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How responsive are housing markets in the OECD? Regional level estimates

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ABSTRACT/RÉSUME

How responsive are housing markets in the OECD? Regional level estimates

Making housing more affordable ranks high on the policy agenda across the world. One way to achieve affordable housing is to ensure sufficiently elastic supply of the housing stock in response to demand shocks. This paper aims at disentangling policy from non-policy drivers in explaining cross-regional differences in housing supply elasticities. It uses GIS data to account for the presence of natural and man-made obstacles to residential construction in functional urban areas across the 12 OECD countries that provide sufficiently long time series for regional house prices. The results suggest that the presence of water, steep land, parks and high-density urban areas all restrict the supply of housing. However, there remain very large differences in supply elasticities across countries, which corroborates the finding from national analysis that policies have a strong influence.

JEL Classification codes: H7, R14, R31, R52

Keywords : Housing supply, rent regulation, land use policy

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Dans quelle mesure les marchés de l’immobilier sont-ils réactifs dans l'OCDE? Estimations au niveau régional

Rendre le logement plus abordable figure en bonne place dans les agendas politiques actuels à travers le monde. Une façon de parvenir à rendre le logement plus abordable consiste à assurer une offre suffisamment élastique du parc de logements en réponse aux chocs de la demande. Ce document a pour objectif de dissocier les facteurs politique des facteurs non-politiques pour expliquer les différences interrégionales de l'élasticité de l'offre de logements. Il utilise les données SIG pour tenir compte de la présence d'obstacles naturels et artificiels à la construction de logements résidentiels dans les zones urbaines fonctionnelles des 12 pays de l'OCDE, qui fournissent des séries chronologiques suffisamment longues pour les prix immobiliers régionaux. Les résultats suggèrent que la présence d'eau, de terrains escarpés, de parcs et de zones urbaines à forte densité restreignent tous l'offre de logements. Cependant, il subsiste de très grandes différences dans les élasticités de l'offre entre les pays, ce qui corrobore la conclusion de l'analyse nationale selon laquelle les politiques ont une forte influence.

Classification JEL : H7, R14, R31, R52

Mots-clés: Offre de logement, régulation du marché locatif, réglementation foncière

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HOW RESPONSIVE ARE HOUSING MARKETS IN THE OECD? REGIONAL LEVEL ESTIMATES

By Manuel Bétin and Volker Ziemann[1]

1. Introduction and main messages

1. The trend increase of house prices in many countries has undermined the affordability of housing. A sufficiently elastic supply ensures that the economy responds to housing needs in a timely manner without large price increases, thus underpinning housing affordability. Internationally comparable price elasticities of residential investment are typically estimated using national aggregates. A recent up-date of an earlier OECD study (Caldera Sánchez and Johansson, 2011[1]) confirms that supply elasticities vary considerably across countries and that these differences can be related to geographical constraints and policy choices in the areas of land use, rental market regulation and taxation (Cavalleri, Cournède and Özsöğüt, 2019[2]). The study also finds that larger tax breaks for housing exacerbate the sensitivity of prices to demand.

2. The present study investigates whether the results for the national level also hold at the regional level. Indeed, housing markets are local in nature and both the levels and dynamics of housing-related variables can vary substantially within countries. Amenities are also unevenly distributed, and so are geographic constraints. The latter are of particular interest as they determine the share of developable land. Moreover, constraints to residential construction, man-made or natural, only affect housing supply when they are binding. Scarcity of developable land is more likely to occur in urban areas, where the share of idle land is lower than in rural areas due to a higher share of built-up areas. Hence, this paper focusses on housing in functional urban areas (FUAs) defined by the OECD as densely inhabited cities and their surrounding commuting zones (OECD, 2012[3]).

3. Accounting for geographic and man-made non-regulatory constraints allows for disentangling policy from non-policy constraints on residential construction and helps establish causality between policy constraints and house prices (Saiz, 2010[4]). Identifying the role of national or sub-national policies in shaping local supply elasticities is crucial to understand how housing markets function. Housing, in turn, has important implications for other areas of policy-making such as employment, health, education and the environment. These linkages underscore the importance of assessing the efficiency of housing markets locally since measures of housing affordability, labour mobility,

1. This report contributes to the OECD Horizontal Housing Project. The authors are members of the OECD Economics Department. The Working Party No. 1 of the Economic Policy Committee discussed an earlier version of this paper. The authors thank members of the Working Party and in particular its Chair, Mr. Arent Skjæveland, for their feedback. The authors are indebted to Luiz de Mello, Alain de Serres, Åsa Johansson, Peter Hoeller and Boris Cournède (OECD Economics Department) for their guidance and Mikkel Hermansen, Aida Caldera Sanchez and Douglas Sutherland for inspiring comments. The authors also express their gratitude to Maria Chiara Cavalleri and Ezgi Özsöğüt for fruitful discussions and close collaboration and to Celia Rutkoski (OECD Economics Department) for editorial support. The authors can be reached at manuel.betin@oecd.org and volker.ziemann@oecd.org.

access to health care and education or environmental quality vary considerably within countries.

4. Several studies have performed similar analyses but mainly focusing on a single country or a single region such as Saiz (2010[4]) for the United States, Hilber and Vermeulen (2016[5]) for England, Öztürk et al. (2018[6]) for the Netherlands and Combes, Duranton and Gobillon (2019[7]) for France. The current study attempts to close this gap and estimates supply elasticities using a panel of regions spanning across a large set of countries to assess the role of national and regional policies as well as natural constraints in shaping local housing supply elasticities.

5. Using a cross-regional analysis covering 12 OECD countries, this paper finds that geographic constraints and policies shape the efficiency of housing markets. It uses GIS data for natural and man-made constraints to residential construction and confirms findings in the literature that the presence of water and steep land acts as a supply constraint and induces upward pressure on prices when demand increases. The presence of parks, natural reserves, cemeteries, green land as well as densely populated areas restrains new supply of housing in similar ways. Moreover, even after adjusting for geographical constraints, there remain very large differences in supply elasticities across countries, which corroborates the finding from national analysis that policies have a strong influence.

6. The evidence also provides indications that a higher degree of decentralisation of land-use policies is associated with lower supply consistent with the home-voter hypothesis predicting that homeowners turn to local politicians in order to protect the value of their housing investment by restricting undesired development of land (Gyourko and Molloy, 2015[8]). Finally, the resulting regional supply elasticities are, on average, in line with the results from the national level analysis (Cavalleri, Cournède and Özsöğüt, 2019[2]). The remainder of this paper is organised as follows. Section 2 sets out the methodology and introduces the data. Section 3 discusses the main results. Detailed statistics and further results are delegated to annexes.

2. Methodology and data

2.1. A model for regional housing supply under constraints

7. Following (Saiz, 2010[4]) and others, this paper builds on the urban land use model first developed by Alonso (1964[9]), Mills (1967[10]) and Muth (1969[11]). Under the assumptions of homogenous residents, perfect mobility, a unique centre (the central business district, CBD, where all firms are located) and proportionally increasing commuting costs, land prices decrease with the distance to the CBD (the so-called Alonso-Muth condition).

8. The size of a city depends on land availability and the number of households. Using the Alonso-Muth condition, one can show that average land prices in the monocentric city are a function of commuting costs t, the interest rate i, number of dwellings H and land availability Λ:

$$LP = \frac{1}{3i} t \sqrt{\frac{H}{\Lambda \pi}} \quad (1)$$

9. Developers sell homes at price HP, which is the sum of construction costs CC, including profits, and land prices LP, which allows expressing average house prices as a function of the number of households (Saiz, 2010[4]):

$$HP = CC + LP = CC + \frac{1}{3i} t \sqrt{\frac{H}{\Lambda \pi}} \quad (2)$$

10. A key obstacle to the analysis of local or regional housing markets is that data for the housing stock at the regional or local level are generally not available. The economic literature has followed several avenues to work around this issue. For instance, the number of permits or the number of new housing units have been used as proxies for residential investment. A major drawback arises from the fact that units do not account for quality and size, while hedonic price indices do, which results in measurement and endogeneity issues that are challenging to address econometrically.

11. Alternatively, a large body of the literature uses population as a proxy for the housing stock. At first sight, this may seem simplistic and potentially engender measurement errors. First, average household size is declining in most countries, which means that population and the number of dwellings are following different trends (United Nations, 2017[12]). Second, the characteristics of dwellings as well as of construction methods change over time, which could drive a wedge between population and the measured volume of construction.

