether, the SCM algorithm appears to aptly build the control unit based on pre-treatment data. Note that if Finland receives all the weight, this implies that Finland represents the best possible match for Denmark. This is similar to letting an algorithm chose the best control group for a difference-in-difference estimation.

Further, we reduce the geography of our data and conduct the SCM analysis at the city-level. The donor pool consists of Canadian non-resource (coastal) cities for which the Teranet repeat-sales house price indices are available.[26] We apply the SCM approach iteratively using the 10 Danish cities as the treated unit.[27] Figure 14 in Appendix

[26] These cities are Halifax, Hamilton, Montreal, Ottawa-Gatineau, Quebec City, Toronto, Vancouver, and Victoria. In robustness checks, we expand the donor pool to cover all major Canadian cities.

[27] These Danish cities are CopenhagenCity, CopenhagenSurroundings, NorthernZealand, EasternZealand, EasternJutland, Fyn, WestSouthZealand, SouthernJutland, NorthernJutland, and West-

E provide a map of Denmark, indicating the location of Copenhagen and the major islands of Denmark.

As seen in the second panel of table 3, the Synthetic Control Units for the Danish cities largely consist of Canadian cities in the Ontario province. For example, the Synthetic match for CopenhagenCity is Ottawa-Gatineau, while that for Copenhagen-Surroundings, Copenhagen's Suburban area, is 86 percent Ottawa-Gatineau and 14 percent Toronto. In general, we view these matches as reasonable since the Ottawa-Gatineau region is Canada's capital city and Toronto is the largest city in Canada with a substantial suburban component. Further, the respective Synthetic Controls provide a much better match for CopenhagenCity and CopenhagenSurroundings than the sample average for the average pre-treatment predictor values in panels 2 and 3 of table 4. For example, the pre-treatment house price growth for CopenhagenSurroundings is 29.75 percent and that for its Synthetic is 31.78. In marked contrast, the average pre-treatment house price growth across Canadian cities is just 23.33 percent. The appropriateness of the match is also highlighted in the low RMSFE values in Table 5. The largest RMSFE occurs when CopenhagenCity is the treated unit with a value of 42.14. Yet even for CopenhagenCity the RMFSE is small in magnitude. Given the monthly periodicity of the data, the average RMSFE per month during the pre-treatment period is 0.90. In comparison the monthly standard deviation of CopenhagenCity house prices during the pre-treatment period is 12.56. Hence, the average RMSFE per month is less than one-tenth of the monthly standard deviation. The RMSFEs over the pre-treatment period for the other cities are all small and less than 10 in magnitude.

We illustrate the effect for the international sample in figure 6. The plot in the top-left panel of figure 6 presents the path of Denmark's house prices versus the sample average, while the plot in the top-right panel shows the path of house prices for Denmark versus the Synthetic Control. In the figure, the red-dashed, vertical line is the IO loan policy announcement date (2003Q1) and the blue solid line is the policy im-

ernJutland.

plementation date (2003Q4). Overall, the Synthetic Control provides a much better pre-implementation period match for Danish house prices relative to the sample average: Between 1998 and 2003Q4 house prices for Denmark and its Synthetic counterpart move in lockstep, while house prices for the sample average deviate noticeably from those for Denmark starting in 2002. Once IO loans are introduced, Danish house prices diverge dramatically from those of its Synthetic Control. As shown by the plot in the top-right panel of figure 6, by 2006 Danish house prices had more than doubled from their 1998 starting point, whereas those for Denmark's Synthetic had only increased by 65 percent. We plot the Gap between Danish house prices and the Synthetic Control in the bottom-left panel of figure 6. The dotted lines represent the largest estimated placebo effect for each period from the permutation test in the bottom-right panel of the figure. Together, the Gap and Permutation plots highlight magnitude and rarity of the estimated effect: After the introduction of the policy, house prices increased substantially in Denmark and this appreciation is unparalleled relative to all other placebo effects. The uniqueness of the estimated treatment effect, relative to those from placebo experiments, supports a causal interpretation of the results. Note that house prices for Denmark's Synthetic Unit also increased markedly during the 2000s, which indicates that that Denmark would most likely have experienced an increase in house prices after 2003 even in the absence of any policy change. Hence, the introduction of IO loans amplified the ascension of house prices in Denmark relative to the counterfactual that also experienced strong house price growth.

The numerical estimates of the impact of the policy are listed in panel 1 of table 5. The table shows the Gap in house price growth between Denmark and its Synthetic during the boom period (2003Q4 - 2006Q4), the bust period (2007Q1 - 2010Q1), and the ratio of the Gap to total house price growth for Denmark over the boom and bust periods. In the table, asterisks represent estimates for house price growth that are larger than all placebo effects.[28] First, the Gap in house price growth during the boom was 35.80 percent, an estimate that is larger than all placebo effects. Hence,

[28]Specifically, for the boom (bust) period, an asterisk indicates that the effect for the treated unit is larger(smaller) than all estimated placebo effects.

due to the introduction of the IO loans, Danish house prices grew an extra 36 percent compared to a counterfactual that also experienced substantial house price growth over the sample period. Additionally, the left column in the far-right panel table indicates that the IO loan policy explains 62 percent of the house price growth in Denmark between 2003Q4 - 2006Q4. Therefore, the majority of house price appreciation during the boom is due to the introduction of IO loans.

However, the effect was not uniform across Denmark. Figure 7 plots the results for CopenhagenSurroundings, the suburban area around Copenhagen. Figure 16 in appendix E displays the permutation test plots for all Danish cities, and shows considerable heterogeneity in the estimated effect. After the IO loan policy is implemented in Denmark, house prices in CopenhagenSurroundings diverge markedly from the Synthetic Control, similarly to the pattern observed for Denmark as a whole.[29] From the start of the sample to the peak of the boom (1999M04 to 2006M07), house prices in CopenhagenSurroundings increased 127 percent, whereas those for the Synthetic increased only 62 percent. The two plots in the bottom of the figure show that this increase in house prices is both rare and extremely large in magnitude. At the peak of the housing boom (2006M07), the Gap between CopenhagenSurroundings and its Synthetic, the estimated effect, is more than twice as large as that for largest estimated placebo effect. Together, the plots in figure 7 indicate that the introduction of IO loans notably changed the dynamics of the CopenhagenSurroundings housing market, amplifying the boom that subsequently reversed during the bust. The second panel of table 5, however, shows that while the introduction of IO loans had a substantial impact in CopenhagenCity, CopenhagenSurroundings, EasternZealand, and NorthernZealand, other areas did not experience a boom related to IO loan use. During the boom the introduction of IO loans led to an increase in house prices of over 50 percent in CopenhagenCity, but just 8 percent in NorthernJutland. Further, in other cities, such as Fyn and NorthernJutland, there was almost no change in house prices

[29]Note that the Teranet and Danish Repeat-Sales house prices indices are reported as a three-month moving average. So, there is a small delay between the implementation of the IO loan policy and an increase in house prices in CopenhagenSurroundings.

due to the introduction of IO loans. These heterogeneous effects lead to large differences in the contribution of the treatment effect to the total growth in house prices. The Gap/Path ratio indicates the that the introduction of IO loans accounts for at least 70 percent of the growth in house prices in CopenhagenCity, CopenhagenSurroundings, and NorthernZealand, but for approximately zero of the growth in several other areas.

Finally, Danish house prices plunged during the bust. After 2006 housing returns started to wane before diving markedly in 2008. By 2010, the level of Danish house prices returned to match its Synthetic Control, erasing all relative gains accumulated during the boom. In total, from 2007Q1 to 2010Q1 (the bust period), house prices in Denmark fell an extra 23.36 percent compared to the Synthetic, an estimate that is larger in magnitude than all estimated placebo effects. Furthermore, house price fell more than the Synthetic Control in several areas that did not experience an increase in prices due to IO-loans in the boom. The above results imply that the introduction of IO loans amplified the boom-bust pattern in house prices.

6.3 Helsinki Placebo Test

In the previous section, we used Canadian cities to construct a Synthetic Control unit for local Danish housing markets. One potential concern with this approach is that a combination of Canadian cities may not yield an appropriate match for a Northern European housing market after 2003 had the IO loan policy not been implemented. To address this issue, we conduct a placebo experiment where we let the treated unit be Helsinki, the capital of Finland. Recall that in section 6.2 we found that Finland was a close match for Denmark during the pre-treatment period. Thus, we can use Helsinki to estimate the placebo effect when the treatment is applied to a similar Northern European capital city housing market. Because the house price index for Helsinki is quarterly, we transform the Teranet house price indices to the quarterly frequency by retaining the last value for the house price index in each quarter. The data run from 1999Q2 to 2008Q4. For this analysis, the outcome variable is house prices and the predictor variables include house prices, GARCH(1,1) housing return volatility, and the pre-treatment house price growth (1999Q2 - 2002Q4). The results are in panel 3 of tables 3 and 5 and figure 17 of appendix E. The Synthetic Control for Helsinki is made up of 57 percent Halifax and 41 percent OttawaGatineau and the top-right plot in figure 17 suggests that the Synthetic yields an appropriate match for Helsinki, especially after 2000. Indeed, the RMSFE during the pre-treatment period is small in magnitude at 27.19. Next, after the IO loan treatment is applied to Helsinki in 2003, there is in no divergence in the path in house prices between Helsinki and its Synthetic. As seen in the bottom two panels of figure 17 in appendix E, the estimated Gap for Helsinki is small in magnitude and in line with the other estimated placebo effects. In total, a combination of Canadian cities closely approximates the path of prices in a non-IO Northern European housing market after 2003.

7 Evaluating Alternative Explanations

In this section we evaluate alternative explanations for the Danish housing boom, and show that the results are not consistent with an shift of credit supply nor with neither increased speculation in housing.

First, we want to be clear that we believe that the introduction of IO-loans did lead to an increase in credit. However, the evidence is more consistent with a move along the credit supply curve, not of a shift of the credit supply curve itself. Such a shift would occur if banks were more willing to lend to consumer for a given level of income or wealth. For example, shifts could occur due to increased securitization, greater risk diversification, an increase in the value of implicit government insurance, increased government intervention in the mortgage market, or greater moral hazard on the behalf of originators. Recall that many of these explanations are limited by Danish mortgage market design (Campbell, 2013). Mortgage banks are legally obliged to retain credit risk and cannot sell this risk on to investors, so greater moral hazard on behalf of originators is ruled out by design. There is no government intervention in the mortgage market and no government insurance of mortgages. Further, official reports state that credit was extended to borrowers based on their ability to afford a 30-year fixed mortgage (Ministry of Economic and Business Affairs, 2007), and *ex post* outcomes such as forced home sales, non-performing loans and mortgage defaults remained low throughout the housing market downturn and the financial crisis. Figure 8 show mortgage arrear as a percentage of outstanding mortgage debt, and the number of homes repossessed by mortgage banks. Mortgage arrears shows the percentage of loans where a large share of total payments have not been met 3.5 months after the latest due date, which peaked at 0.57 percent in Denmark (Association of Danish Mortgage Banks, 2016). Mortgage impairments peaked at 0.2 percent of outstanding mortgages (Rangvid *et al.* , 2013), a rate which the mortgage banks were able to cover themselves, and government intervention was not required. In comparison, delinquency rates on single-family residential mortgages peaked at 10 percent, and non-performing loans to gross loans peaked at slightly below 5 percent in the United States (Board of Governors of the Federal Reserve System (US), 2016; World Bank, 2016).

Furthermore, to examine the claim by mortgage banks that borrowers were evaluated on their ability to repay the standard 30-year mortgage, we compare the distribution of income, financial wealth and mortgage payments as a percentage of income for all house-buyers in each year following the reform to the distribution in 2002. The results are in figure 9-11. For ease of exposition, each plot shows the distribution of each variable in 2002 (black, solid line) and in 2003, 2004, 2005, or 2006 (red, dashed line). Each graph includes a Kolgomorov-Smirnov test for equality of distribution on the right. There is no shift in the distribution towards lower income or wealth, and the distribution of mortgage payments to income shows that buyers were less-risky in 2004 and 2005 compared to buyers in 2002. Instead there is a statistically significant shift towards the right in figure 9 and 10. In figure 11 buyers have lower mortgage payments to income in 2004 and 2005 than in 2002, showing no evidence that households were of worse quality. Therefore, after the policy change, mortgage credit did not disproportionately flow to lower quality borrowers. In 2005 and 2006, we do see a slight rightward movement in the income and financial wealth distributions.

This small shift is in line with our expectations as houses were more expensive in 2005 and 2006 at the peak boom.

To further examine the credit supply hypothesis, we plot the fraction of total mortgage debt held by each income quintile over time. If there was a shift in credit supply, we should see a shift towards low income borrowers in the data. Figure 13 plots the fraction of total mortgage debt held by each income quintile, which is essentially unchanged over time. Low-income borrowers did not expand their holdings of mortgage debt following the reform. In panel (a) we plot results for all households, whereas panel (b) only includes households who buy in the given year.[30] For both panels, the results are very similar – following the reform, we see no evidence that low income borrowers took on a larger fraction of the total debt.[31]

8 Conclusion

In this paper, we use micro- and aggregate-level data to assess the impact of IO loan availability during the 2000s on both the micro and aggregate level. Our results indicate that the introduction of IO loans in Denmark amplified the boom-bust pattern in housing: After the introduction of IO loans, the Danish housing market became much more volatile and speculative in nature. Indeed, due to IO loan availability, house prices jumped an extra 35 percent during the boom compared to a counterfactual that also experienced a housing boom but for which IO loans were not available. Further, IO mortgage availability contributed 60 percent to the increase in Danish house prices between 2003Q4 and 2006Q4. Subsequently, during the bust, Danish house prices reversed and dropped an additional 23 percent due to IO loans. These results cannot be explained by a change in borrower quality as lending standards or borrower quality did not change in Denmark during the 2000s. Further, while the effects of IO loans on housing markets are rare and large in magnitude compared to estimated placebo

[30] Recall that there are no pre-payment penalties for refinancing, and that we could expect that low-income households refinanced into interest-only mortgages, even if they did not purchase a new property.

[31] Note that due to third-party reporting of income and wealth data, there are no concerns regarding misrepresented or fraudulent data in the calculation of these figures. See Mian & Sufi (2015).

effects, they are heterogeneous across local housing markets. Specifically, the impact of the policy change is magnified in housing markets with higher pre-treatment house price growth expectations markets that experienced higher IO loan penetration and substantial house price appreciation during the 2000s.

Altogether, these findings are consistent with a shift in demand for credit following the reform, as the supply of credit did not shift. The results are in line with the predictions from the theoretical model, where a reduction in required amortization payment increases the ability of households to smooth consumption, which in turn increases their willingness to purchase housing. These results have important implications for other countries including the United States where IO loans were widely available. For example, a conservative back of the envelope application of our estimates to California, where IO loans made up nearly half of all new mortgages in 2004, indicates that IO loan availability led to an additional 54 percent increase in California house prices between 2002Q1 and 2006Q4.[32] Last, given the depth of the Great Recession, the implications of our findings are wide reaching and suggest that policymakers should be aware of how new mortgage products can drive housing cycles even in the absence of a deterioration in borrower quality.

[32]FRED Series ID CASTHPI. Here, we assume that IO loan availability contributed 56 to the increase in house prices, the median of cross-sectional estimates across Danish cities.

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A Tables

Table 1: Buyers Pre-and Post Reform – Normalized

	(1) All	(2) All	(3) All	(4) All	(5) All	(6) All
Post Reform	0.0040*** (0.00028)	0.0031*** (0.00034)	0.0031*** (0.00033)	0.0027*** (0.00029)	0.0039*** (0.00028)	
Boom		-0.0018*** (0.00047)				
Post Reform X Boom		0.0025*** (0.00047)				
Housing Supply			0.0036*** (0.00076)			
Post Reform X Housing Supply			0.0065*** (0.00065)			
Post Reform X Income Growth$_t$, Normalized				0.0010*** (0.00005)		
Post Reform X Income Growth$_{t+1}$, Normalized					0.0002*** (0.00003)	
Post Reform X Hand-to-Mouth=0 X Income Growth$_{t+1}$, Normalized						0.0003*** (0.00005)
Post Reform X Hand-to-Mouth=1 X Income Growth$_{t+1}$, Normalized						0.0000 (0.00004)
Constant	-0.1654*** (0.00380)	-0.1638*** (0.00387)	-0.1723*** (0.00390)	-0.1579*** (0.00382)	-0.1665*** (0.00381)	-0.1643*** (0.00378)
Observations	3,792,805	3,792,805	3,792,805	3,792,805	3,792,805	3,792,805

Notes: This table reports the OLS estimation of the probability of buying using data on the full population of Danish households in year 2002 and 2004. All regressions include municipality dummies and the following control variables. Household-level controls: The log difference between disposable income in year t and $t-1$ (Income Growth$_t$), and year $t+1$ and t (Income Growth$_{t+1}$), ; lagged values for mortgage to income and interest payment to income; log income, changes in family size, age, age squared, education level, unemployed, housing tenure, housing tenure squared, and a dummy for owner. Municipality-level controls include (1) new households in the municipality, the share of poor hand-to-mouth, and wealthy hand to mouth; (2) year-over year change in the unemployment rate, mortgage rate, average disposable income, average buyer income, and (3) the lagged annual house price change. All variables with the year-over-year change are normalized by the median income growth in year t to account for business-cycle effects. Robust standard errors in parenthesis.

Table 2: Regression of Interest Only Loans on Pre-Treatment House Price Growth

	IO Loan Penetration		
	(1)	(2)	(3)
Pre-Treatment House Price Growth	0.15***		0.099***
	(0.03)		(0.03)
Buyer Income Growth$_{t+2}$		1.22***	0.92***
		(0.20)	(0.20)
Constant	0.48***	0.45***	0.44***
	(0.01)	(0.01)	(0.01)
N	93	93	93

Notes: Dependent variable is the number of interest-only mortgages as a percentage of all mortgages for each municipality. Pre-Boom House Price Growth is the percentage increase in house prices from 1998Q1 to 2003Q3. Buyer Income Growth$_{t+2}$ is the log difference in disposable income between 2004 and 2006.

