Interest-Only Mortgages and Consumption Growth: Evidence from a Mortgage Market Reform*

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Abstract

We use household-level data to analyze how the introduction of interest-only mortgages in Denmark affected consumption expenditure and borrowing. Using an ex-ante measure of exposure to the interest-only mortgage reform motivated by mortgage-payment and leverage constraints, we show that households more likely to use an interest-only mortgage to relax their mortgage-payment constraint increased consumption following the reform. This increase in consumption is financed by borrowing at the time of refinancing and by borrowers with lower pre-reform leverage and higher needs for liquidity. We find even larger post-reform consumption growth for the leverage-constrained homeowners through house-price growth stimulated by the reform.

KEYWORDS: Consumption; Interest-only Mortgages; Mortgage Borrowing; Financial Innovation
JEL Classification: D14, E21, G21

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1 Introduction

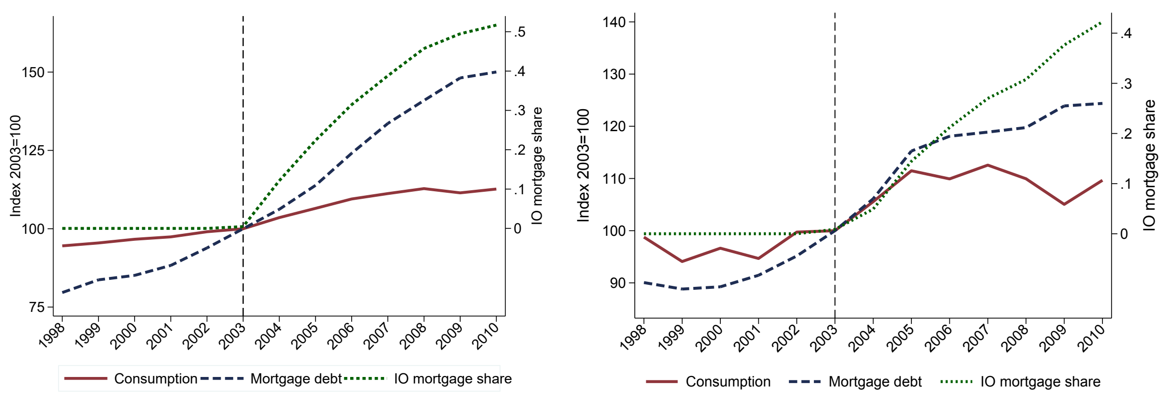
Six years after a 2003 mortgage market reform enacted interest-only (IO) mortgages in Denmark, the new mortgages accounted for almost 50% of all outstanding mortgage contracts and aggregate mortgage debt expanded by 48%, as documented in Figure 1(a). Similarly, in the US IO mortgages and other unconventional mortgage products accounted for approximately 50% of mortgage origination in 2007, having increased from 1% in 2000 (Justiniano et al., 2017).[2] Further, Figure 1(a) shows aggregate consumption in Denmark increased by 11% after the reform, growing twice as fast as the corresponding consumption growth over the six years before the reform. Although the reform sought to increase housing affordability for financially vulnerable and liquidity-constrained groups, homeowners with ongoing mortgages across the income distribution also contributed to the staggering increase in debt and consumption growth by actively refinancing to the newly available IO mortgages. Figure 1(b) shows that by 2009, 47% of homeowners had refinanced their existing mortgage contracts into IO mortgage loans. Their post-reform debt and consumption dynamics are remarkably similar to the nationwide statistics in Figure 1(a). In this paper we investigate the causal impact of the introduction of IO mortgages on individual and aggregate consumption growth, using theoretical insights from recent macroeconomic models that incorporate both payment-to-income (PTI) and loan-to-value (LTV) constraints for borrowing (Greenwald, 2018; Grodecka, 2020; Kaplan et al., 2020), while paying particular attention to the mortgage payment constraint.

An IO mortgage in Denmark allows for a 10-year period without amortization payments. Refinancing to an IO mortgage can already lead to reduced periodic mortgage payments and increased consumption for liquidity constrained households, but should not necessarily lead to an expansion of mortgage debt like the one observed in Figure 1(b). While liquidity needs can potentially drive the popularity of IO mortgages and the subsequent increase in consumption, our analysis shows a limited role of liquidity constraints for consumption expenditure increase via IO mortgages. In the data, the majority of homeowners who refinanced to an IO mortgage extracted equity while refinancing, leading to a significant expansion of debt. This observation motivates us to focus on two constraints immediately related to mortgage borrowing, payment-to-income (PTI) and loan-to-value (LTV) constraints. Complementing the traditional collateral-based models of credit constraints where amortization payments do not affect borrowing directly, models with payment constraints

[2] See also Barlevy and Fisher (2020), Amromin et al. (2018) and Dokko et al. (2020) for evidence in the US, and Scanlon et al. (2008) for data on interest-only mortgages outside of the US.

Figure 1: Consumption, Mortgage Debt, and IO Mortgage Share

(a) Aggregate data (b) Non-Moving Homeowners



Notes: Panel a) plots consumption, mortgage debt, and IO mortgage share from aggregate data. All variables are indexed to 100 in 2003 and are measured in 2006 prices. "Final consumption expenditure (total economy)" from Denmark Statistics is plotted in red color, the blue line shows the outstanding mortgage debt and the green line shows the share of outstanding mortgage debt in IO mortgages, both based on data from Nationalbanken. Panel b) plots consumption expenditure in red, mortgage debt in blue, and the IO mortgage share (green line) for households that owned a property in 2002 and who did not move following the reform. Consumption expenditure and the sample selection are described in Section 4. Sources: Denmark Statistics, Nationalbanken, authors' calculation.

allow for lower amortization payments influencing borrowing capacity in the same manner as lower interest rates (Agarwal et al., 2017; Bhutta and Keys, 2016; Bhutta and Ringo, 2020; Cloyne et al., 2019; Di Maggio et al., 2017). By choosing an IO mortgage, payment-constrained homeowners can lift the constraint by reducing the periodic mortgage payment, and subsequently increase consumption and borrowing.

We start our analysis by deriving an equation for when PTI and LTV constraints are binding.[3] Under simultaneous PTI and LTV constraints, borrowing is determined by the lesser of the two constraints, which helps us formulate the condition for when the mortgage payments are binding: for a sufficiently high *house-value-to-income* ratio, the payments on the mortgage constrain borrowing, not the value of the collateral. This relationship between two constraints has an important implication: for a household with low income but high collateral value, the LTV ratio is a poor proxy for credit constraints. Even though the LTV ratio can be low, any borrowing against the collateral needs to be funded out of a low income. Refinancing to an IO mortgage helps relax the PTI constraint but not the LTV constraint. Households with high house-value-to-income

[3]These two constraints are usually analyzed separately. In particular, there is a large literature that document that leverage is an important driver of consumption growth, either by itself (e.g. DeFusco, 2018) or in connection with the house-price growth (e.g. Mian et al., 2013).

ratios face tighter PTI constraint and can use an IO mortgage to increase consumption and borrowing.

Motivated by the conceptual framework, our empirical strategy is based on the pre-reform house-value-to-income ratios, where a higher ratio predicts the household is under the PTI constraint, whereas a lower ratio predicts the LTV constraint is binding. LTV ratios are typically observed in the data with mortgage debt and house value, but the PTI constraint is more obscured in the data, making the pre-reform house-value-to-income ratios relevant and useful in predicting what constraint is binding. Our predictions are validated in the data. The pre-reform house-value-to-income ratio strongly predicts whether a household will use an IO mortgage by 2009: 59% of homeowners in the top decile of house-value-to-income ratio have an IO mortgage, compared with 28% in the bottom decile. Further, consistent with an interaction between two binding constraints, we confirm empirically the LTV ratio declines in the house-value-to-income ratio. As the PTI constraint is more likely to bind with the higher house-value-to-income ratio, the household is unable to borrow against collateral and the LTV ratio falls.

A number of empirical strategies help us identify the direct consumption effect from relaxing the PTI constraint in the post-reform period. Our empirical design benefits from how rapidly the IO mortgage reform was put into effect, within a few months from its initial presentation to the Danish parliament to its actual implementation. We provide extensive tests for parallel trends in the pre-treatment period and conclude consumption growth is not systematically higher in the pre-reform period than in the post-reform period. We check whether households could rely on other non-mortgage loans to finance consumption expenditures in the post-reform period, which helps us rule out other potentially confounding credit market changes occurring around the reform period. We control for the full interaction of the municipality and year fixed effects in the regressions to address the concern that characteristics unrelated to IO mortgages can be responsible for the differences in consumption growth between low- and high-exposure households. Finally, our findings are robust to controlling for income growth, housing-wealth effects, the interest rate gap, and the pre-reform mortgage position of the household. These controls are important because income, mortgage and interest rates, and house-price growth are tightly linked to the relaxation of the constraints. Controlling for income growth and interest rate gap is important because these factors relax the PTI constraint, leading to higher consumption outside of the IO mortgage design. Controlling for house-price growth is critical in our empirical design because our reference group is the homeowners with high LTV ratios. Following the introduction of IO mortgages, house prices increased dramatically in Denmark (Bäckman and Lutz, 2020), which allows for higher consumption via either the housing-wealth effect or a relaxation of the

LTV constraint (Berger et al., 2018; Mian and Sufi, 2011). Browning et al. (2013) argue that, whereas housing-wealth effects empirically are hardly detected in Denmark, the likely transfer of housing wealth into household consumption expenditure occurs via the collateral channel. We address the concern of house-price channel for consumption growth in several ways. First, we routinely use housing-wealth growth as a control, therefore the reported direct effect of the post-reform consumption growth is net of house-price dynamics driving the changes in consumption expenditure. In a separate analysis we explore the impact of the IO-mortgage reform on house-price dynamics to further quantify the indirect consumption effect for the low-exposure homeowners due to rising house prices.

Using millions of observations of detailed and accurate Danish administrative household-level data, we estimate the impact of the introduction of IO mortgages on consumption expenditure of existing homeowners, taking their pre-reform house-value-to-income ratio as a measure of exposure, where high exposure corresponds to the binding PTI constraint and low exposure corresponds to the binding LTV constraint. We find consumption increased after the introduction of the IO mortgages for the PTI-constrained homeowners. In particular, a one-standard-deviation increase in the house-value-to-income ratio is associated with 0.7% increase in consumption growth for the post-reform period. Our findings are consistent across a variety of specifications and robust to controlling for house-price sensitivity to the IO mortgage reform (Guren et al., 2021) and regional spillovers from high-exposure municipalities to the low-exposure homeowners (Huber, 2022). In aggregate, IO mortgages are linked to a direct increase in consumption of homeowners due to relaxation of the PTI constraints by 1.2% between 2003 and 2010, corresponding to 11.5% of the total increase in consumption expenditure. Since households with high leverage are the control group, strong collateral effects imply our direct consumption effect is conservative. In addition to the increase in consumption expenditure for PTI-constrained households, consumption of the LTV-constrained homeowners can grow non-trivially due to the IO mortgage reform, which implies the overall impact of the IO mortgage reform on consumption expenditure of homeowners is larger.

We explore the heterogeneity in the consumption growth due to the relaxation of the PTI constraint and test whether groups that are more likely to be financially constrained were differentially affected by the introduction of IO mortgages. We use the liquidity constraint and borrowing (LTV) constraint as proxies for financial constraints, frequently used measures in the empirical literature on constrained consumption choices. In our baseline empirical design, higher pre-reform LTV ratios predict a lower consumption response, consistent with the binding LTV constraint limiting the response to lower amortization payments.

Further, we find that lower liquidity is associated with a larger consumption response during the post-reform period only for homeowners with high house-value-to-income ratio, that is, for the PTI-constrained homeowners. Low liquidity alone cannot explain consumption growth due to refinancing to IO mortgages.

We complement our estimates of the direct consumption effect from the relaxation of the PTI constraint with the estimates of the consumption effect for the low-exposure households arising from relaxation of the LTV constraint. We show pre-reform house-value-to-income ratio is strongly correlated with the subsequent house-price growth. We use this correlation to estimate the measure of sensitivity of the local house prices (as in Guren et al., 2021) to the penetration of the IO mortgages in municipalities and re-estimate our baseline equation adding this sensitivity measure as a control variable. We find large consumption effect for homeowners with the low exposure arising from house-price growth attributed to the expansion of IO mortgages. Consumption expenditure increased by 3.5% between 2003 and 2010 via relaxation of the LTV constraint due to the IO mortgage reform, which corresponds to a third of the total increase in consumption over this time period.

If IO mortgages relax the borrowing constraints, we expect to see higher borrowing at the time of refinancing (what Greenwald, 2018, calls the "frontloading effect"). We provide evidence for this effect by exploiting the timing of when the household chooses to refinance to an IO mortgage (Druedahl and Martinello, 2020; Fadlon and Nielsen, 2020). Using year and household fixed effects to address endogeneity concerns related to fixed household characteristics and business-cycle effects, we compare the consumption response of households who chose to refinance to an IO mortgage in different years. Our findings suggest the increase in consumption expenditure is driven by higher borrowing at the time of mortgage refinancing: a spike in consumption expenditure at the time of refinancing is followed by a reversion toward the trend of the pre-refinancing period. Nevertheless, this increase in consumption expenditure at refinancing can elevate the overall utility and consumption levels via durability effects. We show that the effect of IO mortgages on aggregate consumption expenditure is driven by a consumption expenditure spike at the time of refinancing on a household level and a large share of the population funding this increase in consumption expenditure by taking out equity when refinancing.

A growing literature investigates consumption, savings, and indebtedness in the period following the introduction of IO mortgages.[4] Our analysis confirms one of the stylized facts in Kuchler (2015), that IO-loan

[4]Studies on borrowing and consumption during the financial crises of 2007-2008 in Denmark include Jensen and Johannesen (2017) and Andersen et al. (2016). Jensen and Johannesen (2017) explain the positive correlation between borrowing and consumption in

holders do not tend to use lower installments for savings or amortizing more expensive debt. We highlight that these households instead extract equity while refinancing and use it to finance consumption, ending up with larger debt and higher LTV-ratios. Larsen et al. (2019) compare the post-refinancing consumption expenditure of households with and without IO mortgages on the sample of homeowners, including those transacting homes, and find households with IO mortgages have higher spending and mortgage debt. While we confirm the findings of higher consumption expenditure and mortgage debt after the introduction of IO mortgages, our study highlights the mechanism for higher consumption driven by the borrowing constraints and quantifies the macroeconomic significance of the increase in consumption due to IO-mortgage reform. Moreover, unlike Larsen et al. (2019), we focus on homeowners who do not move to avoid the possibility that consumption growth can be ambiguously affected by the changes in housing stock at moving via nonseparabilities (Khorunzhina, 2021; Li et al., 2016; Ogaki and Reinhart, 1998; Yogo, 2006) rather than attributed to IO mortgages. Our study is the first to investigate empirically the interplay between PTI and LTV constraints for the decision to refinance to IO mortgages. We show that other financial constraints, e.g. liquidity constraint used in De Stefani and Moertel (2019), can be a poor proxy to the borrowing constraints to motivate refinancing to IO mortgages. We also show households, who are more likely to be PTI-constrained, were more likely to refinance to IO mortgage. Furthermore, these households increased spending substantially during the post-reform period. We find this increase in consumption was funded by the increase in borrowing through equity extraction and its pattern is consistent with the purchases of durable goods. Finally, we show progressive large-scale refinancing to IO mortgages in the post-reform period results in aggregate consumption increases, supporting a dramatic growth in the mortgage debt and consumption documented in Figure 1.

