The Consequences of Interest Only Loans for the Housing Boom and Bust

Claes Bäckman*
Copenhagen Business School

Chandler Lutz†
Copenhagen Business School

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Abstract

We use a natural experiment in Denmark to assess the impact of interest-only (IO) mortgages during the 2000s. Our results indicate that IO mortgages amplified the boom-bust pattern in housing: IO loan availability caused house prices to increase 35 percent during the boom and then subsequently reverse during the bust. These effects, which cannot be explained by changes in lending standards or credit supply, are magnified in more inelastic housing markets and have a large impact on the real economy. Together, findings are consistent with households using IO loans to capitalize on optimistic house price expectations during the 2000s boom.

*Department of Economics. Email: cb.eco@cbs.dk
†Department of Economics. Email: cl.eco@cbs.dk

The 2000s housing boom coincided with the permeation of interest-only (IO) mortgage loans across housing markets that imploded into the worst economic downturn since the Great Depression, yielding the following key question: What is the impact of IO loans on house prices? Given the high penetration of these mortgage products in many housing boom regions, it would be easy to blame such loans for the recent economic malaise.[1] Yet the relation between IO loans and house prices is far from clear. For example, consider figure 1 that shows the house price indices for Australia, Canada, Spain, and the United Kingdom. In the years leading up to the housing boom, IO loans were prominent in Australia and the United Kingdom, but nonexistent in Canada or Spain.[2] Yet despite these differences in mortgage product offerings, all four countries experienced a housing boom that eventually collapsed in 2007-2008. In particular, consider the case of Australia, whose mortgage banks introduced IO loans in 1995 (independent of any change in regulatory structure).[3] By 2005, IO loans made up over 30 percent of all Australian mortgages (Scanlon *et al.*, 2008) and house prices had nearly doubled. Clearly, any analysis of the Australian (or related) case is subject to issues of *endogeneity through reverse causality* – did the introduction of IO loans cause the house price boom or did mortgage originators introduce IO loans in anticipation of a boom and a substantial increase in demand from mortgage customers?

Further complicating the relationship between IO loans and house prices is the change in lending standards that occurred in many countries during the 2000s. For example, in the US, where IO loans were readily available, lending standards declined markedly and some researchers contend that an increase in credit to low-quality borrowers was the key driver of the housing boom and bust (e.g. Mian & Sufi, 2009). Hence, confounding changes in lending standards present an additional endogeneity issue in the measurement of the effects of IO loans on house prices.

To address these issues and identify the causal impact of IO loans on house prices and the real economy during the 2000s, we exploit a natural experiment that introduced IO

[1] For example, in 2006, Bloomberg called IO loans "Nightmare Mortgages" that are "...going to kill all the people but leave the houses standing."
`http://www.bloomberg.com/bw/stories/2006-09-10/nightmare-mortgages`

[2] See Scanlon *et al.* (2008) for an overview of IO loans in different countries.

[3] The introduction of new mortgage products in Australia is regularly described as a result of increased competition in the banking sector. See e.g. Australian Prudential Regulation Authority & Reserve Bank of Australia (2008).

loans to Denmark in 2003. The results from this analysis have important implications for our understanding of the 2000s boom as (1) Denmark's mortgage finance system is substantially similar to that of the United States (Campbell, 2013); (2) like many other countries, Denmark experienced a large house price boom during the 2000s; and (3) IO loans were popular globally among borrowers in high house price growth areas, including in US and UK bubble regions such as California and London where half of all new mortgages were IO loans at the peak of the boom.[4]

First, we employ a unique micro-level dataset to show that buyer characteristics and thus lending standards did not change in Denmark during the housing boom years or following the introduction of IO loans in 2003. These results match accounts from official government reports that also find that lending standards remained stable during the 2000s. Hence, in our analysis of the impact of IO loans on house prices, we can abstract from changes in lending standards and shifts in credit supply as potential confounds.

Next, using the Synthetic Control Methodology (SCM) and several cross-country panel datasets, we analyze the causal impact of a 2003 Danish law change that legalized IO mortgages. Our results indicate that the introduction of IO loans into the Danish mortgage finance system amplified the boom-bust pattern in Danish housing markets. Relative to a carefully chosen control group of housing markets that also experienced a boom but for which IO loans were not available, the legalization of IO loans caused (1) a dramatic increase in house prices immediately following the policy intervention; (2) a tremendous plunge in prices as the global housing bust permeated across markets; and (3) an increase in overall housing market volatility during the 2000s. More specifically, the introduction of IO loans during the 2000s caused Danish house prices (at the national level) to increase 35 percent relative to what they would have been otherwise in absence of the treatment. 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 counterfactual that also experienced a housing bust. Hence, the introduction of IO loans played a leading role in the increased volatility of Danish home prices over the 2000s boom and bust.

[4] See `http://www.nytimes.com/2009/09/09/business/09loans.html?pagewanted=all` and `http://goo.gl/9ymmLe`.

Further, we examine the effects of the policy innovation on the cross-section of Danish cities. These results indicate that the consequences of the IO loan policy are heterogeneous and vary based on the housing market elasticity across local housing markets. Specifically, we find that the penetration of IO loans is significantly larger in more inelastic housing markets and that the introduction of IO loans caused noticeably higher house price growth in these markets. A Danish city where housing elasticity was one standard deviation more inelastic than the mean had a 1.5 percentage point higher penetration of IO mortgages. This same city also experienced house price growth that was approximately 13 percentage points higher than the mean during the boom, but 2 percentage points lower than the mean during the bust. Hence, low supply elasticity intensifies the IO loan amplification mechanism in local housing markets. Altogether, these results are consistent with households using IO loans to capitalize on bullish house price growth expectations during the boom as expectations are likely to be more optimistic in inelastic housing markets (Glaeser *et al.*, 2008).

Finally, the combination of the SCM and the introduction of IO loans in Denmark yields a clean experiment that allows us to measure the marginal propensity to consume (MPC) out of housing wealth and thus the impact of IO loans on the real economy. To the best of our knowledge, this is the first natural experiment that estimates the MPC out of housing wealth over the recent period. The results indicate that the MPC out of increasing housing wealth due to IO loans during the boom (2003Q4 - 2006Q4) was 6 percent, while that out of declining housing wealth during the bust (2007Q1 - 2010Q1) was 4 percent. In comparison, the literature on aggregate housing wealth effects (Bostic *et al.*, 2009) typically finds an MPC of 5 to 17 percent.

We use the SCM to identify the causal impact of the introduction of IO loans. This approach yields a transparent and flexible procedure to estimate causal effects of interventions taking place at aggregate units. Intuitively, the SCM is a data-driven method to evaluate comparative case-studies. More technically, we construct a "Synthetic Denmark," a counterfactual based on a convex combination of a carefully selected control group, that best matches the most relevant characteristics of Denmark, the treated unit, during the period prior to the policy intervention, the pre-treatment period. This approach is transparent in nature as we can easily compare the characteristics of the treated unit to those of its

Synthetic Control. Differences in the path of treated unit and its Synthetic counterpart then yield the time-varying causal impact of the policy intervention. Further, note that the SCM generalizes the usual fixed-effects (difference-in-differences) estimator by allowing for time-varying unit-specific heterogeneity (Abadie *et al.*, 2010).

Our study employs data at both the national- and city-level to measure the impact of IO loans in Denmark. First, we use an international dataset where Denmark serves as the treated unit and the non-IO countries Canada, Finland, Italy, and Spain constitute potential controls.[5] The use of this carefully selected control group is advantageous as the global housing boom engulfed all of these countries during the 2000s.[6] Hence, any estimates of the causal impact of the introduction of IO loans will be in excess of a counterfactual that also experienced a housing boom, making them conservative in nature. Next, we reduce the dimensionality of the data to the city-level, allowing us to measure the heterogeneous impact of IO loans across local housing markets. For this analysis, we only have similar house price indices for Danish and Canadian cities. Yet, as we document below, Canadian cities provide an apt control group for local Danish housing markets over our sample period.

This paper contributes to an important literature that aims to determine the origins of the recent housing boom and its subsequent collapse. For example, Mian & Sufi (2009) contend an outward shift in the supply of credit to low quality borrowers was an important determinant of the recent boom.[7] In contrast, Adelino *et al.* (2015) argue that an increase in house price expectations, and not an outward shift in the supply of credit, was the key driver of the housing boom and bust. Our work extends this literature in the following ways. First, given the dynamics of the treated unit and our carefully selected control group, we can largely abstract from shifts in the supply of credit as changes in credit (e.g the global savings glut of Bernanke, 2007) did not differentially affect Denmark relative to the control group. Second, given the conservative nature of the Danish housing finance system, we can abstract from concerns regarding loosening credit standards, misinformed borrowers, or misrepresented loan documentation.[8] Indeed, IO and non-IO borrowers met

[5]See section 3 for more details.

[6]Between the first quarter of 2000 and the fourth quarter of 2006, house prices in Canada grew by 57%, in Finland by 36%, in Italy by 47%, and in Spain by 87%.

[7]See also Favara & Imbs (2015).

[8]For studies that discuss these issues, see e.g. Keys *et al.* (2010); Nadauld & Sherlund (2013).

the same lending standards in Denmark after the policy change.[9] Third, we show that the introduction of IO loans amplified the boom-bust pattern in housing markets, but that these effects are mitigated in more elastic housing markets where housing supply can adjust to meet demand. In total, these results provide key insights into the origins of the housing boom and highlight the importance of house price expectations. Our results are consistent with households using IO loans to capitalize on optimistic house price expectations during the 2000s. Further, while the drivers behind changes in house price expectations are beyond the scope of this work, our findings do show how IO loans can magnify the effects of house price expectations.[10] Last, the policy implications for this paper are wide reaching as IO loans were prominent across housing markets in the US, UK, and Europe. For example, in California, nearly half of all new mortgages were IO at the peak of the boom in 2004.[11]

1 Econometric Methodology

To estimate the causal 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. Hence, the SCM is well-suited to evaluate the effects of the introduction of IO mortgages using a cross-country panel dataset. Specifically, through this framework, 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 counterfactual 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.

Overall, the advantages of the SCM are manifold.[12] Specifically, Abadie *et al.* (2010) show that the SCM generalizes the fixed effects (difference-in-differences) estimator as the

[9] Mortgages were only granted to households who could afford a standard 30 year fixed interest mortgage (Ministry of Economic and Business Affairs, 2007). See section 3 for an overview of Denmark's mortgage finance system.

[10] See Foote *et al.* (2012), Cheng *et al.* (2014), Shiller *et al.* (2014) and Glaeser & Nathanson (2014).

[11] http://www.nytimes.com/2009/09/09/business/09loans.html?pagewanted=all

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

unobserved unit-specific heterogeneity can vary over time. Formally, suppose that we have $j = 1, \ldots, J+1$ units and $t = 1, \ldots, T$ time periods. Without loss of generality, let unit $j = 1$ receive the treatment so that remaining J units, the so-called donor pool, contribute to the Synthetic Control. Suppose moreover that the intervention of interest occurs at time $T_0 + 1$ and thus that the pre-intervention periods are $t = 1, \ldots, T_0$ and the post-intervention periods are $t = T_0 + 1, T_0 + 2, \ldots, T$. Let Y_{it}^N be the outcome for unit i at time t had unit i not been exposed to the treatment and Y_{it}^I be the observed outcome if unit i had received the treatment. Our goal is to estimate the causal impact of the treatment $\alpha_{1t} = Y_{1t}^I - Y_{1t}^N$ for periods $T_0 + 1, T_0 + 2, \ldots, T$. Note that Y_{1t}^I is observed in the post-intervention period, but Y_{1t}^N is not. Therefore, the aim is to compute $\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N$ for periods $T_0 + 1, T_0 + 2, \ldots, T$, where Y_{1t}^N is estimated via the Synthetic Control.