Table 3: Synthetic Control Weights

Treated	Synthetic Control Weights
	Panel 1: International House Prices
Denmark	Finland: 1.00
	Panel 2: City-Level House Prices
CopenhagenCity	OttawaGatineau: 1.00
CopenhagenSurroundings	OttawaGatineau: 0.86; Toronto: 0.14
EasternJutland	Vancouver: 0.46; Toronto: 0.32; Hamilton: 0.22
EasternZealand	OttawaGatineau: 0.74; Hamilton: 0.26
Fyn	Vancouver: 0.55; Hamilton: 0.45
NorthernJutland	Toronto: 0.67; Vancouver: 0.33
NorthernZealand	OttawaGatineau: 0.93; Toronto: 0.07
SouthernJutland	Hamilton: 0.49; Vancouver: 0.39; Toronto: 0.12
WesternJutland	Vancouver: 0.52; Toronto: 0.48
WestSouthZealand	OttawaGatineau: 0.83; Toronto: 0.17
	Panel 3: Helsinki City-Level House Prices
Helsinki	Halifax: 0.57; OttawaGatineau: 0.41; Hamilton: 0.01

Notes: Synthetic Control unit weights. Only regions with positive weight are listed.

Table 4: Average Pre-treatment Predictor Values

Panel 1: Denmark; House Prices			
	Treated	Synthetic	Sample Mean
Dur Cons per Capita	382.48	235.71	305.80
GARCH Volatility	0.84	0.92	0.96
GDP Per Capita	41505.31	30056.68	26609.96
House Price Index	117.64	116.11	115.22
Pre-treatment HPI Growth	31.65	29.88	37.73
Private Credit Flows	118.37	125.07	132.18
Panel 2: CopenhagenCity; House Prices			
	Treated	Synthetic	Sample Mean
GARCH Volatility	0.64	0.40	0.44
House Price Index	119.73	113.83	109.54
Median Income 2001 Std	-0.45	1.77	0.15
Pop 2001 Std	0.68	0.17	0.67
Pre-treatment HPI Growth	37.05	32.89	23.33
Unemp 2001 Std	1.76	-0.55	-0.12
Panel 3: CopenhagenSurroundings; House Prices			
	Treated	Synthetic	Sample Mean
GARCH Volatility	0.32	0.37	0.44
House Price Index	115.48	113.56	109.54
Median Income 2001 Std	0.96	1.78	0.15
Pop 2001 Std	0.20	0.62	0.67
Pre-treatment HPI Growth	29.75	31.78	23.33
Unemp 2001 Std	-0.42	-0.53	-0.12

Notes: Average pre-treatment predictor values for selected Samples.

Table 5: Synthetic Control–Estimated Effects of IO Loans

Treated Unit	RMSFE	Gap		Gap/Path	
		Boom	Bust	Boom	Bust
Panel 1: International House Prices					
Denmark	15.98	35.80*	-23.36*	0.62	1.60
Panel 2: City-Level House Prices					
CopenhagenCity	42.14	52.32*	-30.20*	0.77	2.98
CopenhagenSurroundings	7.53	40.32*	-32.09*	0.72	2.54
EasternJutland	2.98	8.03	-15.35*	0.19	-45.32
EasternZealand	7.08	34.31*	-31.07*	0.66	2.36
Fyn	2.41	-2.82	-13.58*	-0.08	-9.73
NorthernJutland	3.19	-1.85	-5.89*	-0.07	-0.57
NorthernZealand	9.72	36.53*	-38.43*	0.70	2.06
SouthernJutland	3.12	-4.54	-4.58	-0.16	-0.46
WesternJutland	4.67	-9.38	-0.65	-0.36	-0.04
WestSouthZealand	7.37	19.89*	-26.05*	0.56	3.88
Panel 3: Helsinki City-Level House Prices					
Helsinki	27.19	3.68	NA	0.15	NA

Notes: The estimated causal impact of the introduction of IO loans using the SCM. The first three columns show the sample used in the estimation, the treated unit, and the outcome variable. The fourth column holds the RMSFE from the SCM estimation. The right two panels show the estimated casual effects of the IO policy intervention. When house prices are the outcome variable, Gap is the gap in the house price growth between the treated unit and its Synthetic Control and Gap/Path is Gap divided by total house price growth for the treated unit. The results are computed for the boom period (2003Q4 - 2006Q4) and the bust period (2007Q1 - 2010Q1). For the boom (bust) period, an asterisk indicates that the effect for the treated unit is larger (smaller) than all estimated placebo effects.

Table 6: Summary of Results–Gap in House Prices Across Boom and Bust Periods

	Boom		Bust	
	Estimate	Boot SE	Estimate	Boot SE
Mean–All	30.27*	2.69	-24.44*	1.23
Median–All	34.38*	4.06	-26.25*	1.36
CopenhagenCity	60.53*	3.15	-29.37*	0.32
CopenhagenSurroundings	54.69*	5.47	-29.16*	1.11
EasternJutland	25.33*	7.00	-21.65*	3.23
EasternZealand	46.68*	4.33	-32.57*	0.51
Fyn	18.79*	8.53	-17.32*	3.14
NorthernJutland	7.80	4.12	-17.12*	5.97
NorthernZealand	50.24*	5.16	-37.76*	0.31
SouthernJutland	7.89	5.42	-15.23*	2.86
WesternJutland	12.14	8.48	-18.91*	3.97
WestSouthZealand	17.95*	2.57	-25.47*	4.14

Notes: Summary of results across all of the permutations of the data listed in table 8. In each panel, the left column holds mean gap in cumulative housing returns all permutations of the data; the corresponding bootstrapped standard error is the the right column. The results in the boom period (2003Q4-2006Q4) are in the left panel, while the right panel shows the results over the bust period (2007Q1 - 2010Q1). The first two rows show the mean and the median the estimated causal effects over all permutations of the data; the remaining rows show the results for specific Copenhagen Cities. An asterisk represents a bootstrapped p-value of less than 0.05.

B Figures

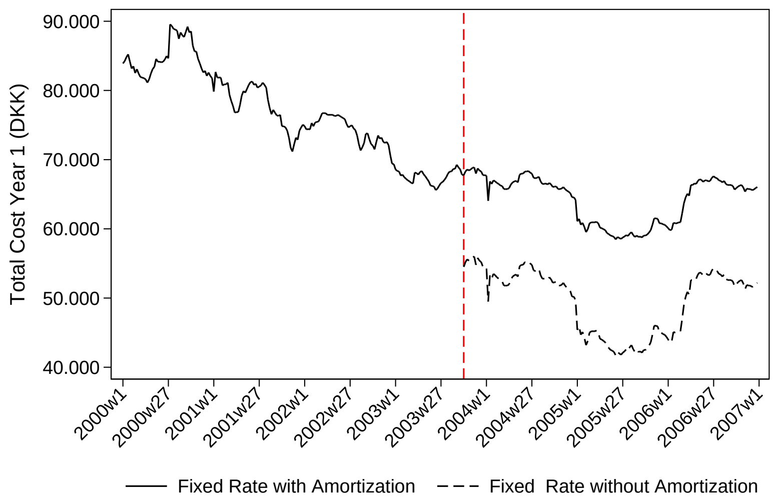


Figure 1: First Year Payments

Notes: The red vertical line indicates the introduction of interest-only mortgages. The figure plots the total annual cost for a 1 million DKK, fixed rate mortgage contract, with amortization payments (solid line) and without amortization payments (dashed line). Both lines are calculated using the long-bond rate from the Association of Danish Mortgage Banks.
Source: Association of Danish Mortgage Banks and authors' calculations

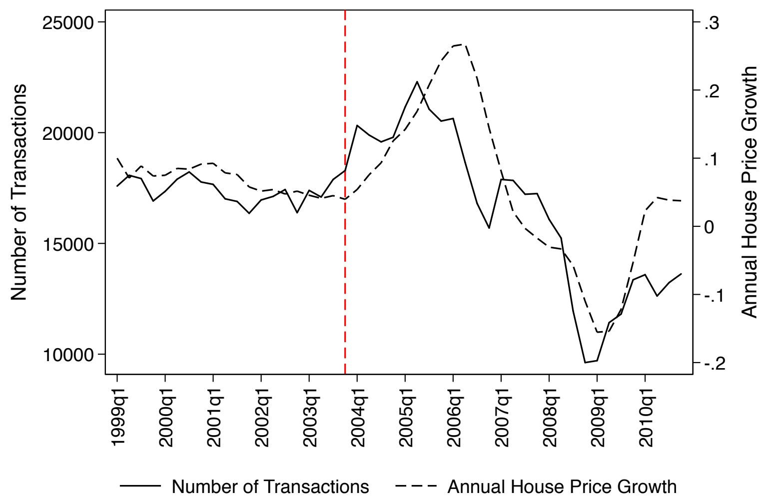
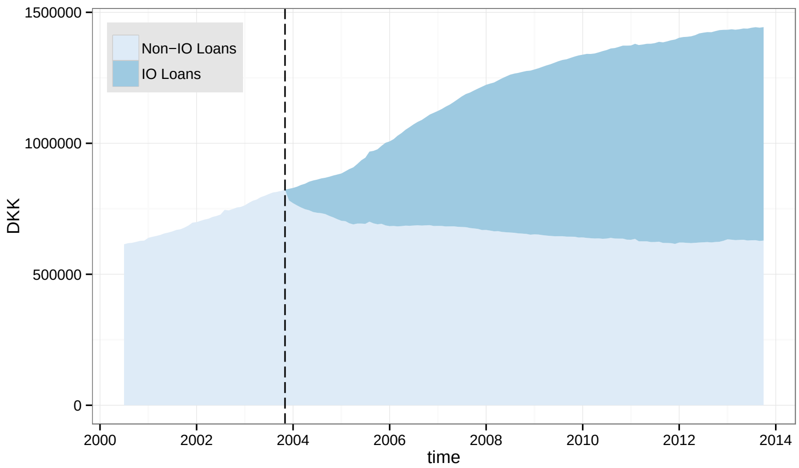


Figure 2: Number of Transactions and House Prices

Notes: Red line shows when Interest-Only mortgages were introduced in Denmark. Solid line shows the seasonally adjusted number of single-family houses and apartment transactions per quarter. Dashed line shows the year-over-year percentage change in the single-family house price index.
Source: Denmark Statistics

Figure 3: Mortgage Loan Types



Notes: Outstanding mortgage debt by loan type. Includes loans for residential properties and vacation homes. Source: Nationalbanken

Figure 4: Interest-Only Loan Penetration in Danish Municipalities

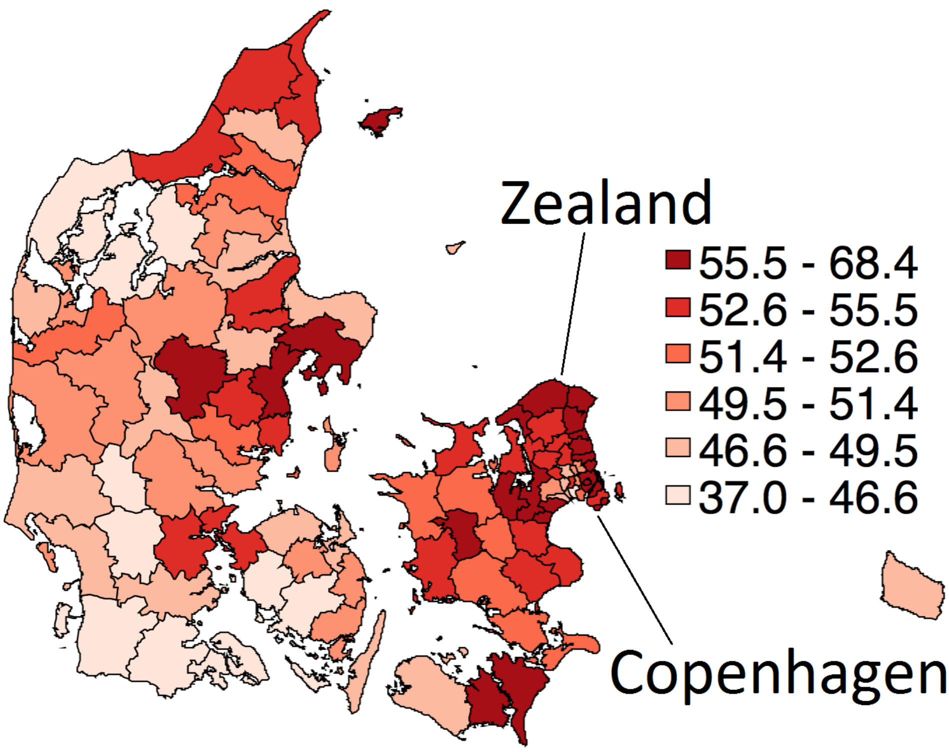
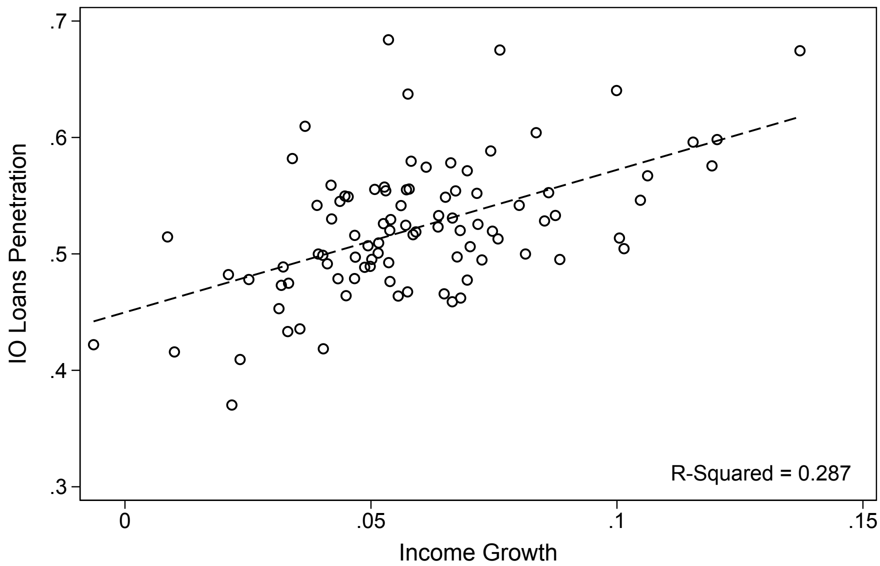
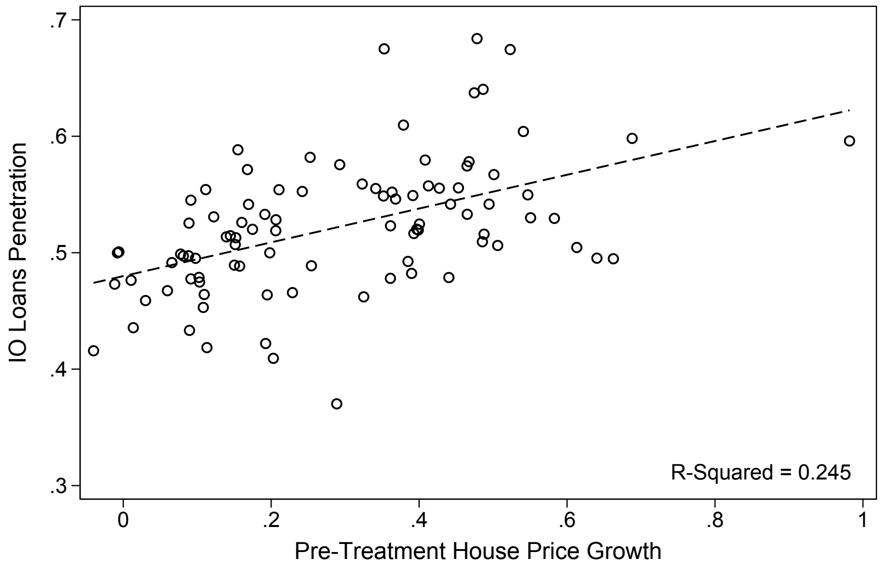


Figure 5: Interest-Only Loan Penetration, Pre-Treatment House Price Growth and Income Growth