12. These stylised facts actually play in favour of using population (*POP*) as a proxy for construction volumes as a covariate linked to real house price indices. Indeed, the latter is typically a hedonic index, which means that it accounts for both changes in the size and quality of dwellings. Total differentiating of (2) and using the corollary that the inverse supply elasticity of housing $\beta^s = \partial lnP / \partial lnPOP$ is decreasing in land availability, Saiz (2010[4]) shows that the supply equation can be rewritten in the following "inverse" form:

$$\Delta lnHP_i = c + \beta_C \Delta \ln CC_i + \beta_0 \, \Delta lnPOP_i + \beta_1 (1 - \Lambda_i) \Delta \ln POP_i + \varepsilon_i \quad (3)$$

where the term $(1 - \Lambda_i)$ denotes the share of unavailable land in the *i*-th region.

13. This "inverse" form of the supply equation contrasts with the specification of the supply equation in the country-level analysis, which explains how construction, on the left-hand side, responds to changes in real house prices (on the right-hand side) adjusting for other controls (Cavalleri, Cournède and Özsöğüt, 2019[2]). However, this direct form used in the national-level analysis cannot be implemented for lack of region-level data on residential construction, which is why this paper, as well as the earlier literature, use the approach encapsulated in Equation (3).

2.2. *Regional house prices*

14. The empirical assessment of housing markets at the local or regional level requires sub-national prices for residential properties. To this end, the OECD has started to collect regional house price indices from various national sources (mainly central banks and national statistical offices).[2] For European countries, the administrative level mostly corresponds to the NUTS2 level except for Belgium, France and the United Kingdom (NUTS1) as well as Estonia and Finland (NUTS3). For non-European countries other than the United States, available regional indices match the administrative level 1 obtained from GADM, a database of global administrative areas (cf. gadm.org). For the

2. This dataset provides the starting point for a broader line of work undertaken under the aegis of the horizontal housing project to produce, maintain and regularly update an OECD dataset of regional house prices.

United States, the Freddie Mac House price indices for metropolitan statistical areas (MSAs) are used. The collected house price indices mostly follow the OECD recommendation of computing hedonic price indices but methodologies differ across countries (Box 1).

Box 1. The OECD's regional house price database

To capture the relative dynamics of house prices in different parts of the territory, the statistical information should be disaggregated into the most detailed regions and, within them, should differentiate between urban and rural areas. However, the limited number of transactions taking place in some parts of the territory can represent an extra challenge. Consequently, available information is in some cases only available for the largest cities.

The international comparability of the data is of prime importance. For this reason, official sources are preferred as they generally follow international standards. As a result, in the study data are sourced from National Statistical Offices (58% of the cases), Central Banks (19.4%), or other departments of the public administration (19%) such as, for instance, land registers. Only in the case of New Zealand, data are privately sourced, though the central bank supervises the collection. The regional house price dataset includes information for 29 OECD countries plus Croatia, Colombia and India. Most countries are European (22 out of 32), with the remaining almost equally distributed between the Americas (5 out of 32) and Asia/Oceania (5 out of 32).

Geographic coverage of the domestic territory may vary significantly across countries. Although the vast majority of countries (71%) collects information on transactions taking place across the entire domestic territory, a substantial number of countries (29%) only covers selected portions of it. The partial coverage is often explained by the small number of transactions taking place in remote areas. For the same reason, in many instances, sub-national data are available exclusively for major cities and in a few the coverage is restricted to the capital city alone. Table 1 shows the time coverage.

Table 1. Starting year of coverage of the regional house price database

Before 1990 (N=7)	CHE,IRL,USA,CAN,AUT,SWE,FIN
Before 2004 (N=14)	BEL,DNK,NZL,GRC,FRA,GBR,NLD,EST,COL,PRT,CHL,AUS, KOR, ISL
After 2003 (N=11)	MEX,CZE,LTU,POL,ESP,SVN,JPN,ISR,NOR,HRV,IND

Prices should refer to properties that are comparable in quality over time. It is therefore vital that countries adhere to the four methods identified by the international standards (OECD, 2013[13]) such as stratification, repeat sales, hedonic regression and the use of property assessment information or a combination thereof. A large group of countries (around 40%) relies on hedonic quality adjustment methods. In some cases, the hedonic method is coupled with stratification while in a few others with double imputation. The second most used adjustment method (11%) is the sales price appraisal ratio followed by stratification (11%) and repeated sales (8%). Three countries employ the index appraisal-based method, while Canada is the sole country currently using the so-called "matched-model index", which only compares newly built properties with similar characteristics.

15. Figure 1 illustrates the distribution of real house price changes between 2003 and 2017 across regions for the countries considered in this study. The coverage is smaller than the 32 countries for which nominal regional house prices are available (Box 1) because, for some countries house price deflators, construction costs (see below) or exogenous drivers of house prices (see below) are not available.

Figure 1. Regional dispersion of changes in house prices between 2003 and 2017

Note: Countries covered in this study are shown. Coverage results from overall data availability, including geographic data. The lines represent the range of observations, boxes are drawn for central mass of observation between the 25th and the 75th percentile, while dots indicate outliers defined as observations with a distance of more than 1.5 times the interquartile range (75th minus the 25th percentile, that is, the length of the box).
Source: OECD Regional House Price Database.

2.3. Addressing endogeneity between house prices and construction

16. The relationship between house prices and residential construction raises endogeneity concerns. While construction responds to price signals, sharp swings in construction can also affect prices through their effect on the stock of housing. Estimating supply elasticities, or inverse supply elasticities from (3) using standard OLS techniques, could, therefore, result in biased elasticities. A standard technique to deal with this risk is to use instrumental variables. The questions regarding possible endogeneity in the regional regressions and the ways to address them differ from those applicable to country-level regressions for at least two reasons. First, the specification of the region-level analysis differs from the country-level one in terms of both the form of the equation (direct or inverse) and the variable explained (construction in country equations versus population in regional equations for lack of regional construction data). Second, house price differentials influence geographic differences in population growth across regions but hardly so across countries.

17. A large body of the literature has built on Bartik (1991[14]) and used exogenous shifts in the composition of employment as instruments for residential construction (proxied by population, see above) in the supply equation (Saks, 2008[15]; Saiz, 2010[4]). The idea is that exogenous shocks to labour demand are correlated with the demand for housing but uncorrelated with supply shocks that affect house prices and residential construction simultaneously. The measure is built by interacting initial local industry shares with national growth rates for these industries.

18. In addition to Bartik's (1991[14]) instrument, a second instrument builds on Monnet et al. (2016[16]), who find that growth rates of the 20-49 age cohorts are correlated with residential investment corroborating the idea that first-time buyers fall into this age group. Since current growth rates of regional population cohorts are likely to be endogenous to residential construction, the authors suggest using the growth rate of the young age cohort 20 years before the estimation window. While the correlation with current residential construction in the region remains high, the endogeneity concern is alleviated, which makes it a potentially interesting instrument.[3]

19. Accordingly, this study uses the Bartik and fertility measures as instruments for the change in the local population to capture the demand component in residential construction. The OECD's Regional Demography dataset provides employment data by industry and region going back to the early 1990s for most countries as well as panels for regional age cohorts over time. Since the window over which changes in house prices and residential population are observed spans from 2003 to 2017, it is reasonable to define the fertility measure as the 5-year growth of the 0-14 age cohort as of 1995. The Bartik measure is the inner-product of local industry shares of employment (z_{ik}) (with i the location and k the industry) in 2004 and the national growth rate of employment (g_k) of the respective industries between 2004 and 2014:

$$B_i = \sum_k z_{ik} g_k$$

2.4. *Construction costs*

20. Labour and material costs, which account for much of construction costs, vary across countries and regions depending in particular on natural obstacles, remoteness, different levels of unionisation of building workers or the degree of competition among construction firms. Real house prices are not tightly co-moving with real construction costs: the latter are relatively flat while the former exhibit more volatility and stronger growth (Gyourko and Molloy, 2015[8]). Nevertheless, the large degree of heterogeneity in construction costs as a share of sale prices across cities and countries could alter the relationship between house price dynamics and residential construction. In the absence of harmonised construction costs at the regional or municipal level, this study uses the national deflator of residential investment from the OECD National Account database.

3. Further instruments to capture the demand component in the change of population or residential construction have been tested including migration or hours of sun (Saiz, 2010[4]). The former cannot totally exclude the risk of reverse causality. For instance, independent supply shocks, such as the arrival of a big company in town, could increase both prices and construction while triggering an inflow of workers. Migration would be an invalid instrument in this case. Saiz (2010[4]) uses hours of sun as a proxy for the value of amenities which is found to capture some of the heterogeneity of housing demand across metropolitan areas in the United States. It remains to be tested, however, whether such an instrument also works within other countries.