Following Abadie *et al.* (2010), we can use a general model to show how the SCM identifies the treatment effects for the potential outcomes of all units. Let $Y_{jt}^N = \delta_t + \upsilon_{jt}$ and $Y_{jt}^I = \alpha_{jt} + \delta_t + \upsilon_{jt}$, where $j = 1, \ldots, J+1$, δ_t is a common factor, and υ_{jt} is an idiosyncratic component. Assume that υ_{jt} can be expressed by the following factor model:

$$\upsilon_{jt} = U_j \theta_t + \lambda_t \mu_j + \varepsilon_{jt} \tag{1}$$

where U_j is a vector of covariates that can be time-varying or time-invariant that are not affected by the treatment, θ_t is vector of time specific parameters, μ_j is a unit-specific unobservable, λ_t is an unknown common factor, and ε_{jt} are zero-mean transitory shocks. In our case U_j will consist of the pre-treatment outcome variable and all pre-treatment predictor variables.[13] Note that the unit-specific unobservable, μ_j, is augmented with a time-varying common factor, λ_t and hence can vary over time. In contrast, the typical difference-in-differences or fixed effects estimators require that λ_t be constant. Thus, as shown by Abadie *et al.* (2010), the SCM generalizes typical econometric methods and deals with endogeneity from omitted bias due to unobserved cofounding characteristics that evolve over time.

Next, consider a linear combination of pre-intervention outcomes, $\bar{Y}_i^K = \sum_{t=1}^{T_0} k_s Y_{is}$,

[13] U_j can also include the post-intervention covariates as long as they are not affected by the treatment. In our study, only pre-treatment predictor values will be included in the treatment. See Abadie *et al.* (2010) for more details.

$K = (k_1, \ldots, k_{T_0})$, and a $(J \times 1)$ vector of weights $W = (w_2, \ldots, w_{J+1})$ such that $w_j \geq 0$ and $\sum_{j=2}^{J+1} w_j = 1$. Abadie *et al.* (2010) suggest to choose W^* so that the Synthetic Control best approximates the treated unit with regard to the covariates U_i and the linear combination of pre-intervention outcomes $\bar{Y}_i^K$. Specifically, if we select W^* so that $\sum_{j=2}^{J+1} w_j^* \bar{Y}_j = \bar{Y}_1$ and $\sum_{j=2}^{J+1} U_j = U_1$ hold (or hold approximately), then

$$\hat{\alpha}_{1t} = Y_{1t} - \sum_{j=2}^{J+1} w_j^* Y_{jt} \tag{2}$$

is an unbiased estimator for α_{1t} in periods $T_0 + 1, T_0 + 2, \ldots, T$. To implement the Synthetic Control numerically, Abadie *et al.* (2010) minimize the distance between a vector of characteristics for the treated unit, $(U_1, \bar{Y}_1)$ and a convex combination of the corresponding characteristics for the control units subject to a positive semi-definite weighting matrix. An optimization algorithm chooses the weighting matrix to minimize mean squared prediction error of the pre-treatment interval and hence the weights are chosen in a completely non-parametric fashion. Finally, note that while it is typical to only print the average pre-intervention characteristics of the treated unit and its Synthetic Control, the optimization algorithm minimizes the distance between the time-series in every period as U_j comprises both time-varying and time-invariant predictor variables.

Inferential techniques within the SCM can be carried out through placebo studies. Specifically, a placebo study randomly assigns the treatment to unit $j \neq 1$ of the control group.[14] 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 actually occurred (e.g. compare α_{1t} and α_{jt}). 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.[15] The magnitude and rarity of the treatment effect can then be assessed relative to the set of estimated placebo effects. In our application, we apply the treatment to all

[14]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.

[15]See Abadie *et al.* (2010, 2011) for more details.

members of the control group and this will yield our so-called permutation test.[16] The permutation test will then be used for inference.

Lastly, note that the SCM is susceptible to endogeneity through reverse causality if market participants anticipate the policy change and alter their expectations accordingly. Technically, the key assumption is that the predictor variables did not change in response to the anticipation of the reform. In our case, as noted below, the introduction of IO loans in Denmark was largely unexpected.

2 Data

To assess the effects of the introduction of IO loans on housing markets during the 2000s housing boom, we utilize both micro-level and aggregate data. The following two sections describe these datasets in turn.

2.1 Micro-Level Data

First, we collect high-quality micro-data from Statistics Denmark. Our dataset covers property transactions as well as detailed demographic and economic information on the universe of all Danish households from 1994 to 2010. Individual- and household-level variables include household level demographic information, along with financial information such as financial wealth and household income. We are able to match the data on property transactions to each household using ownership registers.

Next, we construct a measure of the elasticity of housing supply for Danish cities. For each city, we sum the size of all properties and divide it by city size.[17] In this respect, our measure can be compared to the elasticity measure developed by Saiz (2010).[18] Indeed, as in Saiz (2010), our elasticity proxy quantifies the ease with which housing supply can expand in different geographic areas. We standardize our measure of housing supply elasticity to have zero mean, unit variance, and so that positive values represent more elastic housing markets. The ranking of cities by elasticity is presented in appendix C, where a rank of 1

[16]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.

[17]City size does not include any area covered by water.

[18]Saiz (2010) excludes any area lost to water and wetlands within a 50-km radius of the city center. Saiz also excludes land with a slope above 15 percent. Although we do not have access to this type of geographic data, we believe that this is a limited concern simply because Denmark is generally a very flat country.

corresponds to the least elastic city and 10 corresponds to the most elastic city. The least elastic city is CopenhagenCity, and the most elastic city is WesternJutland. Overall, these rankings match our expectations.

2.2 Aggregate-Level Data

Next, we outline the aggregate-level data used to identify the causal impact of IO loans during the 2000s boom within the Synthetic Control framework. In the following paragraphs, we describe the international and city-level data in more detail. Appendix D contains a complete list of all variables and their sources.

First, we consider data at the highest level of aggregation, the country-level. Using the country-level data, our aim is to estimate the casual impact of IO loans in Denmark where the donor pool of potential control units consists of countries where IO loans were not available. Unfortunately, the availability IO loans were pervasive across many European countries and the United States, limiting the number of potential control units. We discuss IO mortgages across countries and these issues in more detail in Section 3. Our set of non-IO loan countries includes Canada, Finland, Italy, and Spain. For each country, our data include house prices, GDP per capita, durable consumption per capita, and the growth in private credit flows to the non-financial sector.[19] House prices proxy 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.

We also build a city-level dataset where we compare Danish and Canadian cities. As discussed in detail below, the housing finance systems of Denmark and Canada are similar during the pre-treatment period, which makes the Danish-Canadian comparison apt for our study. For the city-level data, we iteratively implement the SCM so that each Danish city represents the treated unit and the Canadian cities contribute the Synthetic Control.

[19]The housing prices are the quality-adjusted housing price indices from the Bank of International Settlements. See `http://www.bis.org/statistics/pp.htm` 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.

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.[20] 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.[21] To match the Teranet Canadian data, we construct single family repeat-sales house price indices for Danish cities using same methodology employed by Teranet. In our main analysis, we employ Canadian and Danish repeat-sales indices. These indices are constructed to ensure comparability – we closely follow the Teranet methodology when we construct the Danish repeat-sales index. Yet 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. Further, note that in our main results, we exclude Canadian cities that experienced a resource boom during the sample period from the donor pool.[22] The inclusion of Canadian resource cities does not qualitatively affect our results.

Last, 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 total, this allows us to match pre-treatment characteristics at different points in the distributions of Denmark and Canada and is beneficial if institutional or data collection methods, for example, differ across countries. In our main results below, we report our findings for the "standardized" macro data.

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

[21]Teranet cities include Calgary, Edmonton, Halifax, Hamilton, Montreal, Ottawa-Gatineau, Quebec City, Toronto, Vancouver, Victoria, Victoria, and Winnipeg.

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

A robustness check confirms that our findings are similar when we use the unadjusted macro data.

3 Mortgage Markets

The following sections describe the mortgage finance system in Denmark and the sample countries, and the significant structural reform in Danish mortgage finance that occurred in 2003.

3.1 Housing Finance in Denmark

The mortgage finance system in Denmark is highly rated internationally, and is similar to the mortgage market in the United States (Campbell, 2013). 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, and can fund an additional 15 percent using higher interest bank debt. Traditionally, mortgage loans had to be amortized over a maximum of 30 years. 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. Denmark does not have a continuous credit-score system and there are no requirements on positive equity for refinancing. Households can extract equity by increasing the principal balance, on the condition that the borrower has good credit standing and that the new principal amount does not exceed the legally mandated 80 percent of house value. If a borrower defaults, the mortgage credit bank can trigger a forced sale of the underlying asset. Any residual claim is converted into a personal claim, making mortgage loans in Denmark full recourse.

Mortgage credit in Denmark is extended to borrowers through specialized lenders called mortgage credit banks, who act as intermediaries between borrowers and investors. These mortgage credit banks face strict underwriting criteria that require them to assess the credit worthiness of all borrowers upon granting a mortgage. Lenders are required to themselves assess both the value of the underlying property and the borrowers ability to afford payments if interest rate increase (International Monetary Fund, 2011). Mortgage credit banks originate mortgage loans to borrowers, and use the proceeds to issue mortgage bonds sold to investors.[23] The interest rate for borrowers is entirely decided by investors in mortgage bonds and not by the issuing lender. The lender is legally mandated to hold the mortgage bond on their balance sheet throughout the loan period, meaning that lenders retain any credit risk. If a mortgage bond defaults, the mortgage credit bank is required to replace the defaulting bond by one with similar characteristics. The investor in mortgage bonds therefore faces no credit risk, provided the issuing lender remains solvent. In over 200 years of operation, no mortgage bond has ever defaulted (Andersen *et al.*, 2014). The investors in mortgage bond instead assume interest rate- and pre-payment risk of mortgage bonds.

Although evidence from previous research suggests that looser credit and lending standards contributed to the housing boom and bust in the United States, there is little scope for such concerns in Denmark.[24] For mortgage credit banks, strict underwriting criteria together with the retention of credit risk combine to limit concerns about predatory lending.

3.2 Mortgage Reform in 2003

The Danish mortgage market changed considerably in the early 2000s.[25] Interest-only mortgages were introduced on October 1, 2003, through a rapidly implemented law change.[26] The law proposal was introduced on March 12, 2003, and passed the Danish parliament on June 4, 2003 with a large majority voting in favor of the proposal. The political aim was to 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. Although the reform explicitly targeted these select groups, the new mortgages rapidly became a popular choice for households across the population.

More specifically, the law change allowed mortgage credit institutions to offer households a mortgage product where principal repayments could be postponed for up to 10 years.[27]

[23] A small fee for borrowers is typically added to cover administrative costs, credit risk and profits, typically around 50 basis points. Prior to 2007 there was no difference in fees based on loan types.

[24] See e.g. Mian & Sufi (2009); Keys *et al.* (2010); Nadauld & Sherlund (2013) for evidence from the United States.

[25] Adjustable rate mortgages were introduced in 1996, although they did not gain in popularity until the early parts of the 21st century.

[26] Interest-only mortgages are referred to as deferred amortization mortgages in Denmark. Following convention, we denote them as interest-only mortgages.

[27] Technically, the law 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 new loans. See e.g. Politiken (2003).

Similar to traditional 30 year fixed rate mortgages, the interest rate on these new mortgages is set by the market, through investors purchasing mortgage bond issued by mortgage credit banks. Prior to 2007, the interest rates and the fees collected by the mortgage credit institutions did not differ between mortgage products.[28] According to the financial industry IO mortgages were only granted to households who could afford a standard 30-year fixed interest mortgage (Ministry of Economic and Business Affairs, 2007). 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 Credit Banks, 2011).

Deferred amortization loans rapidly became a popular choice across all types of households. Figure 2 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 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 from approximately 892 billion DKK (120 billion EUR) in 2003Q3 to 1,329 billion DKK (178 billion EUR) in 2007Q1. Nearly all of this growth is attributable to IO loans.

The government argued in the law proposal that the expected effect on house prices was small and likely to be offset in the longer run. Deferred amortization mortgages allow for better consumption smoothing across the life-cycle by better matching savings decisions to the long-term earnings potential of households.[29] Because amortization payments are not a cost, but rather a form of savings, they do not directly influence the cost of housing. The effect on aggregate consumption was also discussed, but was similarly expected to be small. After an initial increase in consumption, the higher interest payments would offset the increase in available cash. The expected decrease in mortgage repayments was 2-3 billion DKK per year. Given that the disposable income was 700 billion DKK at the time, the law proposal was not expected to have a large impact on aggregate consumption. A priori, the

[28]Fees for IO loans differed after the bust in 2007.

