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Effects of borrower-based regulation on housing demand

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Abstract

Various borrower-based macroprudential policies have become widespread across the world after the Great Financial Crisis. This memo quantifies the direct and indirect effects on housing demand of different policies influencing borrowing conditions across residential housing market segments in Denmark.

We focus on three conventional measures: the loan-to-value (LTV), debt-to-income (DTI) and debt-service-to-income (DSTI) ratios, and present two sets of results showing that restrictions on these measures impact households and housing units differently. First, while tighter regulation on the LTV ratio directly impact young and less wealthy households, restrictions on the DTI and DSTI ratios primarily impact housing buyers in the largest cities. Second, by modelling housing buyers' preferences and budget constraints, we find that while any regulation would push net demand to suburban areas, restrictions on the DTI ratio leaves demand for small apartments in the Copenhagen area unaffected.

Prior to the Great Financial Crisis, Danish house prices rose substantially as a house price bubble emerged.[1] Similar developments in housing markets occurred in many countries.[2] Alongside the increase in house prices, household debt rose as well, contributing to stress in the financial sector and, as the developments turned, a prolonged consolidation period in the household sector.[3] The contribution of loose credit conditions to the house price bubble and household borrowing has led regulators in Denmark and abroad to propose and implement various macroprudential measures in order to safeguard the financial system and the real economy from similar events in the future.[4]

A subset of these measures is borrower-based, limiting credit availability for highly leveraged households. While the direct implications on individual households are relatively well-understood ex-ante, little is known about the indirect effects these measures might have on housing demand, i.e. how households would substitute between different housing units once their budget constraints are affected by regulations.[5] It is well known that house price developments tend to ripple across geographical housing segments, and a similar conjecture could be made about the housing market implications of tightening borrowing conditions.[6]

This memo quantifies and compares the potential impact on demand across residential housing market segments from imposing different policies tightening borrowing conditions. Specifically, we investigate the implications on moving patterns of a strict borrowing constraint based on the loan-to-value (LTV) ratio

1 See Hviid, Simon Juul (2017), A leading indicator of house price bubbles, Danmarks Nationalbank Working Paper, no. 114.
2 See Engsted, Tom, Simon Juul Hviid and Thomas Quistgaard Pedersen (2016) Explosive bubbles in house prices? Evidence from the OECD countries, Journal of International Financial Markets, Institutions and Money, vol. 40.
3 See Hviid, Simon Juul and Andreas Kuchler (2017), Consumption and savings in a low interest-rate environment, Danmarks Nationalbank Working Paper, no. 116.
4 See Rangvid, Jesper et al (2012), Den finansielle krise – årsager og konsekvenser, Erhvervs- og vækstministeriet, rapport.
5 Israeli data show that restrictions on LTV limits make households move further away from city centres to more affordable neighbourhoods, see Tzur-Ilan, Nitzan (2020), The Real Consequences of LTV Limits on Housing Choices, Working Paper.
6 See Hviid, Simon Juul (2017), A regional model of the Danish housing market, Danmarks Nationalbank Working Paper, no. 121, and Meen, Geoffrey (1999), Regional House Prices and the Ripple Effect: A New Interpretation, Housing Studies, vol. 14.

versus a comparable constraint on the debt-to-income (DTI) ratio or the debt-service-to-income (DSTI) ratio of housing buyers.

First, we examine and compare which housing buyers would be directly affected by limits on the borrowing measures. Not surprisingly, we find that a tighter restriction on the LTV ratio impacts young and less wealthy households relatively more than others, while limits on the DTI ratio and the DSTI ratio impact primarily housing buyers in the largest cities and low-income housing buyers.

Second, we quantify the substitution effects of housing demand across housing segments from the tighter borrowing conditions. As the imposed borrowing restrictions prevent buying in relatively more expensive segments, households can substitute into relatively more affordable housing segments. Based on observed moving patterns and household characteristics – including borrowing constraints – we apply a revealed-preferences approach, and exploit a flexible machine learning model to estimate housing demand across segments conditional on the current state of the housing and credit markets.

Based on the estimated preferences, we simulate the effects of tightening the borrowing constraints of the housing buyers due to strict macroprudential policies. While such tightenings reduce the number of transactions in some segments – as a result of the substitution effect– it increases in other segments. Overall, we find that tightening of borrower-based measures, in general, creates a negative net demand shock in the largest cities and pushes demand toward less populated areas.

However, introducing restrictions on the DTI ratio has mixed substitution effects in the Copenhagen area. While restrictions on DTI directly reduce demand for large single-family homes and large apartments, the substitution effects of these restrictions push demand out of the cities and towards smaller housing units within the city, counteracting the direct negative impact. While our approach does not allow us to quantify the impact on house prices per se, it does indicate the direction of which prices would need to adjust on the housing market segments in order to ensure a balance between supply and demand.

