The Costs of Agglomeration: House and Land Prices in French Cities

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Abstract: We develop a new methodology to estimate the elasticity of urban costs with respect to city population using French house and land price data. After handling a number of estimation concerns, we find that the elasticity of urban cost increases with city population with an estimate of about 0.04 for an urban area with 100,000 inhabitants to 0.10 for an urban area of the size of Paris. Our approach also yields a number of intermediate outputs of independent interest such as the share of housing in expenditure, the elasticity of unit house and land prices with respect to city population, and distance gradients for house and land prices.

Key words: urban costs, house prices, land prices, land use, agglomeration

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1. Introduction

As a city's population grows, three major changes potentially occur. First, larger cities are expected to be more productive as agglomeration effects become stronger. Second, larger cities are expected to become more expensive as the cost of housing and urban transportation rises. The price of other goods may also be affected. Third, larger cities may differ in how attractive they are regarding the amenities they offer as these may change as cities grow. From past research, we know a fair amount about agglomeration, we have some knowledge about urban amenities but we know virtually nothing about urban costs and how they vary with city population. Although high housing prices and traffic jams in Central Paris, London, or Manhattan are for everyone to observe, we know of no systematic evidence about urban costs and their magnitude. This paper seeks to fill that gap.

To that end, we develop a new methodology to estimate the elasticity of urban costs with respect to city population using French data about house and land prices and household expenditure. Our preferred estimates range from about 0.04 for an urban area with 100,000 inhabitants to 0.10 for an urban area of the size of Paris. Put differently, a 10% larger population in a small city leads to a 0.4% increase in expenditure for its residents to remain equally well off. For a city with the same population as Paris, the same 10% increase in population implies a 1% increase in expenditure. These figures are 'all else constant', including the urban area of cities. Allowing cities to increase their physical footprint reduces the magnitude of the elasticities of urban costs by a factor of three to four. In the 'short run', we also find much larger elasticities as housing supply does not fully adjust to population increases. Our approach also yields a number of intermediate outputs of independent interest such as distance gradients for land and house prices, the share of housing in expenditure, and the elasticities of land and house prices with respect to city population.

Plausible estimates for urban costs are important for a number of reasons. In many countries, urban policies attempt to limit the growth of cities. These restrictive policies, which often take the form of barriers to labour mobility and stringent land use regulations that limit new constructions, are particularly prevalent in developing countries (see Desmet and Henderson, 2015, for a review). The underlying rationale for these policies is that the population growth of cities imposes large costs to already established residents by bidding up housing prices and crowding out the roads. Our analysis shows that in the French case, the costs of having larger cities are modest for most cities and of about the same magnitude as agglomeration economies. This lends little support to the imposition of barriers to urban growth. Quite the opposite, urban costs increase much faster when cities are prevented from adjusting their supply of housing.

More generally, households allocate a considerable share of their resources to housing and transportation. In France, homeowners and renters in the private sector devote on average 33.4% of their expenditure to housing and 13.5% to transportation (CGDD, 2015).[1] As we document below, there are sizeable differences across cities in how much households spend on housing as the cost of housing varies greatly across places. Understanding this variation is thus a first-order allocation issue.

Urban costs also matter for theory. Following Henderson (1974) and Fujita and Ogawa (1982), cities are predominantly viewed as the outcome of a tradeoff between agglomeration economies and urban costs. Much of contemporary urban theory relies or builds on this tradeoff. Fujita and Thisse (2002) dub it the 'fundamental tradeoff of spatial economics'. The existence of agglomeration economies is now well established and much has been learnt about their magnitude.[2] To assess the fundamental tradeoff of spatial economics empirically, evidence about urban costs is obviously needed.

To measure how urban costs vary with city population, three challenges must be met. The first regards the definition and measurement of urban costs since they can take a variety of forms. Using a simple consumer theory approach, we define the elasticity of urban costs with respect to city population as the percentage increase in expenditure that residents in a city must incur when population grows by one percent, keeping utility constant. When a simple spatial equilibrium condition is satisfied, this increase in expenditure offsets any change in income due to stronger agglomeration effects and changes in urban amenities that affect utility directly. Importantly, we also show that this elasticity is, to a first approximation, equal to the product of the share of housing in expenditure and the elasticity of housing prices at the city centre with respect to city population. Because we estimate this elasticity and this expenditure share for central locations, this should

[1] Our figure of 33.4% for housing is the mean between the figure for renters and the figure for homeowners for 2006-2011 in the French expenditure survey. It is higher than the aggregate share of housing in expenditure of 27% reported by CGDD, (2015) because we exclude rural areas where housing is less expensive and renters living in public housing who often pay well below market price. The figure for transportation is from 2010 and covers the entire country. In the US, households spend 32.8% of their expenditure to housing and 17.5% to transportation (US BTS, 2013). In both countries, transportation is defined as all forms of personal transportation but most of it is road transportation. Air transportation represents only 6% of transportation expenditure in France and 5% in the US.