[29]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`.

introduction of IO loans was expected to have little or no effect on the housing market and the real economy.

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 8 in appendix C 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).[30] 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.[31] Next, all countries except Canada allow mortgage interest deductions, and all countries except the United States have full recourse laws. Denmark and the United States allow fee-free repayment of mortgages and equity withdrawal. Yet after taking into account all mortgage costs, the effective repayment and equity withdrawal costs are likely similar across Denmark, the US, and Canada (Kiff, 2009; Campbell, 2013).[32]

Residential mortgage debt to GDP and 1998Q1-2002Q4 house price growth vary significantly between countries. Denmark's mortgage debt to GDP ratio of 73.4 percent in 2003 is the highest of all sample countries. 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. Last, in appendix E, we plot the growth in private credit

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

[31] 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).

[32] Finland also allows for mortgage equity withdrawal.

flows, 10-year government bond yields, mortgage rates, and house prices for our Canada, Denmark, Finland, Italy, and Spain.[33] 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.[34]

Finally, 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. For example, 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, such 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. Finally, Spain legalized IO mortgages in April 2006. Scanlon *et al.* (2008) report that 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.

3.4 Mortgage Markets in Canada and Denmark

In this section, we provide a more detailed comparison between the Canadian and Danish housing markets as local Canadian housing markets will serve as our control group in our city-level analysis. Note that Denmark is often compared to the United States (Andersen *et al.*, 2014; Campbell, 2013), but the Danish housing market may more closely resemble that of Canada. First, neither Denmark nor Canada experienced a deterioration of lending standards during the 2000s housing boom. Therefore, an increase in the supply of credit to marginal borrowers is an unlikely explanation for the house price increases in Denmark

[33] Mortgage rates over our sample where only available for Canada and Denmark.

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

and Canada during the 2000s. In marked contrast, the flow of credit to low-quality, subprime borrowers has often been blamed for the recent US housing cycle (Mian & Sufi, 2009). Second, mortgages in both Denmark and Canada are full recourse, whereas recourse in the US is not available, impractical, or too expensive (Pence, 2006). Thus, bonds and securities backed by mortgages in Canada and Denmark are less risky than those in the US. Next, only 30 percent of mortgages are securitized in Canada and these securities are often guaranteed by the government owned Canada Housing and Mortgage Corporation (Kiff, 2009). As noted above, Danish mortgage banks retain the credit risk associated with mortgage bonds and hence Danish mortgage bonds also carry little default risk. In marked contrast, 60 percent of US mortgages are securitized and are considered much riskier securities than their Canadian counterparts (Kiff, 2009). Fourth, variable and fixed rate mortgages are available in both Canada and Denmark. In Denmark, fixed rate mortgages have a term up to 30 years, while the typical Canadian mortgage amortizes over 25 years, is re-negotiated every 5 years, and is subject a repayment penalty. However, note that mortgage fees are low in Canada and thus the effective cost of refinancing in Denmark and Canada is likely similar. For instance, (Kiff, 2009) finds that the cost of mortgage financing is similar across both the US and Canada for prime borrowers after accounting for all costs. Last, non-traditional mortgage products were never available in Canada and IO loans were introduced to Denmark in 2003. In total, 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.[35]

4 The Channels Through which IO Loans Can Affect House Prices

In the traditional model of housing prices developed by Poterba (1984), houses are treated as a financial asset. The price of housing is determined by the cost of housing services and an arbitrage relationship between owning and renting. Amortization payments (or lack thereof) do not impact the cost of housing services since amortization payments are a form of savings. In these types of models, the introduction of IO mortgages has no effect

[35] 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.

on house prices.[36] However, as Wheaton (1999) emphasizes, the traditional approach to modelling house price dynamics cannot account for observed time series variation without some deviation from rationality. Indeed, irrational and overly optimistic households have often been blamed for the crisis.[37] We formulate the view that overly optimistic households buy housing in anticipation of capital gains as the *house price expectations hypothesis*.[38]

Ortalo-Magne & Rady (2006) instead construct a model where the ability of young households to afford a mortgage down payment can have an effect on house prices. Analogously, IO mortgages can be used to purchase more housing at current income, implying that the introduction of IO mortgages may lead to an increase in the purchasing power of current income for young or related households. This in turn would raise the demand for housing and lead to an increase in house prices. We formulate this as the *young household housing demand hypothesis*. Recall that the young household housing demand hypothesis was the rationale for the 2003 Danish introduction of IO loans – the loans were intended for students, young adults, and other cash-constrained households. Supporting this hypothesis using UK panel data dating back to the 1980s, Cocco (2013) finds that the availability of IO loans is correlated with relative increased demand among younger households.[39] Note that neither Cocco nor similar work attempts to connect IO loans to a change in prices.

Related to the housing demand hypothesis, is the buyer *income-based* hypothesis. Here, growth in buyer income will lead to an outward shift in housing demand and thus an increase in house prices.

Finally, Mian & Sufi (2009) contend that an expansion of credit to low quality borrowers led to the rapid increase in house prices. They find that the amount of mortgage credit to sub-prime zip-codes greatly increased in the run-up to the crisis, and that income growth

[36]Glaeser *et al.* (2012) uses an extended user-cost model to explain the increase in house prices in the United States from 1996 to 2006. The authors find that low interest rates can explain around 20% of the increase in house prices.

[37]See Case *et al.* (2012) for survey evidence on new US homebuyers' expectations of future house price increases.

[38]Favara & Song (2014) and Adelino *et al.* (2015) provide theoretical and empirical evidence in favor of the expectations hypothesis during the run-up to the financial crisis.

[39]In particular, Cocco (2013) finds that buyers with high income growth expectations used IO mortgages to smooth housing consumption. Gerardi *et al.* (2007) finds similar evidence from the US, and argues that an increase in mortgage market efficiency through increased credit enabled households to better match current income to their desired life-cycle consumption of housing.

became negatively correlated with the growth in mortgage credit.[40] Undoubtedly, IO loans would lower monthly mortgage payments for marginal borrowers, making home ownership more affordable. We denote this as the *credit supply hypothesis*.

5 Results–Home Buyer Characteristics During the 2000s

In this section, we examine how the characteristics of Danish home buyers changed following the reform to evaluate the channels through which IO loans can affect house prices. We start by outlining the change in the distribution of all home buyers around the policy intervention. Our results show that the income and wealth profiles of households who purchased housing before and after the reform are nearly identical. Further, the fraction of mortgage debt held by households in the lower end of the income distribution is remarkably stable across time. Finally, we use data on the penetration of IO mortgages to show that they were more prominently used in more inelastic areas of Denmark.

As we can observe all transactions on the Danish property market, we investigate how the market changed following the reform and whether the credit supply, housing demand, or income-based hypotheses are consistent with observed household behavior. Specifically, we plot the income, financial wealth, housing size (square meters) to income, and age distributions for all households who purchased a property for each year from 2002-2006. The results are in figure 4. For ease of exposition, each plot shows the distribution of each variable in 2002 (black line) and in 2003, 2004, 2005, or 2006 (red line). Recall that the IO loan reform was announced and implemented in 2003.[41]

The top two panels in figure 4 show the distributions of income and financial wealth for homeowners in 2003-2006 relative to 2002. Clearly, there is almost no change in these distributions between 2002 and 2003 or between 2002 and 2004. Therefore, after the policy change, mortgage credit did not disproportionately flow to lower quality borrowers, ruling out the credit supply hypothesis. These results are also inconsistent with the income-based hypothesis as there was no rightward shift in the income or financial distributions in 2003 or 2004. In 2005 and 2006, we do see a slight rightward movement in the income and financial

[40] Favara & Imbs (2015) similarly find evidence that an increase mortgage credit supply caused to an increase in house prices during the 1990s.

[41] We also use the year 2000 as the base year, and all results are unchanged.

wealth distributions. This small shift is in line with our expectations as houses were more expensive in 2005 and 2006 at the peak boom. We also highlight the relationship between mortgage credit and income in figure 5. Here, for each year between 2000 and 2006, we plot the fraction of mortgage credit for each quintile of the income distribution. As seen in the figure, the distribution of mortgage debt across home buyers is remarkably stable over the sample period. Hence, there was no change in lending standards, relative to income, and no increase in credit to the marginal, low-quality borrower. Together, these findings are also inconsistent with the credit supply hypothesis. Lastly, note that given the conservative nature of Denmark's housing finance system, there are no concerns regarding misrepresented loan documentation in the calculation of these figures.

Next, we evaluate the young household housing demand hypothesis through the home buyer distributions of housing size and age over the 2000s. Specifically, as noted above, the availability of IO loans may allow younger households at the beginning of their life-cycles to purchase a home or to purchase a larger home to avoid future housing market transaction costs (Cocco, 2013). Thus, we plot the size-to-income and age distributions for home buyers in 2003-2006, relative to 2002, in the bottom two panels of figure 4. There is almost no change in the distributions of age or size-to-income over the sample, ruling out the young household housing demand hypothesis as the cause of house price changes in the 2000s.[42] Instead, the evidence suggest that house purchases expanded across the entire distribution and not disproportionally towards young households.

Finally, we use data on reported IO loan penetration for Danish municipalities, made available in a Danish newspaper article from 2012 (Politiken, 2012). The data was provided to the newspaper by one of the mortgage credit bank (Realkredit Danmark), and covers their customer base. Figure 3 plots the portion of IO mortgages for each municipality. 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. In table 1, we provide formal evidence that more

[42] While IO mortgages were certainly used by younger households, the evidence presented in figure 4 suggests that cash-constrained households were not the main driver behind the Danish housing boom.

inelastic municipalities had a higher penetration of IO loans. The coefficient on elasticity in Column 1 is negative and significant, showing that a more inelastic municipality had a higher penetration of IO mortgages. Adding controls for demographics in Column 2 and for income in Column 3 does not change the results. As expectations are likely to be more optimistic in inelastic housing markets (Glaeser *et al.*, 2008), these results are consistent with households using IO loans to capitalize on high house price growth expectations during the 2000s (house price expectations hypothesis). Indeed, cross-sectional survey evidence from 2005 suggests that house price growth expectations were more bullish in inelastic housing markets.[43]

6 Results–Synthetic Control

In the following sections, we employ the SCM using both international and city-level data to estimate the causal impact of IO loans during the 2000s housing boom. First, we let the outcome variable be house prices. Then, in section 6.6, the outcome variable is durable consumption–this will allow us to compute the MPC out of the housing wealth and the impact of IO loans on the real economy.

6.1 Synthetic Control–International Results

To start, data at the highest level of aggregation, the country-level, are used to assess the causal impact of IO loans during the 2000s boom and its aftermath within the SCM framework. Specifically, this international dataset covers Canada, Denmark, Finland, Italy, and Spain. Denmark represents the treated unit; all other countries will be relegated to the donor pool and can potentially contribute to Denmark's Synthetic Control. 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 outcome variable is house prices from the BIS and the pre-treatment predictors include house prices, housing return GARCH(1,1) volatility, GDP per capita, durable consumption per capita, private credit growth to the non-financial sector,

[43] Expectations were highest in the Greater Copenhagen area (a highly inelastic housing market) where 30 percent of respondents expected annual price increases of at least 5 percent over the next five years (Dam *et al.*, 2011).

and the pre-treatment house price growth (1998Q1 - 2002Q4). 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.

The results from the SCM estimation are in tables 2, 3, and 4 and figure 6. First, panel 1 of table 2 shows the contribution of each country to Denmark's Synthetic Control. For brevity, only countries with positive weight are listed. As seen in the table, Finland receives the all of the weight, while Canada, Italy, and Spain receive no weight. In total, this match appears appropriate as Finland is a northern European economy that is closely integrated with Denmark. Also, Finland, like Denmark, experienced a strong house price growth during the pre-treatment period. The top panel of table 3 shows the average pre-treatment predictor values for Denmark, its Synthetic Control, and the sample average. The results in this table 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. In contrast, the sample average pre-treatment house price growth is 37.73 percent, indicating that the Synthetic Control unit yields a much better match for Denmark than the sample average. 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. Altogether, the SCM algorithm appears to aptly build the control unit based on pre-treatment data.