These results should not be seen as specific suggestions for future regulation but rather as an endeavour to better grasp the anatomy of a selection of conventional tools in the macroprudential toolkit. Similarly, this memo does not seek to evaluate the current regulation but rather addresses the implications for the housing market of constraints on LTV, DTI, and DSTI ratios conditional on the current regulation.

Data

We collect data on all housing transactions in 2017 and 2018 of single-family homes and apartments bought by households in Denmark. We combine data on transactions with information on household characteristics such as family size, education level, age, income, net wealth, job position and location of the workplace. Furthermore, we observe the previous housing unit owned by the household, as long as the unit was bought after 1998. The final dataset consists of 120,040 observations of housing transactions.

Computation of credit constraints

During the past decade, Danish regulators have imposed various borrower-based measures intending to increase the resilience of households and banks.[7] Most measures have been implemented as consumer protection legislation, which is legally binding, but comes with a relatively high degree of

[7] The measures include the following: A minimum down payment of 5 per cent, so-called growth area guidelines that put several restrictions on banks' and mortgage banks' lending in Greater Copenhagen and Aarhus, including limits to DTI and LTV for homeowners that do not choose 30-year fixed-rate repayment mortgages, a requirement that interest-only or variable-rate mortgages can only be granted to homeowners that would be able to service a 30-year fixed-rate repayment mortgage, and general limits to the mortgage product supply for homeowners with a high DTI and LTV: Interest rate fixation should be at least five years, and interest-only option can only come with 30-year fixed-rate mortgages.

flexibility. The measures are rather complex, and the only general cap is a 5 per cent minimum down payment requirement. Besides that, there are certain restrictions on mortgage choices for households with high DTI and LTV ratios and additional borrowing restrictions in the growth areas covering greater Copenhagen and Aarhus.[8]

We exploit household-level information to calculate LTV, DTI and DSTI ratios at the household level. LTV is defined as housing debt relative to the value of the property. DTI is defined as overall debt relative to gross income. DSTI is defined as overall debt service payments relative to disposal income (after tax). By definition, the DTI and DSTI ratios are based on the total debt and not only debt related to housing.

Housing debt is the sum of mortgage debt and bank debt related to housing and is the main component in computing the LTV ratio. We define a household as restricted if the household's LTV ratio exceeds the limit.[9]

We compute the DTI ratio as the household's overall debt relative to gross annual income. DSTI measures the total debt service (interest paid after tax deduction and instalments) relative to disposable income. However, the overall debt service depends on interest rates and time to maturity for individual loans, and actual loan choices depend on household risk preferences and therefore vary by mortgage choice. Hence, to ensure comparability we compute a standardised DSTI for the households based on a 30-year fixed-rate mortgage loan and an additional 20-year bank loan on the debt that might exceed 80 per cent of the transaction price, where both loans are with amortisation.[10]

This choice reflects current lending rules, according to which households have to be able to service a 30-year fixed-rate mortgage with amortisation, and provides a standardised DSTI measure across households, independent of individual risk preferences and mortgage choices.

Borrower-based regulation affects differently across housing buyers' characteristics

Restrictions on mortgage borrowers has a direct effect on housing buyers. This section shows that different types of borrower-based regulation, when calibrated to affect the same number of households, affect different parts of the population.

For comparability, we calibrate the tightening of the restrictions on DTI and DSTI ratios to match the nationwide number of affected households to a corresponding restriction resulting from an increased down payment requirement from 5 per cent to 10 per cent of the transaction price, equivalent to tightening the LTV ratio to 90 per cent.[11] Imposing a 350 per cent constraint on DTI or a DSTI constraint to 25 per cent of a household's income would roughly match this number. These restrictions should not be seen as recommendations but are solely chosen in order to make the effects of different types of regulations comparable.

We focus on households who have bought a residential property in 2017 and 2018, and define them as *restricted* if the purchase had not been possible given the restrictions. We consider four dimensions of heterogeneity in the exposure to restrictions. We begin by comparing the direct

[8] Bentzen, Christian Sinding, Cokayne, Graeme, Gerba, Eddie and Roulund, Rasmus Pank (2020), Stricter lending requirements have made homeowners more robust, *Danmarks Nationalbank Analysis,* no. 1, January.

[9] We allow restricted households to use other financial assets to finance the down payment. In practice, we recalculate housing debt by subtracting household net liquid wealth (assets and deposits) from the loan value. We allow the household to make use of most of their wealth, as we require kr. 50,000 remaining wealth.

[10] Debt service differs for different loan types as it depends on the interest rate, time to maturity and whether the household is amortising or not. However, according to one of the requirements in God Skik, households must 'be able to service the debt associated with a 30-year fixed-rate mortgage with regular principal repayments', cf. Bentzen et al. (2020). Interest rates used for computation correspond to the level at the end of 2018.