(a) Income Growth

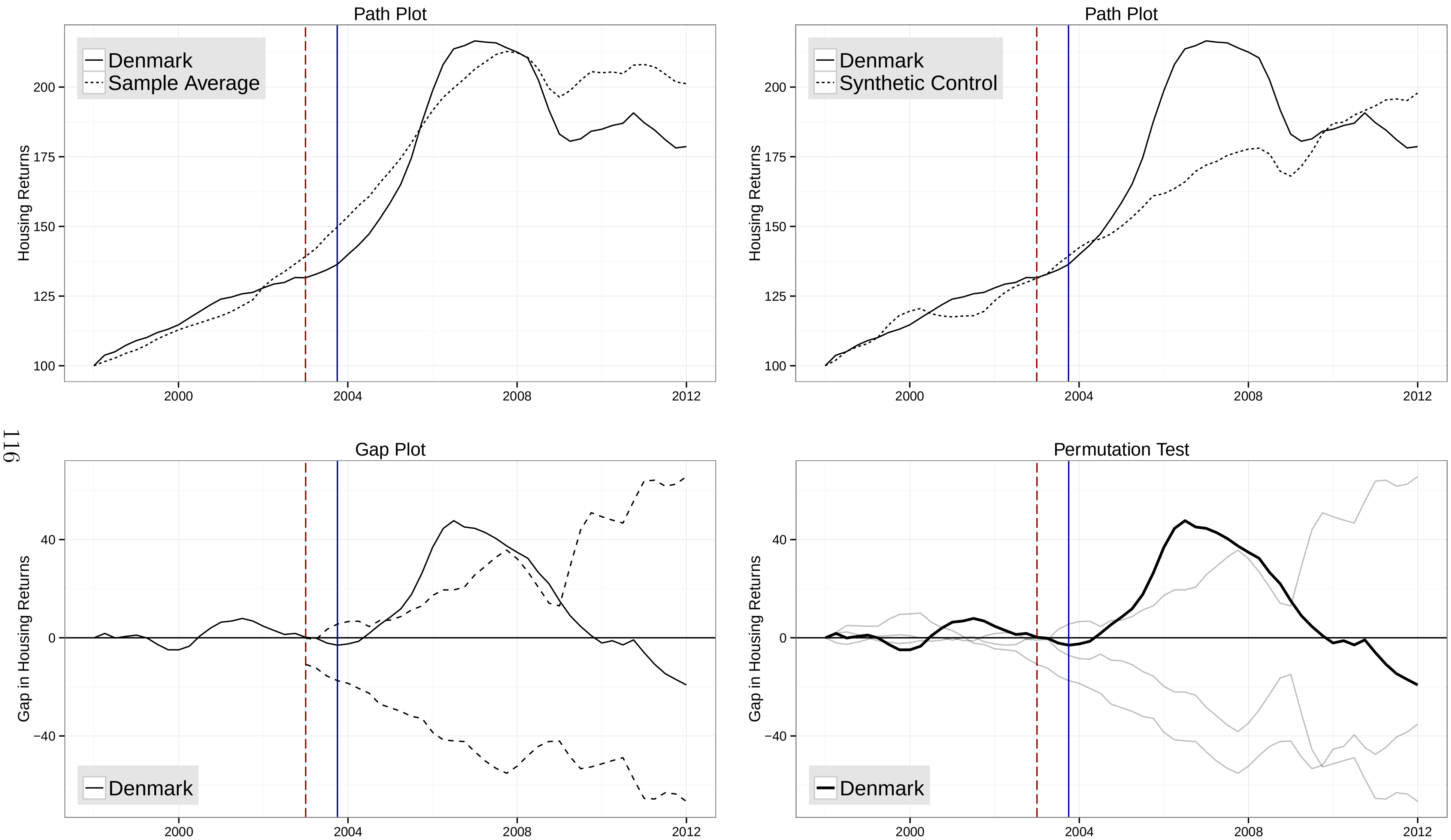


(b) Pre-Treatment House Price Growth



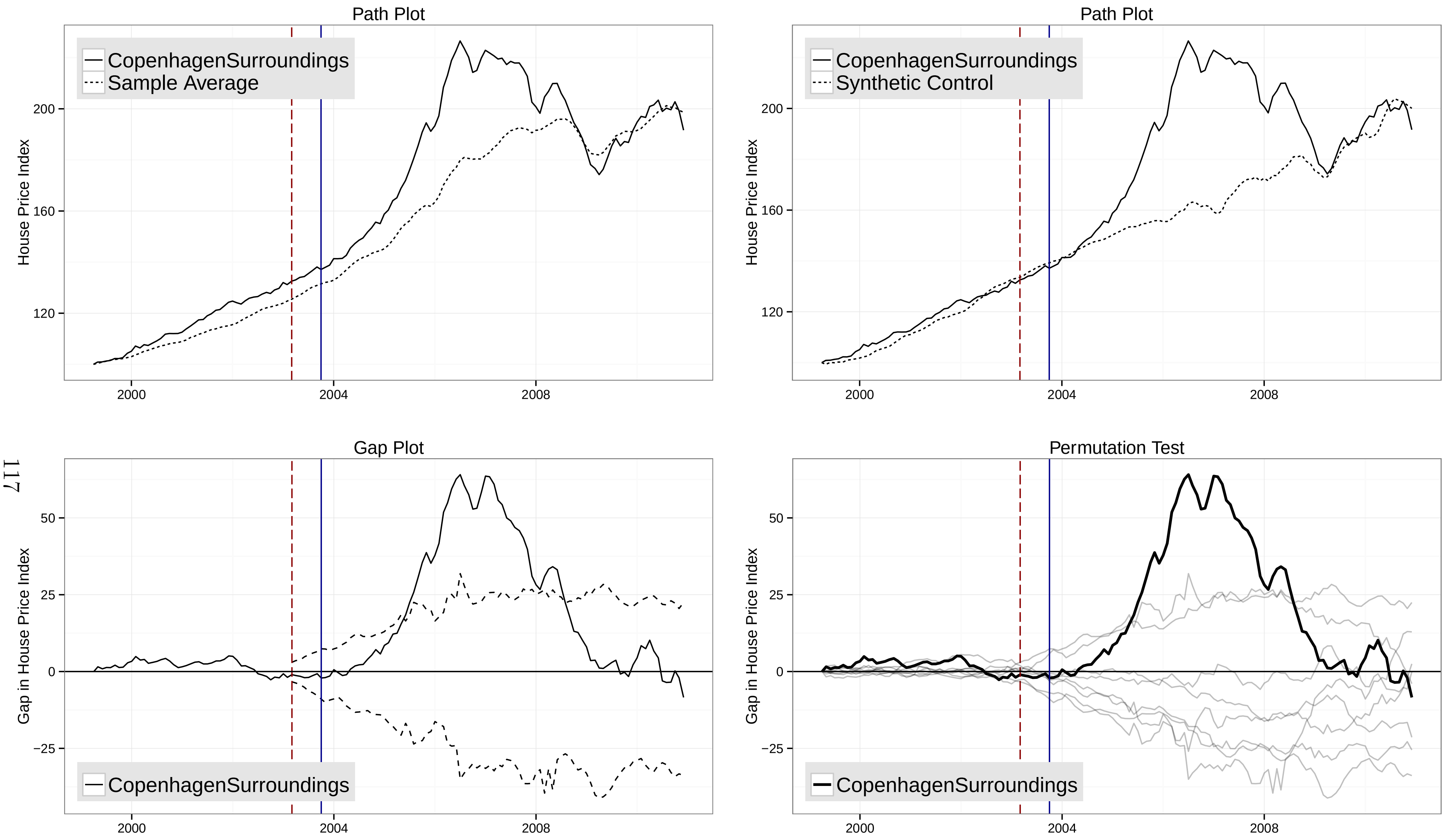
Notes: IO Loan Penetration is the percentage of Interest-only loan in each Danish municipality. Pre-Boom House Price Growth is the percentage increase in house prices from 1998Q1 to 2003Q3. Buyer Income Growth$_{t+2}$ is the log difference in disposable income between 2004 and 2006. R-squared is from a linear regression of IO loan penetration and the x-axis variable.

Figure 6: House prices–Denmark, International Average, and Synthetic Control



Notes: House prices for Denmark, the International Average, and Denmark's Synthetic Control. The top-left plot shows the path plot of house prices for Denmark and the International average; the top-right plot shows the path plot of Denmark and its Synthetic Control; the bottom-left gap plot shows the difference between Denmark and its Synthetic Control where the dotted lines represent the largest estimated placebo effects for every time period; the bottom-right panel shows the plot based on the permutation test where black line is the gap for Denmark and the gray lines are the placebo effects when the treatment is iteratively applied to each member of the control group. The dashed red vertical line signifies the policy announcement in 2003Q1 and the solid blue vertical line signifies the policy implementation date in 2003Q4. The donor pool comprises Canada, Finland, Italy, and Spain.

Figure 7: House prices–Copenhagen Surroundings, Canadian Average, and Synthetic Control

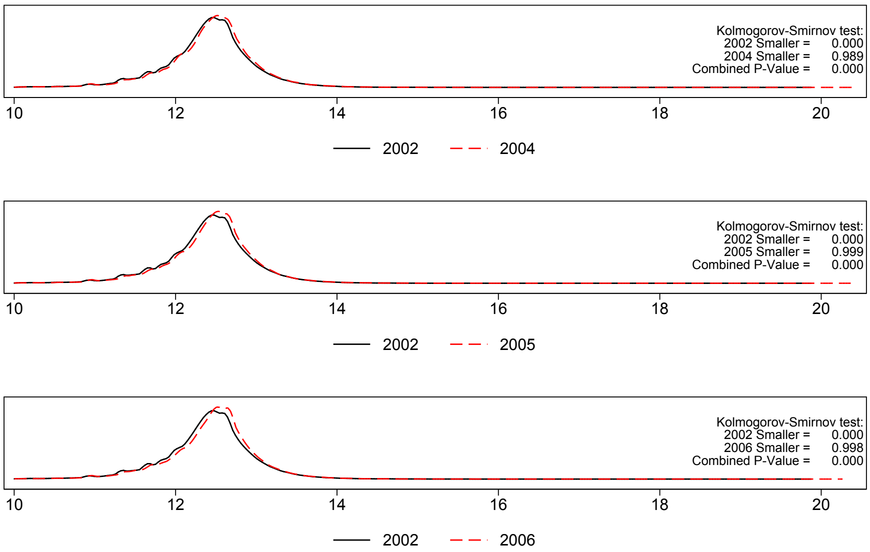


Notes: See the notes for figure 6. The repeat-sales city level data are monthly and the donor pool consists of Canadian non-resource cities. The dashed red vertical line signifies the policy announcement in 2003M03 and the solid blue vertical line signifies the policy implementation date in 2003M10.

Figure 8: Mortgage Arrears and Repossessed Homes

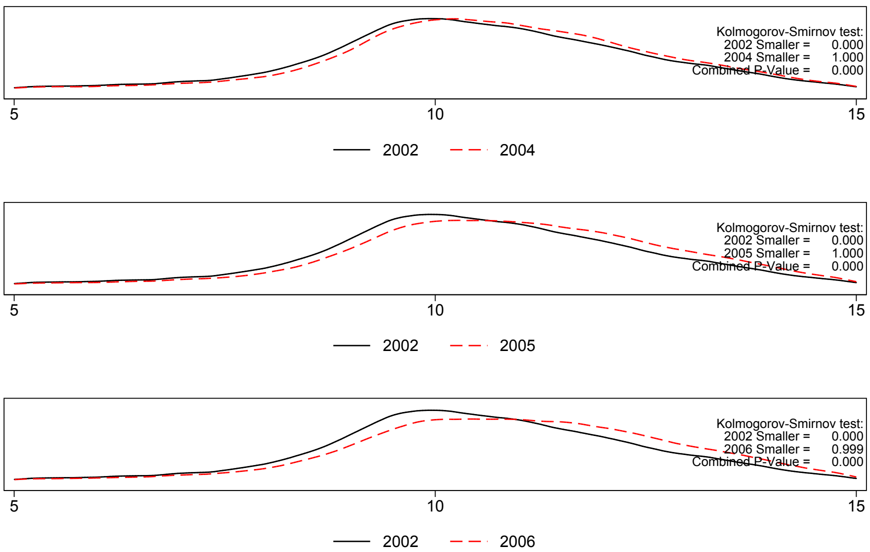
Source: Association of Danish Mortgage Banks

Figure 9: Distribution of Income, for House-Buyers



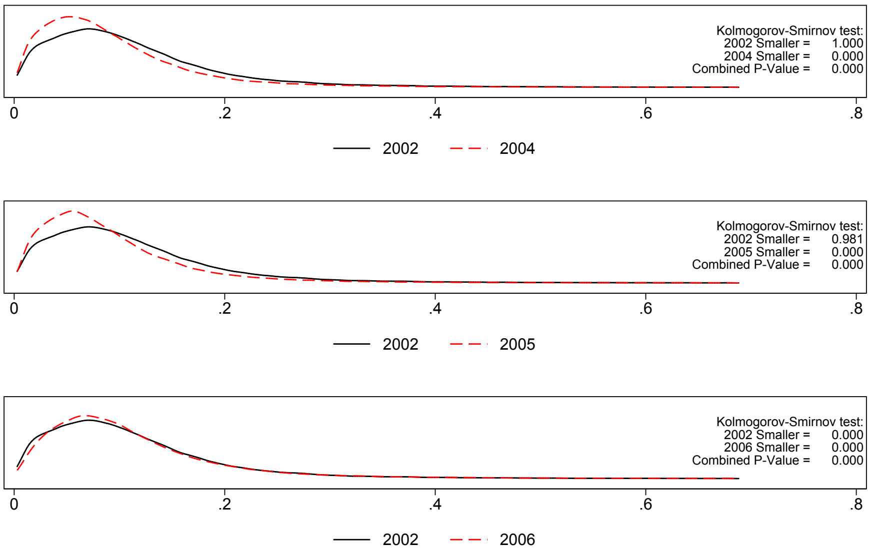
Notes: Distribution of income for households who purchased real estate in 2002 (black, solid line) and subsequent years (red, dashed line). Income is total income from labor including transfers, in logs.

Figure 10: Distribution of Financial Wealth, for House-Buyers



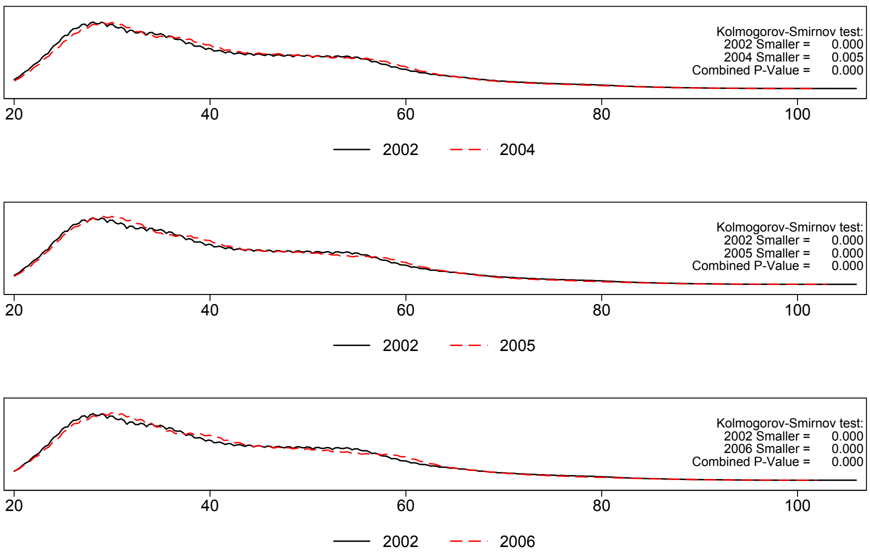
Notes: Distribution of financial wealth for households who purchased real estate in 2002 (black, solid line) and subsequent years (red, dashed line). Net wealth is the sum of stocks, bonds and cash deposits in logs.

Figure 11: Distribution of Mortgage Payments to Income, for House-Buyers



Notes: Distribution of mortgage interest payments divded by income for households who purchased real estate in 2002 (black, solid line) and subsequent years (red, dashed line).

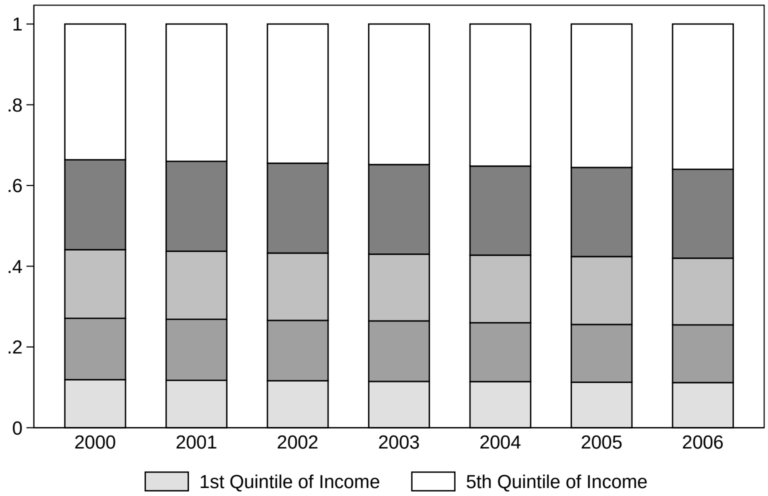
Figure 12: Distribution of Age, for House-Buyers



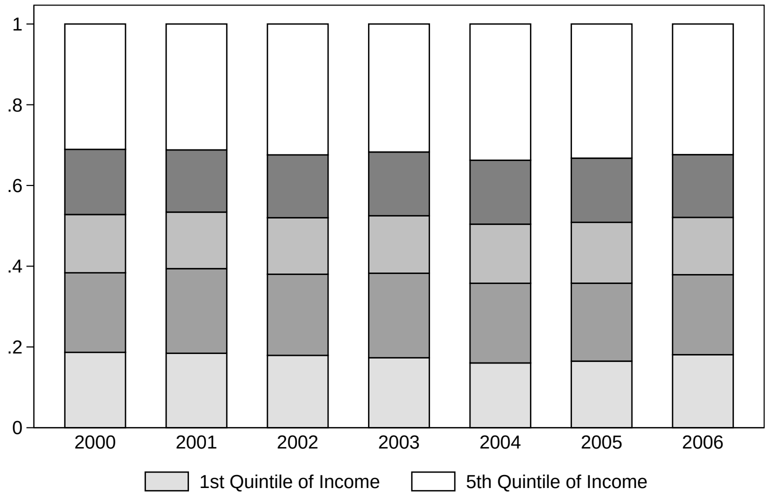
Notes: Distribution of age for households who purchased real estate in 2002 (black, solid line) and subsequent years (red, dashed line).

Figure 13: Mortgage Debt by Income Quintile

(a) All Households



(b) Buyers



Notes: The figures show the fraction of total mortgage debt held by each income quintile. Mortgage debt is measured at end-of-year values. Panel (a) show the results all households who hold mortgage debt. Panel (b) shows the results for households who purchased housing in the given year.

C Appendix: Data (For Online Publication)

Table 7: Data List

	Mnemonic	Short Description	Time Period	Source
		International Data		
1	**ESGW6R	Population: Total, 15 - 64 Years; Annual	1998-2012	DS
2	**ESNFVCD	GDP; 2005 Chained Prices, Euros	1998Q1 - 2012Q4	DS
3	**QIR080R	Yield 10-Year Govt Bonds	1998-2012	DS
4	**ESEW5OC	Final Consumption Expenditure of Households, Dur Gds; Euros	1998Q1 - 2012Q4	DS
5	Q:**:A:H:A	Private Credit Flows to the Non-financial Sector	1998Q1 - 2012Q4	BIS
6	**BPPRESF	House Price Index - nominal residential property prices	1998Q1 - 2012Q4	DS
		City-Level Data		
1	CNTNHP**	Canada Teranet Repeat Sales House Price Indices (1999M04 = 100)	1994M04-2010M12	DS
2	CN**	Canada New House Price Indices (1999Q2 = 100)	1999Q2-2010Q4	DS
3	NA	Denmark Repeat House Price Indices (1999M04 = 100)	1994M04-2010M12	Author's Calc
4	NA	Denmark Average House Price Indices (1999Q2 = 100)	1999Q2-2010Q4	Stats DK
5	NA	Canadian Unemployment	2001	StatCan
6	NA	Canadian Population	2001	StatCan
7	NA	Canadian Median Income	2001	StatCan
8	NA	Danish Unemployment	2001	Stats DK
9	NA	Danish Population	2001	Stats DK
10	NA	Danish Median Income	2001	Author's Calc

Notes: Mnemonics represents variable codes. ** indicates that the mnemonic changes by country/city. DS is Datastream, BIS is the Bank of International Settlements, Stats DK is Statistics Denmark, and StatCan is Statistics Canada.