Our findings are relevant for the discussions of mortgage innovation well beyond the Danish realm. Scanlon et al. (2008) report that between 1995 and 2006, interest-only mortgages were introduced in Australia, Finland, Greece, Korea, Portugal, and Spain; even for countries where such products existed previ-

the downturn of 2007-2008 through the channel of credit supply, focusing on banks particularly distressed by the financial crisis. Andersen et al. (2016) find a negative correlation between pre-crisis household indebtedness and spending growth during the crisis (see also for US evidence Dynan, 2012; Mian et al., 2013), arguing for a spending normalization occurring when highly levered households borrowed more on the eve of the crisis to fund consumption. We exploit the positive correlation between borrowing and consumption to argue the borrowing opportunity via refinancing to IO mortgages in aggregate led to substantial consumption growth. We make a step further to decompose the borrowing and spending dynamics on the household level, and show households increase debt when refinancing to IO mortgage and have a rapid increase in spending followed by a rapid drop a year after, consistent with the purchases of large durable goods, as also alluded to in Andersen et al. (2016).

ously, interest-only mortgages make up an increasing share of new mortgage debt. Amromin et al. (2018) show mortgage innovation in the US largely involved mortgages with lower amortization payments, reporting that "complex" mortgages increased from 2% of origination in 2003 to 30% in 2005. Justiniano et al. (2017) report similar figures. An intriguing extension to our paper is to examine how such mortgage products affected consumption growth and borrowing in the 2000s in the US and in other countries.[5] Our findings are also important for policies that guard against future crises. Macroprudential policies in Sweden (Svensson, 2016) and the Netherlands (Bernstein and Koudijs, 2020) in recent years have sought to increase amortization payments to combat growing indebtedness, which poses a considerable macroeconomic risk. Our results indicate this policy may affect borrowing directly and can have a substantial macroeconomic impact if it relates to a sufficiently large share of the population. More generally, given the similar response to lower interest payments and amortization payments, macroeconomic stabilization can to some extent be conducted by changing amortization payments instead of interest rates. This idea is reminiscent of a recent theoretical model where amortization payments are reduced in a recession (Cocco et al., 2021). In addition to the cash-flow effect expanded on in the above study, our results suggest amortization payments have a direct effect on borrowing capacity and can play an even larger role in stabilization policies.

2 Conceptual Framework

In this section, we build a conceptual framework to investigate how consumption may respond to a relaxation of borrowing constraints induced by an IO mortgage. We focus on households-homeowners, who possibly hold mortgage debt and may choose to refinance to an IO mortgage once it becomes available. A useful starting point is to consider a financially unconstrained household that borrows freely and consumes without restrictions. An unconstrained household can set a desired consumption path, borrow when current resources are low relative to lifetime resources, and pay down debt when current resources are high relative to permanent resources. Absent any shocks, relaxing borrowing constraints through an IO mortgage should not affect consumption, because the household already can borrow and consume as much as desired.[6]

For borrowing-constrained households, consumption is below the desired level. Relaxing borrowing constraint induces higher consumption through higher borrowing, which is typically modeled in the litera-

[5] A growing literature studies how mortgage innovations affect house prices in the US (Dokko et al., 2020; Barlevy and Fisher, 2020; Griffin et al., 2020) and in Denmark (Bäckman and Lutz, 2020; Karpestam and Johansson, 2019).

[6] We abstract from precautionary savings, which a household may reduce when credit access is easier.

ture by relaxing LTV constraint (see Guerrieri and Uhlig, 2016, for a comprehensive overview). The LTV constraint allows the household to borrow an amount M up to a fraction θ_H of house value H:

$$M \leq \theta_H H. \tag{1}$$

Relaxing this constraint involves either a higher collateral value H or a higher LTV limit θ_H. If the household faces only this constraint, an IO mortgage will not affect borrowing, because amortization payments are not a part of the constraint.

Recent models have also incorporated a PTI constraint, where borrowing is limited by mortgage payments (Greenwald, 2018; Kaplan et al., 2020). A PTI constraint limits borrowing by restricting interest (r_m) and amortization (γ) payments to a fraction θ_Y of income Y:

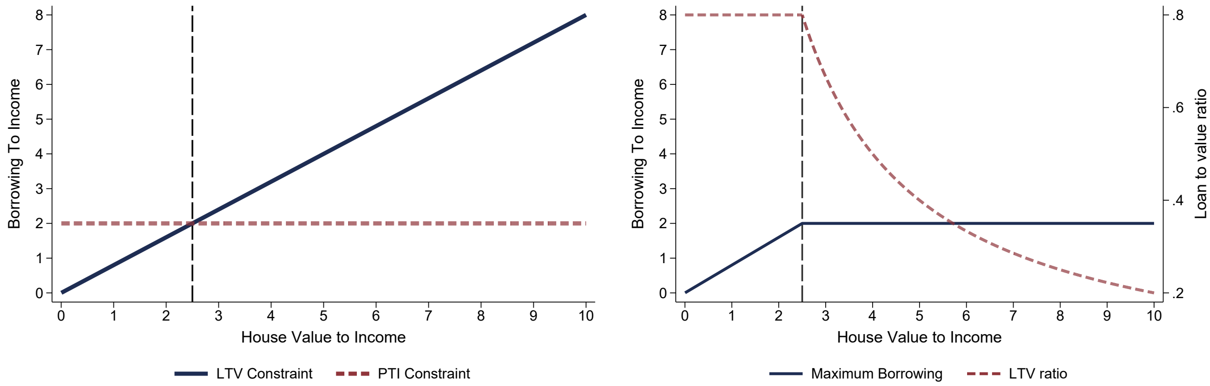
$$M(\gamma + r_m) \leq \theta_Y Y. \tag{2}$$

Relaxing this constraint involves either a higher PTI limit θ_Y, higher income, or a lower amortization or interest payments. Although the focus has mainly been on lower interest payments and a higher PTI limit (see, e.g., Greenwald, 2018), amortization payment has a similar effect. For instance, a household with a mortgage interest rate of 5% and a 3% amortization rate that wishes to keep its mortgage payment below 20% of income is limited to borrowing at most 2.5 times current income. If amortization payments were postponed, borrowing can increase to four times the income.[7] An equivalent increase in maximum borrowing would occur if the mortgage rate were reduced to 2%.

Whether IO mortgages can affect borrowing depends on what constraint is binding. If the PTI constraint is binding, moving to an IO mortgage increases borrowing. If the LTV constraint is binding, an IO mortgage does not affect borrowing. We can rewrite the above constraints as $\bar{M}^{ltv} = \theta_H H$ and $\bar{M}^{pti} = \theta_Y Y/(\gamma + r_m)$, where $\bar{M}^{ltv}$ and $\bar{M}^{pti}$ denote the maximum borrowing under the LTV and PTI constraints, respectively. For a borrower who has to fulfill both constraints simultaneously, borrowing capacity is determined by the lower

[7]Borrowing to income in the initial example is equal to $0.20/(0.05+0.03) = 2.5$. With lower amortization payments, the borrowing capacity is equal to $0.20/0.05 = 4$ times income.

Figure 2: Borrowing under two constraints



(a) Borrowing with a PTI and LTV Constraint

(b) Maximum Borrowing and LTV ratios

Notes: Panel a) plots the maximum borrowing to income against the house value to income ratio for the LTV constraint (blue line) and the PTI constraint (red line). Panel b) plots the maximum borrowing (blue line), defined as the lower of the PTI and LTV constraints, and leverage, defined as maximum borrowing divided by house value. We set the interest rate to 7%, amortization payments to 3%; the LTV constraint θ_H is 0.8 and the PTI constraint θ_Y is set to 0.2.

of the constraints, $\min(\bar{M}^{ltv}, \bar{M}^{pti})$. The PTI constraint is binding if $\bar{M}^{pti} < \bar{M}^{ltv}$, or

$$\frac{\theta_Y Y}{(\gamma + r_m)} < \theta_H H. \tag{3}$$

Rearranging, we get an expression for when the PTI constraint is binding:

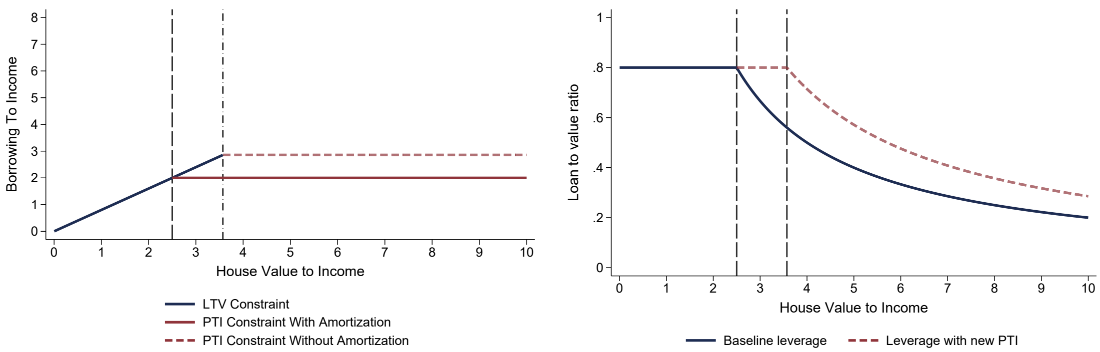
$$\frac{H}{Y} > \frac{\theta_Y}{\gamma + r_m} \frac{1}{\theta_H}. \tag{4}$$

From above, the PTI constraint is binding for sufficiently high values of H/Y. Intuitively, for sufficiently high H/Y, the mortgage payment is binding and not the value of the collateral. Even if the collateral value is high enough for the LTV constraint to not be binding, the household is unable to take advantage of higher collateral and cannot borrow more.

We illustrate this result in Figure 2, where we plot borrowing in panel (a) and the maximum borrowing in panel (b) according to each constraint. House value and borrowing are scaled by income. We set θ_Y to 20% of income and follow the institutional framework in Denmark in setting θ_H to 80% of the house value.[8] The LTV constraint implies maximum borrowing is linear in collateral values – as the house-value-

[8] The Danish institutional framework does not require enforcing the PTI constraint, although mortgage banks consider their own

Figure 3: Increase in borrowing from lower amortization payments



(a) Borrowing with the relaxed PTI constraint

(b) LTV ratios with relaxed PTI constraint

Notes: Panel a) plots maximum borrowing to income when amortization payments are positive (red solid line, baseline case) or set to zero (red dashed line). Maximum borrowing to income under the LTV constraint with no amortization payments is shown in the blue solid line. Panel b) plots the LTV ratio with positive (blue line) and zero (red dashed line) amortization payments. We set the interest rate to 7%, amortization payments are either 3% or 0%; the LTV constraint θ_H is 0.8 and the PTI constraint θ_Y is set to 0.2.

to-income ratio increases, so do maximum borrowing. The LTV constraint in action is shown by the blue line, where the slope is equal to θ_H. The PTI constraint is represented by the red dashed line. This constraint is not affected by the value of the collateral – the PTI constraint is constant over H/Y. With an interest rate of 7% and amortization payments of 3%, maximum borrowing is equal to 2 times the income.

In Figure 2(b), we plot maximum borrowing, where the borrowing constraint switches from the LTV constraint to the PTI constraint at the threshold in equation (4). For values of H/Y above 2.5, the PTI constraint is binding, indicated by the dashed vertical line in Figures 2(a) and 2(b).[9] While collateral values are sufficient to meet the LTV constraint, the payment on any borrowing above the level of 2.5 will not satisfy the PTI constraint. The household is not fully using the collateral above the H/Y value of 2.5, which leads to another implication: the LTV ratio (borrowing divided by house value) is declining in H/Y once the PTI constraint is binding. The household is unable to borrow against the available collateral and the maximum LTV ratio falls. For H/Y below 2.5, the LTV constraint is binding and the household can only borrow 80% of the collateral value, even though the PTI constraint is slack.

Now, consider borrowing under the two constraints when IO mortgages become available. In Figure 3,

PTI limits. For illustrative purposes, we use $\theta_Y = 0.2$ that is similar to 0.25 used in Grodecka (2020) for examining payment-to-income constraints in Sweden. The LTV constraint is set by law to 80% of the valuation of the house.

[9] The PTI constraint is binding if H/Y is greater than $0.2/(0.07 + 0.03) \times 1/0.8 = 2.5$.

we plot the change in borrowing when the amortization payment is set to zero, and the maximum borrowing capacity increases for a household restricted by the PTI constraint, illustrated by the red dashed line. For values of H/Y below 2.5, removing amortization payments has no impact on borrowing. For H/Y above 2.5, borrowing increases. For some house-value-to-income ratios, the binding constraints switch from PTI to LTV, creating an angled upward slope of the red dashed line. Borrowing is therefore increasing in H/Y, although the effect is non-linear in three sections of the H/Y values: (1) zero when the LTV constraint is binding, (2) equal to the borrowing constraint on the LTV ratio between the new and old threshold values due to a constraint-switching effect, and (3) equal to the increase in the PTI limit if the LTV constraint is not binding. The switch from the PTI to the LTV constraint in the second part of the H/Y distribution is emphasized in Greenwald (2018) and implies the full advantage from the potential increase in borrowing is only be available to households with H/Y values above the new threshold.[10]

3 Background

3.1 The Danish Mortgage Market

The predominant mortgage contract in Denmark has historically been the 30-year fixed-rate mortgage, which made up over 90% of outstanding mortgages in the early 2000s. Variable-rate mortgages were introduced in 1997. The interest rate on mortgages is decided by investors in mortgage bonds and not by the mortgage banks.[11] A comprehensive overview can be found in Campbell (2013) and Kuchler (2015).

Before issuing a mortgage debt, mortgage banks assess the credit risk of the borrower. Danish mortgage banks are legally required to evaluate the income and house value for each borrower to assess whether the borrower can repay a standard 30-year fixed-rate-mortgage loan even in the face of increasing interest rates. Mortgage banks use the proceeds from their borrowers to issue mortgage-backed bonds to investors. These banks receive fees from borrowers but do not receive interest income and mortgage payments, which instead accrue to the bond investor. To limit moral hazard, mortgage banks are legally required to retain all credit

[10]Figure B1 in Appendix B shows how borrowing changes when the LTV ratio is changed. Borrowing increases if the LTV constraint is binding, but a higher LTV ratio also makes the PTI constraint tighter. This result arises because the household can borrow more against the collateral, which makes the PTI constraint binding faster.