[2] See Puga (2010) and Combes and Gobillon (2015) for reviews. See also Combes, Duranton, and Gobillon (2008), Combes, Duranton, Gobillon, and Roux (2010), or Combes, Duranton, Gobillon, Puga, and Roux (2012) for some work on French cities.

account for higher transportation costs which should be reflected in property prices in equilibrium. In turn, the elasticity of housing prices can be decomposed as the product of the share of land in housing and the elasticity of land prices at the city centre.

After this conceptual clarification, our second challenge is thus to gather data to estimate the elasticity of both house and land prices with respect to city population and the shares of both housing in expenditure and land in housing. For the elasticity of house prices, we rely on detailed price indices that are estimated for French municipalities between 2000 and 2012. We focus on house prices but verify our result using broader property price indices that also include apartments. For the elasticity of land prices, we exploit a unique record of transactions for land parcels with a development or redevelopment permit from 2006 to 2012. We estimate the share of housing in expenditure in France from the French Consumer Expenditure Survey, allowing it to vary with city population. For the share of land in housing, we rely on the results obtained in our companion paper (Combes, Duranton, and Gobillon, 2016) which provides a detailed investigation of the production function for housing. Finally, we gathered a vast array of data at the level of municipalities and urban areas.

Our third challenge is to identify our main elasticities and expenditure shares. For each city, we first need an estimate of house and land prices in a fixed (central) location to make them comparable across cities and account for differences in transportation costs.[3] This first exercise poses two main difficulties: functional form and the potential selection of houses or land parcels depending on their location in the city. We show that our results are robust to the exact specification we use to estimate house and land prices at central locations, to the definition of these central locations, and to potential selection problems.

Next, when regressing house and land prices at the center on city population, our main worry is the simultaneous determination of these prices and city population. For house prices, we provide estimates exploiting both population differences across cities and population changes over time within cities. We develop various instrumental strategies for both types of estimation. For land prices, our period of study is too short for the time variation in land prices and population to be meaningfully used but we duplicate the approach we use for house prices in the cross-section of French urban areas. We also show that working with both house and land prices implies roughly

[3]When the price of land at the urban edge is determined by agricultural use, we expect very little variation across cities in the price of land at their edges. Residents at these edges may nonetheless experience vastly different transportation costs depending on the population of their city.

similar estimates for the elasticity of urban costs. Finally, we also address a number of concerns regarding the estimation of the share of housing in expenditure.

Tolley, Graves, and Gardner (1979), Thomas (1980), Richardson (1987), and Henderson (2002) are the main antecedents to our research on urban costs.[4] To the best of our knowledge, this short list is close to exhaustive. Despite the merits of these works, none of their estimates has had much influence. We attribute this lack of credible estimate for urban costs and the scarcity of research on the subject to a lack of integrated framework to guide empirical work, a lack of appropriate data, and a lack of attention to a number of identification issues — the three main innovations of this paper.

The elasticity of housing prices with respect to city population is also estimated by Albouy (2008), Bleakley and Lin (2012), and Baum-Snow and Pavan (2012). These papers estimate one of the quantities we are interested in here but do so with very different objectives in mind. They also ignore the location of properties within their metropolitan area, a first-order empirical issue as we show below. There is also a literature that measures land values for a broad cross-section of urban (and sometimes rural) areas (Davis and Heathcote, 2007, Davis and Palumbo, 2008, Albouy and Ehrlich, 2012). We enrich it by considering the internal geography of cities and by investigating the determinants of land prices, population in particular, at the city level.

On the other hand, our objectives are more similar to those of Au and Henderson (2006) who are also interested in the tradeoff between agglomeration benefits and urban costs. They use nonetheless a very different approach and investigate the net productivity gains associated with city size instead of trying to separate the costs from the benefits of cities.

2. Model

The utility of a resident at location ℓ in city c with population N_c is given by $U(h(\ell),x(\ell),M_c)$ where M_c denotes the quality of amenities in the city, $h(\ell)$ is housing consumption, and $x(\ell)$ is the consumption of a composite good. Utility is increasing in all arguments and is strictly quasi-concave. Although our model ignores amenities specific to a location or a neighbourhood within a city, our empirical analysis considers them.

[4] Thomas (1980) compares the cost of living for four regions in Peru focusing only on the price of consumption goods. Richardson (1987) compares 'urban' and 'rural' areas in four developing countries. Closer to the spirit of our work, Henderson (2002) regresses commuting times and rents to income ratio for a cross-section of cities in developing countries.