Table 8: Description of Samples

Sample	DonorPool	CanadianHPI	DanishHPI	Controls	Frequency
CityDstNewAll	All Canadian Cities	New HPI	Stats DK	21	Quarter
CityDstNewAllStd	All Canadian Cities	New HPI	Stats DK	21	Quarter
CityDstNewCoastal	Canadian Non-Resource Cities	New HPI	Stats DK	16	Quarter
CityDstNewCoastalStd	Canadian Non-Resource Cities	New HPI	Stats DK	16	Quarter
CityRepeatTeranetAll	All Canadian Cities	Teranet	Repeat Sales	11	Month
CityRepeatTeranetAllStd	All Canadian Cities	Teranet	Repeat Sales	11	Month
CityRepeatTeranetCoastal	Canadian Non-Resource Cities	Teranet	Repeat Sales	8	Month
CityRepeatTeranetCoastalStd	Canadian Non-Resource Cities	Teranet	Repeat Sales	8	Month
International	Canada, Finland, Italy, Spain	National BIS	National BIS	4	Quarter

Notes: Description of different samples. Stats DK is the house price index from Statistics Denmark and New HPI is the new house price index from Statistics Canada.

D Appendix: Tables (For Online Publication)

Table 9: Mortgage Market Characteristics

Country	Typical Loan Term	Mortgage Loan Type	Maximum LTV Ratio	Mortgage Debt (% of GDP)	House Price Growth (1998-2002)
Denmark	30	Fixed	80%	74.3	32%
Finland	15-18	Variable	80%	31.8	30%
Canada	25	Mixed*	80%	43.1	27%
Italy	15	Fixed	80%	11.4	28%
Spain	15	Variable	100%	32.3	66%
U.S.	30	Fixed	NA	58.0	49%
	Interest-rate Deduction	Full Recourse	Fee-free Pre-Payment	Equity Withdrawal	Interest-Only Mortgages
Denmark	Yes	Yes	Yes	Yes	Yes
Finland	Yes	Yes	No	Yes	No
Canada	No	Yes	No	Yes	No
Italy	Yes	Yes	No	No	No
Spain	Yes	Yes	No	Limited	No
U.S.	Yes	No	Yes	Yes	Yes

Notes: We define a country as having fixed interest rates if a majority of loans have a fixed interest rate for 5 or more years. House price growth defined as the percentage increase in the BIS house price indices for all countries from 1998Q1 to 2002Q4. Mortgage debt is defined as residential mortgage debt in 2002 for all countries.
Sources: Catte *et al.* (2004), ECB (2003), Scanlon *et al.* (2008), and Cardarelli *et al.* (2008).
* The predominant loan type in Canada is defined as mixed, as Canadian mortgages typically have a fixed 25-year term, where the interest rate is negotiated every 5 years.

E Appendix: Figures (For Online Publication)

Figure 14: Map of Denmark

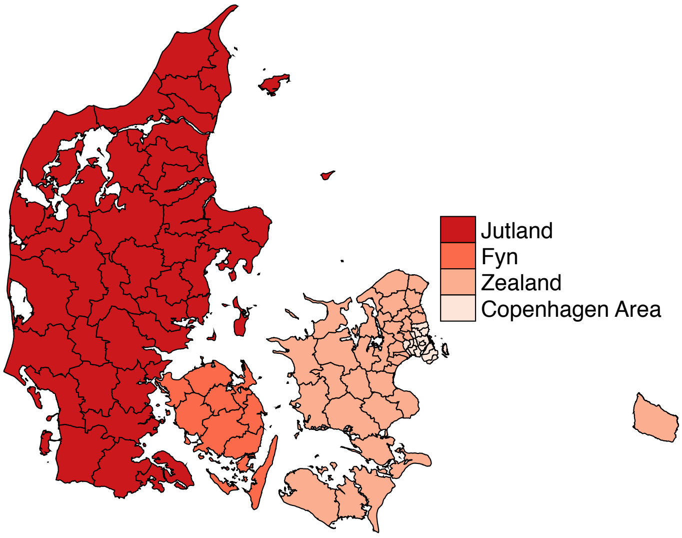
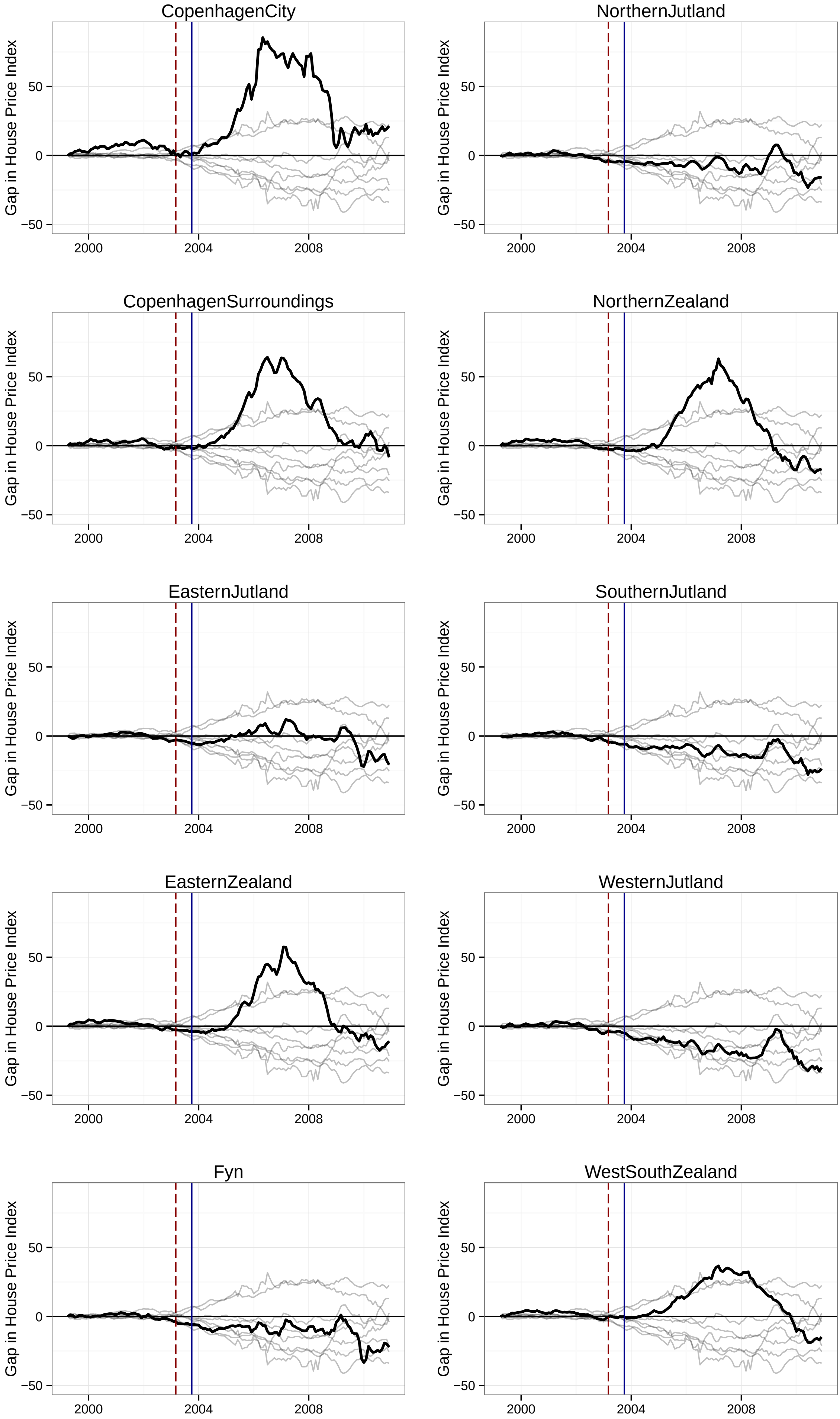


Figure 15: Private Credit Flows, Mortgage Rates, and 10-Year Government Bond Yields

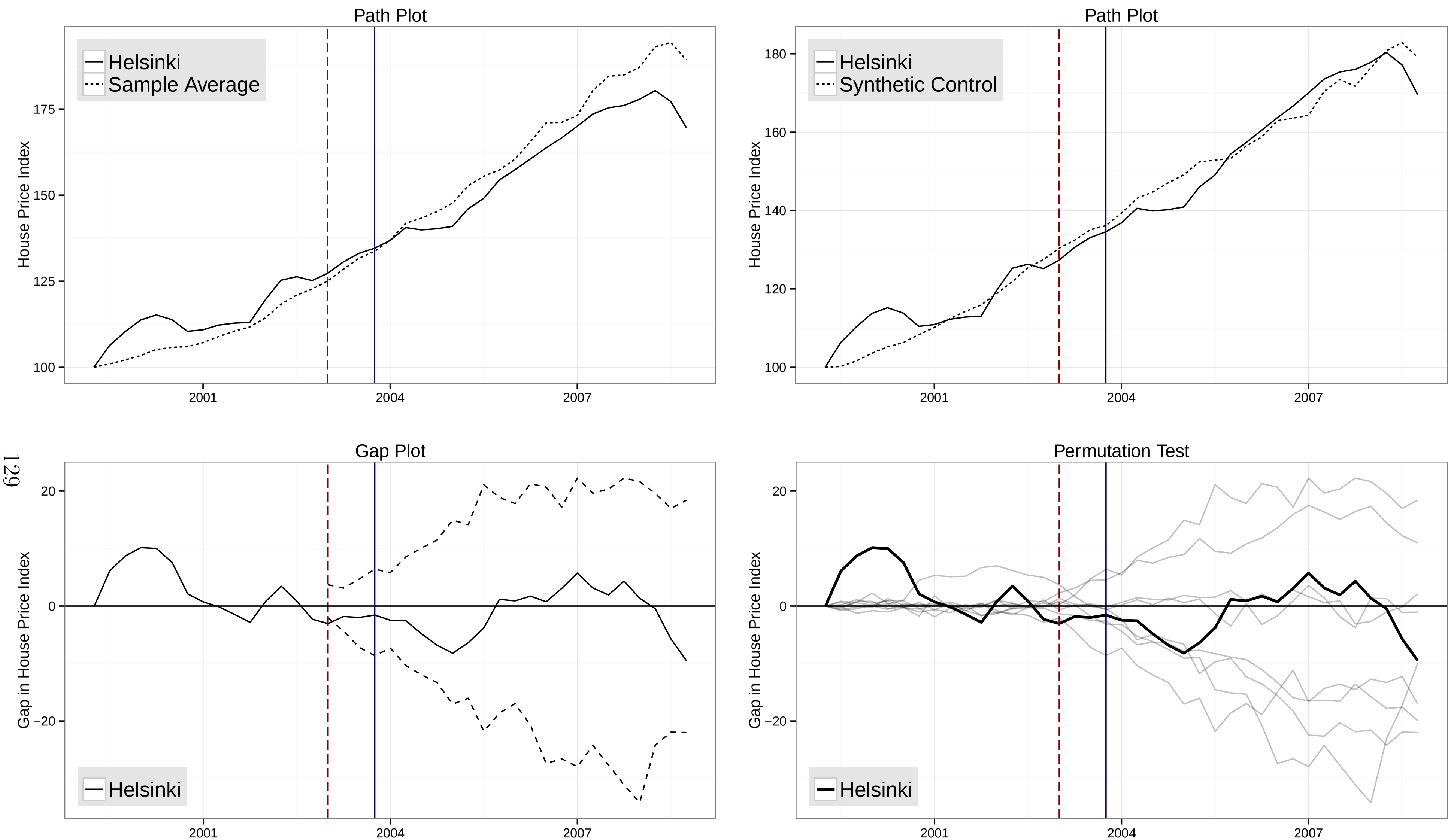
Notes: See table C for variable definition and sources. Mortgage rates for Denmark is the average long bond rate for mortgage bonds from the Association of Danish Mortgage Banks.

Figure 16: City-Level House Price Permutation Tests



Notes: See the notes for figure 7. These plots show the permutation tests for Danish cities where the donor pool consists of Canadian non-resource cities.

Figure 17: House prices–Helsinki, Canadian Average, and Synthetic Control



Notes: See the notes for figure 7. The Helsinki house prices are from Datastream. The data are quarterly

F Appendix: Synthetic Control Gap Estimates (For Online Publication)

Table 10: Synthetic Control–Estimated Effects of IO Loans

		Gap		Gap/Path	
Treated Unit	RMSFE	Boom	Bust	Boom	Bust
Panel 1: Coastal Cities; Unadjusted Macro Data					
CopenhagenCity	42.14	52.32*	-30.20*	0.77	2.98
CopenhagenSurroundings	7.52	40.32*	-32.09*	0.72	2.54
EasternJutland	2.96	8.48	-14.61*	0.20	-43.11
EasternZealand	5.21	35.98*	-31.18*	0.70	2.37
Fyn	2.37	-3.04	-14.71*	-0.08	-10.54
NorthernJutland	3.19	-1.82	-5.89*	-0.07	-0.57
NorthernZealand	9.67	36.58*	-38.42*	0.70	2.05
SouthernJutland	3.09	-5.44	-6.63*	-0.19	-0.67
WesternJutland	4.67	-9.37	-0.65	-0.36	-0.04
WestSouthZealand	7.33	19.94*	-26.03*	0.56	3.87
Panel 2(a): All Cities; Standardized Macro Data					
CopenhagenCity	42.14	52.32*	-30.20*	0.77	2.97
CopenhagenSurroundings	7.53	40.29	-32.06*	0.72	2.54
EasternJutland	2.06	5.65	-36.14*	0.13	-106.69
EasternZealand	5.94	34.05	-31.36*	0.66	2.38
Fyn	1.58	-4.11	-31.18*	-0.11	-22.33
NorthernJutland	2.64	-3.61	-19.94*	-0.14	-1.92
NorthernZealand	9.78	36.52	-38.75*	0.70	2.07
SouthernJutland	2.12	-6.81	-25.34*	-0.24	-2.55
WesternJutland	3.60	-10.61	-20.54*	-0.41	-1.29
WestSouthZealand	7.34	19.94	-25.99*	0.56	3.87
Panel 2(b): All Cities; Unadjusted Macro Data					
CopenhagenCity	42.14	52.32*	-30.20*	0.77	2.98
CopenhagenSurroundings	7.52	40.32*	-32.09*	0.72	2.54
EasternJutland	2.06	5.63	-36.21*	0.13	-106.88
EasternZealand	5.21	35.97	-31.23*	0.70	2.37
Fyn	1.60	-4.51	-30.81*	-0.12	-22.06
NorthernJutland	2.61	-3.31	-19.68*	-0.13	-1.89
NorthernZealand	9.77	36.52	-38.74*	0.70	2.07
SouthernJutland	2.16	-7.55	-25.22*	-0.26	-2.54
WesternJutland	3.62	-11.01	-20.86*	-0.42	-1.31
WestSouthZealand	7.33	19.94	-26.03*	0.56	3.87

Notes: See the notes for table 5.

Table 10 Continued

Treated Unit	RMSFE	Gap		Gap/Path	
		Boom	Bust	Boom	Bust
Panel 3(a): Quarterly HPIs; Coastal Cities; Standardized Macro Data					
CopenhagenCity	16.57	68.73*	-28.55*	0.82	1.40
CopenhagenSurroundings	2.36	69.10*	-26.26*	0.82	1.43
EasternJutland	1.47	43.73*	-17.71*	0.70	1.54
EasternZealand	3.77	58.29*	-33.93*	0.79	1.29
Fyn	0.81	40.89*	-11.61	0.74	1.51
NorthernJutland	1.69	19.25*	-10.13	0.53	2.31
NorthernZealand	3.20	63.94*	-36.93*	0.81	1.28
SouthernJutland	0.76	23.70*	-10.42	0.62	1.74
WesternJutland	3.54	34.36*	-27.16*	0.69	1.41
WestSouthZealand	0.77	21.28*	-18.26	0.63	21.65
Panel 3(b): Quarterly HPIs; Coastal Cities; Unadjusted Macro Data					
CopenhagenCity	16.57	68.73*	-28.55*	0.82	1.40
CopenhagenSurroundings	2.36	69.10*	-26.25*	0.82	1.43
EasternJutland	1.47	43.73*	-17.72*	0.70	1.54
EasternZealand	3.77	58.29*	-33.93*	0.79	1.29
Fyn	0.93	42.65*	-11.84	0.77	1.54
NorthernJutland	1.72	21.25*	-9.63	0.59	2.20
NorthernZealand	3.20	63.94*	-36.93*	0.81	1.28
SouthernJutland	0.80	23.61*	-10.24	0.62	1.71
WesternJutland	3.56	34.39*	-27.15*	0.69	1.41
WestSouthZealand	0.49	28.34*	-3.02	0.84	3.58
Panel 3(c): Quarterly HPIs; All Cities; Standardized Macro Data					
CopenhagenCity	16.57	68.73*	-28.55*	0.82	1.40
CopenhagenSurroundings	2.31	69.03*	-26.24*	0.82	1.43
EasternJutland	1.47	43.71	-17.74*	0.70	1.54
EasternZealand	3.77	58.28*	-33.92*	0.79	1.29
Fyn	0.81	40.43	-12.85	0.73	1.67
NorthernJutland	5.48	10.92	-56.43*	0.30	12.87
NorthernZealand	3.20	63.94*	-36.94*	0.81	1.28
SouthernJutland	0.72	20.03	-19.79*	0.53	3.31
WesternJutland	3.51	34.38	-27.15*	0.69	1.41
WestSouthZealand	0.35	7.15	-39.17*	0.21	46.43
Panel 3(d): Quarterly HPIs; All Cities; Unadjusted Macro Data					
CopenhagenCity	16.57	68.73*	-28.55*	0.82	1.40
CopenhagenSurroundings	2.30	69.02*	-26.22*	0.82	1.43
EasternJutland	1.47	43.71	-17.72*	0.70	1.54
EasternZealand	3.77	58.27*	-33.92*	0.79	1.29
Fyn	0.83	40.84	-11.96	0.74	1.55
NorthernJutland	1.74	21.61	-9.38	0.60	2.14
NorthernZealand	3.20	63.94*	-36.94*	0.81	1.28
SouthernJutland	0.72	20.12	-19.62*	0.53	3.28
WesternJutland	3.50	34.34	-27.13*	0.69	1.41
WestSouthZealand	0.35	7.13	-39.24*	0.21	46.52

Chapter 3 - Consumption and Housing Wealth: Theory and Evidence

Consumption and Housing Wealth: Theory and Evidence

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September 29, 2016

Abstract

In this paper we establish that house price growth is correlated with consumption growth and that the main channel is through collateral constraints. In the empirical analysis, we use detailed Danish micro-data and a household-level consumption expenditure measure to show that there is a strong correlation between house price changes and consumption, driven primarily by borrowing constrained households. We find no correlation between house price changes and consumption after we remove household who borrow against housing collateral, suggesting collateral borrowing is the main driver of the observed correlation between house prices and consumption. We obtain similar results when we instrument house prices with housing supply.