2.5. Unavailable land

2.5.1. Natural constraints

21. The presence of geographic obstacles to construction is quantified by matching digital maps of OECD-defined functional urban areas (FUAs) with digital raster maps, which contain information on the steepness of the land, the presence of sea or inland water and the existence of non-constructible land due to the presence of parks, natural reserves, historical buildings or touristic areas. Table A.1 reports the number of FUAs by country as well as summary statistics for their size, share of built-areas and population in 2015 obtained from the Global Human Settlement Layer (GHSL) datasets. NASA data sourced through the CGIAR Consortium for Spatial Information (CGIAR-CSI) provide digital raster maps for elevation and the presence of inland water. The open data platform "Natural Earth" (https://www.naturalearthdata.com/) provides raster maps for the presence of oceans.

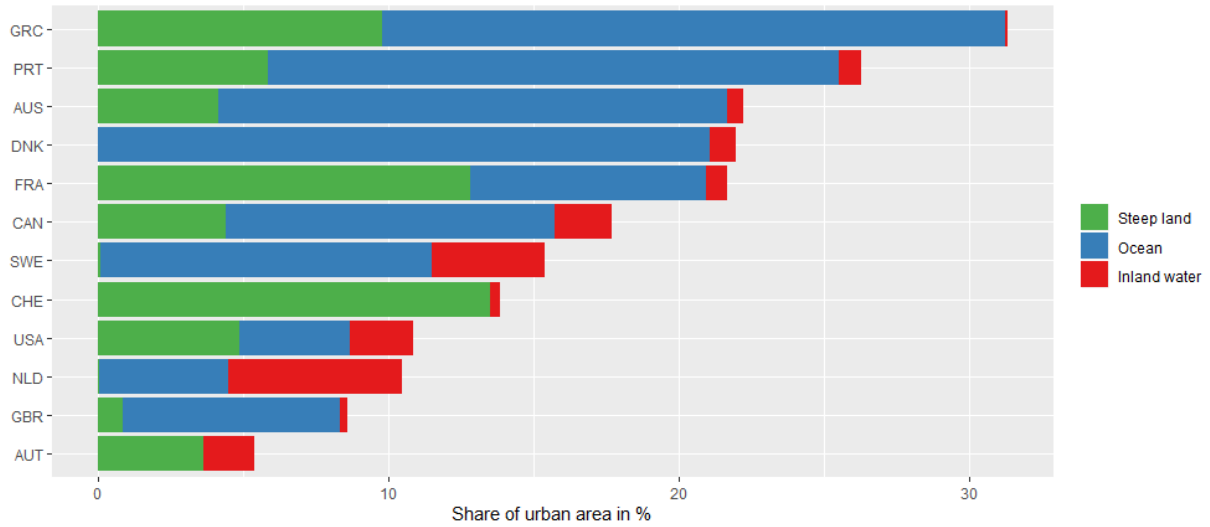
22. The FUA boundaries are themselves endogenous to the presence of natural obstacles. Hence, the measurement of natural constraints needs to include the land that lies immediately outside this boundary because the geographic circumstances of the land may be the very reason why it is not populated. Accordingly, an arbitrary buffer of 0.1 arc degrees (roughly 11km) is added to the FUA area. Slopes are computed for each 250m x 250m cell, following Saiz (2010[4]). Cells with slopes more than 15° steep are deemed undevelopable. Inland water and the presence of oceans are additional constraints to the extension of the urban area. Figure A.1 illustrates the idea of the buffer with the example of Nice (France). Nice has a border with the Mediterranean and also straddles the Alps, which both restrict the extension of its urban area. As a result, Nice exhibits a high share of ocean (23%) and a high share of steep land (57%) in its extended urban area. Close to 80% of the area is undevelopable.[4]

23. The study focusses on FUAs rather than entire regions, for which house prices have been collected because such geographic constraints on residential construction are only binding in urban areas. Moreover, regional house prices are usually transaction-weighted indices and therefore mostly determined by house prices in urban cores and the surrounding commuting area. If one region contains more than one FUA, the share of steep land, as well as the presence of water, are averaged across these FUAs weighted by the FUAs' population. Figure 2 displays country averages. Housing supply in urban areas and the surrounding commuting zone is most constrained in Portugal, Greece and Australia. Cities in Spain and Switzerland face more than 10% of steep land within the boundaries of the functional urban areas, which can make construction impossible or costly in these parts. The lowest geographic constraints are observed in the United Kingdom, the Netherlands and Austria. In Austria, this finding is mainly driven by the fact that Vienna is the only urban area retained in the analysis, as house price data are unavailable for other urban areas in Austria.

4. Steep land and, to a lesser extent, the presence of water do not entirely exclude the construction of residential buildings. Nonetheless, both constraints act in a similar way as non-developable land as they make projects very costly, which reduces the supply elasticity.

Figure 2. Natural constraints to residential construction in urban areas

Average region for each country



Note: Steep land is defined as grids with slopes above 15°. Ocean is the sea area comprised within a 0.1 arc degree (~11km) buffer around the functional urban area. Inland-water covers rivers and lakes. Table A.2 shows the detail for the 50 most populated regions in the dataset.
Source: OECD; CGIAR Consortium for Spatial Information (CGIAR-CSI).

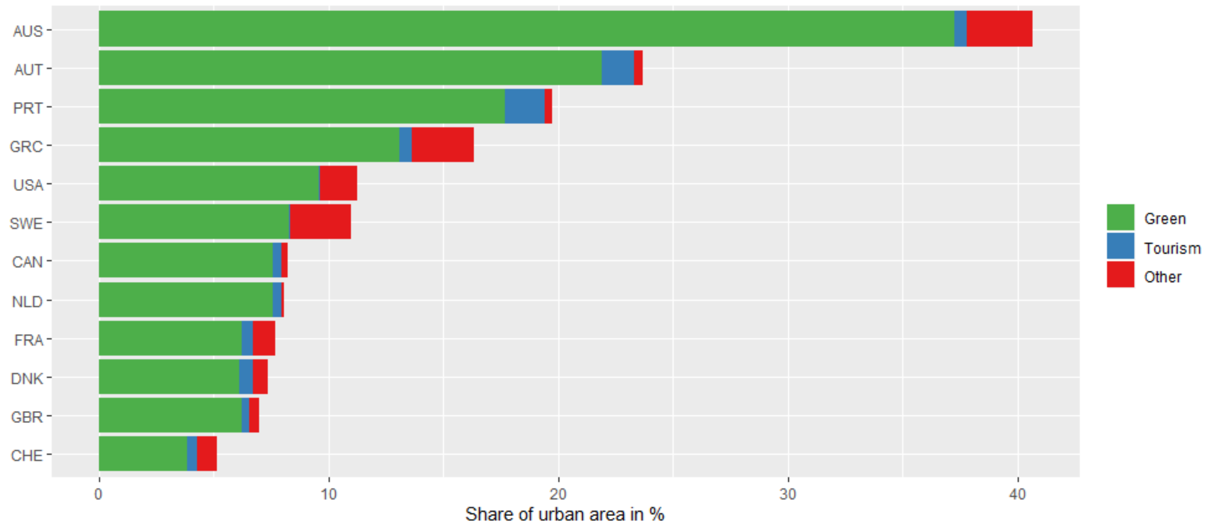
2.5.2. Man-made obstacles

24. In addition to natural obstacles, there are also man-made obstacles to residential construction resulting from urban development plans. Certain zones are designated for non-housing infrastructure to meet the people's cultural and recreational aspirations, or to pursue other government objectives. These zones are therefore unavailable for residential construction and restrict the supply of residential construction.

25. The open-source project OpenStreetMap (OSM) allows to compute the shares of urban areas that are occupied by parks, natural reserves, military facilities, historical buildings and touristic zones. Figure 3 shows the average shares of man-made obstacles in urban areas across countries. Parks, natural reserves, zoos and cemeteries account for the largest share of man-made obstacles.