The budget constraint is,

$$W_c = \tau(\ell) + Q_c\, x(\ell) + P(\ell)\, h(\ell)\,, \tag{1}$$

where W_c is the city wage, $\tau(.)$ measures the cost of transportation associated with each location, Q_c is the city price of the composite good, and $P(.)$ is the price of housing at each location. We note that a special case of our model is the monocentric model of Alonso (1964), Mills (1967), and Muth (1969). In this model, ℓ measures the distance to the central business district (CBD) where all the jobs are located. Residents must commute to this CBD at a cost $\tau(\ell) = \tau \times \ell$. The results that follow do not rely on these restrictions.

Residents maximise their utility with respect to the choice of their location ℓ, their consumption of housing $h(\ell)$ at this location given its price $P(\ell)$, and their consumption of the composite good $x(\ell)$ given its price Q_c. The expenditure on these two goods is equal to the wage net of the cost of transportation. At the spatial equilibrium within the city, the rental price of housing adjusts so that residents are indifferent across all occupied residential locations in the city: $U(h^*(\ell), x^*(\ell), M_c) = \overline{U}_c$.[5] Omitting the city subscript c, the expenditure function for a resident at location ℓ is thus $E(P(\ell), Q, M, \overline{U})$ and utility maximisation implies $E(P(\ell), Q, M, \overline{U}) = W - \tau(\ell)$.

We consider the location in the city where the price of housing is the highest, $\overline{P}$. In equilibrium, this is also where the transportation cost is the lowest, $\underline{\tau}$. We then examine the effect of a marginal increase in population in the city. Totally differentiating the expenditure function leads to,

$$\frac{\mathrm{d}E(\overline{P}, Q, M, \overline{U})}{\mathrm{d}N} = \frac{\partial E(\overline{P}, Q, M, \overline{U})}{\partial \overline{P}} \frac{\mathrm{d}\overline{P}}{\mathrm{d}N} + \frac{\partial E(\overline{P}, Q, M, \overline{U})}{\partial Q} \frac{\mathrm{d}Q}{\mathrm{d}N} + \frac{\partial E(\overline{P}, Q, M, \overline{U})}{\partial M} \frac{\mathrm{d}M}{\mathrm{d}N}\,. \tag{2}$$

This equation indicates that the change in expenditure associated with a change in population keeping utility constant works through three channels: the change in expenditure that arises from the change in housing prices, the change in expenditure due to the change in the price of the final good, and the change in expenditure associated with the change in amenities.[6]

[5] We rely on a standard spatial equilibrium concept involving utility equalisation, first within cities, then across cities. We acknowledge the limitations of this type of approach but note that theoretical developments where the spatial equilibrium does not involve full utility equalisation are still in their infancy (e.g., Behrens, Duranton, and Robert-Nicoud, 2014) and empirical applications have yet to materialise (Kline and Moretti, 2015). Empirically, we treat household heterogeneity within or across cities as a nuisance to be conditioned out.

[6] This approach shares some formal similarities with Albouy (2008). We focus nonetheless on a different question: how much more does it cost to live in a city when its population increases? Albouy (2008) is instead primarily concerned with deriving an amenity valuation given constant expenditure.

Applying Sheppard's lemma to equation (2) and omitting the arguments of the expenditure function to ease notations, we obtain

$$\frac{\mathrm{d}E}{\mathrm{d}N} = h(\overline{P},Q,\overline{U})\frac{\mathrm{d}\overline{P}}{\mathrm{d}N} + x(\overline{P},Q,\overline{U})\frac{\mathrm{d}Q}{\mathrm{d}N} + \frac{\partial E}{\partial M}\frac{\mathrm{d}M}{\mathrm{d}N}\,, \tag{3}$$

where $h(\overline{P},Q,\overline{U})$ is the compensated demand for housing and $x(\overline{P},Q,\overline{U})$ is the compensated demand for the composite good. Equation (3) shows that, to keep utility constant following an increase in city population, the change in expenditure plus the valuation of the change in amenities should be equal to the sum of the increase in expenditure on both goods. Dividing both sides of equation (3) by E/N, we can rewrite this result more compactly as:

$$\epsilon_N^E = s_{W-\underline{\tau}}^h \epsilon_N^P + (1 - s_{W-\underline{\tau}}^h)\epsilon_N^Q + \varepsilon_M^E \epsilon_N^M\,, \tag{4}$$

where ϵ_Y^X is the elasticity of X with respect to Y and $s_{W-\underline{\tau}}^h$ is the share of housing in consumption expenditure. To avoid confusions, ε_M^E denotes the partial equilibrium elasticity of expenditure with respect to amenities. Loosely speaking, this is the willingness to pay of residents for higher amenities in terms of foregone consumption, all else equal.[7]