Keywords: Wealth, Housing Wealth, Consumption, House Prices

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1 Introduction

Why does consumption increase when house prices increase? An extensive empirical literature argues that household consumption responds strongly to changes in house prices, suggesting that volatility in house prices can have a large impact on aggregate consumption dynamics. In standard models, this increase in consumption is explained by an increase in wealth following from rising house prices. The alternative explanation is that rising house values facilitate an increase in borrowing to fund consumption expenditure for constrained households. As most studies focus on the combined effects of these two channels, their relative importance is unclear. The purpose of this paper is to examine the collateral and wealth effect theoretically and empirically in an attempt to disentangle the two effects. The main questions that we seek to answer are 1) does changes in house price affect consumption; and if so, 2) is this effect driven by a wealth effect or a collateral effect?

Determining whether household consumption change because of a wealth effect or relaxed borrowing constraints has important implications for macroeconomic policy (DeFusco, 2015). On the one hand, if relaxed credit constraints lead to growth in borrowing and thereby cause consumption to increase, Bernanke & Gertler (1989) and Kiyotaki & Moore (1997) show that even small shocks can have large effects on aggregate consumption.[1] In addition, the increase in mortgage debt implied by the collateral channel has potential consequences for macroeconomic stability (Mian & Sufi, 2015; Mian *et al.*, 2015). On the other hand, an increase in consumption due to the wealth effect implies that policies that affect house prices transmit directly into consumption. The literature however, often assumes that the housing wealth effect is limited (Campbell & Cocco, 2007; Berger *et al.*, 2015), because the positive effect for certain households is offset by a negative effect for others. Since housing is both a consumption good and a financial asset, there are well-founded theoretical reasons to expect that the wealth effect for housing is different than for other assets. For instance, Sinai & Souleles (2005) show that the implicit cost of consuming housing services rises at the same rate as house prices, which eliminates any wealth effect. An alternative is that rising

[1] See also Iacoviello (2005).

house prices may have a negative wealth effect for renters, which can reduce or eliminate wealth effect on the aggregate level (Buiter, 2010; Flavin & Nakagawa, 2008).

We formulate a model of consumption and housing with constrained and unconstrained homeowners to guide the empirical analysis. The model shows that the consumption response to house prices may have three separate components: a wealth effect, a substitution effect and a collateral effect. The consumption of unconstrained consumers reacts to house price changes for two reasons. First, if house price returns are included in the inter-temporal return, an increase in house prices causes households to increase consumption in the current period as their future wealth is larger.[2] Second, if there is a substitution effect between housing and non-housing consumption, a rise in the cost of housing consumption leads to an increase in non-housing consumption.[3] Constrained households borrow against housing collateral to fund consumption, and increases in house prices raises their borrowing capacity and thereby their consumption.

In the empirical analysis we start with the full population of Danish households from 1996 to 2010, but limit our attention to two-adult households who own housing assets. For each household, we calculate total consumption expenditure using an accounting identity and data on disposable income and changes in wealth (Browning & Leth-Petersen, 2003; Koijen *et al.*, 2015). In the empirical estimation, we estimate the effect of changes in house prices on consumption growth, using an extensive set of controls to account for common factors that may influence the results. In a robustness check, we use housing supply as an instrument for house prices in an attempt to address any remaining endogeneity concerns, following Mian & Sufi (2011) and Mian *et al.* (2013).

The main specification implies that the marginal propensity to consume is approximately 1 cent on the dollar. This estimate is smaller in magnitude than previous estimates in the

[2]The existence of a wealth effect relies on house price changes being permanent (Browning *et al.*, 2013; Lettau & Ludvigson, 2004). In this paper, we refrain from adressing permanent versus transitory shocks to house prices and instead focus on overall effect.

[3]We show that if there is non-separability between housing and consumption, house price appreciation lead to an increase in non-consumption. This effect is discussed in Iacoviello (2004) and Berger *et al.* (2015), and is mentioned in Campbell & Cocco (2007) and Mian & Sufi (2011). In the estimation we focus on the wealth and collateral effect, as the substitution effect is difficult to observe directly in our data.

literature (see Bostic *et al.*, 2009, for an overview), but is similar to the results in Browning *et al.* (2013) and Gan (2010), who both use household-level data. We find little difference in the estimated effect across age groups, which is possibly due to the sample being limited to two-adult households. The estimated effect varies over time, where the largest estimated effect is observed between 2003 and 2006, when the Danish housing market expanded at a historically rapid pace.[4] The estimated elasticity is five times higher in 2005 than the baseline estimates, but is insignificant and very close to zero in 2007 and 2008 when the Danish housing market declined dramatically.

Moreover, credit constraints are an important source of heterogeneity in the estimated effect. The previous empirical literature has often relied on indirect proxies such as available liquidity or age to identify households who are credit constrained to provide evidence for the importance of the collateral channel, and do not separately estimate the wealth and collateral effect (Cooper, 2013).[5] We confirm the importance of credit constraints, but only for those related to housing equity. Specifically, households with high loan-to-value (LTV) ratios respond strongly to house price changes, but the estimated effect for households with low LTV ratios is close to zero. We find no difference in the consumption response to house price changes between liquidity constrained and unconstrained households. This finding is consistent with the theoretical model and with Kaplan & Violante (2014), as constrained households are affected by house prices because it raises their available home equity, not because it increases liquidity.

The implicit assumption behind using proxies for credit constraints is that these households respond more strongly because they borrow against home equity. Rising house prices facilitate further borrowing against housing collateral for credit constrained households, which leads to a larger estimated effect. However, it is not certain that this is due to increased borrowing. Carroll & Kimball (1996) show in a model of consumption under uncertainty that the marginal propensity to consume is declining in wealth. The larger esti-

[4]See Rangvid *et al.* (2013), Dam *et al.* (2011) and Bäckman & Lutz (2016) for an overview of the Danish housing market in this time.

[5]Important exceptions who estimate collateral effects without wealth effects include Leth-Petersen (2010), DeFusco (2015) and Agarwal & Qian (2016).

mated effects could be due to lower wealth instead of increased borrowing.[6] To test whether the effect is actually driven by collateral borrowing, we re-estimate our baseline equation on the sub-sample of home-owners who do not extract equity. Consistent with a dominant role of the collateral channel, we find that the estimated effect is considerably lower once we remove households who borrow against housing collateral. Indeed, the magnitude of the coefficient on house price changes is close to zero. Similarly for borrowing constrained households, we find that once we remove households who extract equity, the effect of house price changes on consumption is close to zero.

We also find suggestive evidence against unobservable factors that may increase both consumption and house prices simultaneously, as the consumption of renters does not respond to house price changes in any year of the sample. Nevertheless, the set of controls in the empirical model may not capture all unobservables that affect both consumption and house prices. We therefore provide a robustness check where we instrument municipality-level house prices with housing supply (Saiz, 2010). The rationale behind the instrument is that a common shock to the Danish housing market, for example lower interest rates, can affect house prices differently in elastic versus inelastic areas.[7] With instrumented house prices, we find that the estimated effects are an order of magnitude larger than the corresponding OLS estimates. Using the same proxies for credit constraints we find that the effect is driven by households who are constrained, both in terms of liquidity and borrowing. Additionally, we find an even stronger effect for young households. There is no significant effect for unconstrained households, although the standard errors include sizable effects. In summary, the IV results show that house price changes have substantial and economically significant effect; the marginal propensity to consume out of housing is 0.12 in the baseline estimation.

Overall, our results indicate that house price changes impacts the real economy, but that

[6] Another alternative is that low levels of liquidity proxies for self-control problems.

[7] Housing supply is a commonly used instrument for house price growth. However, supply constraints may be correlated with a number of demand factors (Saiz, 2010; Davidoff *et al.*, 2016) that potentially invalidate the exogeneity of the instrument. We provide evidence and a discussion on the validity of the instrument in section 5.

the effect is different across different time periods and for different groups of people. Collateral constraints and collateral borrowing are likely the most important channels through which house prices affect consumption, and there is only a limited role for housing wealth effects.

The paper proceeds as follows. Section 2 develops a model of housing and consumption, section 3 describes the data, the sample selection and the empirical strategy, section 4 presents results from the OLS estimation, and section 5 presents results from the instrumental variable estimation. Section 6 concludes.

2 Model

In what follows, we construct a model of consumption and housing for existing homeowners to support the empirical analysis. In the spirit of Iacoviello (2004, 2005), we allow the economy to be populated by *unconstrained* and *constrained* households. Unconstrained households save and borrow unrestrictedly. Constrained households do not have sufficient savings to finance consumption expenditures, and experience restrictions in how much they can borrow. Constrained households can use their housing as collateral for borrowing. Additionally, we account for *"rule-of-thumb"* households, who neither borrow nor save, and instead simply consume out of their current income.[8]

We focus on households who are continued homeowners, i.e. those who do not buy or sell housing assets. Households choose consumption and housing today and derive utility from their choices. Homeowners hold positive amounts of housing stock, H_t, priced at P_t. Housing stock is chosen and managed by household, and is affected by depreciation, δ, and active adjustments to housing stock h_t (also priced at P_t), for example maintenance, renovations or home improvements:

$$H_t = (1 - \delta)H_{t-1} + h_t, \tag{1}$$

[8]The *"rule-of-thumb"* households who do not save may also be more likely to suffer from self-control problems, as in Laibson (1997), and may therefore want to consume out of housing wealth to finance current consumption.

Households receive a random endowment Y_t, they consume C_t and save B_t (or borrow if negative). They invest savings B_t in a single asset with the net return r_t. If no purchase or sale of a new home occurs, the flow of funds is given by:

$$C_t + P_t h_t + B_t = Y_t + (1 + r_t)B_{t-1}. \tag{2}$$

Unconstrained households

Unconstrained households maximize lifetime utility:

$$E_t \sum_{s=t}^{T} \beta^{s-t} U(C_s, H_s) \exp(\phi' z_s), \tag{3}$$

where E_t denotes expectation formed at time t, β is time discount factor, and $\exp(\phi' z_t)$ is utility taste shifter, which depends on demographic characteristics z_t. Households choose consumption C_t optimally by maximizing (3) subject to the constraints (1)-(2). The first-order condition for an optimum give:

$$E_t \left\{ \beta(1 + r_{t+1}) \frac{U_C(C_{t+1}, H_{t+1})}{U_C(C_t, H_t)} \exp(\phi' \Delta z_{t+1}) \right\} = 1, \tag{4}$$

where U_C is household marginal utility with respect to consumption. Equation (4) is the standard Euler equation that connects the marginal cost of foregoing one unit of consumption today to the discounted marginal benefit of consuming next period adjusted by the rate of return earned in the next period. Under rational expectations, Euler equation (4) can be written as follows:

$$\beta(1 + r_{t+1}) \frac{U_C(C_{t+1}, H_{t+1})}{U_C(C_t, H_t)} \exp(\phi' \Delta z_{t+1}) = 1 + e^C_{t+1},$$

where e^C_{t+1} is the expectation error. Taking logs, applying first order Taylor series expansion to $\ln U_C$, and writing the resulting equation one period back, we obtain estimatable Euler equation in log-linearized form:

$$\Delta c_t = \gamma_0^c + \gamma_1^c r_t + \gamma_2^c \Delta\hbar_t + \phi \Delta z_t + \epsilon_t^c, \tag{5}$$

where r_t is the net return between periods $t-1$ and t, $\Delta c_t = \ln(C_t/C_{t-1})$, $\Delta\hbar_t = \ln(H_t/H_{t-1})$.

Shocks to house prices may affect consumption indirectly through non-separability in preferences over consumption and housing. Equation (5) shows that consumption is directly related to housing stock through non-separability in preferences over consumption and housing, determined by the coefficient γ_2^c. Changes in house prices may also enter the equation through r_{t+1}, if house price growth properly belongs in r_{t+1}.

Constrained households

In addition to the flow of funds given by (2), constrained households can borrow up to a fraction m_t of the value of real estate holdings:

$$-B_t \leqslant m_t P_t H_t, \tag{6}$$

where m_t represents the limiting fraction on household's net obligations. To illustrate the problem faced by constrained households, we assume that they assign a high weight to today's consumption and do not discount the future (Iacoviello, 2004, makes the same assumption in a related model). Constrained households borrow up to the constraint, which will be binding in equilibrium. Constrained households choose consumption C_t and housing investment h_t optimally by maximizing their period utility $U(C_t, H_t)\exp(\phi' z_t)$ subject to the constraints (1)-(2) and (6). Constrained households do not save, and their inter-temporal decisions are not affected by r_t. The first-order conditions for the optimum give:

$$\frac{U_H(C_t, H_t)}{U_C(C_t, H_t)} = (1 - m_t)P_t, \tag{7}$$

from which it follows that the marginal cost of reducing consumption by one unit is equal to the marginal benefit of shifting a unit of consumption to housing, adjusted by real estate prices and borrowing limit. There is no discounting, and the future marginal utility of consumption does not appear.

We can express marginal utilities as $U_X(C_t, H_t) = u_X(C_t, H_t)/X_t$ for $X = \{C, H\}$. Equation (7) can then be presented as:[9]

$$C_t = (1 - m_t)P_t H_t \left[\frac{u_C(C_t, H_t)}{u_H(C_t, H_t)}\right]. \tag{8}$$

We perform a logarithm transformation of the equation (8) and take first differences to obtain the following empirical model:

$$\Delta c_t = \delta_0 + \delta_1 \Delta \hbar_t + \delta_2 \Delta p_t + \varphi \Delta z_t + \epsilon_t, \tag{9}$$

where the signs of δ_1 and δ_2 are expected to be positive, and demographic and financial characteristics in equation (9) can capture individual differences in m_t, which is a life-cycle specific limit to borrowing.

The empirical model of consumption for constrained households in equation (9) differs from the corresponding equation for unconstrained households in equation (5) in several ways. The consumption of constrained households depends directly on their borrowing capacity, which is determined by the borrowing limit. An expansion of borrowing and therefore of consumption can be achieved by either higher house prices, or by a reduction in the limiting fraction m_t. Fluctuations in housing prices raise the amount that can be borrowed and therefore affect household consumption regardless of the form of intra-temporal dependencies between consumption and housing.

"Rule-of-thumb" households

Campbell & Mankiw (1990, 1991) consider a consumption model where households simply consume out of their current income. Empirically, myopic consumption behavior is detected for many countries. Jappelli & Pagano (1989) and Campbell & Mankiw (1991)

[9] To illustrate this transformation, suppose households have the following preferences $U(C_t, H_t) = C_t^{\zeta} H_t^{\xi}$. Then $u_C(C_t, H_t) = \zeta U(C_t, H_t)$ and $u_H(C_t, H_t) = \xi U(C_t, H_t)$. Substituting these quantities in equation (8) obtains $C_t = (1 - m_t)P_t H_t[\zeta/\xi]$. With arbitrary preferences over consumption and housing, the residual term $[u_C(C_t, H_t)/u_H(C_t, H_t)]$ in (8) may be a more complex function of C_t and H_t.

provide evidence of the quantitative importance of such "rule-of-thumb" households based on estimates of a modified Euler equation in the United States, the United Kingdom, Canada, France, Sweden, and other industrialized economies. Empirical evidence in Bayoumi & MacDonald (1995) indicates that Denmark is not an exception in having a significant share of myopic households. We will therefore include the consumption modeling set-up of Campbell & Mankiw (1990), where a fraction of households consumes only their income:

$$\Delta c_t = \lambda_0 + \lambda_1 \Delta y_t + \epsilon_{it} \tag{10}$$

where $\Delta y_t = \ln(Y_t/Y_{t-1})$ and λ_1 captures the share of myopic consumers in economy.

3 Data, Methodology and Identification

In the first part of this section we present the data that we use in the empirical estimation and describe how we construct consumption expenditure and other variables. In the second part we discuss the empirical strategy and identification issues.

3.1 Data

We construct a dataset with consumption expenditures, income, financial wealth, homeownership, leverage, house prices, and demographic characteristics for all households in Denmark from 1996 to 2010. We collect individual data on income, financial assets and liabilities through the Danish Tax and Customs Administration (SKAT). We use property transaction records collected from the Danish Official Gazette (Statstidende) to keep track of homeowners and their housing assets, and to construct a municipality-level house price index. Detailed demographic data is provided by population records. Individual information is aggregated to the household level using a family identification number.

Imputing Consumption

Consumption expenditure is normally not available on the population level. To construct a measure of total household consumption expenditure, we follow a procedure developed in Browning & Leth-Petersen (2003). The procedure, based on an accounting identity, defines total consumption expenditure as disposable income minus the change in net wealth. This method of imputing consumption is frequently adopted for administrative data (Leth-Petersen, 2010; Browning *et al.*, 2013; Andersen *et al.*, 2014; Koijen *et al.*, 2015), and for survey data (Ziliak, 1998; Cooper, 2013; Khorunzhina, 2013). To construct imputed consumption, we collect information on disposable income, financial assets and liabilities. Disposable income is a sum of income after taxes, interest payments, rental value of owned properties, alimony payments and repaid social benefits. Financial assets consist of individual holdings of stocks, bonds and bank deposits. Liabilities include separate categories for bank debt and mortgage debt. All values are deflated to a base of 2006 using the consumer price index from Denmark Statistics.

The main concern with imputed consumption is that only active savings should be considered, and that changes in observed asset values that derive from capital gains (passive savings) should be excluded. We can fully control for passive and active savings for housing assets. As we observe all property transactions, any observed change in the value of housing assets for those who do not transact is due to capital gains. We therefore remove all households who we observe buying or selling in the housing market, and exclude changes in housing wealth from the imputation. We also remove households who buy or sell housing in $t-1$ because their financial decisions may be different in years right after the purchase.