Figure 3. Man-made obstacles to residential construction in urban areas

Average region for each country



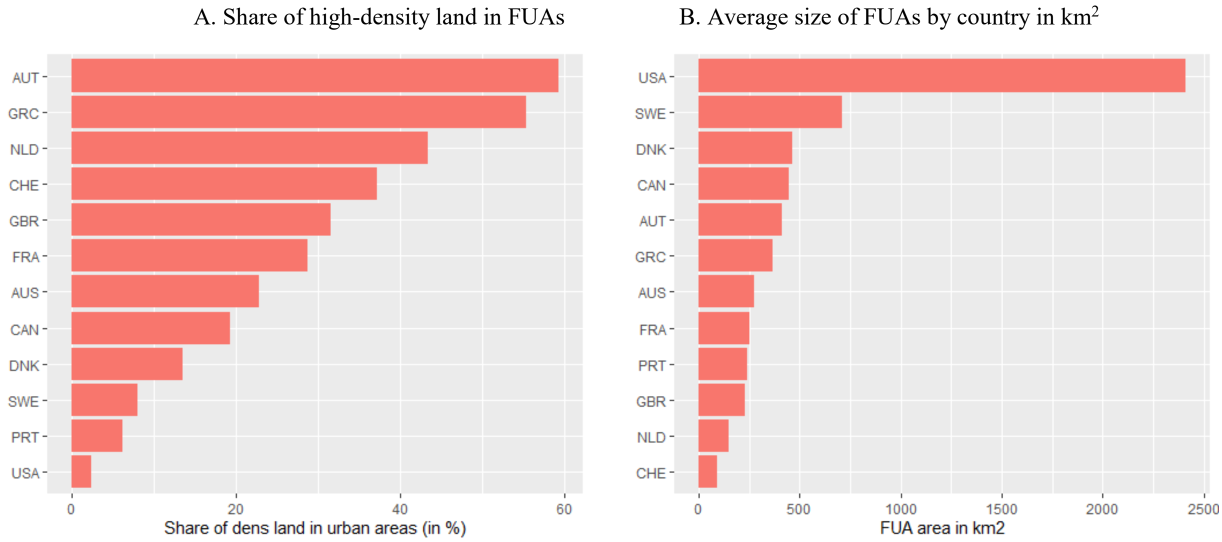
Note: "Green" refers to parks, natural reserves, zoos and cemeteries. "Tourism" denotes museums, touristic attractions (including a buffer of 100m) and viewpoints. "Other" comprises stadiums and military zones unavailable for residential construction.
Source: OpenStreetMap (OSM).

2.5.3. High-density areas

26. Urban cores with high population density often lack available land and restrict building height. In this study, areas with more than 3 500 inhabitants per km^2 are considered undevelopable for new construction. Similar to natural constraints, this also captures cases where construction in these areas actually may occur but is very costly. Figure A.2 shows the population density in Tokyo and its commuting area. Close to 50% of the functional urban area exhibits density levels above 3 500 persons per km^2.

27. Panel A in Figure 4 displays the average share of dense land across each countries' functional urban areas. FUAs are considerably less dense in the United States, including in its metropolitan cities than in other countries. This partly reflects the fact the FUAs tend to be much larger in the United States, suggesting that either urban sprawl is more prevalent or that people commute more, or both.

Figure 4. Share of dense land in urban areas and size of functional urban areas



Note: High-density land is defined as grids with population density above 3 500 persons per km^2. The average region for each country is shown. Table A.2 shows the share of high-density land for the 50 most populated regions in the dataset.
Source: OECD; Global Human Settlement Layer (GHSL).

3. Delineating the drivers of regional supply elasticities

3.1. Deriving and decomposing supply elasticities

28. The empirical strategy is to infer long-term supply elasticities from inverse supply elasticities obtained by regressing changes in real house prices (from 2003 to 2017) on long-run changes in residential construction proxied by local population POP_i. The latter is endogenous to house prices mainly, but not exclusively, due to simultaneity between prices and housing investment: independent supply shocks may affect both at the same time. To overcome this drawback, changes in local population are instrumented by using variables that are a priori independent from supply shocks but correlated with housing investment. Two instruments capturing the demand for housing are used: the Bartik measure (B), which predicts current demand for housing based on exogenous shifts in labour demand; and a fertility measure (F), which predicts changes in the 20-49 age cohort exerting demand pressure on the construction of new homes. Accordingly, the first stage regression takes local population as the dependent variable and the Bartik and fertility measures as exogenous predictors:

$$\Delta \ln POP_i = c + \beta_1 \mathrm{B_i} + \beta_2 F_i + \varepsilon_i \qquad (12)$$

29. The results show that both measures are significant in predicting changes in population across regions. Tests for weak instruments and OLS-consistency are both rejected confirming the usefulness of the instruments to deal with potential simultaneity between population (used here as a proxy for residential construction) and house prices. Predictions from the first stage regression ($\Delta\widehat{POP}_{i,t}$) are subsequently plugged into the reduced form equation. Several specifications are tested accounting for the presence of inland-water, adjoining oceans or lakes (W), the presence of land assumed to be undevelopable due to steep slopes (S), the share of high-density areas (D) and the share of green land (G) including parks, natural reserves and cemeteries within the functional urban areas i in country c:

$$\Delta lnRHP_i = c + \gamma lnCC_c + \beta \, \Delta ln\widehat{POP}_i$$
$$= c + \gamma lnCC_c + \left(\beta_0 + \beta_w W_i + \beta_s S_i + \beta_d D_i + \beta_g G_i\right)\Delta ln\widehat{POP}_i + \varepsilon_i \quad (13)$$

30. In their seminal work, Porta, Lopez-de-Silanes and Shleifer (2008[17]) find that the legal origin shapes countries' governmental regulation framework as well as judicial and financial institutions all of which are likely to affect, directly or indirectly, housing markets. Accordingly, all regressions include dummies for legal origins and an extra dummy for US regions to control for unobserved heterogeneity.[5] The interaction of obstacles with the change in population serves two purposes. First, it is consistent with the idea that constraints only affect prices in the presence of demand pressures; conversely, housing demand pressures affect prices more where there are greater obstacles to residential construction. Second, factorising the interaction terms yields a decomposition of the inverse supply elasticities, which introduces heterogeneity of elasticities across regions that depends on the natural characteristics and the density of their urban areas. Table 2 shows the results.

31. The first column shows the results for the standard reduced form equation with only population and construction costs as explanatory variables. The inverse supply elasticity is 0.68, which suggests a supply elasticity of around 1.5. This situates the numbers well in the 1-3 range typically found in the literature (Saiz, 2010[4]). The second column adds inland-water as a supply constraint interacted with the demand variable population. The elasticity can be decomposed into a part that is independent of inland water and a part that transmits through the presence of inland-water. Indeed, adding inland-water reduces the basic elasticity from 0.68 to 0.63. Put differently, more than 7% of the observed inverse supply elasticity is explained by inland-water.

32. Similarly, columns (3) to (7) add one by one respectively ocean, water (inland-water plus ocean), the share of steep land, the share of dense and green land to the standard form without constraints (column 1). All of the natural and man-made obstacles exert the expected supply-reducing (inverse supply augmenting) impact with steep land and green areas (parks, etc.) explaining the biggest share of the elasticity since the stand-along coefficient on population diminishes the most.

5. The additional dummy for US regions is motivated by the methodological differences between the US and non-US regions. In the latter, functional urban areas (population, geographical constraints) are matched to administrative regions (house prices) while in the former all data directly refer to US metropolitan statistical areas.

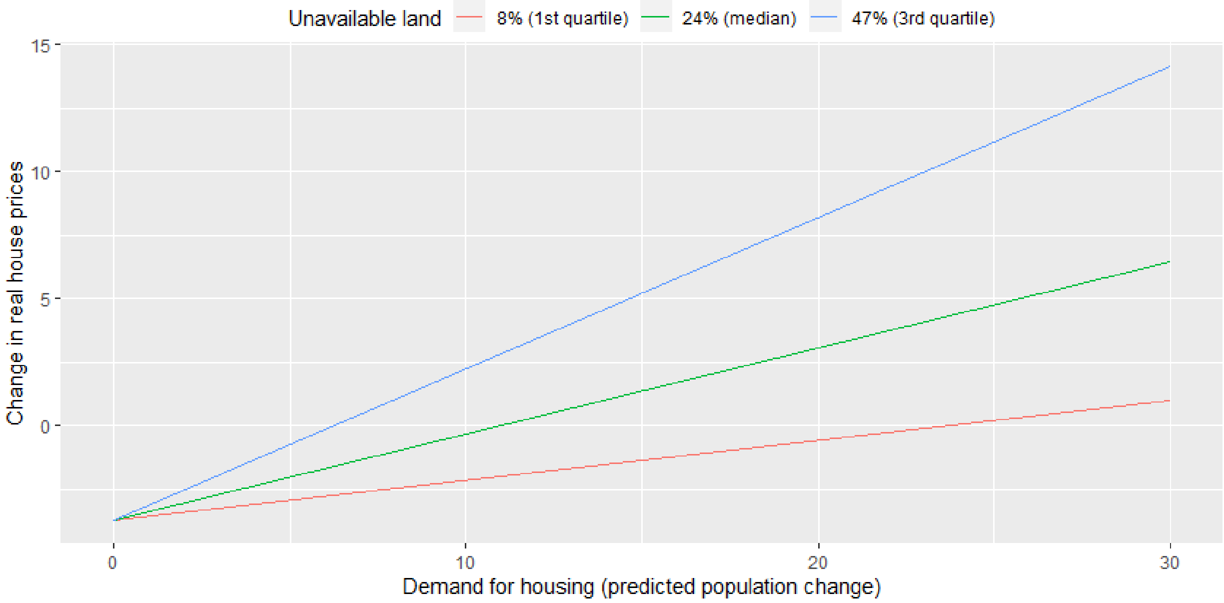
Table 2. Housing supply elasticities with endogenous population