Assuming free mobility across cities, utility $\overline{U}$ is achieved in all cities in equilibrium and we should observe:

$$\epsilon_N^E = \epsilon_N^{W-\underline{\tau}} = s_{W-\underline{\tau}}^h \epsilon_N^P + (1 - s_{W-\underline{\tau}}^h)\epsilon_N^Q + \varepsilon_M^{W-\underline{\tau}} \epsilon_N^M\,. \tag{5}$$

At the full spatial equilibrium with utility equalisation both within and between cities, the elasticity of the income net of minimum transportation costs with respect to population can be decomposed as the sum of three products. The first is the product of the share of expenditure in housing by the elasticity of the price of housing. The second is the product of the share of the composite good by the elasticity of its price. The third is the product of the partial elasticity of the net income with respect to amenities by the elasticity of amenities.

Many models of urban structure assume that $\underline{\tau} = 0$ and this is perhaps a reasonable first-order approximation in the centre of cities where a non-negligible share of residents report extremely low travel times for the trips they undertake.[8]

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[7]Importantly $\varepsilon_M^E \times \epsilon_N^M$ does not simplify into ϵ_N^E. Instead, the elasticity of expenditure with respect to population has both an amenity component and an urban cost component as made clear by equation (4).

[8]Using the same US individual travel data as Duranton and Turner (2016), we compute that 25% of residents of US metropolitan areas with a million inhabitants or more that live within 2 kilometres of the CBD also live within one kilometre of their workplace and, overall, the median distance to work of these more central residents is 3 kilometres. For those living more than 20 kilometres away from their CBD, the 25th percentile of distance to work is above 5 kilometres and the median is 11 kilometres.

In addition, work by Handbury and Weinstein (2015), which uses bar-code data, strongly suggests that the price of individual varieties in groceries is mostly invariant with city population in the US.[9] Using broader product categories, Combes *et al.* (2012) confirm this result for French cities. Hence, as another empirically relevant first-order approximation, we assume free trade in the composite good so that $\epsilon_N^Q = 0$. After these two simplifications, we can rewrite equation (5) as:

$$\epsilon_N^W = s_W^h \epsilon_N^P + \varepsilon_M^W \epsilon_N^M \,. \tag{6}$$

In the particular case where $U(h,x,M) = M\,u(h,x)$ and $u(h,x)$ is homogenous of degree one, this expression simplifies further into $\epsilon_N^W = s_W^h \epsilon_N^P - \epsilon_N^M$.[10]

As already mentioned, there is a large literature concerned with the measurement of the agglomeration elasticity ϵ_N^W. The empirical work that follows is instead concerned with the estimation of $\epsilon_N^{UC} \equiv s_W^h \epsilon_N^P$, the elasticity of urban cost with respect to city population. Knowing about the agglomeration elasticity and the urban cost elasticity and assuming a spatial equilibrium across cities, we can indirectly estimate the amenities elasticity as in Roback (1982) and the large literature that followed, most notably Albouy (2008) who focuses on how urban amenities vary with city population.

So far, we have relied only on consumer theory. To develop our framework further, we consider that housing is produced using land L and non-land K inputs, available at prices $R(\ell)$ and r^K respectively. To produce an amount of housing $H(\ell)$ at location ℓ, competitive builders face a cost function $C(r^K,R(\ell),H(\ell)) = C(\ell)$. Since free entry among builders at location ℓ implies $P(\ell)\,H(\ell) = C(\ell)$, we can rewrite the elasticity of housing prices with respect to city population as,

$$\epsilon_N^P \equiv \frac{\mathrm{d}P(\ell)}{\mathrm{d}N}\frac{N}{P(\ell)} = \frac{\mathrm{d}\frac{C(\ell)}{H(\ell)}}{\mathrm{d}N}\frac{N}{P(\ell)} = \frac{N}{P(\ell)H^2(\ell)}\left(H(\ell)\frac{\mathrm{d}C(\ell)}{\mathrm{d}N} - C(\ell)\frac{\mathrm{d}H(\ell)}{\mathrm{d}N}\right) . \tag{7}$$

We assume that the cost of non-land inputs remains constant.[11] Since $\frac{\mathrm{d}r^K}{\mathrm{d}N} = 0$, totally differentiating the cost function leads to,

$$\frac{\mathrm{d}C(\ell)}{\mathrm{d}N} = \frac{\partial C(\ell)}{\partial R(\ell)}\frac{\mathrm{d}R(\ell)}{\mathrm{d}N} + \frac{\partial C(\ell)}{\partial H(\ell)}\frac{\mathrm{d}H(\ell)}{\mathrm{d}N} \,. \tag{8}$$

From the builders' first-order condition for profit maximisation, we have, $P(\ell) = \frac{\partial C(\ell)}{\partial H(\ell)}$. This condition can be rewritten as $C(\ell) = H(\ell)\frac{\partial C(\ell)}{\partial H(\ell)}$ after substituting for $P(\ell)$ using the zero-profit

[9] They also find that larger cities also offer a larger number of varieties, which we think of here as consumption amenities.