It is important to account for portfolio returns when imputing consumption expenditures from data on income and net wealth (Koijen *et al.*, 2015). Since we do not observe the exact type of assets in the stock portfolio, we approximate capital gains on stock portfolios with the market portfolio return. Specifically, we multiply the value of stock holdings at the beginning of the year with the over-the-year growth in the Copenhagen Stock Exchange C20 index, and calculate active savings as the end-of-year holdings minus stock holdings at the beginning of the year adjusted for the capital-gains.

Variable Description

Demographic characteristics on individual level include marital status, number of children, years of education, age, area of residence, and a unique identification number on both the individual and household level. We define household level education as the level achieved by the most educated spouse, and household age as the age of the oldest spouse. We construct an indicator for young households equal to one if the oldest spouse is less than 40 years of age.

The registry data contain information about housing wealth for all individuals, which allows us to confidently identify house owners. We define a household as an owner if his/her registered housing wealth is positive. To construct measures of housing wealth and household leverage we use an end-of-year official property valuation from SKAT, adjusted by a scaling factor to approximate market values (see Andersen *et al.*, 2014, for a similar treatment of housing wealth from Danish administrative data). The scaling factor is calculated as the sales price divided by the tax valuation for all sold properties, for each municipality, year and property type (single-family houses and apartments).[10] Whenever we discuss housing wealth, we are referring to the adjusted market value of owned properties.

The model emphasizes the importance of credit constraints. While direct measure of household's credit constraints or borrowing needs is not available, data on financial assets and income is helpful in identifying potentially credit-constrained household (Gross & Souleles, 2002). A standard approach to identify credit constrained households is to examine their liquid financial assets relative to income. Households with lower levels of liquid savings relative to their income are more likely to borrow to finance their expenditures. In the absence of other easily available means to raise liquidity, those households are more predisposed to using housing equity as collateral than households with higher levels of liquid wealth. In practice, the amount of housing wealth available determines the borrowing capacity for constrained households, as housing can be used as inexpensive collateral for loans. We construct two indicator for financial constraints: one indicator for borrowing constraints based on mortgage to housing values, and another indicator based on available liquidity relative

[10] A similar scaling factor is provided by Denmark Statistics for the years before 2006. For the years after the Danish municipality reform of 2006 we calculate this factor ourselves. We do not find substantial differences between the scaling factor that we calculate and the one provided by Denmark Statistics for the data directly comparable before and after the reform.

to income. Specifically, we define a household as borrowing constrained if their mortgage value is more than 0.5 times his/her housing wealth, and we define a household as being liquidity constrained if the value of their liquid assets is lower than 1.5 months of disposable income. Liquid assets are defined as the sum of bonds, stocks and bank deposits.

We identify whether a household extracted equity in the given year by examining whether nominal mortgage balances increased by more than 10 percent year-over-year. Andersen *et al.* (2015) briefly discuss equity extraction in Danish data, and chose a 10 percent threshold to remove households who withdraw equity.[11] On top of the increase in mortgage balance, we require that nominal mortgage interest payments are unchanged or higher compared to the previous year. These two requirements help us identify households who borrow against home equity.

We construct house price indices for all municipalities. Constructing municipality-specific house price indices and geographical controls is complicated by a Danish municipality reform in 2006 that created new municipalities and divided Denmark into five regions based on these new municipalities. To ensure that regions and municipalities are geographically consistent over time, we match households to the new municipalities based on a unique geographical match provided by Denmark Statistics, and assign each municipality to the new region. After cleaning the transaction data, we use the average square meter price of traded single-family houses for each municipality as our municipality-level house price index. More details on the house price index can be found in Appendix A.

Finally, we calculate housing supply as the total area of each municipality that is covered by properties. Specifically, we take the sum of the square meter size of all property divided by the total land mass of the municipality (excluding areas covered by water). A greater fraction of land covered by properties corresponds to a smaller area available for new construction, and therefore to a more inelastic supply.

Sample Selection

Our theoretical model applies to households-homeowners with no drastic household com-

[11] Bhutta & Keys (2016) chose a 5 percent threshold. We chose a higher threshold because mortgage debt is measured in market values in the data, which fluctuates year-over-year.

position changes, and we select our sample accordingly. The sample selection is similar to studies who use Danish administrative data (Browning *et al.*, 2013; Andersen *et al.*, 2014). The starting sample after we remove households with missing demographic information is approximately 2.6 million households per year. We select all two-adult households (either married or cohabiting) between age 22 and 55 with or without children (to reduce concerns over family composition and retirement incentives), and exclude households whose members are entrepreneurs, as their income and wealth variables are less accurately reported. We exclude households from three small island municipalities as their housing and financial situation is likely different from the rest of Denmark.[12] As noted previously, we also remove households who buy or sell housing assets in year t and $t-1$.

Browning & Leth-Petersen (2003) find that consumption imputed from an accounting identity corresponds well to the self-reported consumption on average, but occasional outlier values can be problematic.[13] We remove outliers by excluding observations where the growth in imputed consumption is above the 99th percentile or below the 1st percentile, any observations with negative imputed consumption, and a small number of households who have no housing wealth but who have positive mortgage debt. After taking first differences and removing non-homeowners, the final data sample of homeowners consists of approximately 5 million households-year observations, for 1996 to 2010, which amounts to approximately 500,000 households per year. A full sample selection table is available in Appendix A.

Summary Statistics

Table 1 presents summary statistics on demographic characteristics (Panel A) and financial variables (Panel B). Column 1 presents summary statistics for the estimation sample, Column 2 and 3 divides the sample into young and old households, where the age cutoff is 40 years of age. Column 4 and 5 splits the sample between liquidity constrained and unconstrained households. The average annual total household consumption expenditure over the sample years is 428K Danish kroner, which corresponds to approximately 57K Euros.

[12] The municipalities in question are Christiansø, Bornholm and Ærø.

[13] Koijen *et al.* (2015) point to a similar issue for imputed consumption in Swedish administrative data.

This figure is close to the value of 395K Danish kroner (53K Euros) reported for two-person households with children in the Danish Consumer Expenditure Survey. Figure 1 further shows that both imputed and survey-based consumption closely match in levels and growth rates. The close match between imputed consumption expenditure and survey consumption is consistent with the findings in Browning & Leth-Petersen (2003). Moreover, the values of consumption, disposable income and housing wealth are comparable to previous studies that use Swedish and Danish administrative data.[14] Housing wealth is approximately four times larger than disposable income, similar to the values reported for Swedish households in Campbell *et al.* (2007) and Betermier *et al.* (2014).

3.2 Identification

We estimate the following equation, which encapsulates the consumption response to house price changes of three groups of households, as defined in equations (5), (9), and (10):

$$\Delta c_{ikt} = \alpha_0 + \alpha_1 r_{ikt} + \alpha_2 \Delta q_{kt} + \alpha_3 \Delta y_{ikt} + \varphi \Delta z_{ikt} + \lambda_t + \epsilon_{ikt}, \tag{11}$$

where Δc_{ikt} is log-difference in total consumption expenditure for household i living in municipality k between periods $t-1$ and t, r_{ikt} is the inter-temporal interest rate between periods $t-1$ and t, Δq_{kt} log-difference in house prices for municipality k between periods $t-1$ and t, Δy_{it} log-difference in disposable income for household i living in municipality k between periods $t-1$ and t, and Δz_t is the change in demographic characteristics between periods $t-1$ and t. A set of region, year and region-year fixed effects is denoted by λ_t.

As suggested by the discussion in section 2, unconstrained consumers react to a shock to house prices if housing is a part of the net return, which thereby influences the decision of how consumption is allocated over time. This can channel the wealth effect from life-cycle models, where consumption is related to life-time resources (Browning *et al.*, 2013; Campbell & Cocco, 2007). Alternatively, house price shocks could impact consumption

[14] Koijen *et al.* (2015) find that Swedish homeowners' imputed consumption expenditure equal to 328K Swedish kronor (approximately 36K Euros).

if there is non-separability in preferences over consumption and housing. For constrained households, house price shocks affect borrowing capacity, and enable additional borrowing against housing collateral to finance consumption.

Econometric estimation of equation (11) should take endogeneity into account. A major concern is that both house prices and consumption may be driven by a common factor (Altug & Miller, 1990). For example, the productivity hypothesis states that expectations of future income growth can affect both consumer spending and house prices (King, 1990; Pagano, 1990; Muellbauer & Murphy, 1997; Attanasio *et al.*, 2009). Equation (6) informs us about an additional source of endogeneity. Common factors may also affect the household's willingness to borrow against home equity, captured by m_t. For example, easier credit conditions or lower interest rates can induce households to borrow larger amounts against their home equity, and can simultaneously raise house prices.[15] While the maximum loan-to-value ratio (the legal equivalent to m_t) remained constant at 80 percent over the entire sample period, the household-specific value of m_t may be affected by an increase in income, a reduction in risk or demographic changes. Furthermore, when obtaining equation (5) for unconstrained homeowners, first order Taylor series expansion leaves higher order terms for changes in consumption and housing (e.g. variance) outside of the equation. These higher order terms are potentially contained in the error term ϵ_t in equation (5), which may invalidate orthogonally between the error term ϵ_t and changes in house prices. Equation (9) for constrained homeowners is obtained through direct log-linearization, therefore the endogeneity due to approximation error in Taylor series expansion is not an issue.

Our strategy to address these concern is twofold. First, we estimate equation (11) with OLS, and include an extensive set of interactions to control for aggregate factors that affect households in a given year and region, and household-level income growth and changes in demographic to both proxy for changes in individual-level income expectations, and to address concerns over changes in m_t.[16] The key identifying assumption is that the set of

[15]For example, Bhutta & Keys (2016) finds that equity withdrawal is strongly related to interest rates. In urban economics, house prices is also strongly related to interest rates in the user-cost model (Poterba, 1984).

[16]Our measure of total consumption expenditure incorporates both housing and non-housing consump-

interactions and time-varying controls at the individual, regional and year level capture potentially confounding factors that drive the change in consumption. Note that we are including controls for region-year effects, but use house prices on the municipality level. As Denmark is a small country, the regions are small enough to capture local labor market conditions, but large enough so that there is still variation in house price growth. To use an analogy to the United States, we are essentially controlling for MSA-year (city-year) effects and using county-level variation in house price growth.[17] Year, region and year-region indicators capture lower interest rates and credit conditions set on a national or regional level. For example, shift in credit supply at a local level, for example from a local bank, would be captured by a region-year interaction. Identification is threatened if there are any remaining shocks orthogonal to the controls but correlated with consumption decisions. While the extensive set of controls increases our confidence that we are taking the relevant common factors into account, we still caution a causal interpretation. In a robustness check we estimate whether the consumption of households without registered housing wealth is affected by changes in house prices. The idea is that the consumption of renters should not be affected by changes in house prices through wealth effects, but could be affected through the productivity hypothesis.

In another robustness check, we use an instrumental variable strategy in an attempt to account for common factors that may influence both house prices and consumption. Specifically, we use housing supply as an instrument for house price growth (Saiz, 2010), similar to the strategy used by Atif Mian and Amir Sufi in a series paper (Mian & Sufi, 2011; Mian *et al.*, 2013; Mian & Sufi, 2014). Intuitively, for an equivalent demand shock, the slope of the supply curve determines the effect on prices. In a more elastic market housing supply can be easily increased in response to a positive demand shock, an adjustment that is likely more difficult in inelastic areas. The theoretical insights behind this mechanism are

tion, which implies that a shift from housing to non-housing consumption leaves total which leaves total consumption expenditure unchanged. Substitution effects is therefore not relevant in our empirical setup, or alternatively are very difficult to identify.

[17] A Metropolitan Statistical Area (MSA) is concentrated around a city, but also includes nearby areas with close economic ties. A MSA can cover several legal administrative areas such as counties.

discussed in Glaeser *et al.* (2008), and Hilber & Vermeulen (2015) find evidence in support of the mechanism. Bäckman (2016) provides evidence that housing supply in Denmark is an important determinant of how shocks affect local housing markets, by showing that the serial correlation in prices is negative in municipalities with low housing supply but is positive in more constrained areas. In other words, house prices revert downwards faster following a positive shock in elastic areas, which is precisely the intuition behind the instrument. Figure 2 shows that the annual house price growth is consistently higher in areas with constrained (inelastic) supply, thus illustrating that the intuition behind using housing supply as an instrument holds for Denmark. We provide more formal tests in section 5.

Throughout our analysis, we estimate and discuss four specifications. The first two specifications include the entire sample of households, and differ by the presence of a control for changes in disposable income in the second specification. In the last two specifications, we split the full sample into young and old households.[18] Household age is informative of whether there is a housing wealth effects, or if common factors are influencing the results. According to the wealth hypothesis, older households respond stronger because any wealth shock is consumed over their (shorter) remaining life-span. The productivity hypothesis has the opposite prediction. House price changes, if they proxy for unobserved income expectations, have the strongest impact on young households as they have a longer life-span to enjoy higher income growth (Attanasio *et al.*, 2009).[19] Additionally, the varying composition of constrained and unconstrained consumers in economy is likely associated with the life-cycle stage of the household. For example, young households are more likely to be credit constrained, as more of their wealth is in intangible human capital. Risk and uncertainty linked to household age could affect willingness of households to borrow based on housing collateral. For these reasons, we present results for young and old households in all tables, and present results in figures with more granular age cohorts.

Finally, theory suggests that constrained households may use their available collateral

[18] We chose to split our sample instead of using interactions. A robustness check show that the qualitative conclusions are not affected by the choice of sample splitting.

[19] Berger *et al.* (2015) find that a more expansive model can produce the result that young households react more than old households.

to increase borrowing and thereby their consumption.[20] We therefore report results where we exclude households who borrow against their home-equity to test for any effect of house prices in the absence of collateral borrowing. Whether house prices affect consumption even after we remove those who refinance is informative of whether the housing wealth effect is an important channel.

4 Results

This section presents the results for the OLS estimation of equation (11). We begin by estimating (11) for the full sample of households, and proceed to investigate whether the effect varies depending on available liquidity or leverage. Overall, we find that the effect is small compared to the previous literature. We find an important role for borrowing constraints, but no substantial difference based on available liquidity. Additionally, we find that once we remove those who refinance, the estimated effect is small. Finally, we show that the consumption of renters, who do not have access to housing wealth, is not affected by changes in house prices.

Table 2 shows the estimation results for the baseline consumption model (11), where we use the full sample of households in columns (1) and (2), and then split the sample into young and old households in columns (3) and (4) respectively. All regressions include controls for age, education, change in family size, a household-specific portfolio return, along with year and region fixed effects and their interaction. The coefficient on house price growth in column (1) is equal to 0.047. This corresponds to a marginal propensity to consume (MPC) out of housing of approximately 0.01 (or 1 percent of the increase in house value).[21] This is on the lower end of the empirical literature, where the estimated effect range from 0.02 in Gan (2010), to around 0.17 in Case *et al.* (2005).[22] The coefficient is reduced to 0.039 after

[20] Cooper (2013) claims that the entire effect is driven by constrained households, who are borrowing against collateral.

[21] The marginal propensity to consume is calculated as: MPC = Elasticity * Consumption / Housing Wealth. Note that the average housing wealth and consumption of homeowners (column (6) of table 1) are 1,824,272 DKK and 428,672 DK respectively.

[22] Gan (2010) points out that international comparisons of MPC is not always productive, as institutional differences in mortgage and financial markets imply that the consumption-housing value ratio varies widely

controlling for income, but remains positive and highly significant. We do not find large differences in the response of consumption expenditures to house price growth for different age cohorts, in contrast to previous studies (see e.g. Campbell & Cocco, 2007; Attanasio *et al.*, 2009; Mian & Sufi, 2011). While the coefficient on Δq_{kt} is larger for young households, the coefficients over age groups are similar after taking standard errors into account. Figure 3 illustrates this result more clearly. Note that while Attanasio *et al.* (2009) interpret a large coefficient for young households as evidence against the wealth effect, Berger *et al.* (2015) show that this result can arise in a theoretical model because young households have higher debt and thus lower net worth.[23]

The coefficient on Δq_{kt} in column (1) is precisely estimated and matches the level and significance of the estimate reported in Browning *et al.* (2013), who estimate an equation similar to (11) for the period from 1987 to 1996. Unlike Browning *et al.* (2013) however, our coefficient remains statistically significant after controlling for income. As they note, the low elasticity in their study may be because house price variation was low, whereas our sample covers a period with considerable variation. Figure 4 shows that the estimates are low and of limited statistical significant for the period between 1998 and 2002, a period of relatively small changes in house prices. The magnitude of the coefficients increase dramatically in the period between 2003 and 2007, when prices expanded rapidly (see Bäckman, 2016).[24] Indeed, the estimated effect for 2005 is five times larger than the average effect.

Does the estimated effect vary depending on whether the household is credit constrained? Several previous studies have used low levels of liquid assets as a proxy for credit constraints. However collateral borrowing relies on available home equity, not available liquidity. Low levels of liquid assets do not capture households who are *borrowing* constrained, at least

across countries.

[23] This result may be because we are limiting our sample to two-adult households who co-habit. The prediction from Sinai & Souleles (2005) is that any wealth effect is decreasing in expected tenure, which is presumably just the sample that we are limiting ourselves to. We wish to emphasize that even if we find that old and young households responds similarly to house price changes, it is not certain that for example single households would respond in the same way.

[24] Between 1998 and 2002 house price growth was low, with less variation between municipalities. between 2003 and 2007 house price growth was large in magnitude, with noticeably more variation between municipalities. As our empirical strategy exploits variation in house price growth between municipalities during a given year, the effect may also be due to the larger cross-sectional variation during this time period.

not in the sense emphasized by the collateral channel in our model. In Denmark the ability to borrow against home equity is limited by a maximum LTV ratio of 80 percent, a legal requirement that is strictly enforced.[25] Leth-Petersen (2010) finds that available equity is the key to understanding how households respond to a reform that allowed them to access their home-equity in Denmark. To examine the presence of constraints in a manner consistent with the theoretical model, we therefore estimate equation (11) for borrowing constrained and unconstrained households.[26]

Panel A and B of table 3 report that borrowing constrained households respond strongly to house price changes, but unconstrained households have a small and statistically insignificant response. The estimated coefficients on Δq_{kt} for the constrained group in columns (1)-(4) in panel A are large and precisely estimated, and are considerably larger in magnitude than the estimated coefficients for unconstrained households in panel B. In fact, the coefficient for young, unconstrained households is not statistically significantly different from zero. The coefficients for young households in column (3) are larger than the estimated coefficients for old households in column (4). The coefficients on changes in income are similar across all models. The finer age decomposition, plotted in figure 5, shows that the estimated effect of house prices on consumption for borrowing unconstrained households is close to zero for all age groups, but is positive and significant for all constrained cohorts.