Dependent variable: Change of real house price index between 2003 and 2017								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔPopulation	0.68***	0.63***	0.62***	0.61***	0.47**	0.57***	0.43**	0.12**
	(0.14)	(0.13)	(0.16)	(0.15)	(0.20)	(0.03)	(0.21)	(0.05)
ΔConstruction costs	1.49***	1.50***	1.48***	1.48***	1.48***	1.34***	1.48***	1.31***
	(0.32)	(0.33)	(0.31)	(0.32)	(0.30)	(0.06)	(0.29)	(0.04)
ΔPopulation x Inland-water		1.62***						
		(0.53)						
ΔPopulation x Ocean			0.62***					
			(0.17)					
ΔPopulation x Water				0.53***				0.56***
				(0.11)				(0.06)
ΔPopulation x Steep land					1.76***			1.92***
					(0.27)			(0.18)
ΔPopulation x Dense land						2.92***		3.04***
						(0.33)		(0.31)
ΔPopulation x Green land (parks etc.)							1.00***	0.57***
							(0.13)	(0.03)
Country group dummies:								
English legal origin	-23.20	-23.15	-22.58	-22.66	-21.27	-21.72	-20.79	-17.61
French legal origin	2.81	2.66	2.73	2.69	3.54	-2.33	3.51	-1.48
Other legal origin (Scandinavian, German)	12.98	13.14	13.34	13.34	14.33	5.60	15.64	8.65
Observations	242	242	242	242	242	242	242	242
Adjusted R^2	0.40	0.40	0.40	0.40	0.41	0.44	0.41	0.46
	*p<0.1; **p<0.05; ***p<0.01							

Note: The table shows estimated coefficients from 2SLS OLS regressions where population change is instrumented by the Bartik measure and the growth rate of population aged 0-14 between 1991 and 1995.

33. Our favourite specification is in column (8), combining all significant supply constraints discussed above. Introduced jointly, all constraints remain highly significant and the coefficient on population declines sharply to 0.12. This means that the supply elasticity of a totally unconstrained city (no water, no steep land, low density, no parks) would be around 8, a high but not unreasonably high number given the low likelihood of encountering a totally unconstrained city. Using this last specification, Figure 5 illustrates the effect of land unavailability due to natural obstacles and high-density areas. Moving from the 1st quartile in the distribution of unavailable land (8%) to the 3rd quartile (46%) increases real house prices by more than 8 percentage points over the 14 years from 2003 to 2017 for a median change of 15% in urban population. Further, the figure illustrates that demand shocks (+20% rather than +10% over a given period), have a higher impact on real house prices in more constrained cities (+1.5% for the 1st quartile against +5.5% for the 3rd quartile).

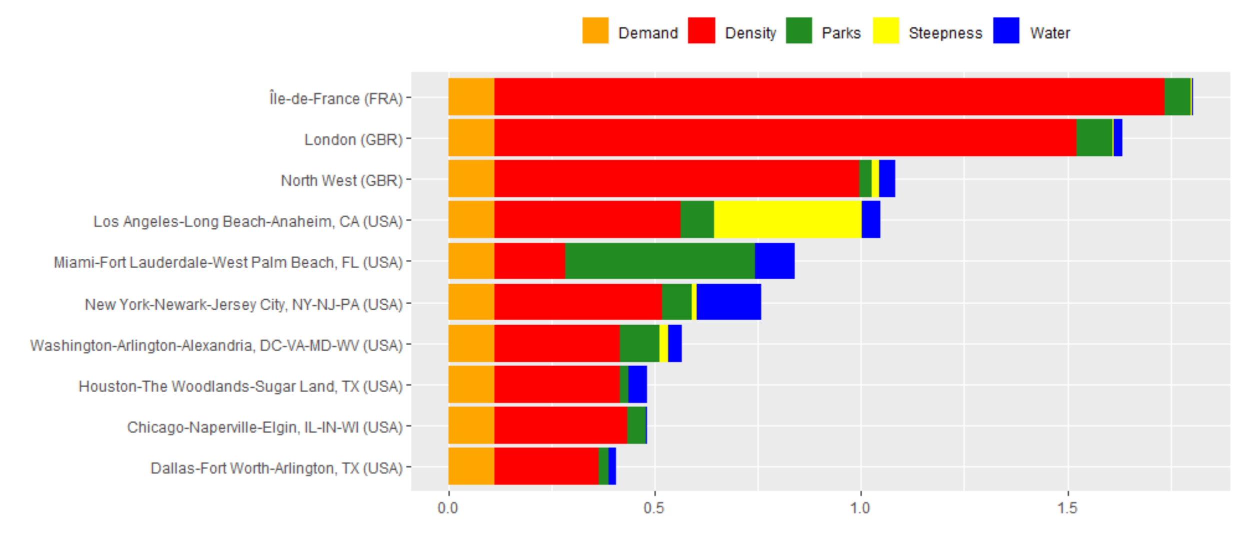
Figure 5. Marginal effect of land unavailability on housing market efficiency



Note: Slopes are obtained from an instrumental variable regression. The dependent variable is the change in real house prices between 2003 and 2017 and the independent variables are: change in population, change in construction costs and the interaction of changes in population and the unavailability of land defined as the sum of shares of water, steep and green land as well as high-density areas. Population is instrumented by the Bartik measure and the growth rate of the population aged 0-14 between 1991 and 1995.
Source: Own calculations.

34. Figure 6 displays the contribution of natural and man-made constraints to the inverse supply elasticities in the biggest 10 regions of the sample. The values imply supply elasticities below 1 for London, Paris and the North-West region in the United Kingdom, while American metropolitan areas yield supply elasticities greater than 1, ranging from 1.3 for New York to around 2.5 for Dallas. The bulk of the inverse supply elasticities in the most constrained mega-cities is related to the high share of already densely populated areas. Surrounding water, mainly due to the presence of oceans constrains available land in New York and Miami. Similar to dense areas this land is not necessarily unavailable as land reclamation projects in the Netherlands and Denmark have shown. However, building in these areas necessarily comes at a cost explaining the positive contribution of the presence of wetlands, lakes and oceans to inverse supply elasticities. Among the ten biggest cities, only Los Angeles faces significant supply constraints due to steep land and green plays a large role in Miami. Again, steepness does not make construction impossible, but it makes it more costly, which reduces supply elasticities.