[11] In practice, we observe households being able to obtain loans corresponding to more than 95 per cent of the transaction price, violating existing LTV constraints. In our simulations, we assume these households would not be able to obtain the same loan under tighter constraints.

impacts of these imposed restrictions across households' financial characteristics (income and net wealth). We then compare these impacts across the age distribution of households measured by the oldest members. Finally, we compare these impacts geographically.

We define the income and wealth distribution by the deciles of the entire population of Danish households – not only those involved in housing transactions. Housing transactions are highly concentrated in the upper half of the income distribution, while the probability of buying a housing unit is more evenly distributed across the net wealth distribution, see chart 1: The bottom 40 per cent of the income distribution constitute only 10 per cent of the total number of buyers in 2017-2018. These numbers suggest that preferences and/or self-imposed restrictions, the current regulation or the credit policies of banks and mortgage credit institutions discourage low-income households from buying in the first place.

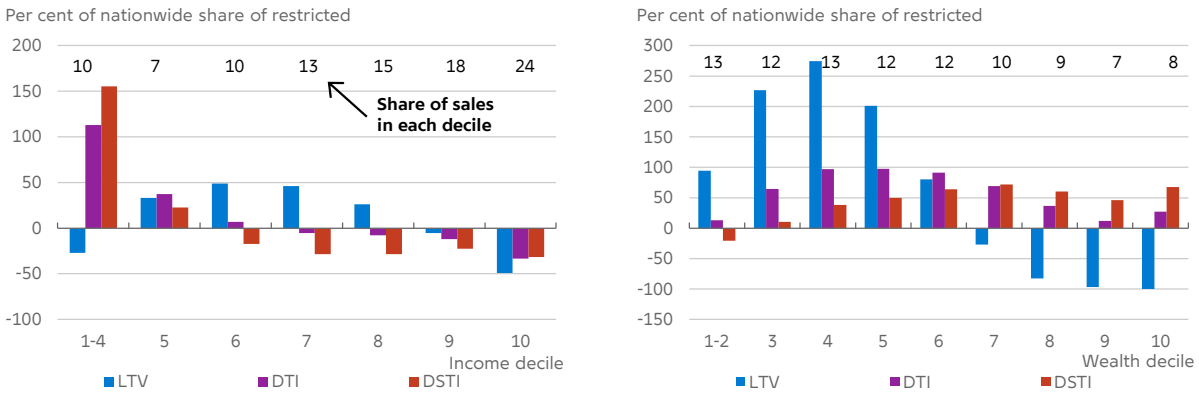
As expected, the share of restricted buyers, due to limits on DTI and DSTI ratios, is highest for the low-income buyers, whereas a tightening of the LTV ratio primarily impacts the middle part of the income distribution. This indicates that high and low-income households that buy housing have relatively larger savings, or potentially have gained on a previously owned housing unit.

Across the net wealth distribution, there is a noticeable drop in the share of housing buyers that are restricted by a tightening of the LTV requirement around the median. The sharp drop could, among other things, be attributed of the differences in wealth accumulation between first-time and second-time buyers, as average house prices have increased in the years prior to our sample.

Restrictions on DTI or DSTI ratios affect nearly the same proportion of households across the high-income deciles, indicating not only that high-income households have higher debt in nominal terms but also that the proportion with high debt relative to income is fairly stable. Furthermore, the share of households with high debt relative to income does not depend on household wealth, as the share of DTI-restricted buyers is roughly stable across wealth deciles.

LTV restrictions affect less wealthy households, whereas DTI and DSTI restrictions affect low-income households the most

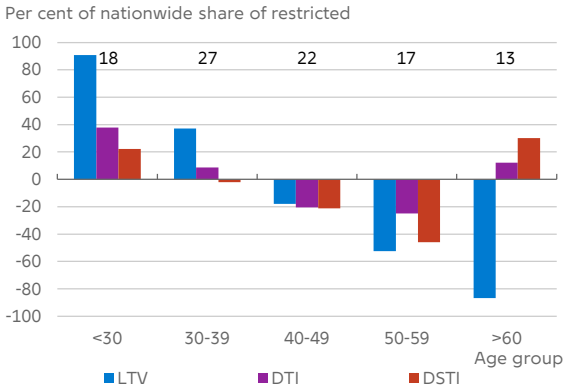
Chart 1



Note: Percentage of restricted households with respect to the restricted number in the population distributed on income (left) and net wealth (right) deciles. Zero corresponds to the nationwide share of restricted households. The blue, purple and red represent households that are restricted due to LTV, DTI and DSTI restrictions, respectively. The percentage above each group of columns specifies the share of observations within each decile. Income and wealth are computed as an average for each household, and deciles are defined based on the entire population. Deciles 1 and 10 correspond to the lowest and highest income and decile, respectively.
Source: Own calculations based on data from Statistics Denmark.

Chart 2 shows that regulation on borrowing impacts younger households relatively more, and in particular tighter LTV restrictions primarily impact the young buyers, which are often first-time buyers.[12] While limits on DTI and DSTI ratios also impact older households, the share of older households with binding LTV constrains is low and they are less inclined to purchase housing units.