[10] It is easy to show that the spatial equilibrium condition $M\,u(h,x) = \overline{U}$ implies $\mathrm{d}W/\mathrm{d}M = -W/M$.

[11] Combes *et al.* (2016) provide supportive evidence to that effect.

condition. In turn, we can use this expression and equation (8) to simplify equation (7) and obtain,

$$\epsilon_N^P = \frac{N}{C}\frac{\partial C}{\partial R}\frac{\mathrm{d}R}{\mathrm{d}N}\,. \tag{9}$$

Applying again Sheppard's lemma, equation (9) can be written as

$$\epsilon_N^P = L\frac{N}{C}\frac{\partial R}{\partial N} = s_h^L \epsilon_N^R\,, \tag{10}$$

where ϵ_N^R is the elasticity of land prices at the most expensive location with respect to city population and $s_h^L \equiv \frac{R\,L}{C}$ is the share of land in construction costs. This implies that the urban cost elasticity, which per equation (6) is equal to the product of the share of housing in expenditure and the elasticity of housing prices with respect to population, can also be measured as the product of three terms, the share of housing in expenditure, the share of land in housing, and the elasticity of land prices with respect to population: $\epsilon_N^{UC} = s_W^h\,\epsilon_N^P = s_W^h\,s_h^L\,\epsilon_N^R$. While the first measure of urban cost proposed in equation (6) relies only on consumer theory and a spatial equilibrium concept with utility equalisation within and between cities, this second measure relies also on the existence of a competitive supply of housing. We implement both approaches in our empirical analysis.

3. Data

To make the discussion of our identification strategy in the next section more palatable, we now describe the data we use. We exploit three main sources of data for housing prices, land prices, and housing expenditure, which we describe in turn. We also use a broad range of municipal and urban area characteristics, which we describe in Appendix A.

Housing prices

Housing price indices at the municipality level for every year of data are estimated from official transactions records.[12] Regional notary associations conduct an annual census of all transactions of non-new dwellings. Although reporting is voluntary, about 65% of transactions appear to be recorded. The coverage is higher in Greater Paris (80%) than in the rest of the country (60%). These transactions data are available from the Ministry of Sustainable Development for every even year over the 2000-2012 period.

[12]Because of institutional constraints, we had to process housing data separately and could only append price indices for each municipality and year to the rest of the data we use. We are grateful to Benjamin Vignolles for his help with this process.

For each transaction, we know the type of dwelling (house or apartment), the number of rooms, the floor area, and the construction period (before 1850, 1850-1913, 1914-1947, 1948-1959, 1960-1980, 1981-1991, after 1991), a municipal identifier, and within each municipality, a cadastral section identifier (comprising on average less than 100 housing units). The floor area is missing for 25.7% of transactions but it can imputed using a complementary dataset (see Appendix A for further details).

To construct municipal housing price indices, the logarithm of the price per square metre is regressed on indicator variables for the construction period and for the quarter of the transaction, separately for every available year and dwelling type. The municipal price index for a given year is then computed as the municipal average of residuals for the year. The constant is added and the explanatory variables are centred so that the resulting indices can be interpreted as a price per square metre for a reference house or dwelling.

To allow for easier comparisons with our land price results, we mainly focus on price indices that pertain to single-family houses in most of our analysis. In robustness checks, we duplicate our results for indices that are computed using transactions for all dwellings, houses and apartments. For houses, there are 184,371 municipality-year observations corresponding to 1,848,081 transactions that took place in mainland France. We further restrict the sample to the 353 French urban areas, for which there are 81,146 observations. For our main sample, we consider the 277 urban areas with more than 3 municipalities for which our entire set of instruments and control variables is available. We end up with 74,621 observations corresponding to 1,199,506 transactions. Because the 76 urban areas that we eliminate are on average small, our sample size declines only slightly with this last selection. When considering all dwellings in robustness checks, we use 75,194 municipality-year observations corresponding to 2,979,655 transactions in the same 277 urban areas.

The municipality identifier allows us to determine in which urban area a dwelling is located. Because French municipalities are tiny (on average, they correspond to a circle of radius 2.2 kilometres), we can approximate the location of dwellings well by using the centroid of their municipality. To measure distance to the centre of an urban area, our preferred metric is the log of the Euclidian distance between the centroid of a dwelling's municipality and the centroid of the urban area to which it belongs. To determine urban area centroids, we weight municipalities by their population.