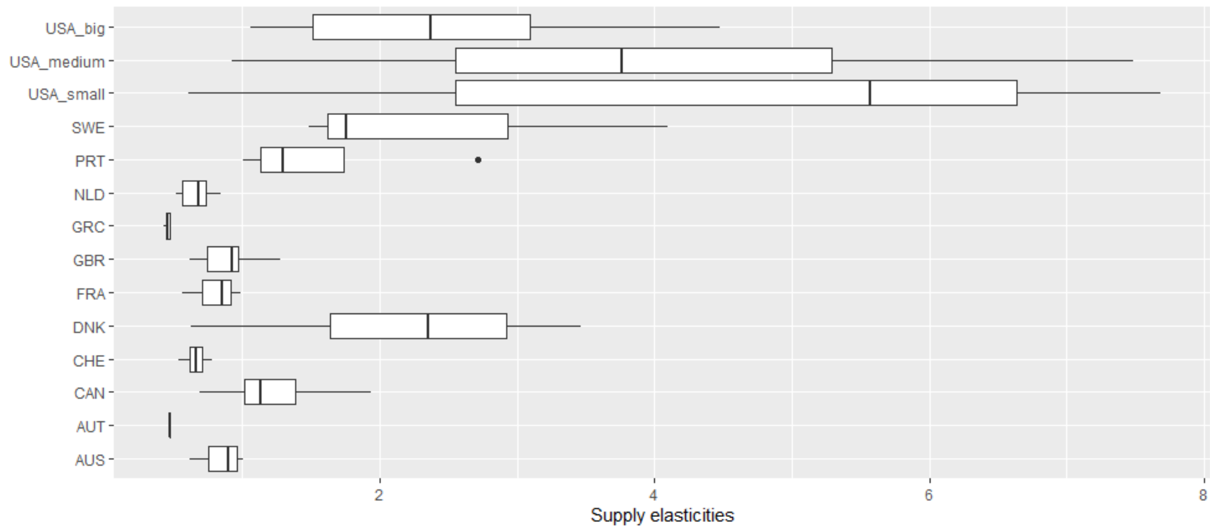
Figure 6. Decomposition of inverse supply elasticities in the 10 biggest regions



Note: The 10 biggest regions by total population are shown. Contributions are obtained from estimated coefficients from specification (8) in Table 2. Accordingly, "Density", "Steepness", "Water" and "Parks" refer to shares of density, steep and water areas and green land within the respective urban area, interacted with population.
Source: Own calculations.

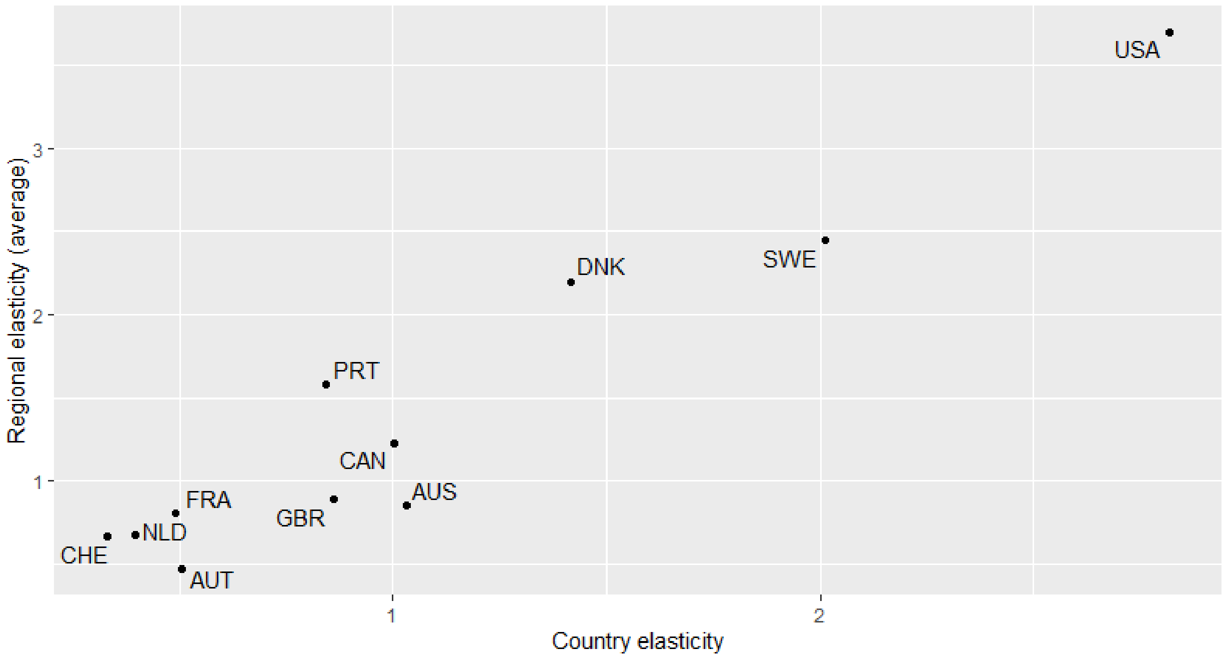
35. Figure 7 shows the ranges of the resulting supply elasticities by country. Housing supply is found most elastic in the United States, Denmark and Sweden with estimated elasticities mostly above 2 except for large and constrained cities like New York, Miami or Los Angeles. Canada and Portugal also mostly display supply elasticities above one while Australia, the United Kingdom and France typically range close to but below 1. The most inelastic supply is obtained for the Netherlands, Austria, Greece and Switzerland where elasticities mostly range between 0.5 and 0.7. Overall, these results are in line with the estimates of the country level analysis (Figure 8).

Figure 7. Ranges of housing supply elasticities by country



Note: Obtained from inverse supply elasticities using specification (8) in Table 2 as $e_i = \beta_0 + \beta_s S_i + \beta_w W_i + \beta_d D_i + \beta_g G_i$. The lines represent the range of observations, boxes are drawn for central mass of observation between the 25th and the 75th percentile, while dots indicate outliers defined as observations with a distance of more than 1.5 times the interquartile range (75th minus the 25th percentile, that is, the length of the box.

Figure 8. Comparing regional to national estimates of housing supply elasticities



Note: The distribution of regional estimates is shown in Figure 7, while country level estimates are from Cavalleri, Cournède and Özsöğüt (2019[2]).
Source: Own calculations.

3.2. The role of policies in determining regional housing supply

36. So far, the analysis abstracted from regulatory constraints that could affect the supply of housing. The analysis controls for constraints resulting from natural and man-made obstacles or saturation but not for policy-induced restrictions A large body of the literature has documented that regulatory constraints reduce residential construction and increase prices (Hilber and Vermeulen, 2016[5]; Glaeser and Gyourko, 2018[18]; Saiz, 2010[4]).

37. If regulatory restrictiveness (R) varies across countries and regions, the present model will give rise to unobserved heterogeneity in the residuals. Assuming that, similar to natural and density constraints, regulatory restrictiveness interacts with housing demand, this would create additional endogeneity and bias the estimation results as the residuals from (13) would be correlated with the independent variables:

$$\varepsilon_i = \mathrm{c} + \Delta POP_i * R_i + \eta_i \qquad (14)$$

38. To address this concern, the proxy for land-use restrictions and the rent control indicator used in the national analysis are added to the baseline regression (specification (8) in Table 2). A proxy for land-use restrictiveness is taken from Cavalleri, Cournède and Özsöğüt (2019[2]) and is based on the assumption that more decentralised governance of land-use policies is associated with more restrictive land use regulations. The rent control index is from the Rental Market Index (ReMaIn) database compiling and quantifying rental legislations in 64 countries over time (Kholodilin, 2018[19]). Similar to natural and density constraints, and consistent with the specification in the national analysis, the policy variables are interacted with the change in housing supply, again approximated by the change in population. Table 3 shows the results.

Table 3. The role of policies in determining regional supply elasticities

Dependent variable: Change of real house price index between 2003 and 2017

	(1)	(2)	(3)
ΔPopulation	0.11**	0.10	0.32***
	(0.06)	(0.09)	(0.07)
ΔConstruction costs	1.31***	1.30***	1.35***
	(0.04)	(0.19)	(0.16)
Rent control		27.79	
		(26.74)	
Land-use restrictiveness proxy			0.37
			(4.08)
ΔPopulation x Water	0.46***	0.50***	0.45***
	(0.07)	(0.12)	(0.01)
ΔPopulation x Steep land	1.80***	1.81***	1.97***
	(0.16)	(0.19)	(0.20)
ΔPopulation x Dense land	3.08***	3.11***	2.93***
	(0.33)	(0.37)	(0.38)
ΔPopulation x Green land (parks etc.)	0.71***	0.66***	0.28***
	(0.03)	(0.11)	(0.07)
ΔPopulation x Rent control		-2.77	
		(4.50)	
ΔPopulation x Land-use restrictiveness proxy			1.30**
			(0.62)
Observations	242	237	242
Adjusted R^2	0.46	0.46	0.48

*p<0.1; **p<0.05; ***p<0.01

Note: The table shows estimated coefficients from 2SLS OLS regressions where population change is instrumented by the Bartik measure and the growth rate of population aged 0-14 between 1991 and 1995. All policy variables refer to values in 2015.

39. The regional analysis, with a different sample and methodology, corroborates the finding from the national analysis (Cavalleri, Cournède and Özsöğüt, 2019[2]) that land-use restrictions significantly reduce housing supply and thereby push up prices in the face of demand shocks as shown in the present setup. The coefficient on rent control is statistically insignificant. The reason is that the region-level cross-section regression reported in column 3 of Table 3 uses policy variables as of 2015, which, by contrast with the national-level analysis, do not include the period of rental market deregulation in the 1980s, when there was a much greater variation in policy settings.