Young and old households are more affected by borrower-based regulation Chart 2



Note: Percentage of restricted households with respect to the restricted number in the population distributed on age groups. Zero corresponds to the nationwide share of restricted households. We distribute households into age groups depending on the age of the oldest person in the household. The blue, purple and red represent the share of restricted households due to LTV, DTI and DSTI restrictions, respectively. The percentage above each group of columns specifies the share of observations within each group.
Source: Own calculations based on data from Statistics Denmark.

Finally, chart 3 shows that tightening borrowing regulations affect households differently across geographical areas. Notably, larger down payment requirements impact most geographical areas and have little effect both in the relatively expensive municipalities north of Copenhagen and in some of the relatively cheaper rural municipalities. These patterns could reflect that, on the one hand, second-time buyers in the capital region have experienced substantial home-equity gains during the past decade, allowing for larger down payments, and, on the other hand, that buyers in the rural areas can more easily afford down payments due to lower price levels.

Larger down payment requirements affect most geographical areas, whereas the impact of limits on DTI and DSTI ratios are highly concentrated around the largest cities and especially affect buyers north of Copenhagen. The results show that buyers in these areas and especially north of Copenhagen pay high down payments but still have high debt relative to income.

Computation of substitution effects

This section describes how we estimate the demand effects from introducing borrower-based restrictions on lending. First, we divide the housing market into segments. Second, we exploit machine learning to predict household housing preferences from household and housing characteristics. Finally, we combine predicted preferences with the change in households' budget constraints to determine the effects on demand from introducing restrictions.

Housing market segments

We divide all sold housing units into subgroups, which describe both the type of the house and its geographical location. We define these subgroups as segments.

The segments group housing units with similar characteristics in order to keep as much information as possible and yet ensure enough observations within each segment. We construct segments from groups of similar housing units in similar geographical locations, such that units within each segment can be seen as very close substitutes for each other. For example, we group small single-family homes in suburban areas within a region, as the distance to the centre might be more descriptive

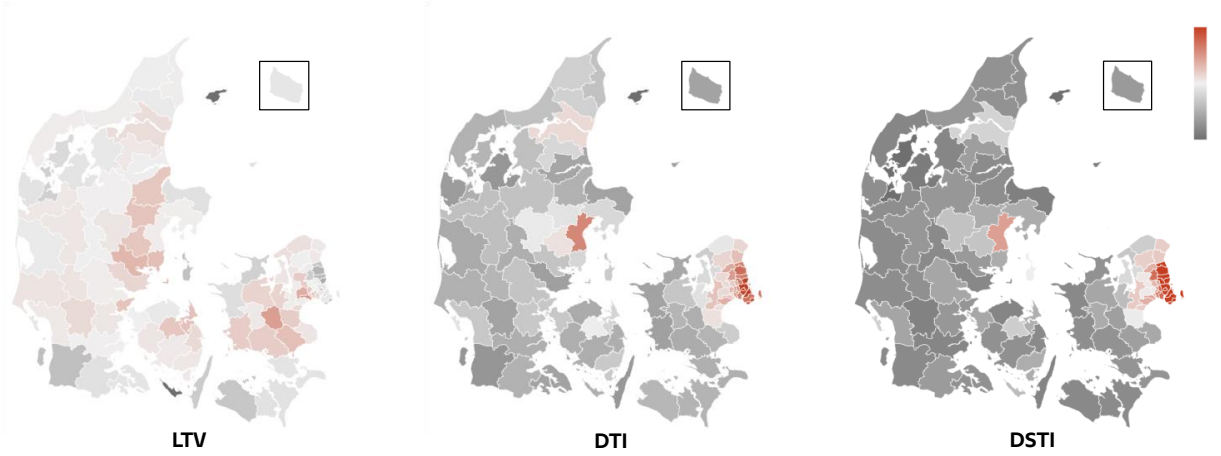
[12] 88 per cent of the households in the age group 0-29 are first-time buyers.

than the specific municipality or postal code for average movements.

preferences across segments at the household level based on household characteristics. The model

Regulatory tools affect geographical areas differently

Chart 3



Note: The three maps show the share of restricted households within each municipality due to tighter restrictions on LTV (left), DTI (middle), and DSTI (right). The colour scale ranks from dark grey to light grey to red for a higher share of restricted households within each municipality. Each map is coloured such that light grey is equivalent to the nationwide share of restricted buyers.
Source: Own calculations based on data from Statistics Denmark.

We define segments based on four parameters: housing type, location within the five Danish regions, municipality group and the geographical zone. First, housing units are grouped according to the type of the house: large and small single-family homes, terraced houses and small and large apartments.[13] Second, housing units are grouped according to their geographical location, which builds on the three remaining parameters: regions, municipality groups and zones (densely or sparsely populated area).[14] Crossing the four parameters and requiring at least 100 observations within each segment results in 91 segments, with the median segment containing 739 house transactions.