We also investigate whether liquidity constraints are an important determinant of consumption responses to house price growth in table 4. The estimated coefficients are similar between constrained (panel A) and unconstrained households (panel B). In contrast to the previous literature, we do not find that a low level of liquidity is associated with a larger response to house price changes (see e.g. Mian & Sufi, 2014, who finds that the housing wealth effect is primarily driven by households with low levels of liquidity).[27] Finally, we have tried to combine the borrowing constraints and the liquidity constraints. Specifically, we selected the sample of borrowing constrained households, and check whether the consumption re-

[25] Refinancing a mortgage is associated with an administrative cost, typically on the order of 5,000 DKK (671 EUR).

[26] See Andersen *et al.* (2014) for further evidence on leverage ratios and consumption.

[27] See also Mian & Sufi (2011).

sponse to house price changes is driven by liquidity constrained or unconstrained consumers. The results show that the effect is mainly driven by liquidity unconstrained consumers. Although the threshold value for liquidity constraints is somewhat arbitrary, a robustness checks confirms that the results are robust to using three and five months as cutoffs. In summary, liquidity constraints are not an important determinant of how consumption responds to house price changes in our sample.

The literature provides some intuition for why liquidity constraints are not important. In essence, low levels of liquidity may not fully characterize borrowing constrained households. Kaplan & Violante (2014) find evidence for a large fraction of "wealthy hand-to-mouth" households, who own large amounts of illiquid assets (such as housing) but low levels of liquid assets. The liquidity constrained households in table 4 are similar to the wealthy hand-to-mouth households, as they own housing but hold low levels of liquid assets. For these households, consuming out of the illiquid asset carries transaction costs, and the equilibrium outcome is to consume all of their income and liquid wealth. While these households respond strongly to a liquidity shock, they likely react less to a housing wealth shock. While their wealth increases, the transaction costs associated with the illiquid asset implies that it is not optimal to fully smooth consumption every period. Cochrane (1989) and Browning & Crossley (2001) present a similar logic, where the benefit of equating marginal consumption across periods is less than the cost of doing so. The larger coefficient on changes in income for liquidity constrained households suggests that they may indeed be liquidity constrained, although this does not imply that they will respond strongly to house price changes.

While it is tempting to attribute the higher estimated effects for borrowing constrained households to collateral effects, high levels of leverage or low levels of liquidity may proxy for other characteristics. Carroll & Kimball (1996) show that the marginal propensity to consume is decreasing in wealth, and Mian *et al.* (2013) finds support for the hypothesis. The crucial element of the collateral channel is that housing assets act as collateral for borrowing when house prices change. Figure 6 plots the fraction of constrained and unconstrained households who extract equity in a given year and shows that borrowing constrained households are more likely to extract equity. Moreover, the fraction of households who extract equity peaks during the housing boom, when house price growth is the highest. The question that we ask is, if we remove these households from the sample, is there still a correlation between house price changes and consumption?

If the correlation between house prices and consumption is driven entirely by a collateral effect, as some studies suggest (e.g. Cooper, 2013), then the estimated housing wealth effect will be zero if we remove the households who extract equity. Table 5 performs such a test, where panel A shows the result for the full sample, and panel B shows the result for the borrowing constrained sample, the part of the population where we found such large effects previously. There is still a positive effect even after we remove those who extract equity, although the coefficient is only marginally significant. After controlling for income growth in column (2), the effect size declines to 0.016. Further, neither coefficient on Δq_{kt} is significant in columns (3) and (4). Panel B repeats the same exercise for borrowing constrained households, with similar results. Overall, our findings suggest that the estimated effect of house price changes on consumption is driven mainly by collateral borrowing, not by the wealth effect.

5 Robustness Check – Instrumental Variable Estimation

In this section we use an instrumental variable strategy to estimate how house prices affect consumption, following a previous literature that use the intuition in Saiz (2010).

The first stage of the IV estimation, presented in table 7, support the contention that housing supply elasticity affects the dynamics of house prices in a municipality. The first stage provides more formal evidence for the pattern in figure 2, where areas with inelastic supply have higher absolute house price changes. The estimated coefficient on housing supply is positive and highly significant, showing that municipalities with more inelastic supply experience a larger increase in housing prices, even after controlling for demographic characteristics and year and region effects. The F-statistic of instruments is substantially higher than the rule of thumb threshold value of 10 suggested by Staiger & Stock (1997) and

Stock & Yogo (2005). However, there is an on-going discussion about the validity of using housing supply as an instrument (Davidoff *et al.*, 2016). Table 12 in the appendix estimates how the housing supply instrument works over time, and finds that there are several years in which housing supply does not predict house price growth quite as well. As such, we include these results as a robustness check to see whether the overall pattern that we find in the previous section is still present.

In the second stage, the coefficient on house price in table 8 is now 0.607 in column (1), which is substantially larger than the corresponding OLS estimate in table 2. This result is robust to controlling for income in column (2). The estimate for young households is equal to 0.596 and for old households is equal to 0.416. The larger estimated elasticity translates into a larger marginal propensity to consume out of housing wealth. Given the values for housing and consumption from table 1 and an estimated elasticity of 0.493 after controlling for income, the marginal propensity to consume out of housing wealth for homeowners corresponds to 0.12 (or 12 percent of the increase in house value), close to the upper range of the literature (see Bostic *et al.*, 2009). The MPC for young and old households is 0.24 and 0.10 respectively. The lower MPC for old household reflect the fact that old household on average hold more housing wealth, even as consumption levels are similar between young and old households. Mian & Sufi (2014) find a marginal propensity to borrow from house price shock of 0.26 using a similar estimation strategy.

We proceed to investigate liquidity constraints in table 9. Panel A and B report results for liquidity constrained and unconstrained households respectively. The estimates for liquidity constrained households are larger in magnitude than the estimates for unconstrained households. The results indicate that young, liquidity constrained households have the largest reaction to house price changes. However, the standard errors in panel B are all large, and even though the coefficients are of marginal significance, the estimates are not substantially different between constrained and unconstrained households. This result is therefore reminiscent of the result in table 4, where there is no substantial difference between constrained and unconstrained households.

As previously discussed, low levels of liquid assets may not necessarily capture credit constrained households. Panel A and B of table 10 therefore again present results for borrowing constrained and unconstrained households, respectively. However, table 10 is not as revealing as the corresponding OLS estimates in table 3. A potential reason is that the instrument is not performing well for borrowing unconstrained households, especially for the young sample. The F-test is below the threshold value of 10 for all regressions in Panel B. Panel A shows that the estimated coefficient for borrowing constrained households is similar in magnitude to the estimated effect for liquidity constrained households in table 9. The estimate for young households is again higher than the estimate for old households, although the estimates are not statistically different from each other.

Overall, we find that the estimated coefficients on house price growth are substantially larger in magnitude when we use an instrumental variable strategy. However, the standard errors are large, especially for the sub-sample of households who are borrowing constrained. The pattern in the IV estimation is similar to the pattern in the OLS estimation, although the magnitude of the coefficients differs considerably. The estimated effects are larger for young households, and for those who are liquidity constrained, regardless of whether we use IV or OLS.

6 Conclusion

In this study we investigated how changes in housing wealth affect consumption. The literature has emphasized that the causal effect is due to either wealth effects or due to collateral constraints. This observation forms the basis of our study, where we attempt to determine whether house prices affect consumption and whether this effect is driven by a wealth or collateral effect. We find that there is a correlation between house prices and consumption, and that this effect is indeed stronger for households who are more likely borrowing constrained. Furthermore, we find that the estimated effect is larger during the Danish housing boom. With regards to whether the correlation is driven by a housing wealth effect or a collateral effect, we find that once we remove households who extract equity, as predicted by the collateral channel, we do not observe a statistically significant correlation between house price changes and consumption. This suggest that the wealth effect has a small impact on consumption, and that collateral borrowing against home equity is the main driver of the observed correlation between changes in house prices and consumption.

For future research, we aim to discover how the sample selection influences the estimated results. As we focus on stable two-adult households who do not trade housing assets, we are removing many households for whom an increase in house prices may have larger effects. For example, it is commonly argued that the wealth effect is decreasing in expected housing tenure. Our sample selection likely selects households with a longer expected tenure, as we select two-adult households who already own housing. Indeed, it would also be interesting to see how the sample selection affects not only the estimated effect, but also the presence of liquidity and borrowing constraints, and whether these constraints are in a sense more binding for other households than the ones that are in our sample.

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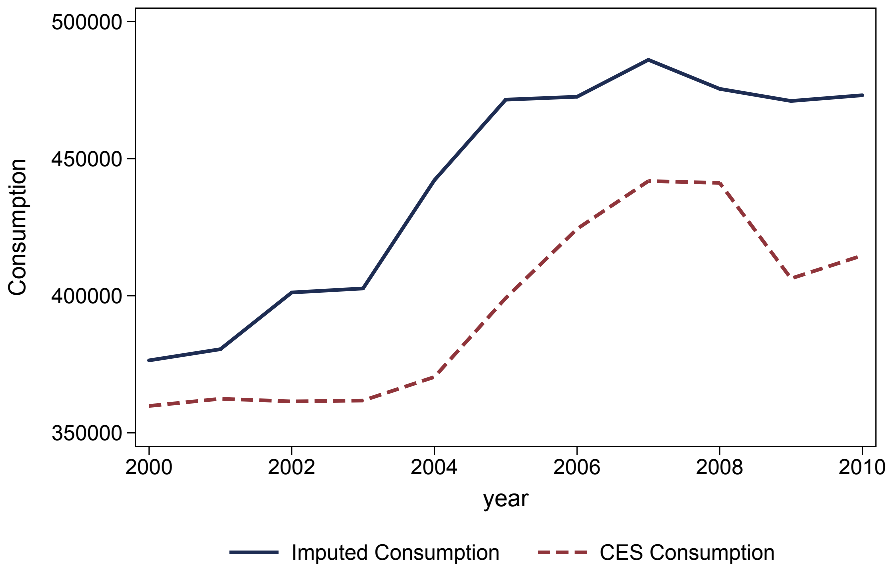
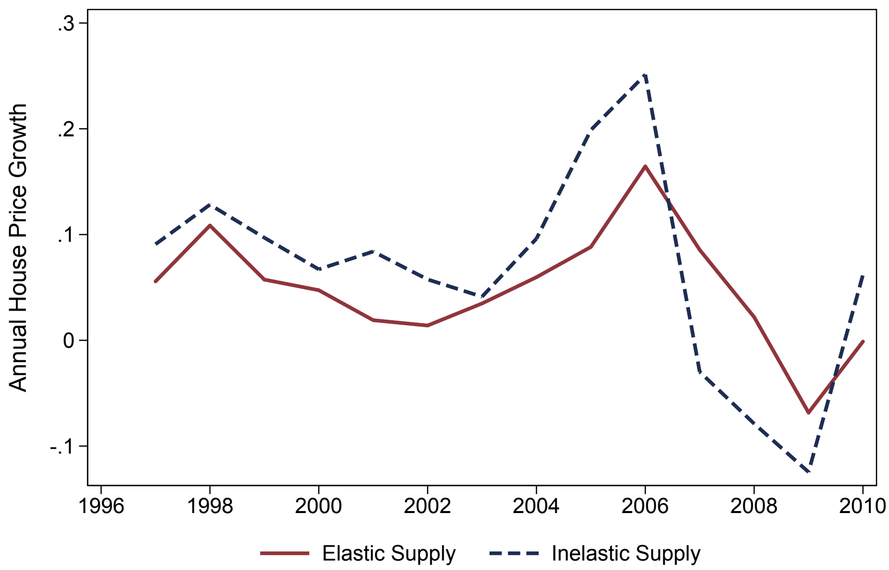
7 Figures

Figure 1: Imputed and Survey Consumption



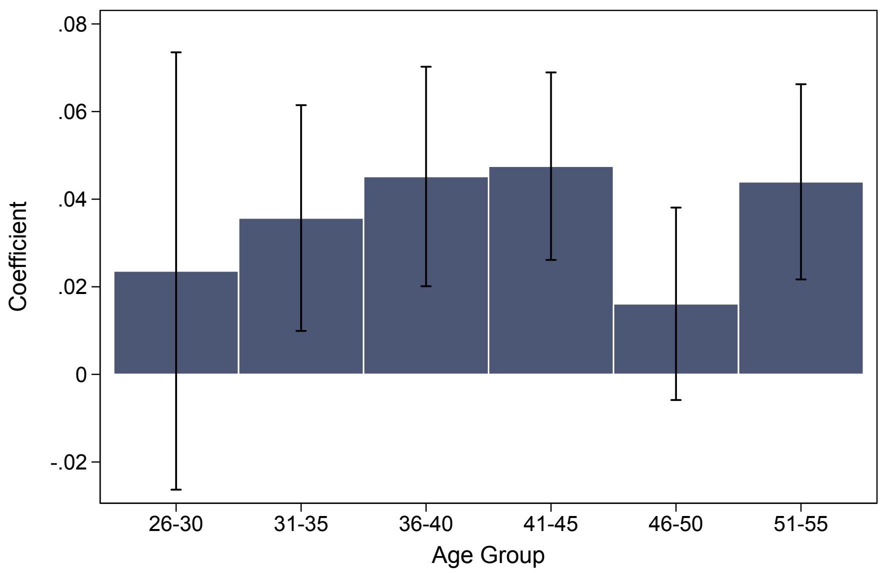
Note: Solid line is data from the Danish Expenditure Survey for total consumption of two adult households with children. Dashed line is imputed consumption from the registry data. All consumption values are deflated to the base of 2006.

Figure 2: Housing Supply and House Price Growth



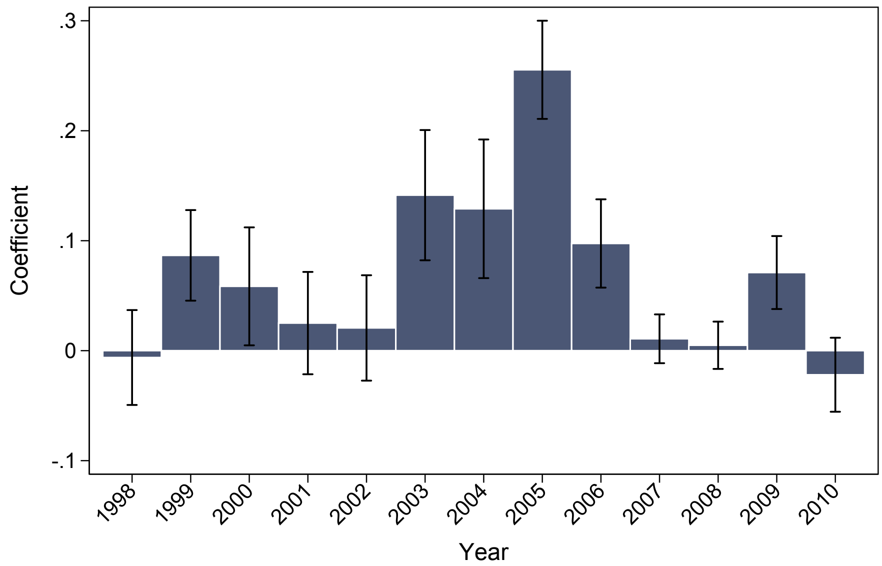
Note: The figure plots the average annual house price growth for the first and fourth quantile of housing supply.

Figure 3: Age Decomposition of Consumption Expenditure Response to House Price Growth



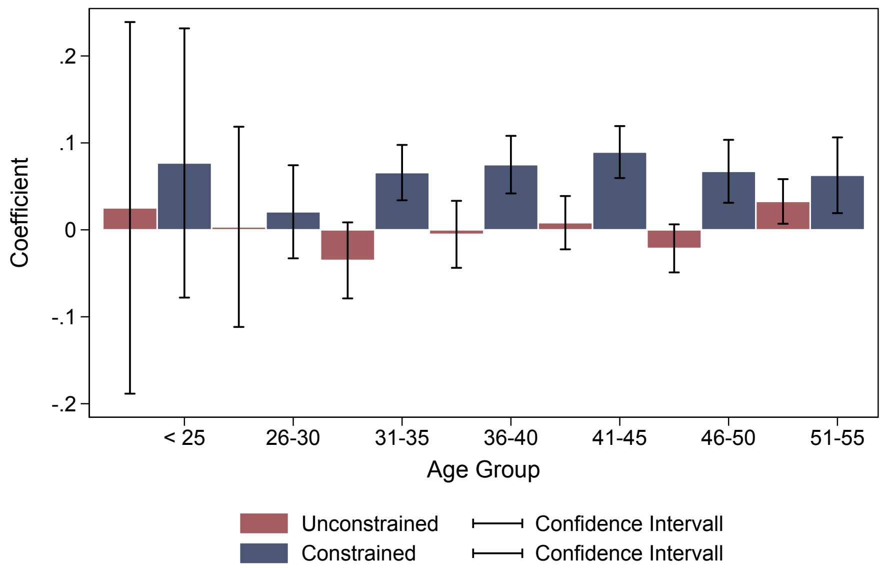
Note: The figure plots the coefficients on Δq_{kt} from an OLS estimation of equation (11). Each bar represents a separate regression, where the sample is split according to the age group. Dependent variable is the change in log consumption. Regressions are estimated using demographic controls for age, education, change in family size, and year, region and region-year fixed effects with clustered standard errors.