[11]Danish mortgage-credit banks provide mortgage loans to households and sell bonds to investors using the payments from the mortgage loans. The mortgage system operates according to a "matched funding" principle, where each mortgage loan is matched by a mortgage bond sold to investors.

risk on their balance sheets. If a borrower defaults, the mortgage bank has to replace the defaulting mortgage with a bond with an equivalent interest rate and maturity. Investors therefore face no credit risk, but instead bear all refinancing and interest-rate risk. This system operates without government intervention or direct guarantees. Overall, mortgage debt is more strictly regulated in Denmark than in the US, with corresponding incentives for both mortgage banks and households to not unduly speculate on rising house prices.[12]

Borrowers are evaluated on their ability to afford a standard 30-year fixed-rate mortgage, and the regulation stipulates that mortgage banks can only offer mortgages without amortization payments or with a variable interest rate if the borrower can afford a standard 30-year annuity with fixed interest and amortization payments (Rangvid et al., 2013). Households have a strong incentive to conform to the borrowing limits and not to overextend themselves, because all debt in Denmark is full recourse (and the laws are enforced). In case of borrower default, the mortgage bank can enact a forced sale of the collateralized property. If proceeds from the sale are insufficient to cover the outstanding debt, the mortgage bank can garnish the incomes of the borrower until the debt is repaid. This mortgage-market design ensures no strategic incentive to default exists in Denmark, regardless of the equity position. Indeed, Denmark experienced no default crisis, even as housing markets declined by 30%, mortgage arrears peaked at 0.6% of outstanding mortgage debt.

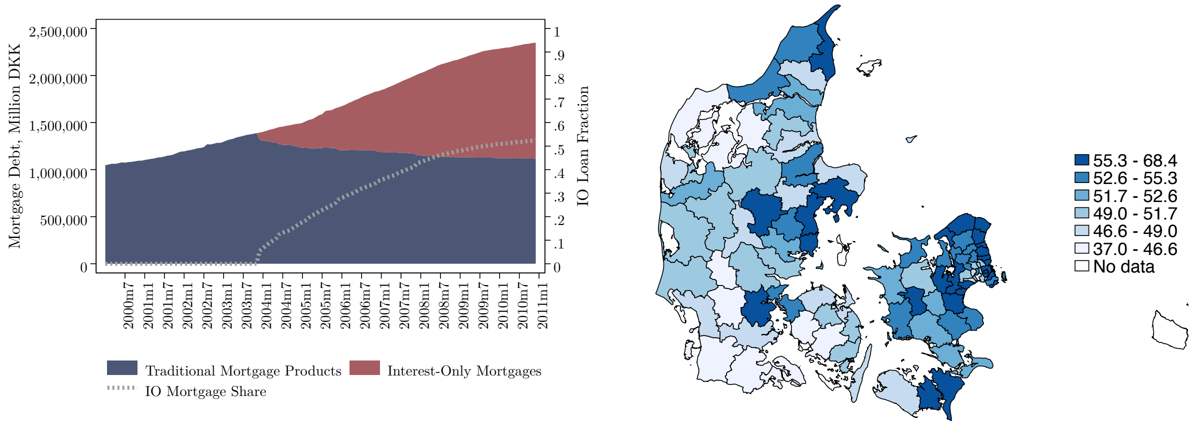
All borrowers can refinance with no pre-payment penalty, regardless of their equity position (Andersen et al., 2020). No lock-in effect of housing equity exists. Households can refinance to extract home equity up to the maximum LTV limit of 80%. This requirement is enforced throughout our study period for all types of mortgages. In case the household decides to refinance, it pays a fee to the government of 1.75% of the mortgage value and the trading cost typically 0.15%-0.25% of the mortgage value (Danske Bank Markets, 2013).

3.2 Interest-Only Mortgages in Denmark

IO mortgages were introduced in Denmark in 2003 through regulatory reform. The regulatory framework specifically details the types of mortgage products the mortgage banks are allowed to offer to their customers. The purpose of the reform was to increase affordability and flexibility for temporarily credit-constrained households. The expectation was that IO mortgages would be a niche product without affecting

[12] Brueckner et al. (2016) argue that because IO mortgages postpone repayments, the higher risk of negative equity makes this product riskier. In their model, this risk is mitigated if house-price expectations are high. See also Barlevy and Fisher (2020). Our focus on existing homeowners and the fact that default is an extremely costly option in Denmark limit the concern that households are using IO mortgages to speculate.

Figure 4: IO Mortgage Penetration



Notes: The figure on the left plots outstanding mortgage debt in DKK divided into traditional amortizing mortgages and IO mortgages. The grey line plots the fraction of all outstanding IO mortgages. The figure on the right plots the share of IO mortgages in each municipality using data from 2009. Source: Nationalbanken

house prices or consumption.[13] The legislation that allowed the mortgage banks to offer IO mortgages, referred to as a "deferred amortization" mortgage (*afdragsfrie lån*), was introduced to the Danish parliament on March 12, 2003, and was voted through parliament on June 4. Mortgage banks could start offering IO mortgages as early as October 2003. The new product allows for a 10-year period without amortization payments, after which the borrower starts repaying the outstanding debt over the remaining life span of the mortgage.

Due to higher principal debt over the first 10 years, total interest payments over the life span of the loan are higher for an IO mortgage than for an amortized mortgage.[14] The law proposal specifically mandates the mortgage banks inform their customers about the higher cost and higher risk associated with IO mortgages. In 2011, a survey of IO mortgage holders by the Association of Danish Mortgage Credit Banks found 89% of surveyed IO-loan holders reported being "very well informed" or "well informed" about the higher cost and higher risk associated with their mortgage choice (Association of Danish Mortgage Credit Banks, 2011).

The left-hand side of Figure 4 shows IO mortgages rapidly became popular among homeowners. IO mortgages are prominently used in areas with high house prices, such as Copenhagen or other larger cities,

[13] Additional material on the process, the motivation, and the debate surrounding the introduction of IO loans can be found at `https://www.retsinformation.dk/Forms/R0710.aspx?id=91430` and `http://webarkiv.ft.dk/Samling/20021/MENU/00766131.htm`.

[14] According to Larsen et al. (2019), in spite of higher debt levels, IO borrowers default as infrequent as traditional mortgage borrowers. These authors note in the housing bust years the average fraction of loans in arrears for 105 days was 0.28% for IO and 0.22% for the traditional mortgages.

but are also popular in other areas. Examining Danish municipalities (approximately equivalent to a US county) for 2009, the right-hand side of Figure 4 shows the lowest penetration is 37% and the highest one is close to 70%. This pattern of mortgage use is somewhat in contrast to evidence from the US, where Amromin et al. (2018) and Barlevy and Fisher (2020) report IO mortgages are prominent in areas where house-price growth is high but not elsewhere. These studies also find IO mortgages in the US essentially disappeared after the housing crash.[15] By contrast, the Danish housing decline and the following recession did not reduce the popularity of these products.

4 Data and Variables

Denmark Statistics provides data on housing and financial wealth, income, and demographic characteristics for the entire population of Denmark. The data are collected through third-party reporting and are highly reliable, accurate, and comprehensive. Starting with the universe of individuals, we collapse the individual-level data to the household level using a unique family identifier, and keep households-homeowners. We exclude households who trade their residential housing during the sample period. We also exclude entrepreneurs because their income and wealth characteristics are reported less accurately. We restrict our study period to 1998 - 2010, immediately after the introduction of variable-rate mortgages in 1997, to ensure households face consistent mortgage choice throughout the sample period. Finally, we select households who are present during all years of our study period and construct a balanced panel.[16]

We take information on demographics such as age, education, marital status, the number of children and municipality of residence. The oldest (most educated) member of a household determines the age (education level) of the household. We also collect asset and debt information such as stock and bond holdings, cash deposits in banks, bank debt, mortgage interest payments, and the market value of mortgage debt, disposable income, and housing information including ownership status, property value, and housing-market transactions. All monetary values are deflated to a base of 2006 using the consumer price index from Statistics Denmark.

Our key outcome variable is consumption expenditure, and we impute it using observed information on income and changes in wealth. Consumption expenditure in a given year is constructed as disposable income

[15] Cocco (2013) documents that IO mortgages in the UK became less prominent after a regulatory change in 2000.

[16] If a household splits due to divorce, each family member is assigned a new family identifier. In our balanced panel households that change their marital status are excluded from the analysis.

minus the change in net wealth. Consumption expenditure imputed from Danish administrative data has been validated in numerous empirical studies by comparing it with survey measures, and generally performs well (Browning and Leth-Petersen, 2003; Kreiner et al., 2015).[17] Jensen and Johannesen (2017) compare an aggregated measure of imputed consumption with the value of private consumption in the national accounts, and show the trend in the two measures is very similar in 2003 - 2011. Browning and Leth-Petersen (2003) find imputed consumption corresponds well to the self-reported consumption on average, but outlier values can be problematic. For this reason, we winsorize consumption expenditure at the 1st and 99th percentiles.

The main concern with imputed consumption is that changes in the valuation of items on the balance sheet, such as unrealized capital gains on stock portfolios, can be captured in consumption. An increase in the interest rate will also lead to a decrease in the market value of a fixed-rate mortgage, increasing net wealth and lowering consumption expenditure. We observe all property transactions and exclude households who trade housing, thus, we do not include changes in housing wealth in the consumption measure. The focus on homeowners who do not change their residence gives us the key advantage because no additional assumptions on the capital gains on housing or transaction costs are needed (Eika et al., 2020). To address concerns regarding the stock portfolio (Koijen et al., 2015), we approximate capital gains on stock portfolios with the market-portfolio return. Specifically, we multiply the value of stock holdings at the beginning of the year with the over-the-year growth in the Copenhagen Stock Exchange (OMX) C20 index and calculate active savings as the end-of-year holdings minus stock holdings at the beginning of the year, adjusted for the capital gains.

An important variable for our analysis is the *house-value-to-income* ratio. We construct this variable using adjusted tax-assessed house value divided by disposable income. Administrative data systematically underestimate actual house value, and we therefore adjust it using a scaling factor, which is a ratio between the actual sales price and the tax-assessed valuation for all housing transactions in a given year. We average the scaling factor for each year-municipality cell and multiply the tax-assessed house value according to the municipality of household residence. We divide this measure of house value by disposable income to obtain the house-value-to-income ratio.

We construct two variables related to credit constraints. First, we measure liquidity constraints based on the ratio of the sum of stocks, bonds and cash deposits, and disposable income. Following Browning et al.

[17]See also Koijen et al. (2015) for a similar procedure using Swedish administrative data, and Ziliak (1998), Cooper (2013), and Khorunzhina (2013) for imputed consumption using survey data.

(2013), we create a dummy for liquid assets less than 1.5 months of income, but also present results using liquidity quartiles. Second, we measure the borrowing constraint as the ratio of the value of outstanding mortgage debt and housing wealth (i.e., LTV or leverage). We present results using LTV quartiles and a dummy for the LTV ratio above 0.5.

We supplement our mortgage data (interest payments and mortgage debt), which are available in the register data because mortgage interest is tax-deductible, with more detailed information about mortgage-debt characteristics. Additional mortgage data are provided annually starting from 2009 by Finance Denmark, containing information from the five largest mortgage banks with a total market share of more than 90% (Andersen et al., 2020). For each mortgage, we observe loan size, bond value, an indicator for an IO loan, an indicator for a fixed interest rate, maturity and the origination date of the mortgage. We use the origination date to assign the mortgage type for the years before 2009. Specifically, we aggregate loan values and other characteristics based on the origination year of the mortgage and then merge these characteristics with households prior to 2009. With this procedure, we cannot fully classify whether a mortgage is IO in the years before the most recent refinancing. The match worsens as we go further back in time, because households may refinance to take advantage of lower interest rates. We therefore focus on the results of the main part of the analysis, where this issue is not present, and consider the results, where we use the direct information about IO mortgages, as an important illustration of the mechanism behind our main results.

Columns (1)-(2) in Table 1 provide summary statistics for households for the year 2002, the year before the reform. We report demographic and financial characteristics. Demographics include age, years of education, and family size. Financial characteristics include disposable income, house value, consumption, liquid assets, mortgage debt, interest payments, house-value-to-income, mortgage-to-income, interest-payments-to-income, liquid-assets-to-income, and mortgage rate (mortgage interest payments divided by the mortgage size). Liquidity constrained is a dummy for liquid assets less than 1.5 months of income, and borrowing constrained is a dummy for mortgage value divided by house value greater than 0.5. The dummy for equity extraction is equal to 1 if nominal mortgage debt increases by more than 10% year-over-year.

Whereas some quantities and characteristics, such as education, income, and consumption, differ only slightly between the groups of households, the largest differences for households with low and high house-value-to-income ratios are precisely in house values. Households with high house-value-to-income ratios live in larger, more expensive homes. These households are somewhat older, which agrees with the slightly lower post-retirement income and consumption. However, Table C1 in Appendix C shows for the sample of

Table 1: Summary Statistics for Households in 2002 prior to the Reform by ex-ante House-Value-to-Income and by ex-post Mortgage Choice

	Ex-ante H/Y ratios		Ex-post Mortgage Choice		
	Low H/Y	High H/Y	IO Mortgage	Traditional Mortgage	Other
	(1)	(2)	(3)	(4)	(5)
Household Demographic Characteristics					
Age	48.87	52.13	49.68	47.21	55.09
	(9.09)	(9.60)	(9.72)	(8.74)	(8.24)
Education Length	14.04	14.12	14.23	14.31	13.68
	(2.50)	(2.68)	(2.44)	(2.37)	(2.91)
Family Size	2.90	2.44	2.87	2.97	2.14
	(1.20)	(1.19)	(1.22)	(1.23)	(1.00)
Household Financial Characteristics					
Disposable Income	356,950	329,361	352,791	351,611	324,627
	(146,855)	(127,113)	(120,005)	(113,633)	(172,912)
House Value	938,020	1,633,490	1,433,864	1,246,472	1,199,352
	(380,810)	(684,465)	(672,048)	(598,280)	(677,562)
Consumption	346,274	326,163	371,672	346,124	292,902
	(266,470)	(1,157,311)	(400,786)	(1,293,563)	(233,647)
Sum of Liquid Assets	169,283	214,839	108,059	125,998	344,617
	(515,800)	(1,191,859)	(227,725)	(1,291,218)	(743,062)
Mortgage Debt	468,508	621,944	800,245	636,899	209,718
	(361,858)	(494,438)	(432,689)	(358,186)	(308,621)
Interest Payments	42,167	47,224	63,476	51,911	19,443
	(28,532)	(35,075)	(31,119)	(26,166)	(21,711)
Housing Wealth to Income	2.63	5.11	4.18	3.63	3.87
	(0.64)	(1.45)	(1.64)	(1.46)	(1.86)
Mortgage to Income	1.31	1.90	2.33	1.86	0.67
	(0.92)	(1.35)	(1.09)	(0.92)	(0.93)
Interest Payments to Income	0.12	0.15	0.19	0.15	0.06
	(0.08)	(0.10)	(0.08)	(0.07)	(0.07)
Share with Mortgage Debt	0.87	0.88	0.98	0.98	0.65
	(0.34)	(0.32)	(0.14)	(0.13)	(0.48)
Mortgage Rate	0.07	0.06	0.06	0.07	0.06
	(0.05)	(0.04)	(0.02)	(0.03)	(0.07)
Liquid Assets to Income	0.44	0.64	0.31	0.34	0.98
	(0.75)	(0.98)	(0.52)	(0.53)	(1.23)
Liquidity Constrained	0.39	0.30	0.48	0.40	0.16
	(0.49)	(0.46)	(0.50)	(0.49)	(0.37)
Borrowing Constrained	0.53	0.37	0.65	0.57	0.11
	(0.50)	(0.48)	(0.48)	(0.50)	(0.32)
IO loan by 2009	0.35	0.51			
	(0.48)	(0.50)			
Equity Extr. after the Reform	0.55	0.56			
	(0.50)	(0.50)			
IO Loan and Equity extraction	0.91	0.90			
	(0.29)	(0.30)			
Observations	148080	148080	86370	113208	96582