Specification of the prediction model

Simulating the substitution effects of regulation requires estimating households' housing preferences. We exploit a gradient boosting tree model to predict exploits several input variables, including family characteristics, job information, education, financial information and previous inhabited segment. The input variables are observed in the year preceding housing purchase to ensure exogeneity in modelling housing decisions. The list of input variables is available in box 1. The model outputs probabilities, which we interpret as relative preferences for each segment conditional on the current prices and regulation. We denote these preferences as *raw preferences*.

The goal of the prediction model is to reveal households' preferences across segments. Therefore, we evaluate the model performance based on the top five predictions. The out-of-sample, top five accuracy score for the prediction model is 0.81. In other words, in 81 per cent of the cases the segment in which the household actually bought a housing

[13] We define large and small single-family homes based on a floor area larger or smaller than 150 square metres. Similar, small and large apartments are defined based on a floor area smaller or larger than 75 square metres.

[14] The geographical segmentation is based on Statistics Denmark's nomenclature. Municipality groups are based on accessibility to jobs and the number of inhabitants in the largest city within the municipality. Furthermore, we group capital and metropolitan municipalites (large cities), and commuter and rural municipalities (small municipalities). Zone refers to whether the housing unit is located in a densely or sparsely populated area within a municipality.

unit is among the five of 91 segments with the highest predicted probability. For comparison, a model solely based on the previous housing segment, which is equivalent to estimating preferences solely based on historical flows across segments, has an out-of-sample, top five accuracy of 0.34. Household characteristics are therefore important for a meaningful estimation of household preferences.

Model for estimating preferences Box 1

We estimate preferences via a histogram-based gradient boosted tree model. This model is an ensemble of decision trees used for classification. The algorithm trains decision trees sequentially, where each tree added to the model attempts to correct prediction errors from the previous tree in the model. The model uses the segment purchased as target feature and combines non-linearly the following features to optimise predictions in a validation set.

- Education (7 binary indicators of the household's highest level of education)
- Job description at t-1 (10 binary indicators of the employee's job specialisation)
- Workplace coordinates at t-1
- Municipality coordinates at t-1
- Family characteristics (size, children, age)
- Financial information (income, wealth) at t-1
- Segment of previous housing unit

To reduce the dimensionality of the feature space, we use the approach proposed by Johannemann et al (2019)[15] to sufficiently represent segments of previous housing units. The resulting feature space has 104 dimensions.

The coordinates for workplace and municipality are each represented by three features: the longitude and latitude coordinates (EPSG:25832) and combined coordinates $\left(\frac{longitude}{700{,}000} \cdot \frac{latitude}{6{,}100{,}000}\right)$.

Chart 4 illustrates the output of the model by showing the flows from the previous segment to the predicted segment for two types of households. For simplicity, we only consider the housing type and disregard geographic segmentation. The left-hand graph shows the flows for a young single-person household. Only a few observations have a valid previous segment value, i.e. they were not owning a housing unit before buying. The model predicts that the majority of the young households prefer either small single-family homes or smaller apartments. For the family household in the right-hand graph, the model predicts that the majority of the households prefer either small or large single-family homes. The two examples confirm the intuition embedded in the model; housing preferences depend on family characteristics.

Conditional preferences: computation of households' budget constraint

The model-predicted preferences are conditional on the current prices and regulations, i.e. household's initial budget constraints. Based on these budget constraints, household affordability is then the number of affordable houses in each segment relative to all affordable housing units across segments. In order to determine the effect of regulation on housing demand, we determine the new budget constraints and the implication on household affordability. We then combine the raw preferences with the change in household affordability to obtain preferences conditional under the new budget constraints.

To determine affordability, we first compute the households' budget constraint by backwards induction from the equations for the LTV and DTI ratios, respectively. For instance, the budget constraint from LTV regulation is found by combining household net wealth with the LTV limit and solving for the property value.[16] Furthermore, we require

[15] Johannemann, J., Hadad, V., Athey, S., and Wager, S. (2019). *Sufficient representations for categorical variables.* Retrieved from https://arxiv.org/abs/1908.09874.