Next, 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 line is the IO loan policy announcement date (2003Q1) and the blue solid line is the policy implementation 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. 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 4. 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.

Once the IO loans are introduced, Danish house prices diverge dramatically from those of its Synthetic Control. Indeed, as evinced by plot in the top-right panel of figure 6, by 2006 Danish house prices more than doubled from their 1998 starting point, whereas those for Denmark's Synthetic only increased approximately 65 percent. Hence, the introduction of IO loans in Denmark led to a large increase in house prices during the boom. 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. Yet the meteoric rise in Danish house prices after 2003 implies that the introduction of IO loans amplified this ascension of house prices in Denmark relative to the counterfactual that also experienced strong house price growth.

To further document the effects of the policy, we plot the Gap between Danish house pries and the Synthetic Control in the bottom-left panel of the figure. 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.

The numerical estimates of the impact of the policy are listed in panel 1 of table 4. Specifically, 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.[44] First, the Gap in house price growth during the boom was 35.80 percent, an estimate that is larger than all placebo effects. Hence, 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.

The results in figure 6 and table 4 also show that Danish house prices plunged during the bust. Indeed, 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.

The above results imply that the introduction of IO loans made the Danish housing market more volatile and thus amplified the boom-bust pattern in house prices. Altogether, these findings, combined with our results from section 5, are consistent with borrowers using IO loans to increase leverage in an attempt to capitalize on high house price growth expectations during the 2000s.

6.2 Synthetic Control–City-Level Results

In this section, we reduce the geography of our data and conduct the SCM analysis at the city-level using Canadian and Danish data. In these results, the donor pool consists of Canadian non-resource (coastal) cities for which the Teranet repeat-sales house price indices are available.[45] In robustness checks, we expand the donor pool to cover all major Canadian cities. The treated units are 10 Danish cities with repeat-sales house price indices over our sample period.[46] We apply the SCM approach iteratively using each Danish city as the treated unit. The outcome variable of interest is repeat-sales house prices at the monthly

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

[45]These cities include Halifax, Hamilton, Montreal, Ottawa-Gatineau, Quebec City, Toronto, Vancouver, Victoria.

[46]These Danish cities are CopenhagenCity CopenhagenSurroundings, NorthernZealand, EasternZealand, EasternJutland, Fyn, WestSouthZealand, SouthernJutland, NorthernJutland, and WesternJutland.

periodicity. Other pre-treatment predictor variables include GARCH(1,1) housing return volatility, median income in 2001, population in 2001, and the unemployment rate in 2001. Further, as noted above, in this analysis we standardize the macro variables (median income, population, and unemployment) across countries to have zero mean and unit variance. The SCM estimates based on other permutations of the data are discussed below and are similar to our main findings. The results are in panel 2 of table 2, panels 2 and 3 of table 3, and panel 2 of table 4. Figure 7 shows the Path, Gap, and Permutation plots from the Synthetic Control analysis when CopenhagenSurroundings (the suburban area around Copenhagen) represents the treated unit. Figure 8 displays the permutation test plots for all Danish cities.

First, as seen in the second panel of table 2, 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 CopenhagenSurroundings, 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 national capital city and Toronto is the largest city in Canada with a substantial suburban component. Further, panels 2 and 3 of table 3 shows the average pre-treatment predictor values for CopenhagenCity and CopenhagenSurroundings, their Synthetic counterparts, and for the Canadian average. Note here that we standardize the pre-treatment predictors across all available Canadian cities, so in this analysis, where only the non-resource (coastal) cities are used, the average across potential control units is not zero. Overall, the Synthetic Control more closely matches CopenhagenCity and CopenhagenSurroundings for key predictor variables than the sample average. 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. Similarly, CopenhagenCity's pre-treatment house price growth is 37.05 percent, compared to 32.89 percent for the Synthetic Control and 23.33 percent for the sample average. Further, when CopenhagenSurroundings represents the treated unit, the pre-treatment predictor variables yield a better match than those of the sample average.

In the second column of panel 2 in table 4, we show the RMSFEs for the city-level estimates. In total, these results indicate that the estimated Synthetic Control units are highly similar to their corresponding treated units during the pre-treatment period. 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. Indeed, 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 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 less than 10 in magnitude.

Figure 7 shows the Synthetic Control plots when CopenhagenSurroundings serves as the treated unit, figure 8 presents the Permutation tests for all treated cities, and the second panel of table 4 displays the estimation output. First, as seen in the top two plots of figure 7, the Synthetic Control represents a much better match for CopenhagenSurroundings than the Canadian average. Indeed, house prices in CopenhagenSurroundings rise much faster during the pre-treatment period than those for the Canadian average, whereas house prices for the Synthetic move in tandem with CopenhagenSurroundings. Therefore, the Synthetic Control appears to present an apt counterfactual for CopenhagenSurroundings over the sample period. After the IO loan policy is implemented in Denmark, house prices in Copenhagen-Surroundings diverge markedly from the Synthetic Control.[47] 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. Indeed, 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. The uniqueness of the treatment effect, compared to all placebo effects, supports a causal inference of the results. 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.

[47]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.

Overall, in line with our previous results, the introduction of IO loans had a substantial impact on Danish housing returns. For example, due to the introduction of IO loans, Danish house prices increased by over 30 percent in CopenhagenCity, CopenhagenSurroundings, EasternZealand, and NorthernZealand. Yet the results also suggest that the effects are heterogeneous across Danish cities. Indeed, 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 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 in the far right panel of table 4 during the boom times 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 none of the growth in several other areas such as WesternJutland or NorthernJutland. As noted above, these latter cities all have much more elastic housing supply, indicating that cities with higher housing market elasticity experienced muted house price growth due to the IO loan policy. A regression of the Gap estimate in house price growth between 2003M10 and 2006M10 on housing market supply elasticity indicates that a housing market with elasticity one standard deviation below the mean (more inelastic) experienced house price growth that was 14.6 percentage points higher during the boom (White t-stat: 5.50). As noted by Glaeser *et al.* (2008), house price growth expectations are likely to be highest in the inelastic housing markets. Thus, our findings in this section, combined with our above result that IO loan penetration was higher in more inelastic housing markets, are consistent with the hypothesis that households exploited IO loans to capitalize on optimistic house price growth expectations. Finally, the plots in figure 8 show the heterogenous impact of the reform graphically: After the policy innovation, house prices increased noticeably in more inelastic housing markets, whereas there was no change in prices for elastic housing markets.

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 6.1 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. The house price index for Helsinki is quarterly and was downloaded from Datastream. To match the periodicities across Helsinki and the Canadian cities, 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 2008M10. 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 figure 9 and panel 3 of tables 2 and 4. First, the Synthetic Control for Helsinki is made up of 57 percent Halifax and 41 percent OttawaGatineau. Next, the top-right plot in figure 9 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 9, 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.

6.4 Extensions and Robustness Checks

This section presents a number of extensions and robustness checks. Specifically, we consider unadjusted (non-standardized) macro data, all Canadian cities for the donor pool, and alternate house price indices. The results are in section F of the appendix.

First, we alter our above analysis by using the unadjusted (non-standardized) macro data. The results are in panel 1 of table 11 in appendix F. In general, the results are similar to our previous findings. Next, in panel 2 of the table, we extend the donor pool to include all Canadian cities. Hence, this analysis uses both Canadian resource and non-resource cities. Panel 2(a) shows the results that use the standardized macro data; panel 2(b) presents our findings for the unadjusted macro data. The results are similar to those described above, but the estimated gap during the housing bust is larger in some cases. This finding is not surprising as Canadian resource cities experienced substantial house price gains in the late 2000s. Last panels 3(a) through 3(d) show our findings that use alternate, quarterly house price indices. The quarterly Canadian house price indices are available for 21 cities and are based on new home construction, while the quarterly alternate HPIs for Denmark use the average sales price in each city. Overall, the results match our previous findings, but are slightly larger in magnitude. For example, using these alternate, quarterly HPIs we find that the increase in house prices in CopenhagenSurroundings due to the introduction of IO loans was 69 percent. Thus, our main results presented above are conservative in nature.

6.5 Summary of Housing Market Results

In this section, we summarize all of our findings across both our main findings and robustness checks in a meta-analysis. The output from this meta-analysis is displayed in table 5. First, in the top two rows, we combine all of the results across all levels of geography (international and city-level) and calculate the mean of house price growth during the boom (2003Q4 - 2006Q4) and bust (2007Q1 - 2010Q1) periods. As seen in the top two rows, the estimated causal impact of the introduction of IO loans during the 2000s is large and magnitude and highly significant. Indeed, the mean (median) house price growth during boom times was 30.80 (34.50) with a bootstrapped standard error of just 2.61 (4.11). Further, we find that house prices dropped dramatically during the bust: The average (median) estimated fall in house prices between 2007Q1 and 2010Q1 due to the introduction of IO loans in Denmark was 23.09 (26.24) percent. In total, these results emphasize our above findings– the introduction of IO loans in the 2000s led to a substantially more volatile and speculative housing market as house prices increased during the boom and plummeted during the bust.

Next, we examine the results across Danish cities. More explicitly, we assess the impact of the introduction of IO loans during the 2000s across elastic and inelastic local housing markets. Specifically, we regress the Gap in house price growth across cities on housing market elasticity. Table 6 presents the results. In the left panel, we show the results using all Danish cities; the right panel displays our findings when the areas in and around Copenhagen (CopenhagenCity and CopenhagenSurroundings) are removed from the sample. The elasticity measure is standardized to have zero mean, unit variance, and so that positive values represent more elastic housing markets. To start, note that the estimate for the intercept matches our findings from table 5 and thus indicates that during the boom the introduction of IO loans causes house prices to increase by approximately 30 percent for the typical city with an average housing market elasticity. These results are similar, but slightly smaller, when we remove the areas in and around Copenhagen from our analysis. Next, the slope coefficients describe the change in the causal impact of the introduction of IO loans across elastic and inelastic housing markets. During the boom, results indicate that a city whose level of housing market elasticity was one standard deviation above the mean (more elastic) experienced a increase in cumulative housing returns during the boom of just $30.20 - 13.08 \cdot 1 = 17.12$ percent. Moreover, during the bust, more inelastic housing markets experienced lower housing returns due to the introduction of the IO loan policy. Indeed, a city whose housing market elasticity was one standard deviation below the mean (more inelastic) experienced a drop in cumulative housing returns of $-24.46 - 2.32 = -26.78$ percent. Therefore, the introduction of IO loans caused a larger fall in prices for more inelastic housing markets. The results in the right panel that estimate the results without Copenhagen and its surrounding areas are similar. In total, as the penetration of IO loans was much stronger in more inelastic housing markets, these findings thus support a expectations-based view of the recent housing bubble and indicate that the availability IO loans magnified the effects of house price expectations.

6.6 Synthetic Control–Durable Consumption

Last, the SCM is used to determine the causal impact of IO loans on the real economy via changes in durable consumption during the 2000s. Durable consumption is often used in the literature to capture real economic effects within in a housing market context (Mian &

Sufi, 2014, 2011). For this analysis, we use our international dataset as it is the only sample for which durable consumption data is available. Here, we let Denmark be the treated unit; Canada, Finland, Italy, and Spain constitute the donor pool. The contribution of each member of the donor pool to Denmark's Synthetic Control is listed in the bottom panel of table 2. The last panel of table 4 holds the cumulative changes in the gap of durable consumption during the boom and bust episodes, and figure 10 shows the corresponding Synthetic Control figures.

The Synthetic Unit for Denmark when durable consumption is the outcome variable consists 37 percent of Canada and 63 percent of Italy. As seen in the top two plots in figure 10, the Synthetic Control matches the pre-treatment path of durable consumption in Denmark, especially compared to the sample average.