Land prices

We use land price data extracted from the 2006-2012 Surveys of Developable Land Prices (*Enquête sur le Prix des Terrains à Bâtir*, EPTB) in France. An observation is a transaction record for parcel of land with a building permit for a detached house. Before 2010, around 2/3 of all building permits were surveyed. From 2010 onwards, all building permits are surveyed and the response rate is about 70%.[13] Overall, the data contain 662,060 observations with some fluctuations across years from 48,991 in 2009 to 127,479 in 2012. As discussed in Combes *et al.* (2016), this survey tracks the bulk of new constructions for single-family houses. Appendix A provides further details about the origin of these data. For each observation, we know the price, the municipality, and a number of parcel characteristics.

The information about each transaction includes how the parcel was acquired (purchase, donation, inheritance, other), whether the parcel was acquired through an intermediary (a broker, a builder, another type of intermediary, or none), and some information about the house built including its cost. We also know the area of a parcel and whether it is 'serviced' (i.e., has access to water, sewerage, and electricity).

We restrict our attention to purchases and ignore other transactions such as inheritances for which the price is unlikely to be informative. That leaves us with 394,818 observations for which detailed parcel characteristics are available. Next, we retain the 380,984 observations for Mainland France for which location is known. Of these observations, 221,397 took place in one of the 353 French urban areas. For our main sample of 277 urban areas, the sample size declines again only slightly to 204,656 observations.

Household expenditure survey

To compute the share of housing in expenditure for French households, we exploit the 2006 and 2011 French household expenditure surveys (*Budget des Familles*). This survey is managed by the French Statistical Institute (INSEE) and is designed to study the living conditions and consumption choices of households like the US consumer expenditure survey. This survey reports resources and expenditure by category. It includes a municipality identifier. The 2006 wave includes 10,240 households while the 2011 wave contains 15,597 households.

[13] We weigh land parcels transactions by their sample weight to mitigate possible selection problems here. This makes no difference to our results.

There are three measures of housing expenditure that can be used. They correspond to two different samples: renters and homeowners. For renters, we know the monthly rent for households in the private rental sector exclusive of fees and taxes. The survey also reports the monthly rent inclusive of fees and taxes. At the sample mean, the difference between the two is small, representing only 3.3% of expenditure.[14] We focus our analysis on rents inclusive of fees and taxes but verify that the results we obtain are robust when using the alternative measure of rents. For homeowners, the survey reports a monthly rent-equivalent (or imputed rent) based on the market rental value assessed by homeowners. The survey also reports information on household income, age, marital status, children, and seven levels of educational achievement.

We compute the shares of housing in expenditure by taking the ratio of the measure of monthly rents defined above for renters or imputed rents for homeowners to monthly household income. We delete observations with missing values (26.4% for imputed rents, 0.4% for rents inclusive of fees and taxes, and 8.0% for rents exclusive of fees and taxes). We also delete observations with missing values of explanatory variables and instruments, and trim the 1^{st} and 99^{th} percentiles to delete outliers. When pooling the two surveys, our sample includes 2,464 observations for renters and 5,984 observations for homeowners.

Some descriptive statistics

Table 1 reports descriptive statistics for houses, parcels, housing expenditure, population, and land area for French urban areas. It is useful to keep in mind that a house in urban France has a mean area of 110 square metres and sells for 2,451 € per square meter (all prices in 2012 €). For land, a parcel has a mean area of 1,060 square meters and sells for 108 € per square metre.[15] For the price of houses per square metre of floorspace and for the price of parcels per square metre of land we report both the mean and some measures of variation. As made clear by this first part of table 1, there is a lot of variation in both house and land prices including a lot of variation between urban

[14]The difference includes local taxes, and management fees and utilities for the common parts for multi-family units. Local taxation in France is generally minimal as public goods are often provided directly by the central government and municipalities are mostly financed through grants. Residential taxation (paid by all residents) represents less than 250 euros per person per year. The revenue from property taxation paid by owners is about 25% larger but arises mainly from commercial properties.

[15]The transactions we observe cover a broad spectrum of prices and areas. This is because we use a systematic and compulsory survey based on administrative records. Unlike land transactions recorded by private real estate firms, ours are not biased towards large parcels.

areas. French urban households devote 31 to 35% of their expenditure to housing, depending on their tenure choice.

Given that our focus below is on the cross-section of French urban areas, table 2 provides further descriptive statistics for four groups of urban areas, Paris, the next three large French urban areas, other large urban areas, and small urban areas. This table further illustrates the cross-city variation in our variables of interest and shows that prices of both floorspace and land appear to increase with population. Households devote a smaller fraction of their expenditure to housing in smaller urban areas though the ordering is less clear for the next three size classes in the raw data.