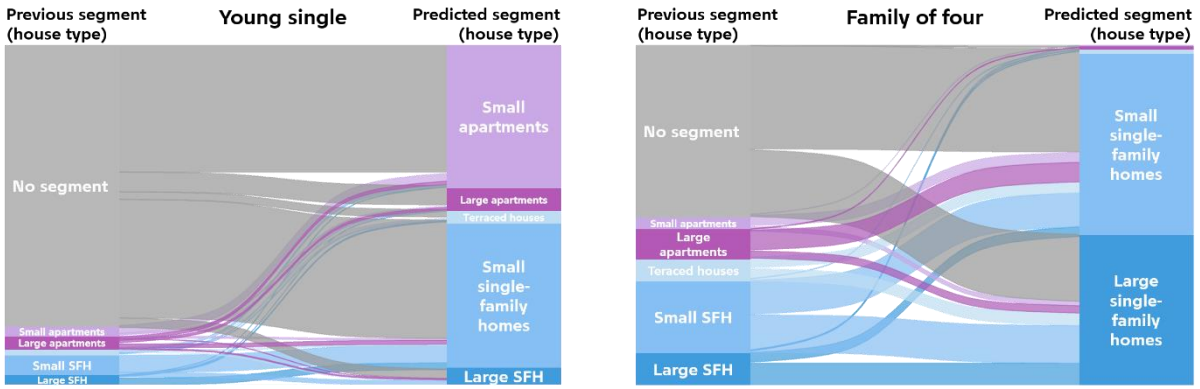
[16] The sample includes households with an LTV above 95 per cent of the house price, violating the existing constraints. We allow these buyers to have a *negotiation space* corresponding to how much they exceed the existing constraints. For example, if a household has bought a house with an LTV of 97 per cent, we compute the household's budget constraint based on an LTV limit on 92 per cent, such that $LTV\ limit_i = 90 + \max(0, LTV_i - 90)$. However, we require at least a 5 per cent down payment, such that the household's individual LTV limit, $LTV\ limit_i$, does not exceed 95 per cent.

that the household is able to service the loan associated with the budget LTV-based limit.[17] Hence, we ensure the maximum house price is consistent with both regulation and the household being able to service the debt.[18]

toward less densely populated areas. However, we find that substitution effects of DTI restrictions push demand out of the cities and towards smaller housing units within the city, counteracting the direct negative impact on small apartments.

Two examples of the prediction model

Chart 4



Note: The charts show flow charts from households' previous segment (LHS) and predicted segment (RHS). The chart to the left represents the estimated predicted flows across segments of households with a young single person under 35 years and without children. The chart to the right represents the estimated predicted flows across segments of a family of four, two adults between 35 and 45 years and two children. Flows originating from *no segment* correspond to first-time buyers. Both previous and predicted segment shows only the housing type of the segment. The predicted segment is the most likely segment based on the raw preferences.
Source: Own calculations based on data from Statistics Denmark.

We use the budget constraint for each household to compute the change in the magnitude of affordable housing units within each segment under tighter lending regulations. Then we combine the raw preferences with the change in affordability by multiplying the two and rescaling such that the conditional preferences sums to one for each household. For a technical description see box 2.

Substitution effects

This section shows that lending regulations in general push demand away from the cities and

Household preferences

We focus on households restricted due to mortgage regulations, and we estimate what these households would likely have bought under the additional constraints. While we allow for households to change their housing choice, not all buyers facing new binding restrictions will still decide to purchase a housing unit, with some potential buyers retreating from the market. We therefore presuppose that 20 per cent of the restricted households do not buy as a result of restrictions, corresponding to a reduction of overall demand of approximately 3 per cent.[19] Furthermore, we assume that mortgage regulation impacts demand simultaneously across all segments,

[17] Households are required to be able to service debt, meaning that the costs of the loan do not exceed 40 per cent of the disposal income. Costs are calculated based on a 30-year fixed-rate mortgage loan with amortisation (rates are set to 2.05 per cent plus an administration fee of 0.75 per cent) and a 20-year bank loan (rate is set to 5 per cent). Rates are based on the 2018 level.

[18] The calculation of the price limit is in practice separated into two steps as the price limit under regulation enters into the calculation of the maximum loan value. This is to account for a mortgage loan that covers a maximum of 80 per cent of the house price, and the remaining part must be financed with bank loans, which typically have higher costs leading to higher payments and thereby lowering the maximum loan value.

[19] While this threshold is arbitrary, the resulting magnitude of demand reduction is consistent with the literature. For example, Fuster, Andreas and Basit Zafar (2021), The Sensitivity of Housing Demand to Financing Conditions: Evidence from a Survey, American Economic Journal: Economic Policy, vol 13(1) show that a change in down payment

implicitly assuming that liquidity is comparable across all segments of the housing market.

Preference estimation Box 2

We define households' characteristics as set of vectors $\boldsymbol{X} = \{x_1, \ldots, x_n\}$ where each $x_i \in \mathbb{R}^m$ represents the raw preferences of household i (conditional on current prices and regulation) and m is the number of transformed input variables[20]. The model outputs probabilities for buying a residential in segment s_j given the characteristics of the household, $p(s_j|x_i)$ for $j \in \{1, \ldots, 91\}$.

The raw preferences and change in affordability are multiplied and rescaled, such that the household's preferences under regulation sum to one across segments, i.e. $\sum_j \overline{p(s_j|x_i)} = 1$. In the computation of the conditional preferences we weight the raw preferences and affordability equally. Hence, the conditional preferences are given by the formula:

$$\overline{p(s_j|x_i)} = \frac{p(s_j|x_i) \cdot \Delta affordability_{i,j}}{\sum_j p(s_j|x_i) \cdot \Delta affordability_{i,j}}$$

We use the change in the households' affordability to account for households having preferences for expensive segments relative to their respective budget constraints as we estimate demand. Thus, the model downscales preferences for segments that are less accessible due to regulation. Changes in demand for each segment are computed as the difference between the number of housing units actually bought and the sum of the conditional preferences across households.