Notes: The table reports summary statistics for households over groups of house-value-to-income ratio (columns (1)-(2)) and for households who refinanced to IO mortgage by 2009 (column (3)), who had a traditional, amortizing mortgage in 2009 (column (4)), whereas column (5) includes households who paid off their mortgage by 2009 (about 80%) and households for whom mortgage type could not be accurately determined (the remainder). IO loan by 2009 is a dummy equal to one if the household held an IO mortgage in 2009. Equity extraction is a dummy equal to one if mortgage debt higher by more than 10 percent year-over-year. Standard deviations are in parentheses.

prime-age households (up to 55 years old), the pre-reform consumption and income levels are similar between the low and high H/Y groups, whereas the house values were almost twice as large for the households with high house-value-to-income ratios. These households also have higher mortgage debt, which puts a substantial financial burden on their incomes. However, relative to house value, their mortgage debt is modest, granting them a larger borrowing capacity against their home equity. These households have higher savings in the form of liquid assets and are seemingly less in need of liquidity.

Table 1 also indicates households with high house-value-to-income ratios in 2002 were substantially more active in refinancing to IO loans by 2009. Refinancing provides an opportunity to extract equity, and we observe both low and high H/Y households were active in extracting equity: equity-extraction activity in the post-reform period accounted for 59% of low H/Y households and 56% of high H/Y households. Prime-age households were even more active in extracting equity (69% and 72%, respectively, as Table C1 in Appendix C shows). We also observe the overwhelming majority of households who refinanced to IO loans (about 90%) extracted equity. This descriptive evidence suggests the major motive in refinancing to IO mortgages was to increase borrowing rather than to enjoy reduced mortgage payments.

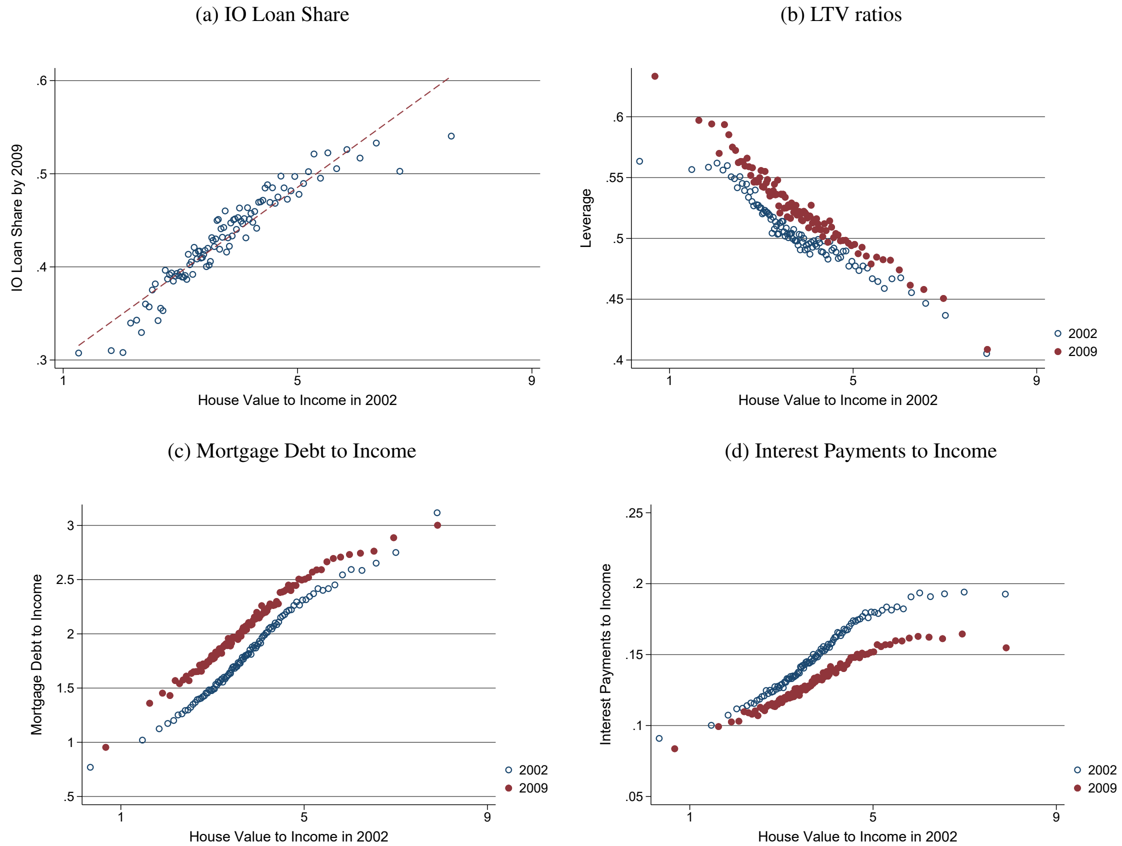
In columns (3)-(5) of Table 1, we split households by their actual mortgage choice observed in 2009: IO-mortgage holders, traditional-mortgage holders, and other. In the "other" category, we include homeowners who paid off their mortgage by 2009 (about 80%) and homeowners for whom mortgage type could not be accurately determined (the remainder). The reported statistics are also for 2002, the year before the reform. Overall, the summary statistics in Table 1 are consistent. Before the reform, IO-mortgage holders were older than traditional-mortgage holders. Income and consumption differ only slightly for them, but we find higher house-value-to-income, mortgage-to-income and mortgage-interest-to-income before refinancing among those who later chose an IO mortgage, suggesting on the larger pre-reform mortgage-payments-to-income associated with the possibly binding PTI constraint. Striking differences between these summary statistics are also around liquidity and borrowing constraints: households who later chose an IO mortgage had not only higher house-value-to-income ratios, but also were liquidity and borrowing constrained, as shown in column (3) of Table 1. Subsequent IO mortgage holders had larger pre-reform LTV ratios (65% of these homeowners compared to 57% of the traditional mortgage borrowers had LTV larger than 0.5), whereas columns (1)-(2) in Table 1 show high H/Y homeowners having low LTV ratios (the share of LTV larger than 0.5 for the low- and high-H/Y households was 53% and 37%, respectively). The finding of larger LTV ratios for the subsequent IO mortgage holders does not agree with our conceptual framework where high LTV households cannot take advantage of the reform. However, the post-reform house-price growth could help relax LTV constraints for households under two constraints simultaneously and enable these households to benefit from the reform. “Other” households are similar to the IO-mortgage holders along many dimensions, including high house-value-to-income ratios, but they have substantially higher liquid assets and lower mortgage debt. In 2002, these households had large savings and were on track to pay off their mortgage debt (in 2002, about 40% of these households did not have mortgage debt; by 2009, their share increased to 80%). Thus, “other” households had similarly high house-value-to-income ratios but were hardly in need of extra liquidity. In our further analysis, we pay attention to liquidity and borrowing constraints, because of their apparent role in encouraging households to refinance to IO mortgages.

5 Empirical framework

From our conceptual framework, an IO mortgage should not affect consumption of an unconstrained household, because the household already can borrow and consume as much as desired. For borrowing-constrained households, borrowing is determined by the lesser of the PTI and LTV constraints. Refinancing to an IO mortgage helps relax the PTI constraint but not the LTV constraint. Motivated by the conceptual framework, our empirical strategy exploits the cross-sectional variation across households in ex-ante exposure to the mortgage reform to assess the economic impact of the IO mortgages on consumption expenditure via the relaxation of the PTI constraint. Specifically, we use the pre-reform house-value-to-income ratio measured in 2002 as the exposure, where a higher ratio predicts the household is under the PTI constraint, whereas a lower ratio predicts the LTV constraint is binding. Households with the lowest exposure serve as the control group, allowing for quantifying the consumption effect from the relaxation of the PTI constraint. Berger et al. (2020) and Mian and Sufi (2012) use a similar strategy to estimate the causal effect of a national policy on groups with various treatment intensity.

Our conceptual framework provides predictions that are validated in the data. First, if IO mortgages relax the binding PTI constraint and this effect can be predicted by the house-value-to-income ratio, IO mortgages will be increasing in the house-value-to-income ratio. Figure 5(a) shows this prediction is born out in the data: the pre-reform house-value-to-income ratio strongly predicts subsequent IO-mortgage use. The figure shows a strong positive correlation between house-value-to-income ratio in 2002 and the IO-mortgage share in 2009 for binned bivariate averages, or “binscatters.” This correlation is robust to controlling for the disposable income, housing wealth, interest rate gap (the difference between contemporaneous interest

Figure 5: IO-loan share, LTV ratios, Mortgage-debt-to-income and Interest-payments-to-income over the House-value-to-income Ratio



Notes: The figures plots household-level IO mortgage share, leverage, mortgage-debt to income and interest-payments to income against the house-value-to-income ratio. The IO mortgage share is calculated using data for the year 2009. All bins control for disposable income, housing wealth, interest rate gap, demographic characteristics and the municipality fixed effects.

rate and mortgage rate), demographic characteristics, such as family size, age, education level, and the municipality fixed effects. We include these controls in all binscatters presented in Figure 5. Next, we plot LTV ratios over the house-value-to-income ratio in Figure 5(b). The decreasing pattern of LTV ratio over the house-value-to-income ratio is consistent with the binding PTI constraint interacting with the LTV constraint as in Figure 2(b). Borrowers with a high house-value-to-income ratio who face two constraints are unable to borrow against home equity, and thus the LTV ratio is lower. Additionally, we observe an upward shift in LTV ratios by 2009 under the relaxed PTI constraint as predicted in Figure 3(b).

Figure 5(c) shows mortgage-debt-to-income increases with the house-value-to-income ratio, with some flattening for high house-value-to-income ratios. Mortgage-debt-to-income is also somewhat higher in 2009 relative to 2002 for all pre-reform house-value-to-income ratios, revealing the increase in borrowing was not limited to the high-exposure households. Finally, the conceptual framework predicts that interest payments are increasing in the house-value-to-income ratio (see Figure B2 in Appendix B), but the interest-payment curve becomes flat as the borrower hits the PTI constraint. Figure 5(d) shows the interest-payment-to-income ratio increases with the house-value-to-income ratio, with some flattening for high house-value-to-income ratios. Notably, the interest-payment-to-income ratios are also smaller in 2009 for high house-value-to-income ratios, suggesting households could take advantage of lower interest rates while refinancing to the IO mortgage. Whereas Figure 5 largely agrees with the predictions of our conceptual framework, it also suggests house-price growth enabled low house-value-to-income households increase mortgage debt, and low interest rates could be an additional motivating factor for refinancing, therefore both house-price growth and interest rates are important factors to take into consideration in our further analysis.

House prices increased dramatically following the introduction of IO mortgages (Bäckman and Lutz, 2020), which could lead to higher consumption for both high and low-exposure households via either the housing-wealth effect or a relaxation of the LTV constraint (Mian and Sufi, 2011). Low-exposure households can be affected by the collateral channel of consumption growth, whereas consumption expenditure of the high-exposure households can react stronger to the housing-wealth effects from a dramatic house-price growth during the boom of 2003-2006. We address the concern of house-price channel for consumption growth in several ways. First, we routinely add housing-wealth growth as a control, therefore the reported effect of the post-reform consumption growth is net of house-price dynamics driving the changes in consumption expenditure. Next, in a separate analysis we explore the impact of the IO-mortgage reform on house-price dynamics to further quantify the effect of rising house-prices due to the reform on the consumption expenditure of low-exposure homeowners.

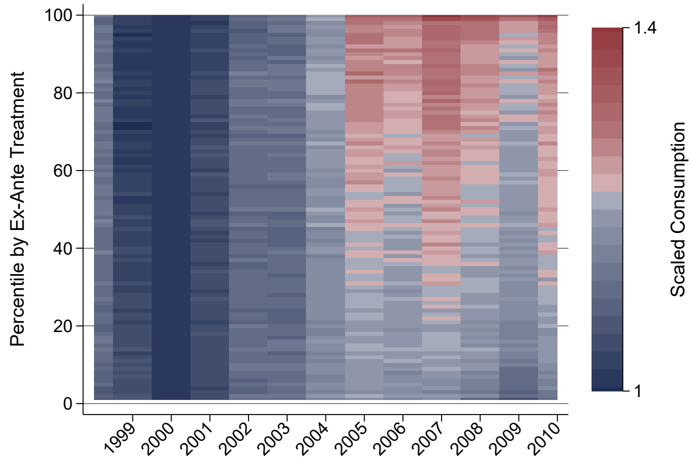
Another potential concern for our empirical strategy is whether lower interest rates drive the increase in consumption expenditure. Indeed, households who are more likely to face PTI constraints (i.e., households with high exposure) would respond similarly to a reduction in amortization payments and interest rates. Although this concern is mitigated by controlling for the pre-reform interest-payment-to-income ratio and the interest rate gap, we also note that interest rates were increasing for a large part of the post-reform period. Figure B6 in Appendix B shows that whereas the mortgage interest rate somewhat declined up to the first half of 2005, it increased between mid-2005 and 2009. Because our findings are robust to controlling for the interest rate gap, the lower interest rates are unlikely to explain our results.