Although durable consumption for Denmark and its Synthetic are similar during the pre-treatment period, they diverge dramatically with the introduction IO loans in 2003Q4 and the subsequent increase in housing wealth. Indeed, during the 2000s boom, the introduction of IO loans caused durable consumption to increase by nearly 1,000 Euros per capita. Further, the estimated placebo effects, displayed in the permutation test in the bottom-right panel of figure 10, document the rarity of these estimated effects and show that they are large in magnitude.

With these estimated effects for the increase in durable consumption in hand, we can calculate MPC out of housing wealth due to IO loans. Using our estimate for Danish house price growth from the top row of table 4 (35.80 percent) and that Danish housing wealth in 2003 was 1.86 trillion Danish Kroner (based on property tax records), the MPC out of increasing housing wealth during the boom (2003Q4 - 2006Q4) was approximately 6 percent. Similarly, during the housing bust (2007Q1 - 2010Q1), the MPC out of declining housing wealth was approximately 4 percent.[48] Hence, the introduction of IO loans in the 2000s had

[48] Calculation for MPC. *Boom*: (1.86*0.358 = 0.66588 trillion DKK) increase in housing wealth; 994.04*7.45 = 7405.598 DKK per capita durable consumption increase; (7405.598*5,390,574 = 39,920,424,033.3) increase in durable consumption; MPC = 39,920,424,033.3/665,880,000,000 ≈ 6 percent. *Bust*: 2.78 trillion DKK housing wealth in 2006Q4; 2.78*0.2336 = 0.649408 trillion DKK decrease in housing wealth; 675.22*7.45 = 5030.389 DKK decrease in durable consumption per capita; 5030.389*5461438 = 27,473,157,639.4 DKK decrease in durable consumption; MPC = 27,473,157,639.4/649,408,000,000 ≈ 4 percent. Note that this calculation does not disentangle the savings in due to deferred amortization from the wealth effect. Accounting for the savings related IO mortgages would lower the MPC calculation during the boom, but increase it during the bust.

a large impact on the real economy. In comparison, Bostic *et al.* (2009) finds that the MPC out of housing wealth is between 5 and 17 percent.

7 Conclusion

In this paper, we use both micro- and aggregate-level data to assess the impact of IO loan availability during the 2000s. 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 effects, they are heterogeneous across local housing markets. Specifically, the impact of the policy change is magnified in more inelastic housing markets that experienced higher IO loan penetration and higher house price growth during the 2000s. The introduction of IO loans to Denmark also had a large impact on the real economy. The MPC out of housing wealth during the boom was 6 percent during the boom period and 4 percent during the housing bust.

Altogether, our results are consistent with households using IO to capitalize on bullish house price expectations in the years leading up to the boom. Further, our results not only explain the cross-section and cyclical variation of house prices in Denmark, but have important implications for other countries including the United States. Denmark's housing finance system is notably similar to that of the US (Campbell, 2013), but IO loans were widely available in the US during the boom. Thus, our results yield key insights into the role of IO loans during the 2000s US housing boom. 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.[49] Last, given the depth of the Great Recession, the implications of our findings are wide reaching and suggest that policymakers should focus on macroprudential regulation as expectations can drive housing cycles even in the absence of a deterioration in borrower quality.

[49]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: Interest Only Loans and Housing Elasticity

	(1)	(2)	(3)
Elasticity of Housing Supply	-1.52*	-1.57*	-1.36*
	(0.57)	(0.52)	(0.53)
Log of Disposable Income		15.68*	17.3*
		(3.59)	(3.63)
Log of Population			1.35
			(0.68)
N	97	97	97

Notes: Dependent variable is the number of interest-only mortgages as a percentage of all mortgages for each municipality. Elasticity of housing supply is defined as the percentage of land in each municipality that is covered by buildings. Elasticity of Housing Supply standardized to have zero mean and unit variance and so that positive values represent more elastic housing markets. Log of Disposable Income is defined as the median disposable income after taxes, transfers, and interest payments for each municipality. Log of Population is the number of households per municipality. All regressions include a constant term. An asterisk represents a p-value of less than 0.05.

Table 2: 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
Panel 4: International Durable Consumption	
Denmark	Italy: 0.63; Canada: 0.37

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

Table 3: 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
Panel 4: Denmark; Durable Consumption			
	Treated	Synthetic	Sample Mean
Dur Cons per Capita	382.48	235.71	305.80
GARCH Volatility	117.64	116.11	115.22
GDP Per Capita	41505.31	30056.68	26609.96
House Price Index	0.84	0.92	0.96
Pre-treatment HPI Growth	31.65	29.88	37.73
Private Credit Flows	118.37	125.07	132.18

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

Table 4: Synthetic Control–Estimated Effects of IO Loans

		Gap		Gap/Path	
Treated Unit	RMSFE	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
Panel 4: International Durable Consumption					
Denmark	2324.3	994.04*	-675.22	0.16	0.94

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 durable consumption, the results are in Euros per capita and accumulated over the boom and bust periods, respectively. To calculate the cumulative decline of the policy during the bust when durable consumption is the outcome variable, we set durable consumption to zero in 2007Q1. For the boom (bust) period, an asterisk indicates that the effect for the treated unit is larger (smaller) than all estimated placebo effects.

Table 5: Summary of Results–Gap in House Prices Across Boom and Bust Periods

	Boom		Bust	
	Estimate	Boot SE	Estimate	Boot SE
Mean–All	30.80*	2.61	-23.09*	1.32
Median–All	34.50*	4.11	-26.24*	2.17
CopenhagenCity	60.53*	3.15	-29.37*	0.32
CopenhagenSurroundings	54.68*	5.48	-29.23*	1.14
EasternJutland	26.29*	6.63	-18.45*	2.39
EasternZealand	46.94*	4.24	-32.62*	0.49
Fyn	19.57*	8.24	-14.95*	2.46
NorthernJutland	8.84*	3.73	-15.04*	6.13
NorthernZealand	50.23*	5.16	-37.84*	0.34
SouthernJutland	8.94	5.05	-12.18*	2.82
WesternJutland	13.43	7.99	-15.60*	4.81
WestSouthZealand	17.93*	2.57	-25.57*	4.14

Notes: Summary of results across all of the permutations of the data listed in table 10. 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.

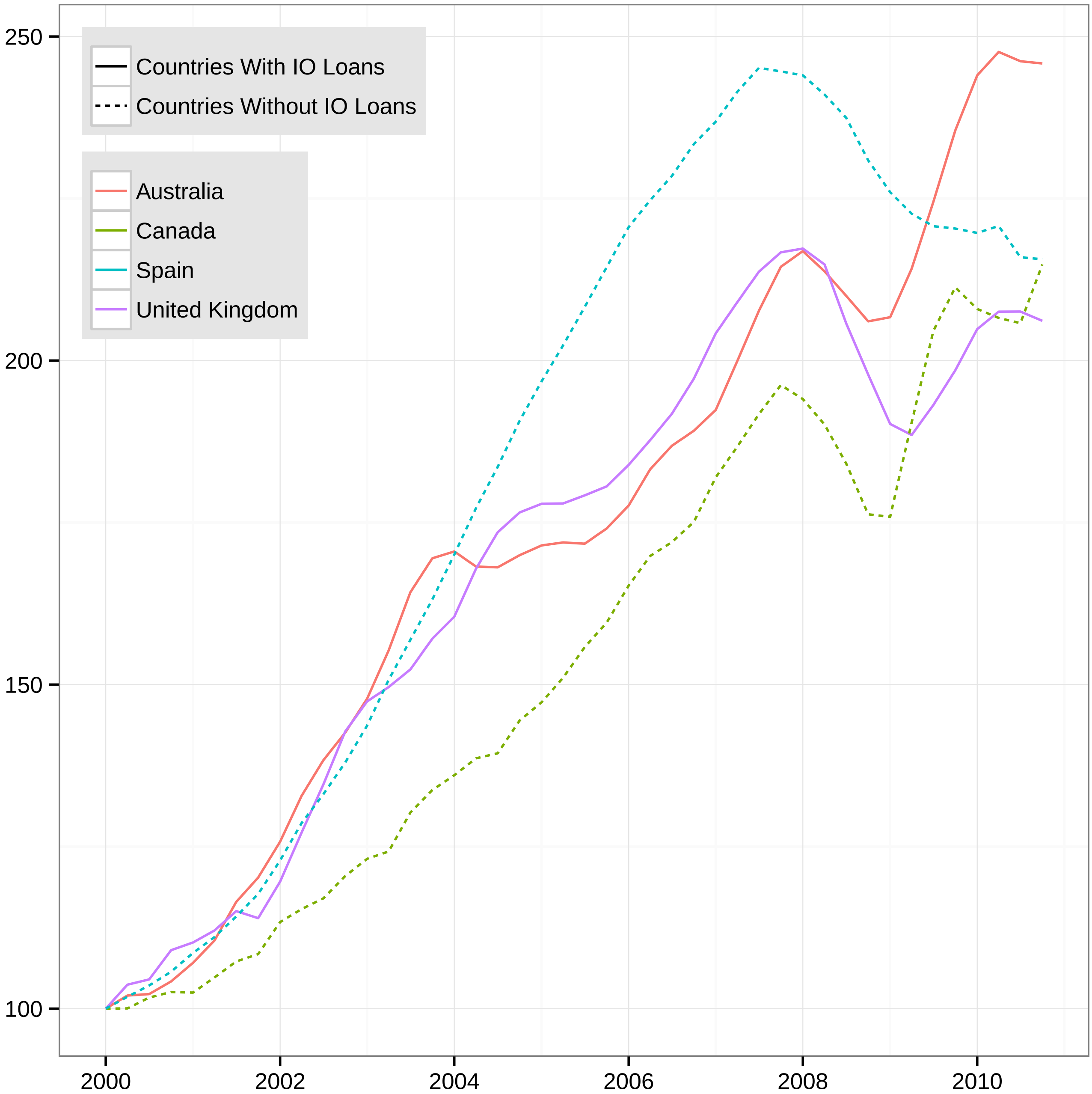
Table 6: Summary of Results–Regression of Gap in House Price Growth on Housing Elasticity

	All Cities		No CPH	
	Boom	Bust	Boom	Bust
(Intercept)	30.20*	−24.46*	23.35*	−23.25*
	(2.33)	(1.18)	(2.14)	(1.22)
Elasticity	−13.08*	2.32*	−15.64*	7.27*
	(1.67)	(0.58)	(2.18)	(0.87)
R^2	0.25	0.04	0.43	0.32
Adj. R^2	0.24	0.03	0.42	0.31
Num. obs.	80	80	64	64

Notes: Meta analysis across all permutations of the city-level data listed in table 10. In each panel, the left column holds the results for the boom period (2003Q4-2006Q4), while the results for the bust period (2007Q1-2010Q1 are in the right column. The left panel presents the results for all Danish cities; the right panel shows our findings for all cities outside of the Copenhagen area (No CPH). Bootstrapped standard errors are in parentheses. An asterisk represents a bootstrapped p-value of less than 0.05