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Annex A. Additional information on the regional analysis

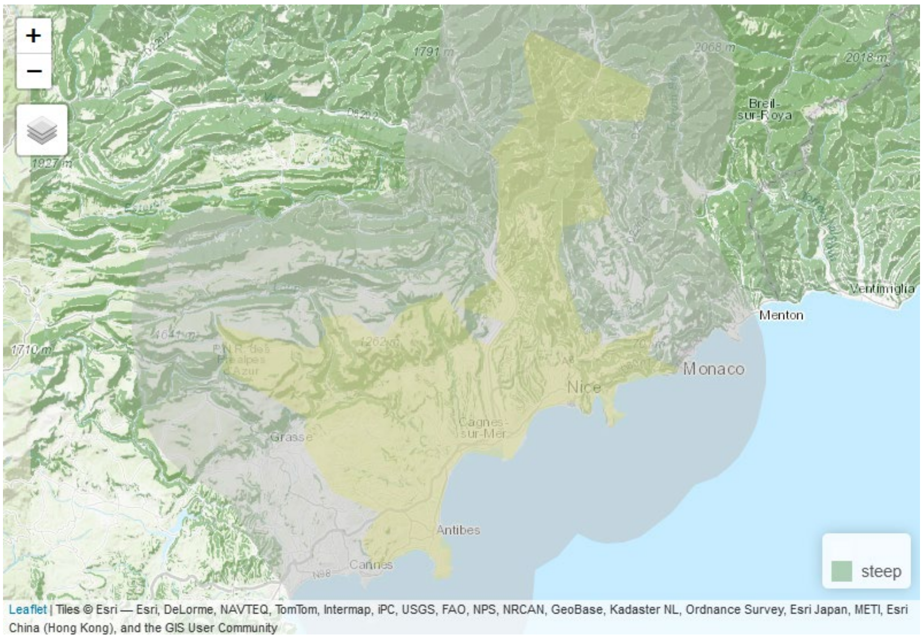
Table A.1. Functional urban areas by country

	Area (in km²)		Built-up area (in %)		Population (in thousands)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
AUS (N=18)	559.9 (783.1)	36.7 - 2905.4	41.6 (12.0)	17.2 - 58.3	795.1 (1287.4)	54.3 - 4239.4
AUT (N=6)	154.9 (128.9)	65.5 - 414.1	33.2 (12.2)	17.1 - 50.4	435.2 (658.7)	95.7 - 1773.4
BEL (N=11)	131.3 (53.8)	38.0 - 203.9	47.2 (17.0)	22.8 - 74.7	279.4 (330.3)	65.1 - 1180.7
CAN (N=26)	927.2 (1369.6)	66.5 - 5965.6	35.5 (17.2)	2.1 - 67.6	796.3 (1361.7)	81.4 - 6352.9
CHE (N=10)	94.8 (57.0)	21.0 - 222.7	33.4 (12.1)	12.2 - 49.8	221.3 (175.0)	56.2 - 620.3
CHL (N=26)	4421.5 (7477.2)	59.8 - 30873.5	2.9 (4.0)	0.0 - 13.5	482.0 (1292.5)	54.8 - 6760.6
COL (N=53)	1378.4 (1420.3)	118.8 - 7051.4	2.3 (4.7)	0.0 - 30.4	562.5 (1317.6)	62.5 - 8839.9
CZE (N=15)	143.7 (127.1)	46.4 - 532.7	24.1 (8.8)	12.2 - 39.1	214.3 (339.7)	46.3 - 1372.3
DEU (N=96)	187.0 (231.6)	35.4 - 1887.1	27.6 (10.4)	9.2 - 57.5	298.8 (557.4)	49.7 - 3552.6
DNK (N=4)	592.8 (371.8)	304.0 - 1138.8	25.1 (19.5)	6.5 - 52.3	477.1 (482.0)	191.2 - 1194.5
ESP (N=81)	321.3 (421.2)	11.2 - 1853.0	16.8 (13.1)	0.5 - 59.0	304.2 (726.6)	44.9 - 5313.6
EST (N=3)	88.9 (62.6)	38.9 - 159.1	28.0 (6.8)	20.3 - 33.4	180.0 (181.7)	55.2 - 388.5
FIN (N=7)	1507.7 (1377.4)	245.4 - 3723.3	5.4 (6.5)	0.4 - 19.1	298.7 (361.4)	112.5 - 1112.7
FRA (N=85)	334.5 (325.8)	20.9 - 2178.9	23.8 (12.6)	4.6 - 74.9	344.8 (1049.2)	62.6 - 9606.8
GBR (N=96)	291.7 (378.4)	26.0 - 2488.9	33.3 (19.8)	2.2 - 74.4	403.7 (1052.1)	64.3 - 9635.4
GRC (N=14)	95.0 (152.2)	12.6 - 613.7	32.2 (15.1)	11.8 - 60.1	368.6 (879.4)	53.2 - 3348.0
HUN (N=19)	239.3 (133.2)	91.3 - 524.9	17.0 (11.6)	9.0 - 54.2	248.8 (467.2)	56.3 - 1794.6
IRL (N=5)	215.1 (396.7)	19.4 - 924.4	31.4 (13.2)	18.0 - 45.9	315.2 (549.3)	45.3 - 1296.5
ISL (N=1)	1040.3 (NaN)	1040.3 - 1040.3	1.8 (NaN)	1.8 - 1.8	210.3 (NaN)	210.3 - 210.3
ITA (N=84)	233.7 (296.2)	20.9 - 2023.9	20.4 (13.9)	2.0 - 58.9	252.2 (602.3)	39.2 - 4026.5
JPN (N=61)	845.3 (1138.4)	81.7 - 7253.1	25.0 (14.8)	3.4 - 62.3	1401.3 (4734.0)	120.2 - 33762.2
KOR (N=22)	857.4 (635.2)	205.5 - 3325.8	11.0 (8.3)	1.9 - 31.9	1751.6 (4469.7)	72.3 - 21333.4
LTU (N=6)	135.7 (135.5)	39.5 - 399.3	29.2 (8.0)	17.7 - 38.3	201.1 (179.1)	63.2 - 526.3
LUX (N=1)	51.6 (NaN)	51.6 - 51.6	44.8 (NaN)	44.8 - 44.8	105.7 (NaN)	105.7 - 105.7
LVA (N=4)	124.2 (119.6)	60.4 - 303.5	24.0 (4.7)	18.2 - 27.8	210.2 (274.8)	56.3 - 621.9
MEX (N=92)	3111.7 (6336.5)	27.3 - 53303.1	8.6 (9.7)	0.1 - 43.5	805.0 (2169.6)	58.7 - 20128.0
NLD (N=35)	190.5 (232.9)	18.2 - 1165.3	33.5 (16.5)	2.4 - 67.0	255.9 (394.8)	63.0 - 2043.4
NOR (N=6)	684.0 (902.7)	70.9 - 2503.3	14.2 (15.0)	0.4 - 42.7	232.2 (215.8)	68.3 - 646.3
POL (N=58)	118.8 (131.0)	21.0 - 744.9	29.0 (7.6)	11.5 - 44.5	208.4 (321.6)	7.3 - 1710.3
PRT (N=13)	337.8 (284.4)	76.2 - 1128.1	18.6 (12.7)	0.0 - 39.7	348.7 (649.9)	61.0 - 2335.1
SVK (N=8)	139.8 (108.2)	70.3 - 367.4	20.1 (4.3)	12.5 - 24.8	137.0 (124.3)	55.3 - 406.4
SVN (N=2)	211.2 (90.2)	147.4 - 275.0	17.3 (3.4)	14.9 - 19.7	200.6 (129.0)	109.3 - 291.8
SWE (N=12)	1354.4 (671.2)	346.4 - 2386.4	7.4 (8.3)	1.5 - 24.8	328.0 (446.7)	107.0 - 1678.0
USA (N=211)	4090.2 (6848.5)	111.3 - 83878.0	13.8 (12.4)	0.7 - 69.8	929.5 (2046.0)	40.4 - 17708.3

Note: Digital maps of functional urban areas are overlaid with raster data for population and built-up area grids from the Global Human Settlement Layer (GHSL) data sets. Number of FUAs in parentheses in first column. Other columns exhibit averages, standard deviations and ranges of areas, share of built-up areas and population across FUAs for each country. All numbers refer to 2015.