Although the IO-mortgage share is strongly correlated with the house-value-to-income ratio, the exposure variable is not randomly assigned across households. Table 1 shows households with high and low exposure differ systematically in several dimensions: households with high house-value-to-income ratios enjoy larger housing wealth; they have larger mortgage debt, yet they have higher savings. Refinancing to an IO mortgage allows for an immediate increase in consumption expenditure via delayed amortization payments for both liquidity-constrained households and those with a high mortgage-debt-to-income ratio. The consumption benefit of removing amortization payments by choosing an IO mortgage could therefore be increasing in mortgage debt to income. Yet, households with high mortgage debt or high interest payments relative to income are more likely to face a binding LTV constraint, and thus may not fully benefit from an IO mortgage. To address the observable differences between low- and high-exposure households in the mortgage debt and savings, we control for the pre-reform mortgage debt to income, mortgage interest payments to income and explore the role of the liquidity constraints in driving the post-reform consumption growth. Finally, we control for income growth, as higher income both relaxes the PTI constraint and allows for higher consumption.[18]

In addition to explicitly incorporating these observable covariates as controls, other empirical strategies help us mitigate concerns about alternative explanations. Importantly, our empirical design benefits from how rapidly the IO mortgage reform was put into effect, within a few months from its initial presentation to the Danish parliament to its actual implementation. Then, we check whether households could rely on other non-mortgage loans to finance consumption expenditures in the post-reform period, which helps us rule out other potentially confounding credit market changes occurring around the reform period. Further, we use the growth rate in consumption relative to 2000 instead of consumption levels as the dependent variable, thereby removing differences caused by different income or consumption levels. Also, we provide extensive tests for parallel trends in the pre-treatment period and conclude consumption growth is not systematically higher in the pre-reform period than in the post-reform period. We test for no-pre-trends by using the exposure to the reform measured in 2000, 2001 and 2002 and find the lack of pre-trend is robust to changes in the year of exposure. Finally, a concern is that characteristics unrelated to IO mortgages can be responsible for the differences in consumption growth between low- and high-exposure households. To address this concern, the rich administrative data with millions of observations allows for including the full interaction

[18]Relatedly, Bernstein and Koudijs (2020) find labor supply is affected by the changes in the mortgage repayment schemes.

Figure 6: Heatmap and the Time-varying Effect of Exposure on Consumption Expenditure



Notes: Figure plots a difference-in-differences, year-by-year heatmap of consumption expenditure. The vertical axis sorts households into 100 bins based on $Exposure_i$, and the horizontal axis shows years. Each cell color corresponds to the level of the outcome variable (consumption scaled by the value of consumption in 2000).

of the municipality and year fixed effects in the regressions, thus absorbing remaining variation driven by the municipal and business-cycle differences in the house-price dynamics and consumption.

6 The Impact of IO Mortgages on Consumption Expenditure

We begin the empirical analysis with a strategy that leverages an ex-ante measure of exposure to IO mortgages in an intent-to-treat analysis. We create a measure of exposure to IO mortgages as the pre-reform house-value-to-income ratio of homeowners measured in 2002. $Exposure$ is normalized to zero mean and unit variance; therefore, the coefficient on $Exposure$ measures how a one-standard-deviation increase in $Exposure$ affects consumption growth in a given period. Our main outcome variable is consumption growth, where we scale consumption by its value in 2000.

6.1 Main Results

We present first evidence on the effect of higher exposure on consumption growth in Figure 6. Following Berger et al. (2020), the figure plots scaled consumption for 100 bins based on the pre-reform house-value-to-income ratio. The vertical axis shows households sorted by their 2002 house-value-to-income ratios, and the horizontal axis indicates year. A higher value on the vertical axis corresponds to a higher house-value-to-income ratio in 2002 (a higher exposure). Each cell shading shows the value of consumption scaled by its year 2000 value. This approach allows for performing the initial graphical pre-trend comparisons without control variables for different groups of the population. Each cell corresponds to the trend in consumption growth for a specific group, where we can use the relative shading before the introduction of IO mortgages in 2003 to examine different pre-trends in consumption growth.

Table 1 and Figure 5(a) illustrate that after the reform, households with high exposure have a consistently higher share of IO mortgages. Moreover, Figure B4 in Appendix B shows the IO-mortgage refinancing gap between top and bottom $Exposure$ deciles grows over time and by 2010 reaches more than 30 percentage point difference. If individuals with high exposure are more likely to refinance to an IO mortgage, we expect to see higher consumption growth for groups with higher exposure once we aggregate individuals into groups. Figure 6 shows that for the period before the introduction of IO mortgages, consumption growth is similar across groups, indicating parallel trends in consumption growth and suggesting the assumption behind our empirical strategy is valid. After 2004, consumption growth is monotonically increasing in the ex-ante benefit of choosing an IO mortgage, showing the results are not driven by outliers. The pattern of consumption growth in Figure 6 is not consistent with cyclical factors such as temporary income shocks or house-price growth that reverse once house prices decline in 2007 and the labor market turns. Importantly, the heatmap indicates no consumption response for the lowest exposure group in the post-reform period and shows this group is a credible counterfactual for evaluating the effect of the IO mortgage reform on consumption growth through the relaxation of the PTI constraint.

Figure 7(a) plots the coefficients from two specifications that estimate year-by-year consumption growth effects:

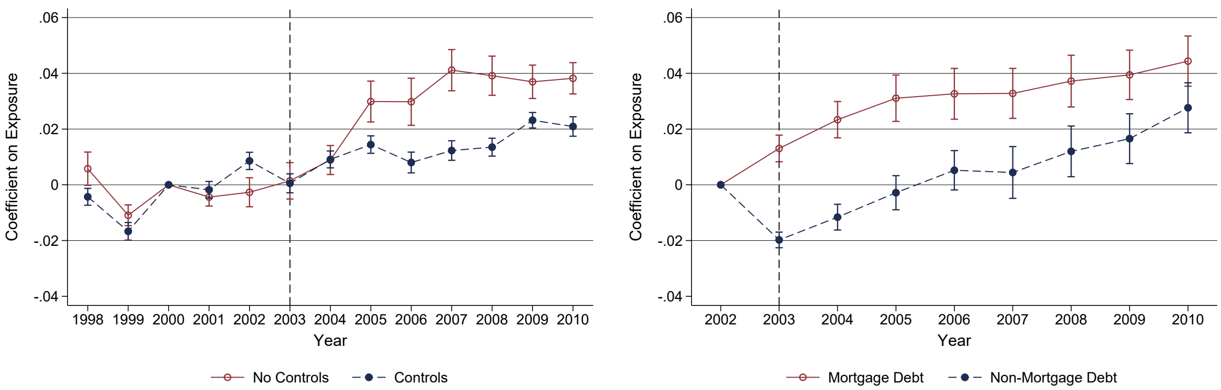
$$\frac{Consumption_{i,t}}{Consumption_{i,2000}} = \alpha + \beta_t Exposure_i + \eta \mathbf{X}_{i,t} + \delta_{kt} + \epsilon_{i,t}, \tag{5}$$

where $Consumption_{i,t}$ is consumption expenditure for household i in year t, $Exposure_i$ is the house-value-to-income ratio in 2002 normalized to zero mean and unit variance, and $\mathbf{X}_{i,t}$ is a vector of control variables. The time-varying coefficient β_t measures the effect of a one-standard-deviation increase in $Exposure$ on consumption growth at time t. The excluded year is 2000. The term δ_{kt} captures year and municipality fixed effects to control for aggregate shocks and time-invariant municipality characteristics. In the specification without control variables, the coefficients on $Exposure$ for 1998 - 2002 are estimated close to zero and mostly not statistically significant, but are positive and statistically significant after the introduction of IO mortgages. Similar results hold for the specification with control variables, where we control for demographic characteristics (education, family size, and age) measured in 2002, a set of pre-reform financial con-

Figure 7: Time-varying Effect of Exposure on Consumption Expenditure, Mortgage and Non-mortgage Borrowing

(a) Consumption Expenditure by Exposure

(b) Mortgage and Non-mortgage Borrowing by Exposure



Notes: Panel a) plots the year-by-year coefficients on $Exposure$ from equation (5) without controls (the solid red line) and with controls (the dashed blue line), whereas panel b) plots the year-by-year coefficients on $Exposure$ regressing on mortgage debt, scaled by mortgage debt in 2002 (the solid red line), and non-mortgage debt, scaled by consumption in 2002 (the dashed blue line). The coefficients measure an effect of a one-standard-deviation increase in house-value-to-income ($Exposure$) on the outcome variable. Control variables include demographic characteristics measured in 2002, a set of pre-reform financial conditions (mortgage debt to income, interest payments to income, liquid assets to income, and leverage), and the contemporaneous financial variables (income growth, interest rate gap, and house-price growth). All specifications control for the municipality and year fixed effects. Standard errors are clustered at the municipality level and the 95% confidence intervals are also reported.

ditions, such as mortgage debt to income, interest payments to income, liquid assets to income, leverage, and the contemporaneous financial variables, such as income growth, interest rate gap, and house-price growth. Although the magnitude of the estimates is reduced for this specification, the coefficients on $Exposure$ are positive and statistically significant after 2003. Overall, the results show that after the reform, consumption expenditure increases more for households with higher ex-ante exposure to IO mortgages.

We estimate equations similar to equation 5, replacing the dependent variable with the mortgage debt normalized by the pre-reform mortgage debt in 2002, and non-mortgage debt normalized by the pre-reform consumption expenditure in 2002, and using the same set of control variables, as well as year and municipality fixed effects. The results are reported in Figure 7(b). We find that mortgage debt steadily grows in exposure over time, whereas the dynamics of non-mortgage debt is mixed: before 2008, households with high exposure did not borrow excessively via non-mortgage loans, but non-mortgage borrowing becomes higher over time. Whereas higher consumption of the PTI constrained homeowners is linked to the higher mortgage borrowing, Figure 7(b) suggests these households did not rely on non-mortgage loans to finance

Table 2: Consumption by Exposure for Pre- and Post-reform Periods and Post-reform Heterogeneity

	(1) Baseline 1	(2) Baseline 2	(3) Liquidity	(4) Leverage	(5) Young
Exposure	-0.003*	0.002	-0.001	-0.001	-0.006***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exposure × PostReform	0.015***	0.007***	0.006***	0.008***	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Z_i			-0.002	-0.004	0.009***
			(0.002)	(0.003)	(0.002)
PostReform $\times Z_i$			-0.003	-0.011***	0.056***
			(0.002)	(0.002)	(0.002)
Exposure $\times Z_i$			0.009***	0.004*	0.008***
			(0.002)	(0.002)	(0.002)
Exposure × PostReform $\times Z_i$			0.002	-0.008***	-0.006**
			(0.002)	(0.002)	(0.002)
Mun.FE	Yes				
Year FE	Yes				
Mun.×Year FE		Yes	Yes	Yes	Yes
Observations	3,710,897	3,710,897	3,710,897	3,710,897	3,710,897

Notes: The table presents estimates of the effect of $Exposure$ on consumption growth, where $Exposure$ is normalized to zero mean and unit variance and where the dependent variable is consumption expenditure normalized by its 2000 value. In all estimations, control variables include demographic characteristics measured in 2002, a set of pre-reform financial conditions (mortgage debt to income and interest payments to income), and the contemporaneous financial variables (income growth, interest rate gap, and house-price growth). *, **, and *** denote statistical significance at the 5%, 1%, and 0.1% levels, respectively. Standard errors clustered at municipality in parentheses.

consumption expenditures, at least not in the early post-reform period. This evidence helps us rule out other potentially confounding credit market changes occurring around the reform period.

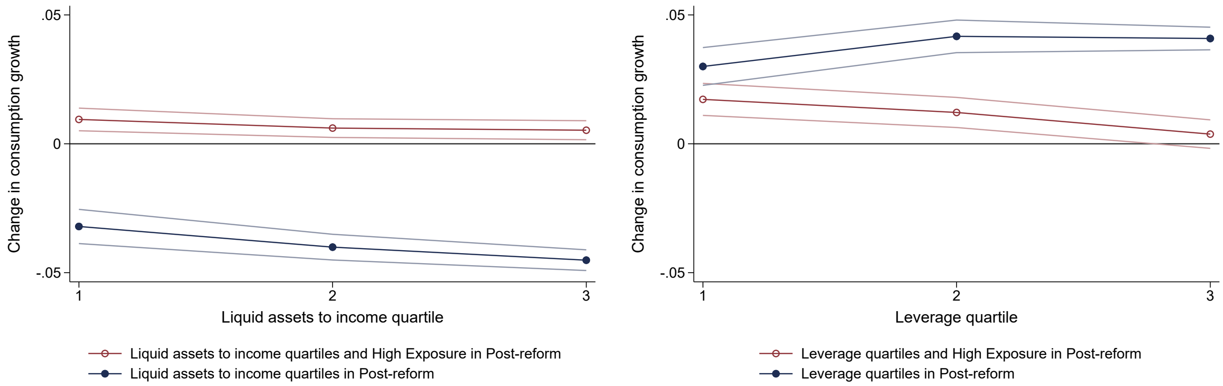
Table 2 provides the average post-reform estimates of the exposure effect for different specifications. We estimate the following equation:

$$\begin{aligned}\frac{Consumption_{i,t}}{Consumption_{i,2000}} &= \beta_1 Exposure_i + \beta_2(Exposure_i \times PostReform) \\ &+ \beta_3(Exposure_i \times Z_i \times PostReform) \\ &+ \gamma_2(Z_i \times PostReform) + \gamma_3(Z_i \times Exposure_i) \\ &+ \gamma_1 Z_i + \eta \mathbf{X}_{i,t} + \delta_{kt} + \epsilon_{it}, \qquad (6)\end{aligned}$$

where Z_i represents a dummy for a group of households with a specific characteristic. We include two time periods in the estimation: a pre-reform period from 1998 to 2002, and a post-reform period from 2003 to 2010. All regressions include demographic variables (education, family size, and age) measured in 2002, a set of pre-reform financial conditions, such as mortgage debt to income, interest payments to income, and the contemporaneous financial variables, such as income growth, interest rate gap, and house-price growth.

The results reported in column (1) of Table 2 control for municipality and year fixed effects separately, whereas the results in column (2) control for the full interaction of the municipality and year fixed effects.

Figure 8: Heterogeneity by Liquidity and Loan-to-Value Ratios



(a) Liquid asset to income

(b) Loan-to-value ratios

Notes: The figures reports estimates of the effect of $Exposure$ on consumption growth in the post-reform period for (a) liquid-asset-to-income deciles, and (b) LTV deciles, both variables measured in 2002, choosing the top decile as reference for both variables. $Exposure$ is normalized to zero mean and unit variance. The dependent variable is consumption expenditure normalized by its 2000 value. The specification and control variables are the same as in Table 2. 95% confidence intervals are plotted.