LTV regulation pushes demand from the cities towards small single-family homes in less populated areas

Table 1 shows that while tighter LTV-based regulation leads to a decrease in net demand for large single-family homes in the largest cities and medium-sized municipalities, it pushes demand toward smaller housing units in small municipalities. However, the results show that the most affected segments only accounts for a small portion of the 2017-2018 housing sales.

LTV regulation pushes demand from the cities toward the countryside Table 1

Segment	Change in net demand	Share of sales
Central Jutland, small municipality (densely populated), small apartment	59%	0.1%
Central Jutland, medium municipality (sparsely populated), small SFH	36%	0.6%
Northern Jutland, large city, terraced house	26%	0.2%
Southern Denmark, small municipality (densely populated), small apartment	25%	0.1%
Southern Denmark, medium municipality (sparsely populated), small SFH	23%	0.2%
…		
Northern Jutland, large city, large SFH	-11%	1.0%
Southern Denmark, large city, large SFH	-12%	0.8%
Zealand, large city, large apartment	-12%	0.2%
Zealand, large city, large SFH	-13%	0.4%
The Capital Region, medium municipality (densely populated), terraced house	-13%	0.3%

Note: Top five and bottom five changes in estimated demand due to tighter restrictions on LTV. Single-family homes are abbreviated SFH. Small and medium-sized municipalities are based on Statistics Denmark's nomenclature and include rural and commuter municipalities and provincial municipalities, respectively
Source: Own calculations based on data from Statistics Denmark.

requirements from 20 per cent to 5 per cent would increase willingness to pay by 15 per cent in household surveys. Our calibration would lead to a change in down payment requirements from 5 to 10 per cent and would reduce housing demand by 3 per cent. Varying the faction does not change the overall conclusions.

[20] As we are using both numerical and categorical data, we make use of a column transformer to pre-process and transform data. Information on the prior segment is included as fixed effects in the column transformation to hold the size of the transformed data to a minimum. Other categorical data are treated with a one-hot encoder. Numerical values are just passed on in the pre-processing as scaling does not affect the performance of the model.

Limits on DTI reduce demand for large apartments and large single-family homes in Copenhagen

We find that limits on the DTI ratio reduce net demand in the largest cities, see table 2. Specifically, demand for large single-family homes and large apartments in Copenhagen declines by 17 per cent. These two segments alone account for more than 9 per cent of 2017-2018 housing sales.

We decompose the effects in the Copenhagen area between direct and substitution effects. Direct effects are those resulting from our assumption of 20 per cent restricted households retreating from the housing market. Substitution effects result in households readjusting their choices according to the estimated preference once their options are restricted by stricter regulations.

Table 3 shows that while restrictions on DTI would reduce demand for large apartments and large single-family homes in Copenhagen by 17 per cent, direct effects only contribute to a reduction of 6 per cent. The remaining negative substitution effect indicates that restrictions strongly affect these segments' affordability, with households substituting them with cheaper options.

These options are small apartments in Copenhagen and large single-family homes in Copenhagen's suburban areas. For these segments, substitution effects are positive and counteract the negative direct effects of regulations such that total segment demand is unchanged, or even increases.

While regulation on DTI ratios can dampen total housing demand in the largest cities, substitution effects counteract these direct effects and can result in increasing demand for certain segments in the same area. Households' preferences for living in the Copenhagen area are strong enough for restrictive regulation to substitute demand within the region, and not just further away, with potentially ambiguous effects on house prices across segments in the capital region.

DTI restrictions pushes demand away from large apartments and large single-family homes in Copenhagen Table 2

Segment	Change in net demand	Share of sales
Zealand, small municipality (densely populated), small apartment	68%	0.2%
Central Jutland, small municipality (densely populated), small apartment	45%	0.1%
Zealand, small municipality (densely populated), large apartment	39%	0.3%
Zealand, large city, small apartment	27%	0.1%
Southern Denmark, small municipality (densely populated), small apartment	16%	0.1%
…		
Central Jutland, large city, large SFH	-13%	1.2%
Central Jutland, large city, terraced house	-14%	0.7%
Northern Jutland, large city, large apartment	-16%	0.7%
The Capital Region, large city, large apartment	-17%	6.2%
The Capital Region, large city, large SFH	-17%	3.0%

Note: Top five and bottom five changes in estimated demand due to restrictions on DTI. Single-family homes are abbreviated SFH. Small and medium municipalities are based on Statistics Denmark's nomenclature and include rural and commuter municipalities and provincial municipalities, respectively.
Source: Own calculations based on data from Statistics Denmark.