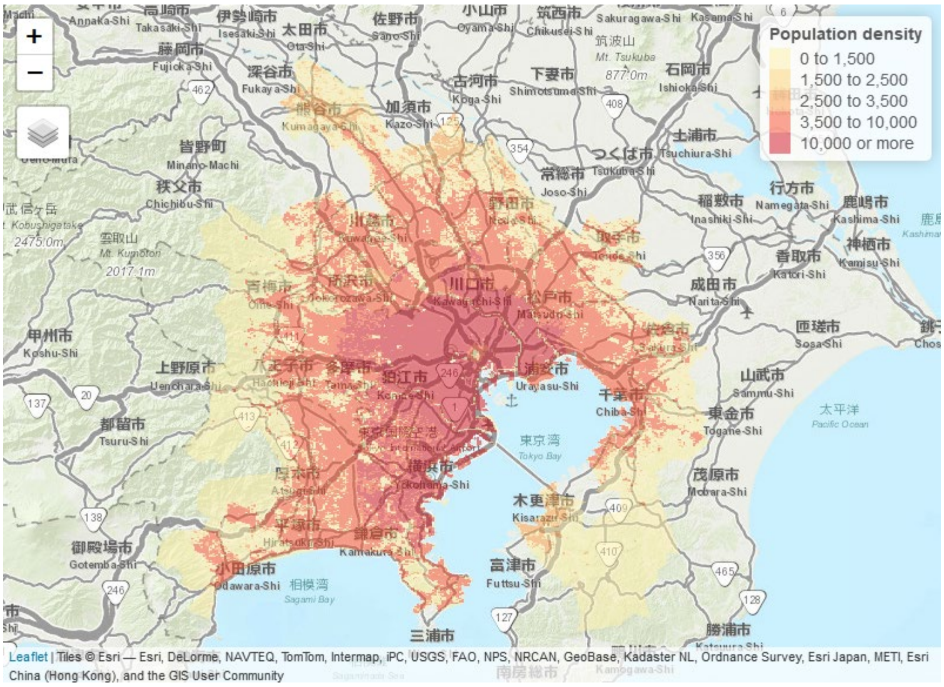
Source: Redefine "Urban" (OECD, 2012); European Commission, Joint Research Centre (JRC); Columbia University, Center for International Earth Science Information Network - CIESIN (2015): https://ghsl.jrc.ec.europa.eu/datasets.php and own calculations.

Figure A.1. Natural constraints to residential construction in Nice (France)



Note: FUA area in yellow, a 0.1 arc degree (~11km) buffer in grey. Steep land is defined as grids with slopes above 15°.
Source: OECD; CGIAR Consortium for Spatial Information (CGIAR-CSI).

Figure A.2. Population density in Tokyo (Japan) in 2000



Source: OECD; Global Human Settlement Layer (GHSL).

Table A.2. Share of constrained urban land by region

Fifty most populated regions in 2017

Region name	Country	Inland water	Ocean	Steep land	Dense land	Parks	Total share of unavailable land
New York-Newark-Jersey City, NY-NJ-PA	USA	8.7	24.8	0.7	13.2	0.1	47.6
Los Angeles-Long Beach-Anaheim, CA	USA	0.4	9.0	19.9	14.6	0.1	44.1
London	GBR	0.4	4.0	0.1	45.9	0.1	50.5
Île-de-France	FRA	0.8	0.0	0.2	52.8	0.1	53.9
Chicago-Naperville-Elgin, IL-IN-WI	USA	0.9	0.0	0.0	10.4	0.1	11.4
Dallas-Fort Worth-Arlington, TX	USA	3.6	0.0	0.0	8.2	0.0	11.9
Miami-Fort Lauderdale-West Palm Beach, FL	USA	4.7	16.4	0.0	5.6	0.7	27.3
North West England	GBR	0.2	7.9	1.0	28.8	0.0	37.9
Houston-The Woodlands-Sugar Land, TX	USA	2.5	7.4	0.0	9.9	0.0	19.8
Washington-Arlington-Alexandria, DC-VA-MD-WV	USA	2.1	4.6	1.2	9.9	0.1	17.8
Sydney	AUS	0.3	19.9	6.2	34.2	0.4	61.0
South East England	GBR	0.1	7.3	0.2	27.1	0.1	34.7
Melbourne	AUS	0.4	9.3	1.2	22.0	0.2	33.2
Phoenix-Mesa-Scottsdale, AZ	USA	0.1	0.0	8.0	2.2	0.2	10.4
Quebec	CAN	0.7	10.1	1.0	25.9	0.1	37.7
West Midlands Region (England)	GBR	0.1	0.0	0.1	36.8	0.1	37.1
Yorkshire and The Humber (England)	GBR	0.1	1.3	1.3	19.7	0.1	22.4
Philadelphia-Camden-Wilmington, PA-NJ-DE-MD	USA	6.7	18.3	1.0	10.7	0.1	36.8
Detroit-Warren-Dearborn, MI	USA	1.5	0.0	0.0	7.2	0.1	8.8
Seattle-Tacoma-Bellevue, WA	USA	1.3	3.7	32.1	2.6	0.2	39.9
Boston-Cambridge-Newton, MA-NH	USA	2.8	7.3	0.3	7.3	0.1	17.8
San Francisco-Oakland-Hayward, CA	USA	2.2	9.0	17.2	9.9	0.1	38.5
Athens	GRC	0.1	28.5	14.8	53.4	0.2	97.0
San Diego-Carlsbad, CA	USA	0.4	4.6	13.6	3.9	0.4	22.9
Provence-Alpes-Côte d'Azur	FRA	0.5	24.4	19.2	11.6	0.1	55.7
Denver-Aurora-Lakewood, CO	USA	0.3	0.0	5.8	3.8	0.1	10.1
British Columbia	CAN	3.2	18.6	23.7	21.2	0.2	66.8
Rhône-Alpes	FRA	0.8	0.0	19.0	21.8	0.0	41.7
Tampa-St. Petersburg-Clearwater, FL	USA	3.9	19.8	0.0	7.0	0.2	30.8
Alberta	CAN	1.7	0.0	0.1	17.2	0.1	19.1
Zuid-Holland (PV)	NLD	10.5	15.7	0.0	52.4	0.1	78.7
Las Vegas-Henderson-Paradise, NV	USA	0.6	3.4	13.1	1.7	0.4	19.2
Brisbane	AUS	0.7	19.6	6.6	21.7	0.7	49.2
Sacramento--Roseville--Arden-Arcade, CA	USA	2.8	3.9	14.1	3.4	0.2	24.3
Minneapolis-St. Paul-Bloomington, MN-WI	USA	4.2	0.0	0.2	5.9	0.1	10.4
Noord-Holland (PV)	NLD	16.4	6.5	0.0	29.1	0.1	52.1
South West England	GBR	0.6	10.1	0.7	41.4	0.1	52.9
San Antonio-New Braunfels, TX	USA	0.5	0.0	0.1	7.7	0.0	8.3
Portland-Vancouver-Hillsboro, OR-WA	USA	0.8	0.0	20.8	5.3	0.1	27.0
Vienna	AUT	1.8	0.0	3.6	59.3	0.2	64.9
East Midlands (England)	GBR	0.0	0.0	0.0	39.3	0.1	39.4
Orlando-Kissimmee-Sanford, FL	USA	10.4	12.7	0.0	4.8	0.2	28.1
Austin-Round Rock, TX	USA	1.6	0.0	0.1	3.4	0.0	5.1
St. Louis, MO-IL	USA	1.3	0.0	0.2	5.5	0.0	7.1
North East England	GBR	0.2	13.1	0.3	28.0	0.0	41.6
East England	GBR	0.5	8.9	0.0	29.3	0.0	38.9
Norte	PRT	0.9	15.1	8.1	15.7	0.0	39.8
Cleveland-Elyria, OH	USA	0.4	0.0	0.0	8.5	0.1	9.0
Kansas City, MO-KS	USA	0.9	0.0	0.0	3.6	0.0	4.6
Perth	AUS	1.1	34.3	0.6	19.0	0.2	55.3

Note: Steep land is defined as grids with slopes above 15°. Ocean is the sea area comprised in a 0.1 arc degree (~11km) buffer around the functional urban area. Inland-water covers rivers and lakes. High density land is defined as grids with population density above 3 500 persons per km^2.
Source: OECD; CGIAR Consortium for Spatial Information (CGIAR-CSI); Global Human Settlement Layer (GHSL).