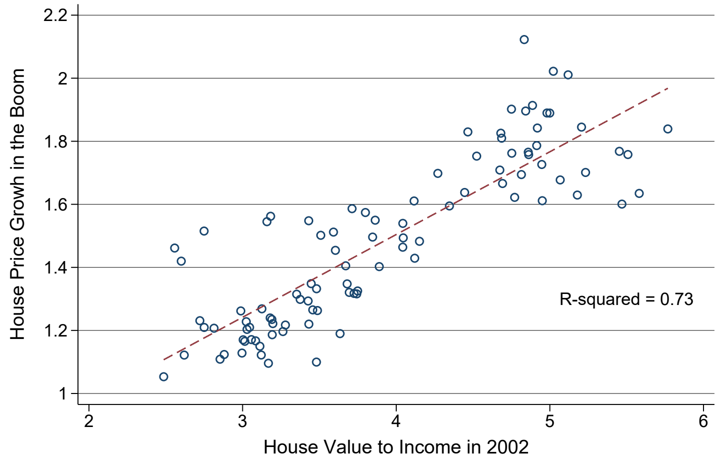
For both estimations, the coefficient on $Exposure$ is close to zero in the pre-reform period, whereas it is positive and statistically significant in the post-reform period. A one-standard-deviation increase in the house-value-to-income ratio for the post-reform period is associated with 1.5% increase in consumption growth in column (1) and 0.7% increase in consumption growth in column (2). The magnitude of the consumption effect in the post-reform period is reduced in the specification where we control for the full interaction of the municipality and year fixed effects, however the coefficient remains highly significant, reassuring on the positive consumption growth after the introduction of the IO mortgages for the PTI-constrained homeowners. Table C2 in Appendix C shows these findings are robust to different years of exposure. We find the lack of pre-trend is robust to changes in the year of exposure, whereas the post-reform consumption effects are even stronger with the earlier definitions of the exposure.

Further, we test whether groups that are more likely to be financially constrained are differentially affected by the introduction of IO mortgages. As proxies for financial constraints, we use the liquidity constraint and borrowing (LTV) constraint defined in section 4. In column (3) of Table 2, we explore the role of the liquidity constrains in driving the post-reform consumption growth. De Stefani and Moertel (2019) argue households facing liquidity constraints could use IO mortgages for consumption smoothing. Refinancing to an IO mortgage allows for an immediate increase in consumption expenditure via delayed amortization payments for liquidity-constrained households. We find that, after controlling for exposure to the reform, liquidity constraints do not play a major role in the post-reform consumption growth. If anything, post-reform consumption of the liquidity constrained homeowners decreases after the introduction of the IO mortgages. This finding is confirmed in Figure 8(a), where we partition pre-reform liquid assets to income by quartiles and estimate equation (6) again: the post-reform consumption declined for the lower quartiles relative to the top quartile. The coefficient on $Exposure$ interacted with the liquidity-constraint dummy and the post-reform dummy is not statistically significant, suggesting lower liquidity is not associated with a larger consumption response if combined with higher exposure during the post-reform period. Figure 8(a) provides a more detailed view, indicating consumption expenditure of the lower quartiles, combined with $Exposure$, slightly increased in the post-reform period compared to the quartile with the largest savings to income. Whereas the results in column (3) of Table 2 for liquidity constraint indicator are mostly insignificant, the significance of our estimates in Figure 8(a) is likely explained by the low sensitivity of the dummy, which is equal to 1 if the household has less than 1.5 months of income in liquid assets (Browning and Leth-Petersen, 2003; Browning et al., 2013; De Stefani and Moertel, 2019), to capture the need for extra liquidity.[19] Our analysis reveals a sizable share of homeowners with considerable liquid assets have consumption responses similar to households with low liquidity.

In column (4) of Table 2, we find lower consumption response to the IO mortgage reform for LTV-constrained households, that is, whose mortgage to house value is greater than 0.5. We further find a negative impact of $Exposure$ on consumption in the post-reform period for households with higher LTV ratios. Both results are consistent with a binding LTV constraint limiting the response to lower amortization payments. Figure 8(b) provides a detailed view on the consumption response for households with various levels of LTV ratios, where we split households into quartiles based on their LTV ratio in 2002, and estimate equation (6) again. The top LTV quartile is the reference category, that is, the most LTV-constrained group of households. The results show households with the lower LTV ratios make larger consumption expenditures in the post-reform period. The effect of $Exposure$ on consumption in the post-reform period is the largest for the lowest LTV ratio quartile and decreasing as LTV ratio approaches its highest values. A lower response by households with higher LTV ratios is in line with the conceptual framework predicting borrowers are unable to increase borrowing to finance consumption expenditure if the LTV constraint becomes binding.

[19] Households under the liquidity constraint indicator fully occupy the first quartile and about half of the second quartile. Our findings with deciles are similar to those with quartiles. The decile counterpart of Figure 8 is available upon request.

Figure 9: House-Price Growth in the Boom by Exposure



In column (5) of Table 2, we find negative impact of $Exposure$ on consumption in the post-reform period for households who were younger than 45 in 2002, that is, older households could increase their consumption expenditure more than younger ones in the post-reform period due to the relaxation of the PTI constraint. We also find a strong overall post-reform increase in consumption expenditure for households, who were younger than 45 in 2002, which likely captures the life-cycle growth in consumption for this group of households.

6.2 House-Price Sensitivity to the Reform and Municipality Spillovers

We examine the house-price channel for consumption growth, by investigating the impact of the IO-mortgage reform on house-price dynamics to further quantify the effect of rising house prices due to the reform on the consumption expenditure of low-exposure homeowners. House prices increased dramatically following the introduction of IO mortgages (Bäckman and Lutz, 2020), which could help relaxing the LTV constraint for the low-exposure homeowners. Pre-reform house-value-to-income is not only associated with the subsequent IO mortgage use: Figure 9 shows pre-reform house-value-to-income on the municipality level is also strongly correlated with the subsequent house-price growth over the boom of 2003-2006. LTV-constrained homeowners living in high-exposure areas can take advantage of this extraordinary house-price growth by borrowing against the increased housing equity and getting consumption boost through collateral channel. In addition to the increased consumption expenditure of high-exposure households, consumption of the low-exposure homeowners can also grow non-trivially due to the IO mortgage reform, which implies the overall impact of the IO mortgage reform on consumption expenditure of homeowners can be larger.

Motivated by the high correlation between $Exposure$ and the post-reform house-price growth in Figure 9, we follow the methodology in Guren et al. (2021) and estimate the effect of the IO mortgage reform on the house-price growth in order to determine the sensitivity of local house-price dynamics to the municipality-level adoption of the IO mortgages. In particular, we estimate the following equation:

$$\frac{HousePrice_{k,t}}{HousePrice_{k,2000}} = \phi_k + \alpha_t Exposure_k + \gamma_k \Delta NationalHousePrice_t + \eta \mathbf{X}_{k,t} + \varepsilon_{kt}, \quad (7)$$

where $HousePrice_{k,t}$ is the average square-meter house price in municipality k and year t, $Exposure_k$ is the average house-value-to-income ratio in 2002 in municipality k normalized to zero mean and unit variance, $\Delta NationalHousePrice_t$ denotes the log annual change in national house prices and $\mathbf{X}_{k,t}$ is a set of control variables. Then we use $\hat{\alpha}_t Exposure_k$, where $\hat{\alpha}_t$ denotes the estimate of α_t from equation (7), as a proxy for local house-price sensitivity to the penetration of the IO mortgages in municipality k. Aggregate innovations to house-prices may load differently in different municipalities for reasons unrelated to the introduction of the IO mortgages, and therefore controlling for national house-price growth is important to capture the contribution of the aggregate housing cycle into the local house-price growth. Other control variables include the interest rate gap and municipality fixed effects. We estimate α_ts using only the variation in local house prices that is orthogonal to aggregate housing cycle and the average mortgage lending conditions.

Using the estimated house-price sensitivity to the IO mortgage reform, we re-estimate our baseline equation, that now takes the following form:

$$\begin{aligned} \frac{Consumption_{i,t}}{Consumption_{i,2000}} &= \beta_1 Exposure_i + \beta_2 (Exposure_i \times PostReform) \\ &+ \gamma_1 Z_{kt} + \gamma_2 (Z_{kt} \times PostReform) + \eta \mathbf{X}_{i,t} + \delta_{kt} + \epsilon_{it}, \end{aligned} \quad (8)$$

where $Z_{kt} = \hat{\alpha}_t Exposure_k$, $\mathbf{X}_{i,t}$ includes the same set of control variables as before, and δ_{kt} captures year and municipality fixed effects. Column (1) in Table 3 presents the estimation results. The estimate by the house-price sensitivity to the reform is 0.013 and highly significant. This result suggests that for homeowners with the low exposure to the reform the consumption increase from house-price dynamics attributed to the availability of IO mortgages is considerable.

Alternatively, cross-household consumption spillovers in high-exposure localities to the low-exposure homeowners can be estimated using a methodology in Huber (2022) and Autor et al. (2014). Assuming all

Table 3: House-Price Sensitivity by Exposure and Municipality Spillovers

	(1)	(2)
Exposure	0.002	0.003*
	(0.001)	(0.001)
Exposure × PostReform	0.006***	0.007***
	(0.001)	(0.001)
House-price sensitivity × PostReform	0.013***	
	(0.001)	
Mun.Exposure × PostReform		0.020***
		(0.003)
Year FE	Yes	Yes
Mun.FE	Yes	Yes
Observations	3,710,415	3,710,415

Notes: The table presents estimates of the effect of $Exposure$ on consumption growth, where $Exposure$ is normalized to zero mean and unit variance and where the dependent variable is consumption expenditure normalized by its 2000 value. In all estimations, control variables include demographic characteristics measured in 2002, a set of pre-reform financial conditions (mortgage debt to income and interest payments to income), and the contemporaneous financial variables (income growth, interest rate gap, and house-price growth). *, **, and *** denote statistical significance at the 5%, 1%, and 0.1% levels, respectively. Standard errors clustered at municipality in parentheses.

homeowners in a municipality can be directly affected by the IO mortgage reform, we construct a "leave-out mean" of the exposure, by averaging $Exposure$ in municipality k for each household i, leaving out $Exposure$ of that specific household i, and re-estimate equation (8) using $Exposure_{-i,k}$ as Z_{kt}. In this case Z_{kt} does not vary over time and hardly varies over households, because the leave-out average for each household uses thousands of observations for each municipality, hence the individual contribution to this mean is negligible. To address the concern that the municipal exposure to the IO mortgage reform may not be exogenous because of its strong correlation with the regional house-price dynamics, we include municipal house-price growth in addition to the usual control for the homeowner's housing-wealth growth that captures micro-geographical level of house prices.

Column (2) in Table 3 presents the estimation results. The post-reform coefficient on the leave-out mean $Exposure_{-i,k}$ is 0.02 and highly significant, suggesting the municipal spillover is sizable. Arguably, consumption expenditure of a low-exposure household increases substantially in high-exposure regions. Importantly, both methodologies deliver the magnitude of the direct consumption effect of the IO mortgage reform similar to those estimated in Table 2, when we control for the full interaction of the municipality and year fixed effects, which gives us confidence in our estimate of the direct consumption effect of the IO mortgage reform arising from the relaxation of the PTI constraints.

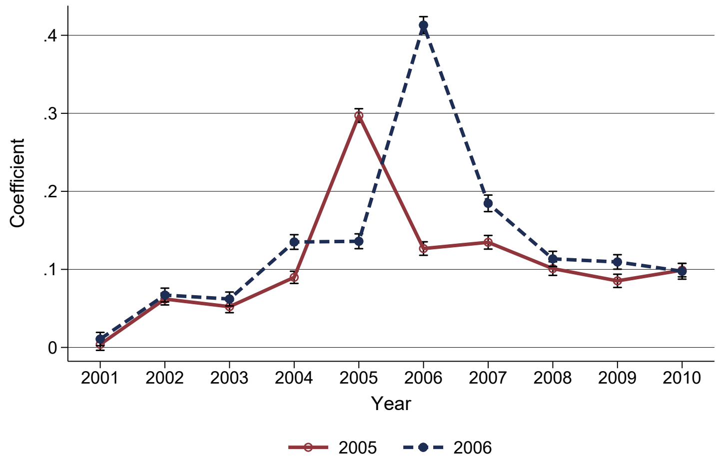
6.3 Aggregate Estimates

Following Berger et al. (2020) and Mian and Sufi (2012), we quantify the aggregate impact of IO mortgages on consumption. The computed consumption effects are not general equilibrium effects, that is, this exercise accounts only for partial equilibrium effects, and the resulting aggregate quantities should be considered an imperfect approximation of the total consumption effect. We compute the direct effect of IO mortgages on consumption by exploiting cross-sectional differences in exposure. We choose the bottom 1% of exposure as the control group, and compute the impact of the reform relative to this group. For each group g, we calculate the aggregate increase in consumption due to IO mortgages as $\beta \times (e_g - e_1) \times Consumption_{g,2002} = \Delta Consumption_g$, where β is the coefficient on the post-reform dummy interacted with $Exposure$ in column (2) of Table 2, e_g is the standardized exposure of group g, e_1 is the standardized exposure of the group with the lowest exposure (the control group), and $Consumption_{g,2002}$ is the consumption expenditure for group g in 2002.

This procedure assumes households with the lowest exposure, e_1, did not receive the direct consumption increase after the introduction of IO mortgages, and all other groups are affected in proportion to their value of $Exposure$. We calculate the direct aggregate impact of IO mortgages on consumption expenditure by summing across all groups. Provided that the bottom group is a legitimate control group, we find the introduction of IO mortgages increased consumption expenditure due to the relaxation of the PTI constraint by 1.2% between 2003 and 2010. Table C3 in Appendix C shows this direct aggregate consumption impact of the reform is quite robust to changes in the size of the control group, decreasing slightly to 1% for the 5% and to 0.9% for the 10% control groups, respectively. Because the total increase in consumption expenditure for our sample over the post-reform period is about 10.6%, the direct increase in consumption of 1.2% due to the reform corresponds to 11.5% of the total increase in consumption over this time period.

Section 6.2 shows the control group can be positively affected by the reform, and its consumption can increase because of the house-price growth following the reform, which implies our aggregate impact on consumption is conservative because our empirical strategy differences out consumption growth by this low-exposure group. To compute the indirect effect of the IO mortgage reform, we follow a similar procedure. The municipality with the lowest average exposure serves as the control group. We compute the aggregate increase in consumption due to higher house prices as $\gamma \times (e_k - e_l) \times Consumption_{k,2002} = \Delta Consumption_k$, where γ is the coefficient on the post-reform dummy interacted with the house-price sensitivity in column (1) of Table 3, e_k is the house-price sensitivity of municipality k, e_l is the house-price sensitivity of the municipality with the lowest house-price sensitivity value (the control group), and $Consumption_{k,2002}$ is the consumption expenditure for municipality k in 2002. Then we calculate the indirect aggregate impact of IO mortgages on consumption expenditure by summing across the municipalities. We find consumption expenditure via relaxation of the LTV constraint increased by 3.5% between 2003 and

Figure 10: Example of Identification Strategy



Note: The figure plots the coefficients and 95% confidence intervals on year dummies estimated from the following equation: $\frac{C_{i,t}}{Y_{i,t}} = \psi_i + \delta_t + \mathbf{X}'\beta + \epsilon_{i,t}$ for households who refinanced to an IO mortgage in 2005 (solid red line) and 2006 (dashed blue line), where ψ_i are household fixed effects and δ_t are the year dummies. Control variables $\mathbf{X}$ include family size, education, the log first difference in disposable income and the change in the mortgage rate. Standard errors are clustered on the individual-borrower level.