To make the variation in house prices, land prices, and population easier to visualise, the three panels of figure 1 map mean house price per square metre, mean land price per square metre, and population by French urban areas. These maps confirm that there is a lot of variation across urban areas with respect to their land area, population, and house and land prices. These maps also suggest strong correlations between these four variables. Much of the rest of our work below will document these correlations more precisely and interpret them.

Finally, to illustrate the reality of the data within particular urban areas, the left panels of figure 2 plot municipal house prices and distance to the center for four urban areas in 2012. The right panels of the same figure use instead land prices. The first urban area represented at the top of the figure is Paris, the largest French urban area with a population of 12.2 million. The second is Toulouse, the fifth largest French urban area with a population of 1.2 million. The fourth is Dijon, a mid-sized urban area, which ranks 25th with a population of 330,000. Finally, the last one is Arras, a smaller urban area, which ranks 68th with a population of 130,000.

These graphs illustrate the importance of using comparable prices across urban areas. For instance, mean house price in Paris is only 28% above the national mean whereas mean house price in Dijon is 17% below the national mean. By contrast, a house located at the centre Paris is 187% more expensive than the national mean whereas a house at the centre of Dijon is just 1% below the national mean. The difference between Paris and Dijon is thus about four times as large when looking at prices at the center relative to mean prices. Hence, comparing mean house prices greatly understates true differences across cities because the mean house in Paris is much further away from the centre than the mean house in Dijon. For land, the contrast is even starker. Mean

Table 1: Descriptive statistics

Variable	Mean	St. Error	1st decile	Median	9th decile
Notary databases – houses					
Price (€ per m^2, sample mean)	2,451	1,187	1,321	2,185	3,820
Price (€ per m^2, urban area mean)	1,817	493	1,306	1,735	2,380
Dwelling area (m^2, sample mean)	110.4	18	92.9	108.2	130.2
Survey of developable land					
Price (€ per m^2, sample mean)	107.7	105	24.9	81.2	216.2
Price (€ per m^2, urban area mean)	78.2	52.8	26.3	64.3	150.1
Parcel area (m^2, sample mean)	1,060	917	436	813	1,921
Family expenditure survey					
Housing expenditure share for homeowners	0.314	0.192	0.152	0.263	0.526
Housing expenditure share for renters	0.352	0.287	0.146	0.277	0.624
Population (urban area mean)	166,020	757,144	17,775	47,909	305,453
Land area (km^2, urban area)	597	1,036	99	349	1,324

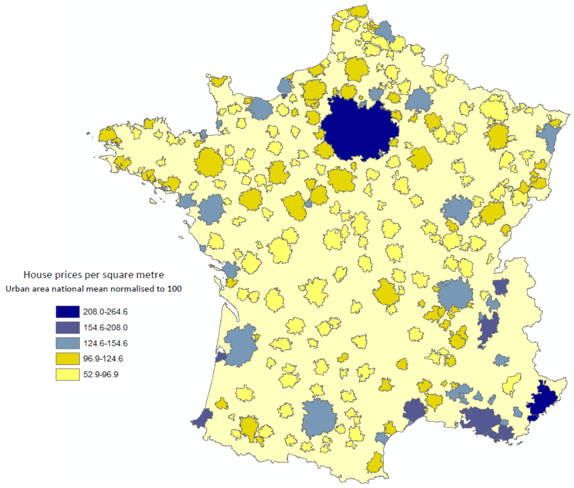
Notes: All prices in 2012 €. 74,621 municipality price indices corresponding to 1,199,506 dwelling transactions for rows 1-3. 204,656 weighted parcel transactions for rows 4-6. 2,464 (resp. 5,984) households renting in the private sector (resp. owning their home) who correspond to 6.79 (resp. 14.1) million weighted observations for row 7 (resp. 8). 277 urban areas for rows 10-11.

Table 2: Descriptive statistics (means by population classes of urban areas)

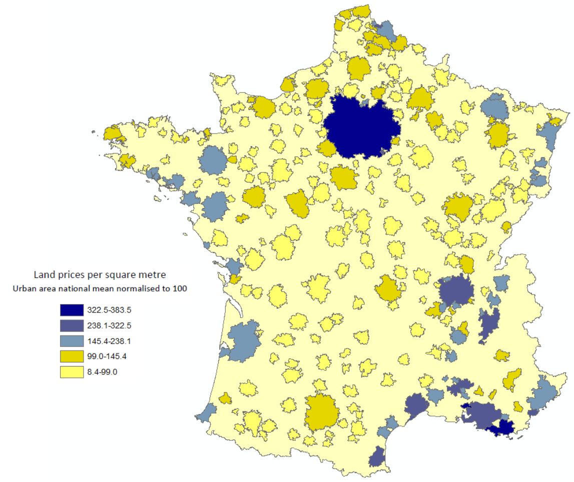
City class	Paris	Lyon, Lille, and Marseille	Population >200,000	Population ≤200,000
Notary databases – houses				
Price (€ per m^2)	3,455	2,558	2,310	1,777
Dwelling area (m^2)	107.9	111.4	112.1	110.1
Survey of developable land				
Price (€ per m^2)	256.3	200.7	114.6	69.5
Parcel area (m^2)	850	1,084	990	1,154
Family expenditure survey				
Housing expenditure share for homeowners	0.344	0.344	0.304	0.293
Housing expenditure share for renters	0.369	0.367	0.382	0.285
Population (urban area)	12,197,910	1,512,162	415,950	54,142
Land area (urban area, km^2)	14,598	2,380	1,486	361
Number of urban areas	1	3	40	233