Conclusions

This memo estimates both the direct impact and the substitution effects of borrower-based regulation across residential housing market segments. We find that different types of regulation, when calibrated to affect the same number of households, impact housing buyers differently, both in terms of which parts of the population are affected and how regulation influences demand.

Substitution effects counteract direct effects in suburban areas and small urban apartments in the Capital Region

Table 3

Segment	Share of sales in the Capital Region	Direct effect	Direct + substitution effects
The Capital Region, large city, small SFH	22%	-5%	-9%
The Capital Region, large city, large apartment	21%	-6%	-17%
The Capital Region, large city, small apartment	17%	-7%	0%
The Capital Region, large city, large SFH	10%	-6%	-17%
The Capital Region, large city, terraced house	10%	-5%	-11%
The Capital Region, small municipality (densely populated), large SFH	2%	-6%	0%
The Capital Region, medium municipality (densely populated), large SFH	1%	0%	6%
The Capital Region, small municipality (sparsely populated), large SFH	1%	-6%	2%

Note: Changes in estimated demand and direct effects due to limits on DTI for selected segments in the Capital Region (Region Hovedstaden). The right most column is the share of sales across the segments. Single-family homes are abbreviated SFH.
Source: Own calculations based on data from Statistics Denmark.

We find that younger buyers are overall more affected by regulations. While LTV restrictions impact less wealthy households, limits on the DTI ratio impact housing buyers in the large cities but equally across wealth deciles. Moreover, we find that both boundaries on the DTI and DSTI ratios affect older buyers.

We introduce a model to predict preferences based on housing choices and household characteristics and combine predictions with household budget constraints to determine changes in demand. We find that tightening LTV requirements push demand away from large single-family homes in the larger cities and medium-sized municipalities and towards small single-family homes and apartments in less populated areas. Limits on the DTI ratio pushes demand away from the largest cities, especially large apartments and large single-family homes in Copenhagen. However, household preferences for living in Copenhagen are so strong that substitution effects tend to shift demand toward other segments in the cities, with ambiguous effects across housing segments within the same metropolitan area.

This memo addresses the first-order effects on housing demand from a selection of borrower-based measures. We leave the investigation of the implications for financial and macro-economic stability of these borrower-based measures for other publications.

MICRO DATA SCIENCE

Data in new ways

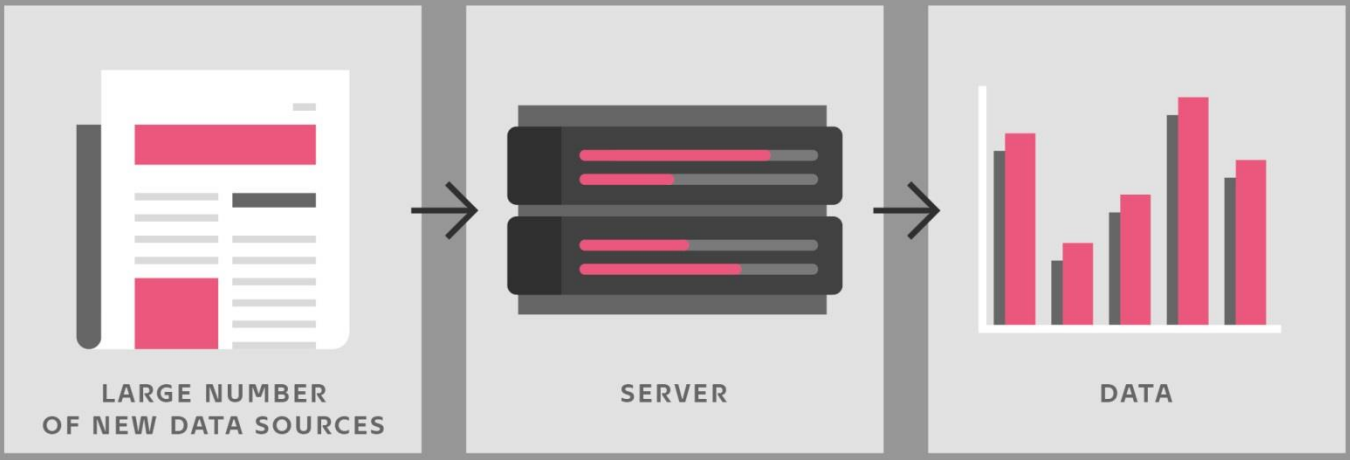
Data volumes have grown exponentially. By 2025, an estimated 450 exabytes of data will be created each day.

This is equivalent to hundreds of millions of personal computers being filled with data on a daily basis. The vast volumes of data are highly diverse, but new and sophisticated methods enable analysis of this data in new and more efficient ways.

New data types and new data collection methods may be used in various contexts in Danmarks Nationalbank's ongoing work.

In order to acquire more knowledge and a better basis for assessing the Danish economy, Danmarks Nationalbank focuses on new data types and methods in a series of publications of which this Economic Memo is one.

New data creates new knowledge



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