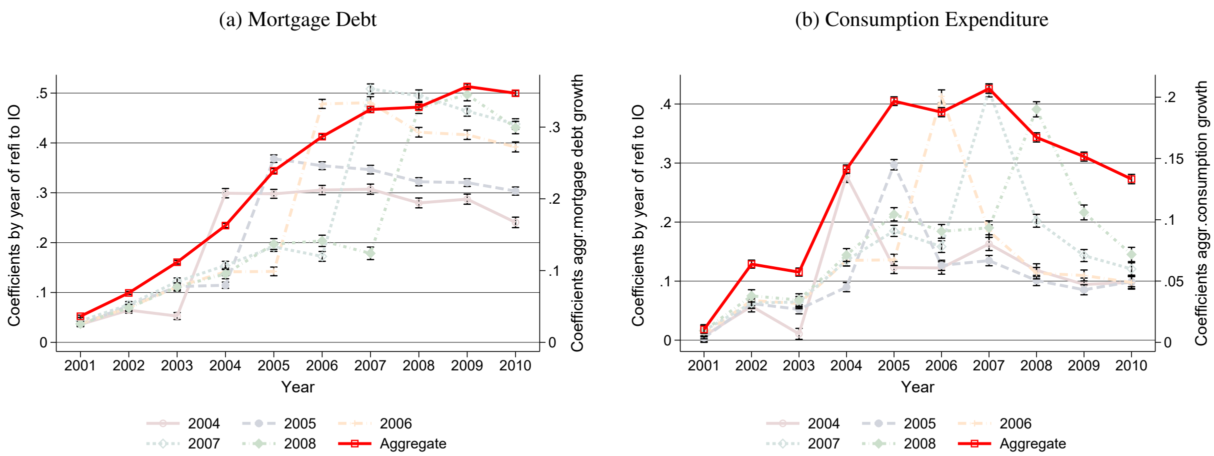
2010, which corresponds to 33.0% of the total increase in consumption expenditure over this time period. The overall increase in consumption expenditure due to the introduction of the IO mortgages is 4.7%, which explains to 44.5% of the total increase in consumption between 2003 and 2010.

7 Consumption after Refinancing to an Interest-Only Mortgage

Section 6 shows consumption increased for homeowners exposed to IO mortgages. In this section, we provide a borrower-level analysis of the consumption response to refinancing. We employ a different identification and use a subsample of households who refinance to IO mortgages between 2003 and 2010. The refinancing date for this exercise is computed backward in time using the mortgage origination date observed in 2009. Both the data construction and the extracted sample of homeowners who refinance to an IO mortgage can raise selection concerns; therefore, we interpret the results in this section with caution. This exercise, however, helps highlight the mechanism behind the increase in consumption.

In general, households who choose an IO mortgage may differ from the rest of the population in ways that affect their consumption expenditure. Although in our baseline estimation we control for a great deal of important covariates, a concern remains that unobserved characteristics simultaneously drive the decision to refinance to an IO mortgage and the consumption response after refinancing. To address concerns over

Figure 11: Consumption and Mortgage Debt at Refinancing to IO Mortgage



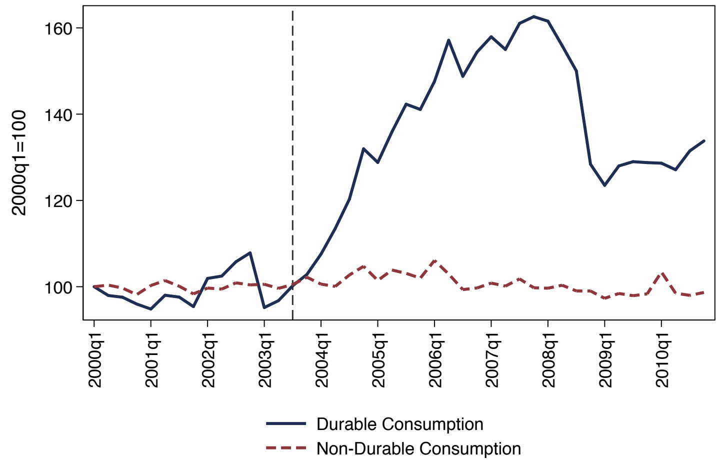
selection into an IO mortgage and to ensure the internal validity of our results, we focus exclusively on households who refinance to an IO mortgage and exploit the difference in timing across refinancing events. This strategy thereby avoids comparing households with an IO mortgage and an amortizing mortgage (as in Larsen et al., 2019), and instead only uses differences in timing across refinancing.

Our approach is illustrated in Figure 10. The figure plots the coefficients and 95% confidence intervals from a regression of the logarithm of consumption expenditure normalized by permanent disposable income on year dummies for households who refinance in 2005 and 2006, respectively, after controlling for household fixed effects and a number of controls, including the change in the mortgage rate and the log of disposable-income growth. We normalize consumption expenditure by permanent income to control for temporary income shocks, but results are similar if we use contemporary income.[20] Druedahl and Martinello (2020) and Fadlon and Nielsen (2020) employ similar strategies to study the effect of inheritances on long-run wealth accumulation and the effect of health shocks on household labor supply. The figure shows parallel trends before refinancing, a spike in the year of refinancing, and a somewhat elevated consumption level in the year following refinancing. Importantly, the lack of a difference in pre-refinancing years suggests households who refinance in 2006 are a good control group for the households who refinanced in 2005.

Expanding the estimation illustrated in Figure 10 for other years in the sample, we find mortgage debt rises substantially and consumption expenditure increases temporarily at the time of refinancing. In Figure 11(a), the pale colors show how mortgage debt increases at the time of refinancing to an IO mortgage by

[20]Following Druedahl and Martinello (2020), we calculate permanent income at time t as a weighted average of past disposable income: $Perminc_t = 0.45 Disposable_t + 0.25 Disposable_{t-1} + 0.15 Disposable_{t-2} + 0.10 Disposable_{t-3} + 0.05 Disposable_{t-4}$.

Figure 12: Durable and Non-Durable Consumption



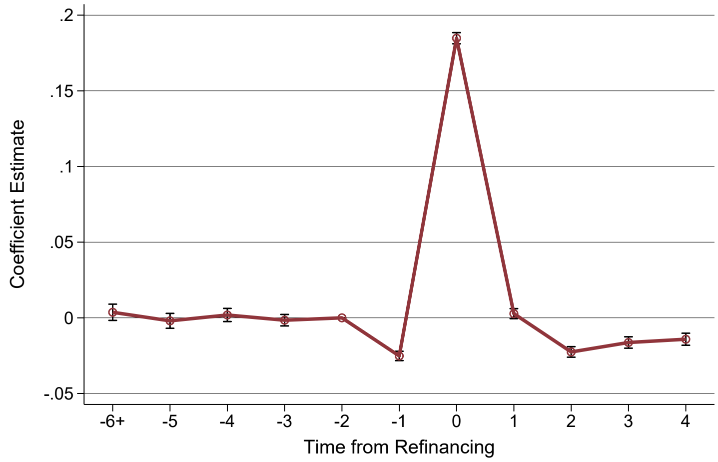
Notes: The figure plots durable and non-durable consumption from 2000Q1 to 2010Q4 for Denmark. The series are normalized to 100 in 2000Q1. Data come from the Denmark Statistics series "NKHC3: Final consumption of households on the economic territory by duration, price unit, and seasonal adjustment." Series is in 2010 prices, chain values, and is seasonally adjusted.

year cohorts of refinancers, and the red bold line shows the overall increase in mortgage debt driven by the refinancing wave (similar to Figure 1(b)). In Figure 11(b), the pale colors show the consumption pattern at the time of refinancing similar to Figure 10 but extended for other years in the sample, and the red bold line shows the resulting aggregate consumption-expenditure wave for homeowners-refinancers. This aggregate consumption pattern is similar to the consumption expenditure shown in the introduction in Figure 1(b) and estimated in Figure 7(a).

What type of consumption expenditure can this wave be associated with? Our measure of consumption is constructed from the accounting identity, where we cannot readily separate total consumption expenditure into durable and nondurable types. However, the evidence from the national accounts in Figure 12 strongly suggests the consumption increase was driven by a boost in durable consumption expenditure exactly in the post-reform period. Durable consumption dynamics in Figure 12 are remarkably similar to the dynamics of the total consumption increase in our sample of homeowners in Figure 1(b) and the subsample of refinancers to an IO mortgage in Figure 11(b), providing a strong indication that the temporary increase in consumption financed by equity extraction at refinancing to an IO mortgage was spent on durable consumption, such as home renovations or car purchases. IO mortgages relax the borrowing constraint related to mortgage payments, and households use the newly available home equity to finance durable purchases.

To compute the average increase in consumption expenditure at the time of refinancing to an IO mort-

Figure 13: Dynamics of Consumption



Notes: The figures show the estimated effects and 95% confidence intervals of refinancing to an IO mortgage on consumption to disposable income. The effects are estimated before and after refinancing to an IO mortgage according to equation 9. Standard errors are clustered at the household level.

gage, we implement the same strategy as above but for all years, following Druedahl and Martinello (2020), and describe consumption at year t of a household i refinancing at time τ_i as

$$\frac{C_{i,t}}{Y_{i,t}} = \gamma_{<-3}\mathbf{1}[t-\tau_i < -3] + \sum_{n=-5}^{-2} \gamma_n^{pre}\mathbf{1}[t-\tau_i = n] + \sum_{n=0}^{6} \gamma_n^{post}\mathbf{1}[t-\tau_i = n] + \delta_t + \psi_i + \epsilon_{i,t}, \tag{9}$$

where δ_t and ψ_i are year and household fixed effects, respectively. For any observation prior to three years before refinancing, $\gamma_{<-3}$ is a normalization. The reference category for γ^{pre} and γ^{post} is two years before refinancing. All regression estimations are clustered at the household level. Druedahl and Martinello (2020) show this approach can be viewed as an event study with separately identifiable year and year-by-cohort fixed effects. The approach maintains the identification assumption of a common difference-in-differences, but allows us to use all available information in the same estimation to identify the effect of choosing an IO mortgage beyond the point where other year-cohort refinancers choose an IO mortgage.

We present the results in Figure 13 and Table C4 in Appendix C. The figure shows that for homeowners who refinance to IO mortgages, consumption expenditure increases by approximately 18.5% of permanent income in the year of refinancing. Before the refinancing event, consumption expenditure is relatively flat. We do not find consumption expenditure is higher after refinancing to an IO mortgage. Instead, consumption dynamics after the refinancing year indicates lower consumption and thus higher savings.

The spike at $t = 0$ corresponds to a large increase in consumption expenditure. Average permanent income between $t = -3$ and $t = -1$ for the sample used in the estimation was 372,038 DKK. A 18.5% consumption increase corresponds to 68,827 DKK ($9,466) on average. This consumption growth is unlikely to be explained by mortgage refinancing costs, because those costs are relatively modest and insufficient to explain this increase in consumption.

Overall, our results show the impact of IO mortgages on consumption is driven by a one-time increase in household consumption expenditure at the time of refinancing. This result is consistent with IO mortgages relaxing the financial constraint related to mortgage payments at the time of refinancing for homeowners who chose an IO mortgage. Our findings suggest borrowing constraints were loosened at the time of refinancing, and although post-refinancing household consumption expenditure continued on a path similar to its pre-refinancing level, the resulting one-time increase in consumption expenditure at refinancing can elevate the overall utility and consumption levels via durability effects.

8 Conclusion

We examine the impact of IO mortgages on consumption growth. Using a measure of exposure to the mortgage reform observed prior to the introduction of the new mortgage product, we find the introduction of IO mortgages has a positive and significant impact on household consumption and borrowing. In aggregate, we find the direct effect of the IO-mortgage reform through the relaxation of the payment constraint explains approximately 11.5% of the growth in consumption expenditure, whereas the indirect effects of the reform through the increase in house prices and relaxation of the maximum-borrowing constraints explain about 33% of the growth in consumption expenditure for homeowners between 2003 and 2010. We examine the mechanisms around the increase in consumption and show refinancing to an IO mortgage is associated with a large one-time increase in consumption expenditure at the time of refinancing.

How do we reconcile the continuous increase in consumption on the aggregate level with the sharp increase in consumption expenditure at the borrower level? Our interpretation is that the introduction of IO mortgages led to a large refinancing wave. Aggregating the one-time adjustment in consumption from a single borrower to the entire economy, our results indicate the aggregate consumption effect comes from a large number of borrowers who refinance and extract equity. Therefore, the increasing refinancing intensity over the post-reform period drives the propagating effect in (most likely durable) consumption growth. Overall, our results show that innovations in mortgage markets targeted at reducing amortization payments have a large impact on consumption expenditure.

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Online Appendices

A Municipality-level Price Index

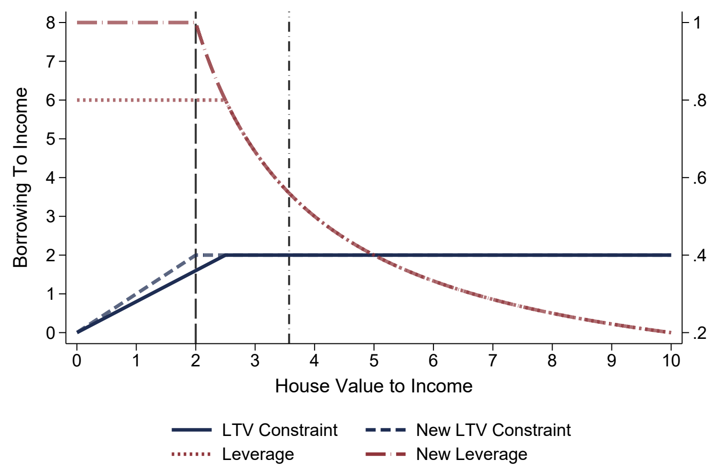
We construct a municipality-level house-price index using data on all transactions in Denmark. The data are from The Danish Gazette (*Statstidende*), and cover the universe of Danish property transactions as part of the judicial process of transferring ownership. We combine the data on property sales with data on individual property characteristics from the Housing Register (*Bygnings- og Boligregister*, BBR). Further, we collect data on property ownership to identify trades between spouses and family members, and to identify trades that occur due to the death of a spouse or due to divorce. These trades are removed from the final sample because they are less likely to be sold at market prices.[21]

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

[21] Removing family trades and similar non-market transactions is common in the construction of real estate indices. See, for example, the S&P Case-Shiller index methodology: http://us.spindices.com/index-family/real-estate/sp-case-shiller.