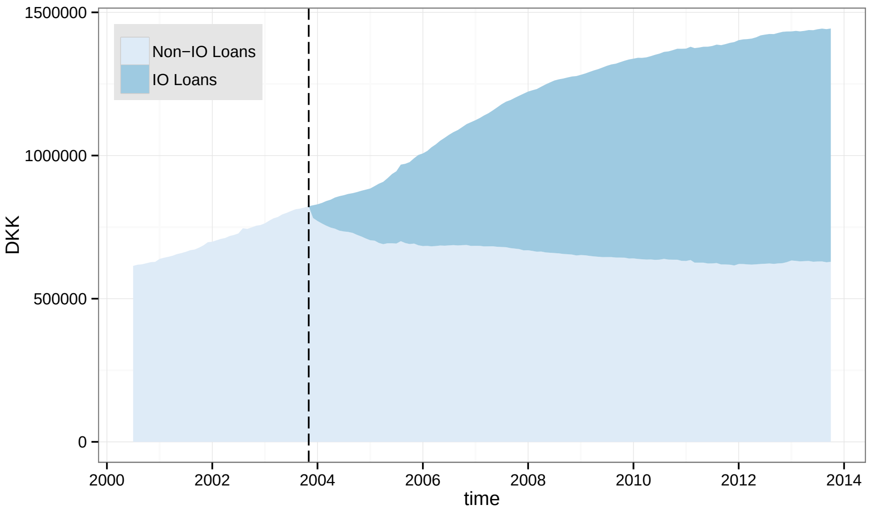
B Figures

Figure 1: House Price Indices



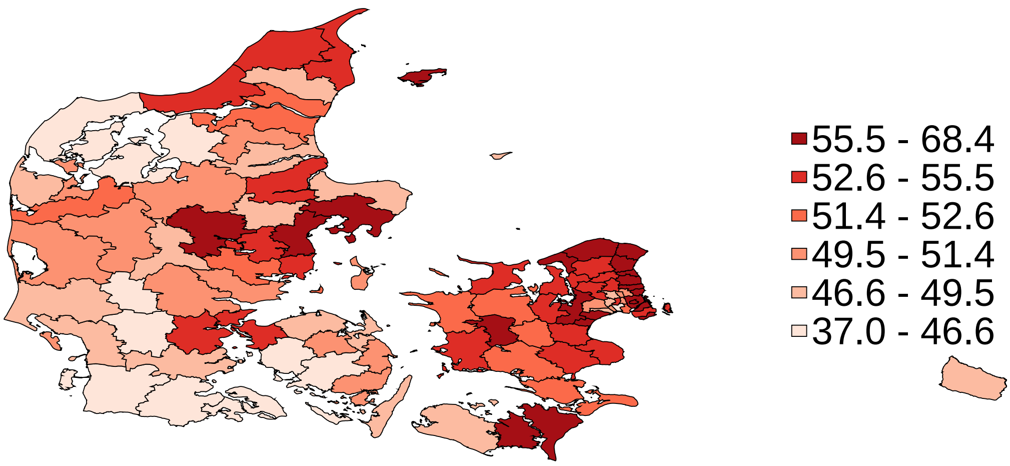
Notes: House price indices for Australia, Canada, Spain, and the United Kingdom from the Bank of International Settlements.

Figure 2: Mortgage Loan Types



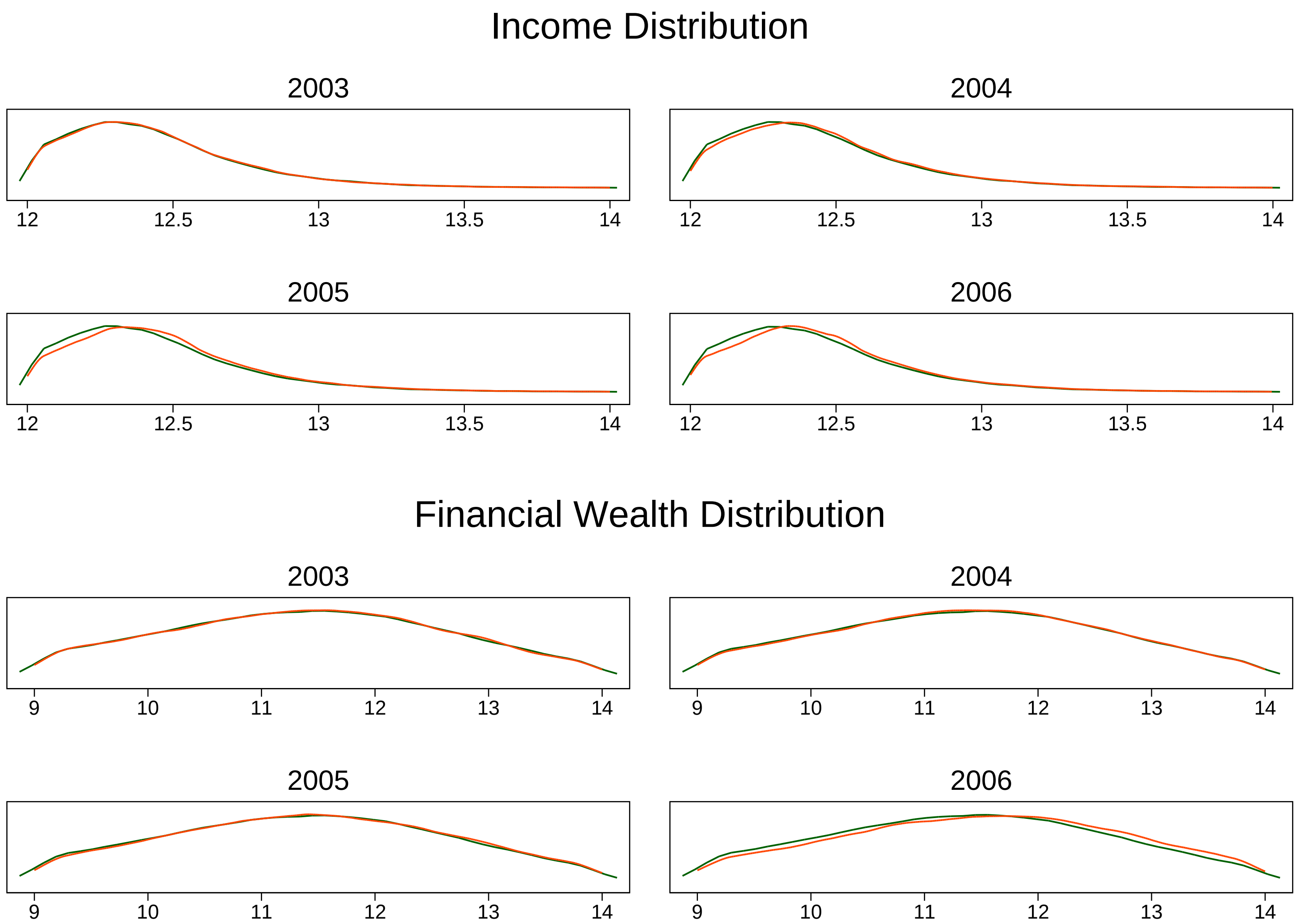
Notes: Outstanding mortgage debt by loan type. Includes loans for residential properties and vacation homes. Source: Nationalbanken

Figure 3: Interest-Only Loan Penetration in Danish Municipalities



Notes: Percentage of Interest-only loan in each Danish municipality. Data for Realkredit Danmark customers from 2012.

Figure 4: Distribution of Income, Wealth, Age, and Size-to-Income for House-Buyers,



Notes: **Figure continued on next page.** Distribution of income, financial wealth, age, and size-to-income for households who purchased real estate in 2002 (black line) and subsequent years (red line). Income is total income from labor including transfers. Net wealth is the sum of stocks, bonds and cash deposits. Age is defined as the age of the oldest spouse. Size-to-income is defined as the square meter size of the purchased property divided with total income from labor including transfers. All variables are in log form.

Figure 4 Continued

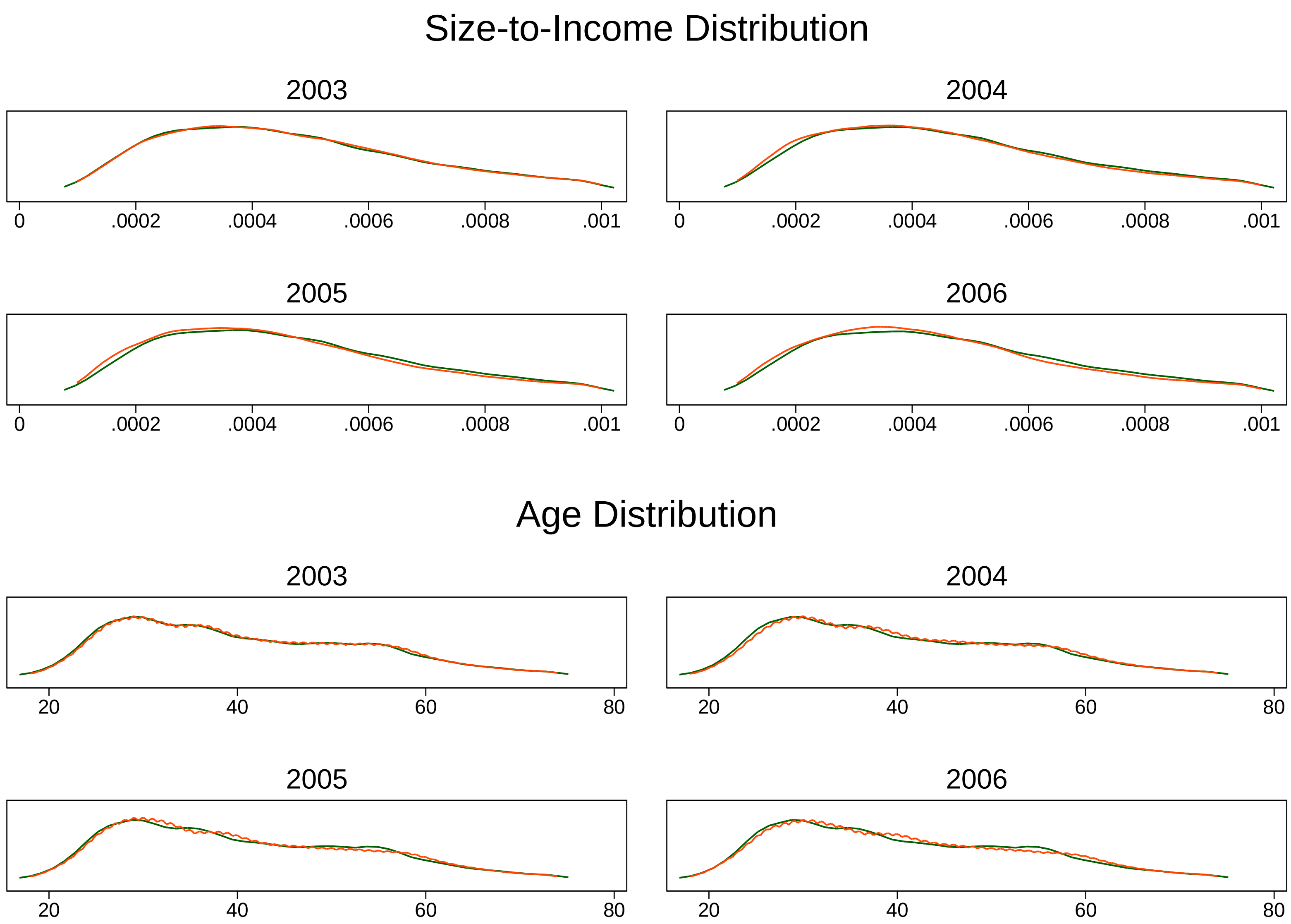
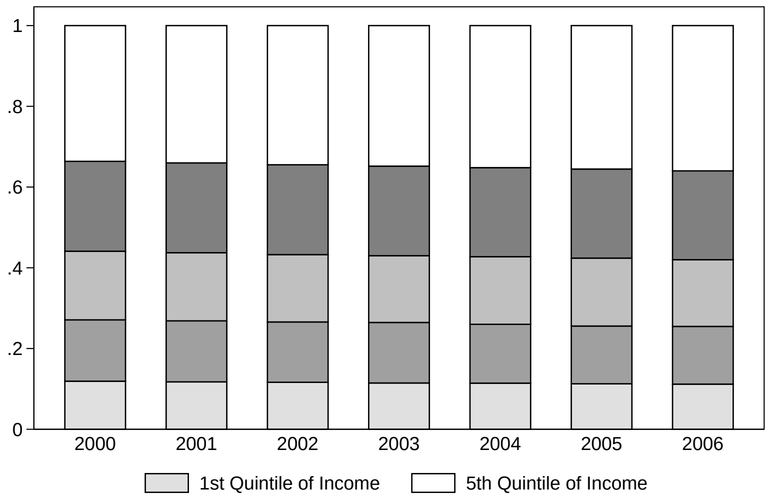
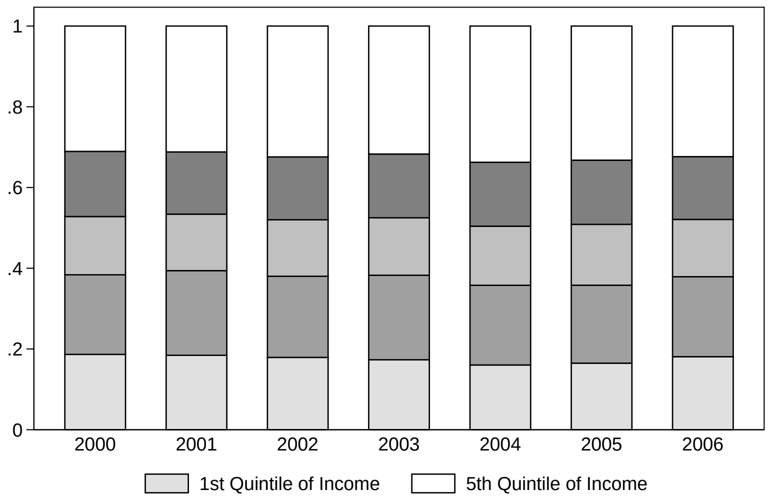