Figure 4: Year-by-Year Estimates of the Consumption Expenditure Response to House Price Growth



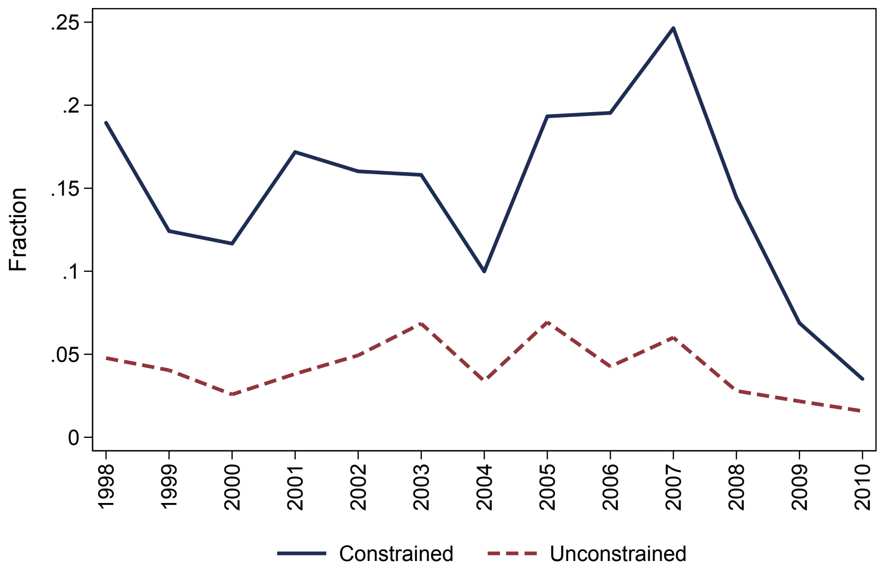
Note: The figure plots the coefficients on Δq_{kt} from an OLS estimation of equation (11). Each bar represents a separate regression for each year. Dependent variable is the change in log consumption. Regressions are estimated using demographic controls for age, education, change in family size, and year, region and region-year fixed effects with clustered standard errors.

Figure 5: Estimated Housing Wealth Effect for Constrained and Unconstrained Households



Notes: The figure plots the coefficients on Δq_{kt} from an estimation of Equation 11. Each bar represents a separate regression, where the sample is split according to age group and whether they are borrowing constrained. The borrowing unconstrained households have a mortgage of less than 0.5 times his/her housing wealth, and borrowing constrained households have mortgages in excess of 0.5 times his/her housing wealth. Dependent variable is the change in log consumption. Regressions is estimated using the same controls as in Table 2 and with clustered standard errors.

Figure 6: Home Equity Extraction by Constrained and Unconstrained



Note: The figure plots the fraction of households in each group who extract equity in a given year in the estimation sample.

8 Tables

Table 1: Summary Statistics

	(1) Full Sample	(2) Young	(3) Old	(4) Constrained	(5) Unconstrained
Panel A: Demographic Characteristics					
Age	43.14	34.28	47.61	42.46	45.35
Number of Children	1.45	1.63	1.36	1.51	1.26
Length of Education	14.91	15.05	14.84	14.81	15.23
House Owner	1.00	1.00	1.00	1.00	1.00
Panel B: Financial Characteristics					
Consumption	428,672	412,124	437,020	421,505	452,026
Disposable Income	426,900	400,503	440,217	411,031	478,609
Assets					
Net Wealth	482,457	167,040	641,572	252,354	1,232,233
Housing Wealth	1,824,272	1,644,253	1,915,084	1,698,423	2,234,342
Liquid Assets	169,033	111,358	198,128	57,765	531,593
Liabilities					
Total Debt	1,512,963	1,621,042	1,462,113	1,543,310	1,427,565
Mortgage Debt	959,301	1,046,127	915,501	962,549	948,719
Observations	5,036,623	1,688,833	3,347,790	3,853,884	1,182,739

Average from year 1998 to 2010. Net wealth is defined as assets minus liabilities. Housing wealth is the tax value adjusted by the scaling factor. Debt is the sum of mortgage debt, bank debt and the value of mortgage deeds. Liquid assets consists of stocks, bonds and bank deposits. Consumption is defined in 3.

Table 2: Baseline results

	(1) All	(2) All	(3) Young	(4) Old
Δq_{kt}	0.047***	0.039***	0.045***	0.034***
	(0.005)	(0.005)	(0.009)	(0.006)
Δy_{it}		0.326***	0.359***	0.310***
		(0.004)	(0.006)	(0.004)
Age	-0.001***	-0.001***	-0.000*	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Education Length	0.003***	0.002***	0.003***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Change in Number of Children	0.007***	0.007***	0.000	0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
Household Specific Return	0.062***	0.049***	0.026**	0.058***
	(0.005)	(0.005)	(0.009)	(0.006)
Municipality-Year Effects	Yes	Yes	Yes	Yes
Constant	0.017***	0.002	-0.032***	0.004
	(0.003)	(0.003)	(0.006)	(0.005)
N	4,976,451	4,976,451	1,665,029	3,311,422

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on year-municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

Table 3: Borrowing Constraints

	(1) All	(2) All	(3) Young	(4) Old
Panel A: Constrained				
Δq_{kt}	0.093***	0.081***	0.096***	0.067***
	(0.009)	(0.009)	(0.013)	(0.011)
Δy_{it}		0.372***	0.393***	0.360***
		(0.005)	(0.008)	(0.007)
Observations	2,336,320	2,336,320	925,073	1,411,247
Panel B: Unconstrained				
Δq_{kt}	0.026***	0.020**	0.023	0.019*
	(0.007)	(0.007)	(0.017)	(0.008)
Δy_{it}		0.336***	0.361***	0.330***
		(0.007)	(0.015)	(0.007)
Observations	1,550,439	1,550,439	253,404	1,297,035

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on year-municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

Table 4: Liquidity Constraints

	(1) All	(2) All	(3) Young	(4) Old
Panel A: Constrained				
Δq_{kt}	0.047***	0.037**	0.038*	0.035**
	(0.013)	(0.012)	(0.015)	(0.012)
Δy_{it}		0.463***	0.472***	0.456***
		(0.007)	(0.009)	(0.008)
Constant	-0.039***	-0.057***	-0.075***	-0.066***
	(0.005)	(0.005)	(0.008)	(0.007)
Observations	2,111,987	2,111,987	846,251	1,265,736
Panel B: Unconstrained				
Δq_{kt}	0.047**	0.040**	0.047*	0.035**
	(0.015)	(0.013)	(0.021)	(0.013)
Δy_{it}		0.263***	0.284***	0.255***
		(0.006)	(0.010)	(0.006)
Constant	0.078***	0.068***	0.030**	0.066***
	(0.006)	(0.006)	(0.010)	(0.008)
Observations	2,860,701	2,860,701	817,996	2,042,705

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on year-municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

Table 5: Housing Wealth Effects Without Equity Withdrawal

	(1) All	(2) All	(3) Young	(4) Old
Panel A: Full Sample				
Δq_{kt}	0.025**	0.016*	0.018	0.013
	(0.010)	(0.008)	(0.012)	(0.008)
Δy_{it}		0.360***	0.396***	0.343***
		(0.005)	(0.008)	(0.006)
Constant	-0.002	-0.019***	-0.022***	-0.039***
	(0.005)	(0.005)	(0.007)	(0.006)
Observations	4,382,716	4,382,716	1,460,665	2,922,051
Panel B: Borrowing Constrained				
Δq_{kt}	0.023*	0.013	0.017	0.005
	(0.011)	(0.011)	(0.012)	(0.013)
Δy_{it}		0.368***	0.396***	0.349***
		(0.006)	(0.009)	(0.007)
Constant	0.024***	0.011*	0.000	0.003
	(0.005)	(0.005)	(0.007)	(0.008)
Observations	2,498,492	2,498,492	1,104,288	1,394,204

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on year-municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

Table 6: Housing Wealth Effects For Renters

	(1) All	(2) All	(3) Young	(4) Old
Panel A: Full Sample				
Δq_{kt}	-0.008	-0.011	-0.012	-0.008
	(0.007)	(0.006)	(0.009)	(0.008)
Δy_{it}		0.671***	0.641***	0.725***
		(0.006)	(0.008)	(0.011)
Constant	0.099***	0.049***	0.066***	0.029***
	(0.004)	(0.004)	(0.006)	(0.008)
Observations	1,218,973	1,218,273	655,353	562,920
Panel B: Liquidity Constrained				
Δq_{kt}	0.003	-0.003	-0.006	0.002
	(0.007)	(0.007)	(0.011)	(0.009)
Δy_{it}		0.760***	0.727***	0.816***
		(0.007)	(0.008)	(0.012)
Constant	0.089***	0.036***	0.060***	0.008
	(0.004)	(0.004)	(0.006)	(0.008)
Observations	943,168	942,960	502,771	440,189

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on year-municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

8.1 Robustness Check: Instrumental Variables

Table 7: First-Stage Regressions

	(1) All	(2) All	(3) Young	(4) Old
Instrument:				
Housing Supply	0.017***	0.017***	0.016***	0.018***
	(0.003)	(0.003)	(0.003)	(0.003)
Controls:				
Δy_{it}		0.008***	0.007***	0.008***
		(0.001)	(0.001)	(0.001)
Region dummies	Y	Y	Y	Y
Year dummies	Y	Y	Y	Y
Preference shifters	Y	Y	Y	Y
Life-cycle controls	Y	Y	Y	Y
Partial R^2 of Instrument	0.002	0.002	0.002	0.002
F-test of Instrument	31.8	31.7	36.0	36.0
Observations	4,972,687	4,972,687	1,664,247	3,308,440

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on municipality in parentheses. Dependent variable is the the change in log square meter price between $t-1$ and t for municipality k., Δq_{kt} Δq_{kt} is Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region and year effects.

Table 8: Instrumental Variables – Baseline Results

	(1) All	(2) All	(3) Young	(4) Old
Δq_{kt}	0.607***	0.493***	0.596***	0.416***
	(0.066)	(0.055)	(0.103)	(0.056)
Δy_{it}		0.323***	0.355***	0.309***
		(0.009)	(0.014)	(0.009)
Age	-0.001***	-0.001***	-0.000	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)
Education Length	0.002***	0.002***	0.002***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Change in Number of Children	0.007***	0.007***	0.001	0.010***
	(0.001)	(0.001)	(0.002)	(0.001)
Household Specific Return	0.056***	0.044***	0.020	0.055***
	(0.007)	(0.007)	(0.011)	(0.008)
Apartment	0.013***	0.011***	0.019***	0.002
	(0.002)	(0.001)	(0.002)	(0.001)
Constant	-0.030***	-0.033***	-0.073***	-0.027***
	(0.008)	(0.007)	(0.011)	(0.007)
Observations	4,972,688	4,972,688	1,664,247	3,308,441
F-test of Instruments	37.38	37.31	40.98	35.34

Note: *, **, *** denote statistical significance at the 5%, 1% and 0.1% level. Standard errors clustered on municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. Δy_{it} is the change in log disposable income between $t-1$ and t. All regressions include controls for age, education level, change in number of children, a household-specific individual return, and with region, year and region-year effects.

Table 9: Instrumental Variables – Liquidity Constraints

	(1) All	(2) All	(3) Young	(4) Old
Panel A: Constrained				
Δq_{kt}	0.674***	0.492***	0.650***	0.369***
	(0.076)	(0.071)	(0.114)	(0.061)
Δy_{it}		0.439***	0.451***	0.430***
		(0.010)	(0.013)	(0.010)
Observations	3,113,842	3,113,842	1,186,077	1,927,765
F-test of Instruments	31.95	31.89	33.94	30.59
Panel B: Unconstrained				
Δq_{kt}	0.476***	0.403***	0.383	0.415***
	(0.126)	(0.118)	(0.327)	(0.114)
Δy_{it}		0.225***	0.234***	0.222***
		(0.012)	(0.020)	(0.011)
Observations	1,858,846	1,858,846	478,170	1,380,676
F-test of Instruments	40.88	40.76	49.20	36.75

Notes: IV estimation of Equation 11 where house prices are instrumented with housing supply. Standard errors clustered on municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. $\Delta logIncome$ is the change in log disposable income between $t-1$ and t. All regressions include controls for age and education level, along with year and region fixed effects.

Table 10: Instrumental Variables – Borrowing Constraints

	(1) All	(2) All	(3) Young	(4) Old
Panel B: Constrained				
Δq_{kt}	0.628***	0.530***	0.566**	0.459**
	(0.177)	(0.153)	(0.181)	(0.141)
Δy_{it}		0.318***	0.348***	0.300***
		(0.009)	(0.012)	(0.009)
Observations	2,982,238	2,982,238	1,291,906	1,690,332
F-test of Instruments	14.17	14.12	11.93	15.52
Panel B: Unconstrained				
Δq_{kt}	0.955	0.792*	2.005	0.574**
	(0.488)	(0.393)	(2.970)	(0.222)
Δy_{it}		0.328***	0.365***	0.318***
		(0.013)	(0.035)	(0.011)
Observations	1,990,450	1,990,450	372,341	1,618,109
F-test of Instruments	2.82	2.80	0.39	4.86

Notes: IV estimation of Equation 11 where house prices are instrumented with housing supply.Standard errors clustered on municipality in parentheses. Dependent variable is the change in log consumption, Δc_{it}. Δq_{kt} is the change in log square meter price between $t-1$ and t for municipality k. $\Delta logIncome$ is the change in log disposable income between $t-1$ and t. All regressions include controls for age and education level, along with year and region fixed effects.

A Appendix

A.1 Municipality-Level Price Index

We construct a municipality level house price index using data on all transactions in Denmark. The data is from The Danish Gazette (*Statstidende*), and covers the universe of Danish property transactions as a part of the judicial process of transferring ownership. We combine the data on property sales with data on individual property characteristics from the Housing Register (*Bygnings- og Boligregister*, BBR). Further, we collect data on property ownership to identify trades between spouses and family members, and to identify trades that occur due to the death of a spouse or due to divorce. These trades are removed from the final sample, as they are less likely to be sold at market prices.[28]

After collecting the data on all property transactions, we connect each house and apartment to the Housing Register (BBR) to find the property type (apartment, single-family house or summer house). We further drop outliers in the sales price by removing the top and bottom 1 percent in the sales price distribution, and by removing any transactions where the transaction price is listed as zero. The resulting sample of households are then used to calculate the average square meter price for traded properties in all municipalities.

[28]Removing family trades and similar non-market transactions are common in the construction of real estate indices. See e.g. the S&PCase-Shiller index methodology: http://us.spindices.com/index-family/real-estate/sp-case-shiller).

A.2 Sample Selection Table

Table 11: Sample Selection

	Droppped	**Remaining**
Demographics		
Initial Number of Observations		40,230,677
Single-adult households	20,249,851	19,980,826
Age 18-21	107,646	19,873,180
Age 55+	7,092,939	12,780,241
Entrepreneur	846,285	11,933,956
Small municipalities	339,088	11,594,868
House Traders and Consumption		
Remaining Observations		11,594,868
Property traders	2,339,239	9,255,629
Renters with mortgage debt	15,75	9,239,879
High/low consumption growth	37,43	9,202,449
Consumption below 0	141,779	9,060,672
Estimation Sample Selection		
Renters	2,361,589	6,699,083
No Demographics	641,957	6,057,126
No House Type	6,599	6,050,527
No Income Change	404,711	5,645,816
No Consumption Change	673,128	4,972,688
Final Estimation Sample		4,972,688

A.3 Robustness of Instrument

Table 12: First-Stage Over time

	(1) Δq_{kt}	(2) Δq_{kt}	(3) Δq_{kt}
Housing Supply	0.0227***		
	(9.49)		
year=1998 X Housing Supply		0.126***	0.128***
		(8.09)	(7.74)
year=1999 X Housing Supply		0.0819***	0.0811***
		(4.50)	(4.36)
year=2000 X Housing Supply		-0.0102	-0.0117
		(-0.65)	(-0.76)
year=2001 X Housing Supply		0.0628***	0.0661***
		(4.36)	(4.63)
year=2002 X Housing Supply		-0.00327	0.00180
		(-0.35)	(0.20)
year=2003 X Housing Supply		0.00217	0.00213
		(0.19)	(0.18)
year=2004 X Housing Supply		0.0872***	0.0880***
		(6.92)	(6.53)
year=2005 X Housing Supply		0.213***	0.212***
		(7.35)	(7.27)
year=2006 X Housing Supply		0.243***	0.244***
		(5.12)	(5.10)
year=2007 X Housing Supply		-0.129	-0.126
		(-1.40)	(-1.37)
year=2008 X Housing Supply		-0.130	-0.122
		(-1.65)	(-1.53)
year=2009 X Housing Supply		-0.219***	-0.219***
		(-5.67)	(-5.67)
year=2010 X Housing Supply		0.0173	0.0169
		(1.03)	(1.00)
Constant	0.0268***	0.0262***	0.0330***
	(34.92)	(33.39)	(12.31)
Observations	4972688	4972688	4972688

Note: Column 1 and 2 are estimated without control variables. Column 3 includes controls for changes in disposable income, age, education level, changes in the number of kids, a dummy for living in an apartment, controls for the interest rate and regional dummies.

Conclusion

This Ph.D. thesis has examined the Danish housing market in detail. While the analysis of the Danish housing market of course interesting in of itself, the mortgage and housing market in Denmark can give several important lessons for economists and policy-makers in other countries. The housing market boom and bust in the 2000s had severe consequences for the Danish economy at the time, and indeed affects the Danish economy even today. The first chapter, "Examining the Housing Boom in Denmark", provides a detailed overview of the mortgage and housing market. The chapter argues that is striking that even though the mortgage market is designed to provide the correct incentives for borrowers, investors and lenders, we still observe such significant boom-bust dynamics. The study also shows that it is misleading to think of one housing boom, as there is substantial heterogeneity in both the amplitude and timing of house price gains. Furthermore, the results suggest that fundamental factors cannot explain the full extent of the boom.

The Danish mortgage market offers a very compelling laboratory to investigate how seemingly small changes can have substantial effects on the housing market itself and on the real economy. In particular, the second chapter, "Prime Borrowers and Financial Innovation in the Housing Boom and Bust", shows how the introduction of interest-only mortgages in 2003, expected to have a small impact on house prices, led to a boom-bust cycle that almost matches the housing boom in the United States in magnitude. The clear advantage of studying interest-only mortgages in Denmark is that many of the proposed explanations for the housing boom in the United States are absent in Denmark due to institutional design. In the third chapter, we study how changes in house prices transmit to the real economy. In particular, we show that the correlation between house price changes and consumption is driven by collateral borrowing, suggesting an important role for credit markets in transmitting house price shock into the real economy.

Overall, this thesis emphasizes that housing market dynamics has an important impact on the aggregate economy, but that the dynamics may look different across different locations. The thesis has shown how seemingly small innovations in mortgage financing can have large impacts, and has shown how the resulting changes in house prices transmits into the economy. As such, effective public policy design should take the potential consequences into account.

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