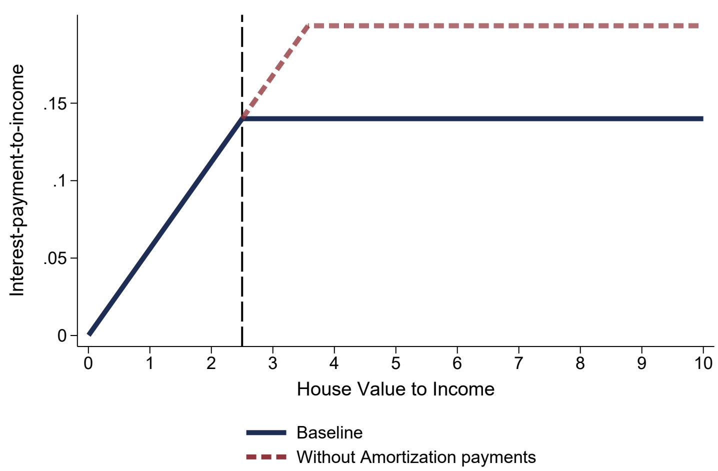
B Figures

Figure B1: Borrowing under Two Constraints



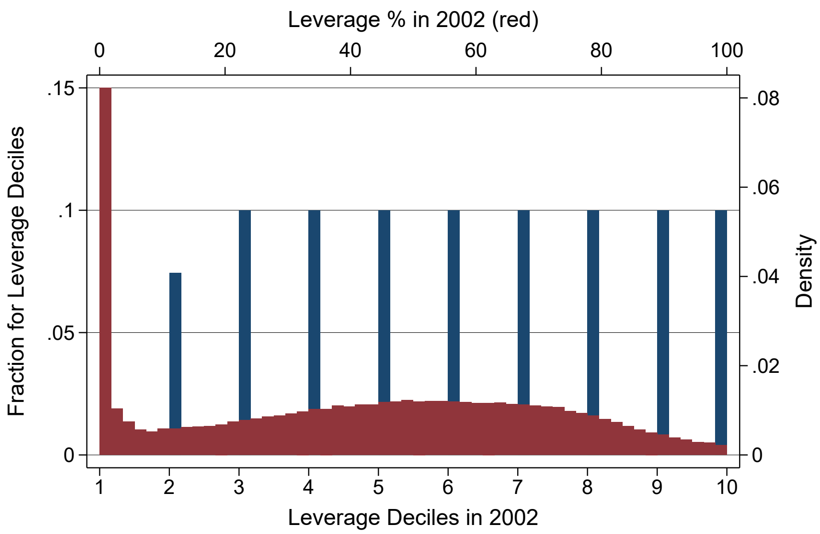
Notes: The figure plots maximum borrowing when we increase the LTV ratio from 0.8 to 1. All parameter values are the same as in Figure 2, unless otherwise indicated. The solid blue (red) line is the maximum borrowing (leverage) under the LTV and PTI constraints. The dashed blue (red) line is the maximum borrowing (leverage) under the new LTV ratio.

Figure B2: Interest-payment-to-income ratio relative to House-value-to-income ratio



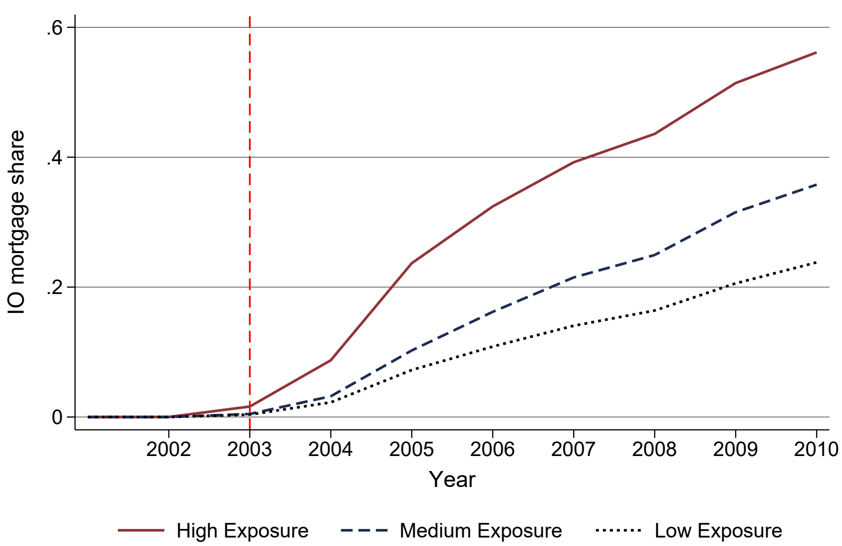
Notes: The figure plots interest payment to income against house value to income. All parameter values are the same as in Figure 2, unless otherwise indicated. Interest payments are calculated as the mortgage debt to income times the mortgage rate. The dashed vertical line shows the threshold where the payment-to-income constraint starts to bind.

Figure B3: Distribution of Pre-reform Leverage



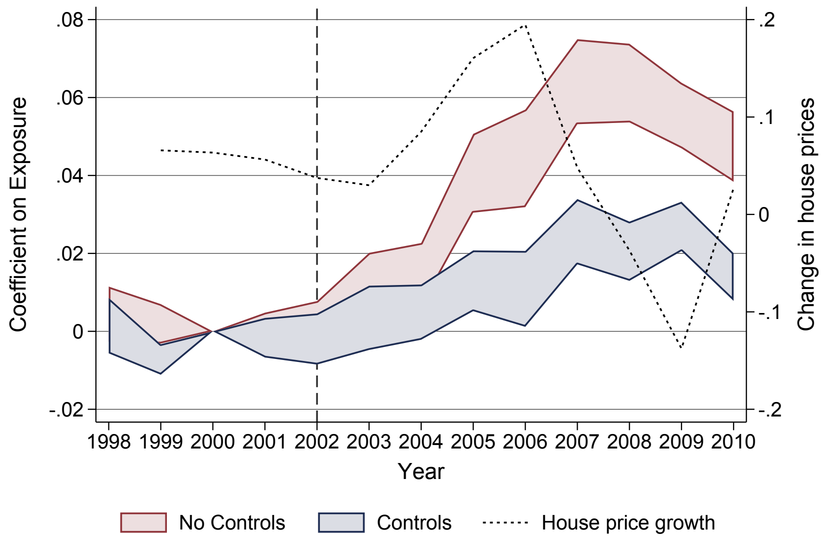
Notes: The figure plots the distribution of pre-reform leverage.

Figure B4: IO-mortgage Share over Time by Exposure



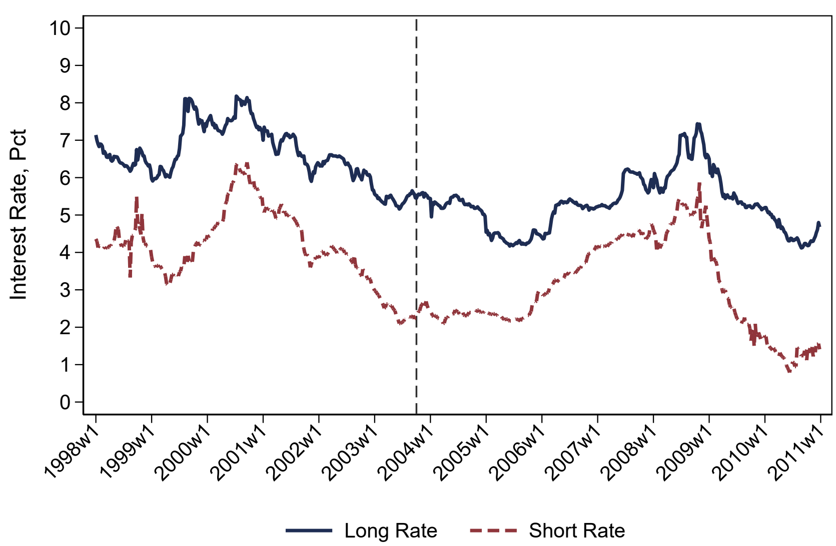
Notes: The figure plots the IO-mortgage share for the groups based on house-value-to-income deciles, top decile (High Exposure), median decile (Medium Exposure) and bottom decile (Low Exposure). The dashed red line indicates when IO mortgages were introduced in 2003.

Figure B5: Consumption Expenditure by Exposure



Notes: The figure plots the year-by-year coefficients on $Exposure$ from equation (5), and the 95% confidence intervals. The coefficients measure an effect of a one-standard-deviation increase in house-value-to-income ($Exposure$) on consumption growth relative to 2000. The solid red line (No Controls) plots the results from basic specification with municipality and time dummies. The dashed blue line (Controls) plots the results controlling for municipality and year fixed effects, and time-varying effects of income growth, mortgage rate, and housing-wealth growth, dummies for age, family size, and education level in 2002. Standard errors are clustered at the municipality level.

Figure B6: Mortgage Interest rates



Notes: The figure plots the long and short mortgage rate on a weekly frequency using data from FinansDanmark. The interest rate is defined as the average bond yield to maturity (YTM) for investors buying mortgage bonds. The dashed line indicates when IO mortgages were introduced in week 40, October 1, 2003.

C Tables

Table C1: Summary Statistics for Households in 2002 prior to the Reform by ex-ante House-Value-to-Income

	Full Sample		Up to 55 years old	
	Low H/Y	High H/Y	Low H/Y	High H/Y
Household Demographic Characteristics				
Age	48.87	52.13	44.80	45.49
	(9.09)	(9.60)	(6.89)	(6.84)
Education Length	14.04	14.12	14.31	14.56
	(2.50)	(2.68)	(2.16)	(2.24)
Family Size	2.90	2.44	3.22	2.90
	(1.20)	(1.19)	(1.21)	(1.31)
Household Financial Characteristics				
Disposable Income	356,950	329,361	366,093	354,532
	(146,855)	(127,113)	(148,097)	(124,897)
House Value	938,020	1,633,490	962,572	1,693,719
	(380,810)	(684,465)	(370,360)	(672,664)
Consumption	346,274	326,163	361,726	356,543
	(266,470)	(1,157,311)	(284,704)	(1,490,506)
Sum of Liquid Assets	169,283	214,839	130,289	151,962
	(515,800)	(1,191,859)	(490,650)	(1,479,615)
Mortgage Debt	468,508	621,944	542,272	794,794
	(361,858)	(494,438)	(351,849)	(490,447)
Interest Payments	42,167	47,224	48,393	59,278
	(28,532)	(35,075)	(27,495)	(34,601)
Housing Wealth to Income	2.63	5.11	2.63	4.87
	(0.64)	(1.45)	(0.63)	(1.28)
Mortgage to Income	1.31	1.90	1.50	2.28
	(0.92)	(1.35)	(0.88)	(1.23)
Interest payments to income	0.12	0.15	0.14	0.17
	(0.08)	(0.10)	(0.08)	(0.09)
Share with Mortgage Debt	0.87	0.88	0.92	0.95
	(0.34)	(0.32)	(0.27)	(0.22)
Mortgage Rate	0.07	0.06	0.07	0.07
	(0.05)	(0.04)	(0.04)	(0.03)
Liquid Assets to Income	0.44	0.64	0.33	0.41
	(0.75)	(0.98)	(0.57)	(0.69)
Liquidity Constrained	0.39	0.30	0.46	0.39
	(0.49)	(0.46)	(0.50)	(0.49)
Borrowing Constrained	0.53	0.37	0.61	0.50
	(0.50)	(0.48)	(0.49)	(0.50)
IO loan by 2009	0.35	0.51	0.33	0.46
	(0.48)	(0.50)	(0.47)	(0.50)
IO loan by 2009	0.35	0.51	0.33	0.46
	(0.48)	(0.50)	(0.47)	(0.50)
Equity Extr. after the Reform	0.55	0.56	0.62	0.66
	(0.50)	(0.50)	(0.48)	(0.47)
IO Loan and Equity extraction	0.91	0.90	0.92	0.92
	(0.29)	(0.30)	(0.27)	(0.27)
Observations	148080	148080	108309	85452

Notes: The table reports summary statistics for households over groups of house-value-to-income ratio for the full sample and the sample up to 55 years old. Borrowing constrained is a dummy variable equal to one if the value of outstanding mortgage debt divided by housing wealth is less than 0.5. IO loan by 2009 is a dummy equal to one if the household held an IO mortgage in 2009. Equity extraction is a dummy equal to one if mortgage debt higher by more than 10 percent year-over-year. Standard deviations are in parentheses.

Table C2: Estimates with different baseline Exposure times

	Exposure: 2000		Exposure: 2001		Exposure: 2002	
	(1) Mun.,Year	(2) Mun-Year	(3) Mun.,Year	(4) Mun-Year	(5) Mun.,Year	(6) Mun-Year
Exposure	-0.000	0.002*	-0.004**	0.000	-0.003*	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Exposure × PostReform	0.021***	0.016***	0.018***	0.011***	0.015***	0.007***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Mun.FE	Yes	No	Yes	No	Yes	No
Year FE	Yes	No	Yes	No	Yes	No
Mun.×Year	No	Yes	No	Yes	No	Yes
Observations	3,710,897	3,710,897	3,710,624	3,710,624	3,710,415	3,710,966

Notes: The table presents estimates of the effect of $Exposure$ on consumption growth, where $Exposure$ is normalized to zero mean and unit variance and where the dependent variable is consumption expenditure normalized by its 2000 value. We define exposure based on house value to income ratio in 2000 (columns 1-2), 2001 (columns 3-4) and 2002 (columns 5-6). In all estimations, control variables include demographic characteristics measured in 2002, a set of pre-reform financial conditions (mortgage debt to income and interest payments to income), and the contemporaneous financial variables (income growth, interest rate gap, and house-price growth). *, **, and *** denote statistical significance at the 5%, 1%, and 0.1% levels, respectively. Standard errors clustered at municipality in parentheses.

Table C3: Aggregate Estimates with Different Size of the Control Group

	10%	5%	1%
Total Consumption Growth (%)	10.6	10.6	10.6
Aggregate Estimate (%)	0.9	1.0	1.2
Percent of Consumption Increase (%)	8.3	9.4	11.5

Table C4: Difference-in-Differences Results

	(1) Mortgage	(2) Consumption
-6+	0.019***	-0.030***
	(0.003)	(0.003)
-5	0.006**	-0.012***
	(0.002)	(0.002)
-4	0.007***	-0.002
	(0.002)	(0.002)
-3	0.004***	-0.001
	(0.001)	(0.002)
-1	-0.046***	-0.019***
	(0.001)	(0.002)
0	0.189***	0.179***
	(0.001)	(0.002)
1	0.164***	0.002
	(0.001)	(0.002)
2	0.129***	-0.026***
	(0.001)	(0.002)
3	0.098***	-0.021***
	(0.001)	(0.002)
4	0.062***	-0.016***
	(0.001)	(0.002)
Observations	920,373	929,607

Notes: The table shows the estimated coefficients and standard errors from estimating equation 9. All regressions include individual fixed effects, year dummies, and control variables: family size, education, disposable income, and mortgage rate. *, **, and *** denote statistical significance at the 5%, 1%, and 0.1% levels, respectively. Standard errors clustered at households in parentheses.