Figure 5: Mortgage Debt by Income Quintile

(a) All Households

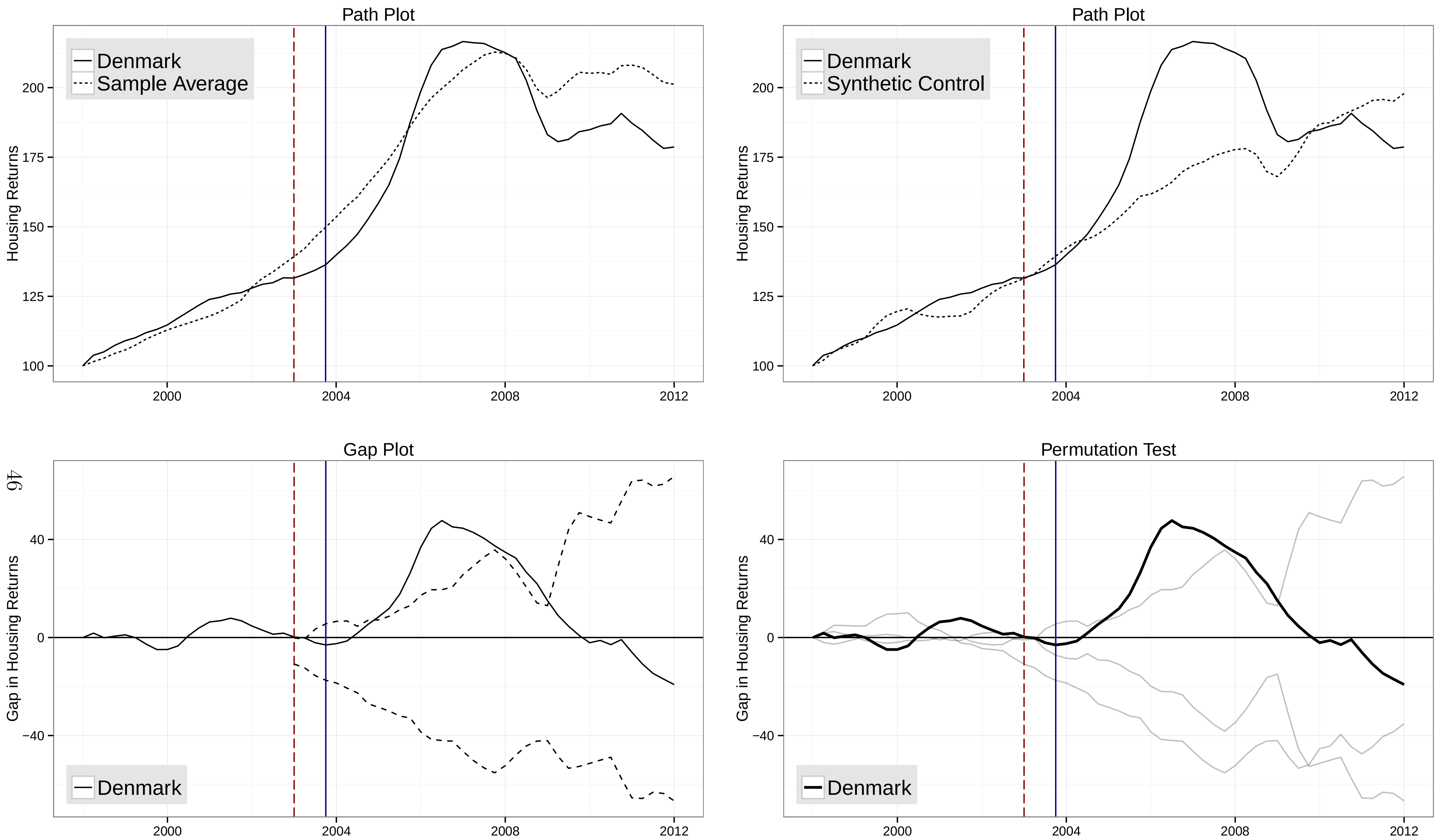


(b) Buyers



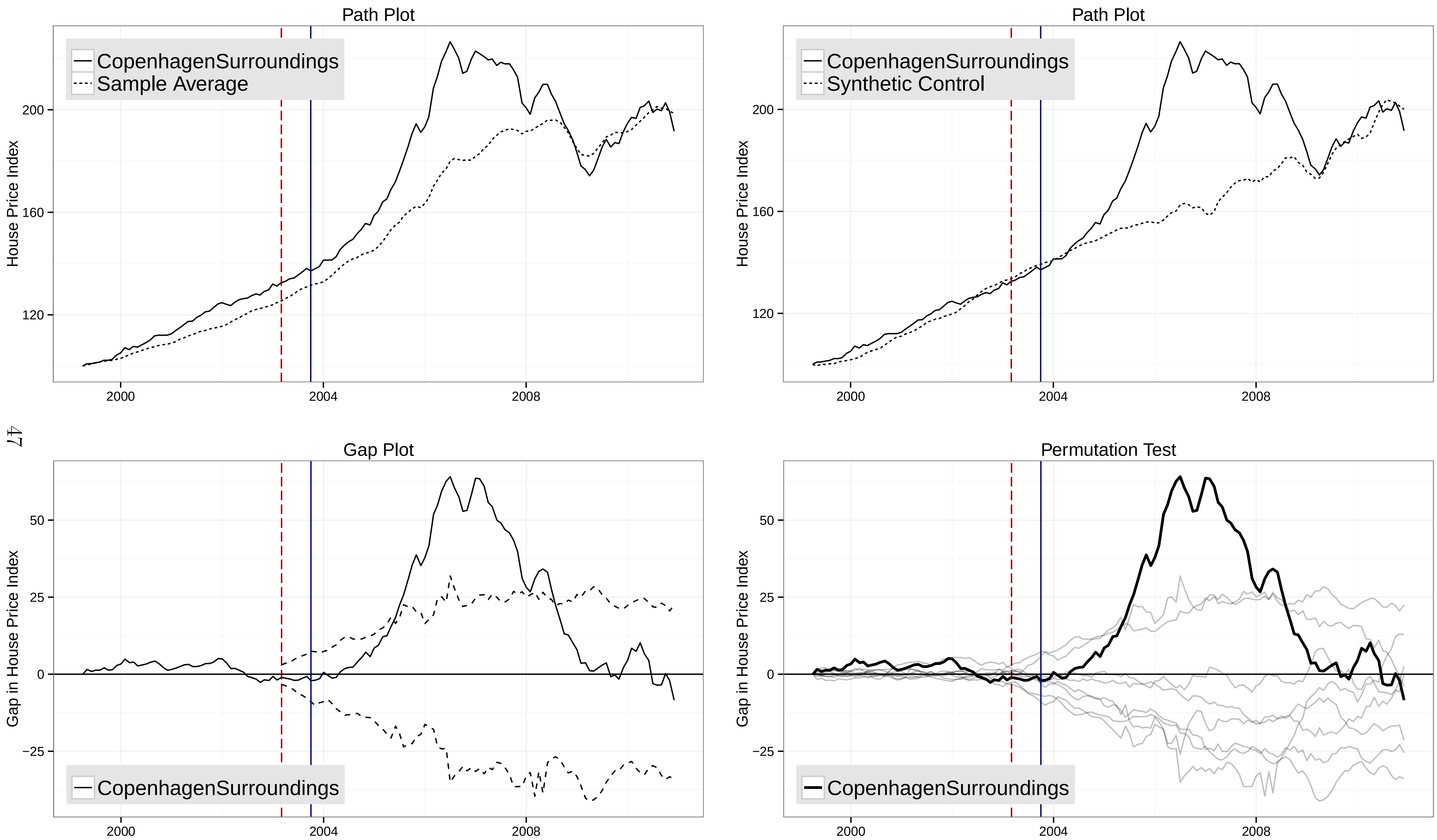
Notes: The figures show the fraction of total mortgage debt held by each income quintile. Mortgage debt is measured at end-of-year values. Panel (a) show the results all households who hold mortgage debt. Panel (b) shows the results for households who purchased housing in the given year.

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



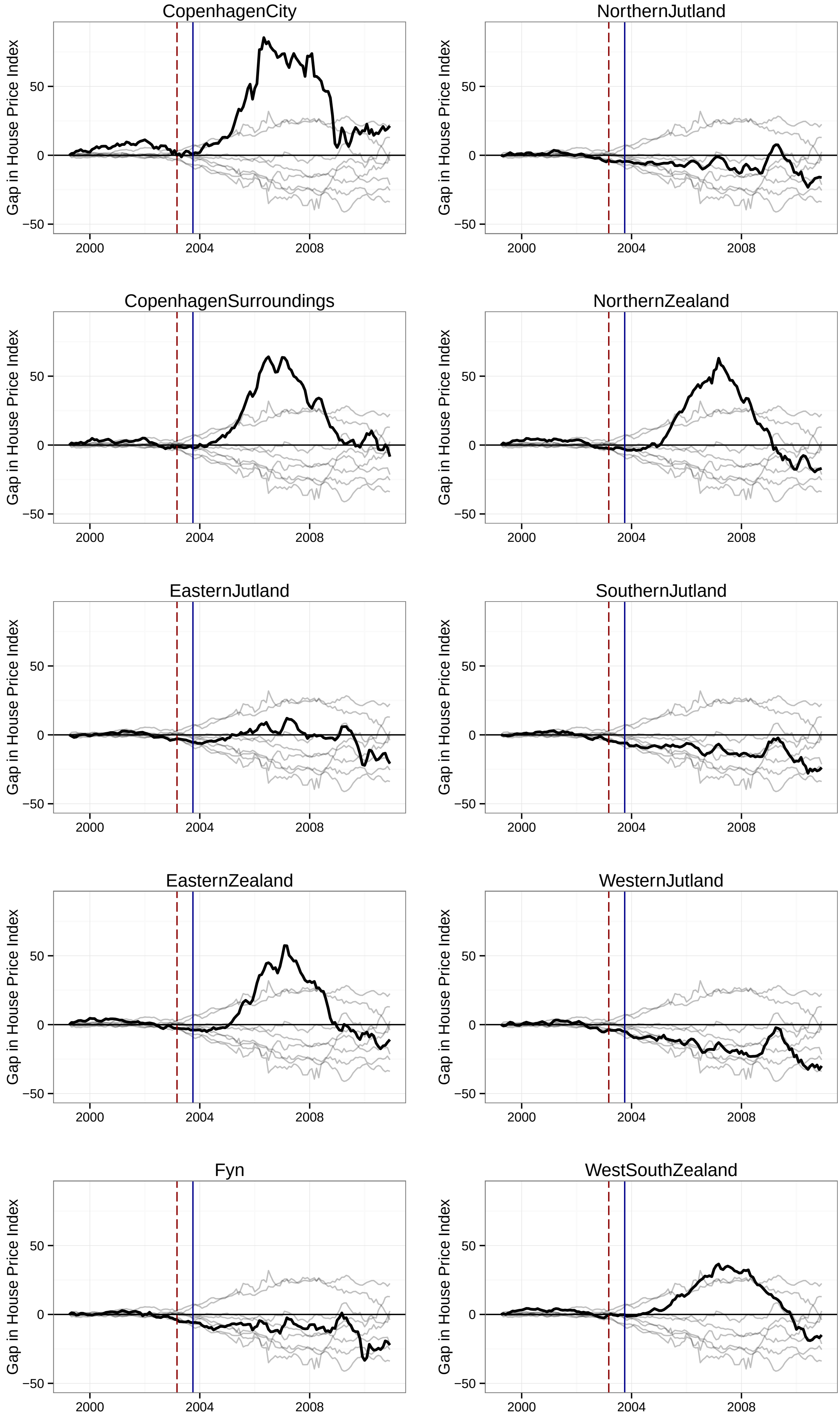
Notes: House prices for Denmark, the International Average, and Denmark's Synthetic Control. The top-left plot shows the path plot of house prices for Denmark and the International average; the top-right plot shows the path plot of Denmark and its Synthetic Control; the bottom-left gap plot shows the 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 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



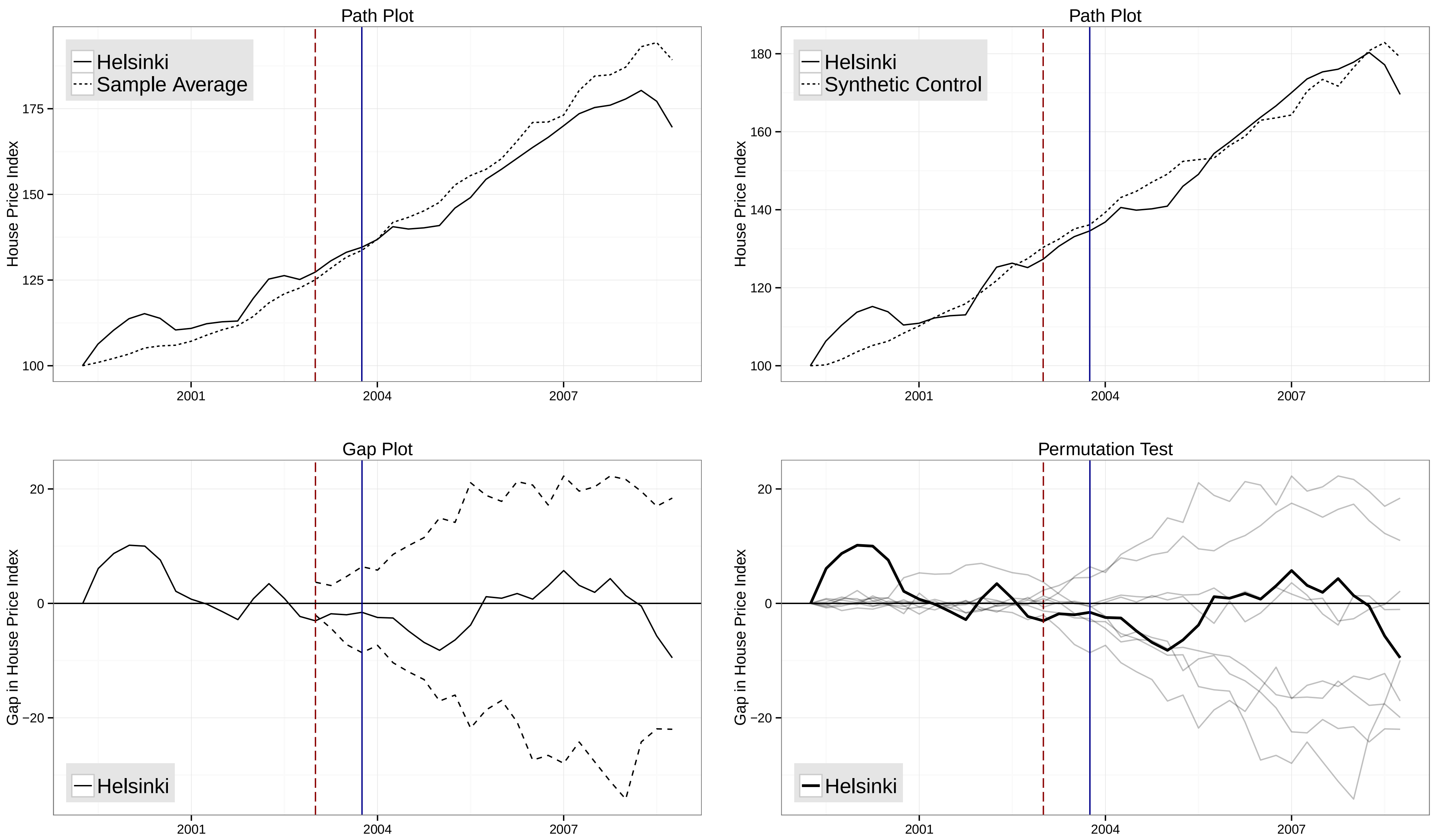
Notes: See the notes for figure 6. The repeat-sales city level data are monthly and the donor pool consists of Canadian non-resource cities. The dashed red vertical line signifies the policy announcement in 2003M03 and the blue vertical line signifies the policy implementation date in 2003M10.

Figure 8: City-Level House Price Permutation Tests



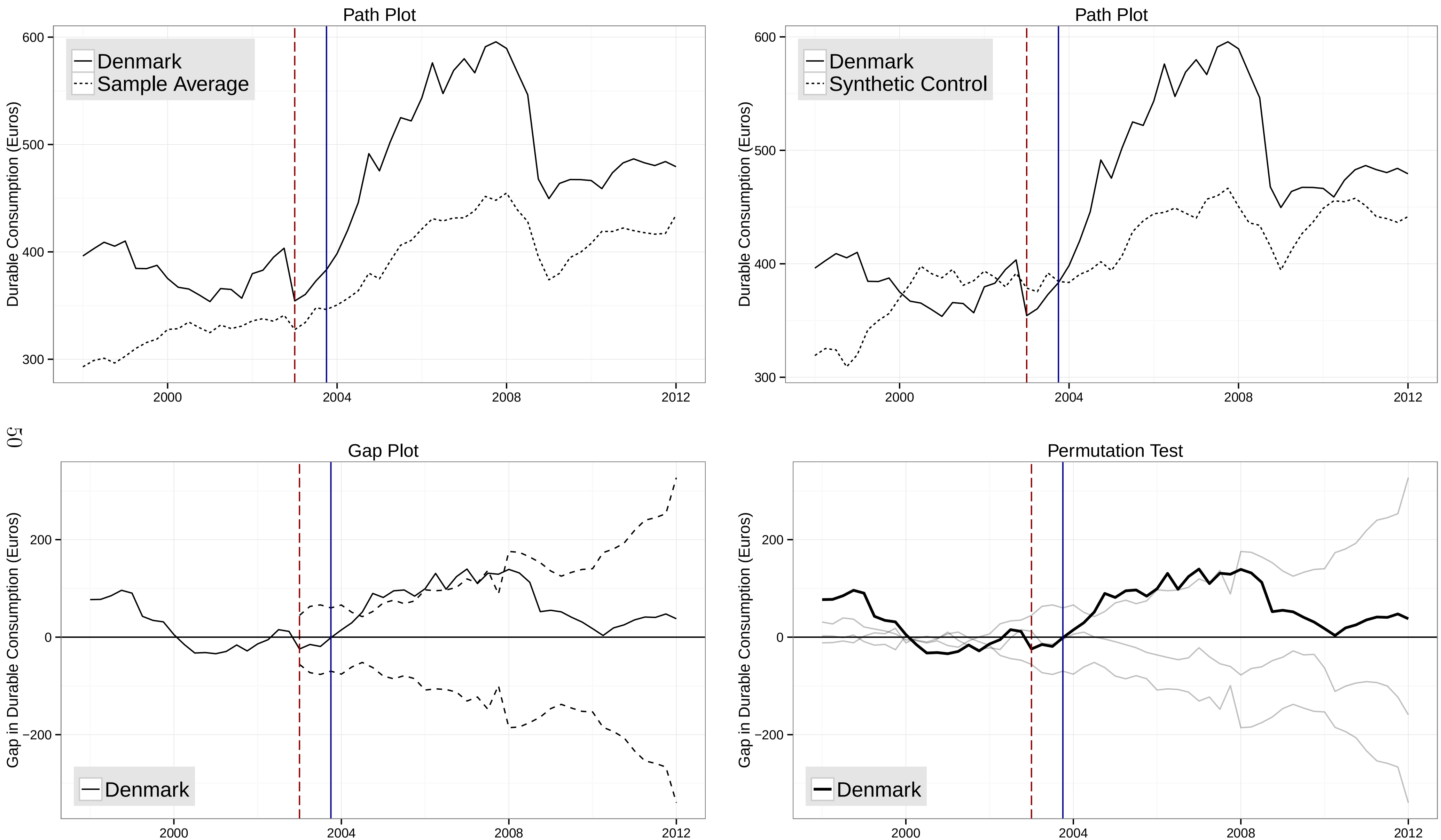
Notes: See the notes for figure 7. These plots show the permutation tests for Danish cities where the donor pool consists of Canadian non-resource cities.

Figure 9: 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

Figure 10: Durable Consumption–Denmark, International Average, and Synthetic Control



Notes: See the notes for figure 6. Durable consumption per capita for Denmark, the International Average, and Denmark's Synthetic Control. The donor pool comprises Canada, Finland, Italy, and Spain.

C Appendix: Tables

Table 7: Housing Elasticity

City Name	Elasticity Ranking
CopenhagenCity	1 (Most inelastic)
CopenhagenSurroundings	2
NorthernZealand	3
EasternZealand	4
EasternJutland	5
Fyn	6
WestSouthZealand	7
SouthernJutland	8
NorthernJutland	9
WesternJutland	10 (Most elastic)

Notes: Ranking based on housing elasticity, where the highest value corresponds to the most elastic area. Elasticities calculated as by summing the square meter size of each building in a city, and thereafter dividing by city size. Source: Statistics Denmark and author's calculations.

Table 8: 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.

D Appendix: Data

Table 9: 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
11	NA	Danish Housing Elasticity	NA	Author's Calc

Notes: Mnemonics represents variable codes. ** indicates that the mnemonic changes by country/city.

Table 10: Description of Samples

Sample	DonarPool	CanadianHPI	DanishHPI	CountryStd
CityNewHpiAll	All Canadian Cities	New Houses	Single Family	No
CityNewHpiAllStd	All Canadian Cities	New Houses	Single Family	Yes
CityNewHpiCoastal	Canadian Non-Resource Cities	New Houses	Single Family	No
CityNewHpiCoastalStd	Canadian Non-Resource Cities	New Houses	Single Family	Yes
CityTeranetAll	All Canadian Cities	Teranet	Single Family	No
CityTeranetAllStd	All Canadian Cities	Teranet	Single Family	Yes
CityTeranetCoastal	Canadian Non-Resource Cities	Teranet	Single Family	No
CityTeranetCoastalStd	Canadian Non-Resource Cities	Teranet	Single Family	Yes
CondosCityNewHpiAll	All Canadian Cities	New Houses	Condos	No
CondosCityNewHpiAllStd	All Canadian Cities	New Houses	Condos	Yes
CondosCityNewHpiCoastal	Canadian Non-Resource Cities	New Houses	Condos	No
CondosCityTeranetAll	All Canadian Cities	Teranet	Condos	No
CondosCityTeranetAllStd	All Canadian Cities	Teranet	Condos	Yes
CondosCityTeranetCoastal	Canadian Non-Resource Cities	Teranet	Condos	No
CondosCityTeranetCoastalStd	Canadian Non-Resource Cities	Teranet	Condos	Yes
International	Canada, Finland, Italy, Spain	National BIS	National BIS	NA
RegionsNewHpiAll	All Canadian Provinces	New Houses	National BIS	NA
RegionsNewHpiCoastal	Canadian Non-Resource Provinces	New Houses	National BIS	NA

*Notes:*Description of different samples. For further information see section 2.

E Appendix: Figures

Figure 11: Private Credit Flows, Mortgage Rates, and 10-Year Government Bond Yields

F Appendix: Synthetic Control Gap Estimates

Table 11: 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 4.

Table 11 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