Notes: See table 1. The numbers in column 3 are for all French urban areas with population above 200,000 excluding Paris, Lyon, Lille, and Marseille.

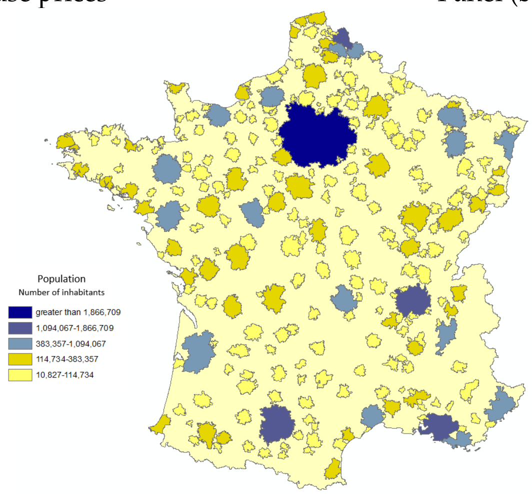
Figure 1: Mean house and land prices per square metre and population in French urban areas, 2012



Panel (a): Mean house prices



Panel (b): Mean land prices



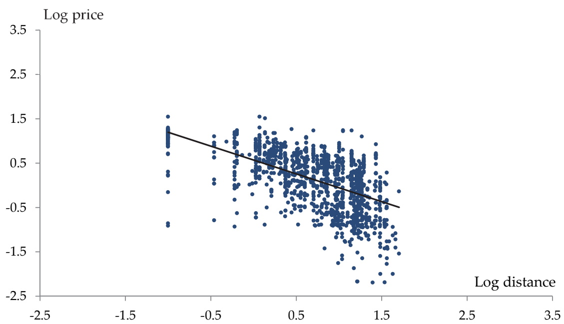
Panel (c): Population

Notes: All maps produced using 2012 data. The classes on each map were created to include about 20% of the French population.

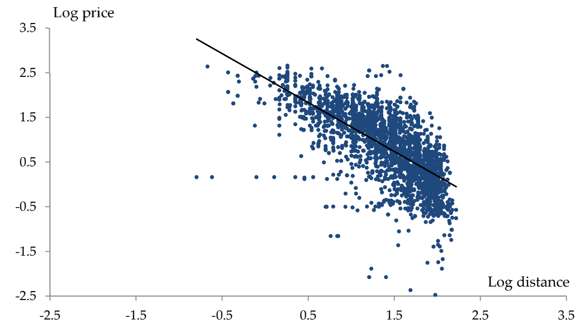
land price is 132% higher than the national mean in Paris and 13% higher in Dijon. Land price at the centre is instead a staggering 1080% higher than the national mean in Paris and only 37% higher in Dijon.

We draw a number of further conclusions from the plots of figure 2. As implied by the figures reported in tables 1 and 2 above, the differences within urban areas in land prices are larger than for house prices. Although house prices are aggregated by municipalities, this is not the only effect at play since the gradient is stronger for land prices. We also note that these gradients appear to differ across urban areas. Despite a lot of heterogeneity across urban areas, the relationship between house prices and population is generally well described by a log linear specification. The fit is less good for land prices but after experimenting with various functional forms, we concluded

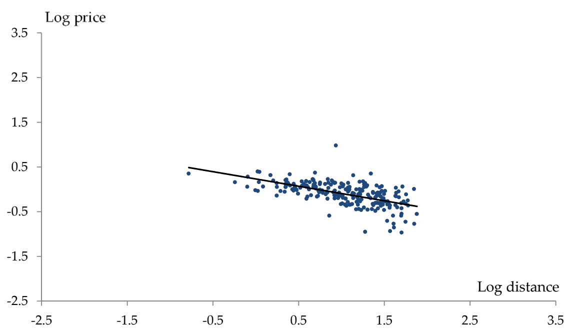
Figure 2: House and land prices per square meter and distance to their centre for four urban areas



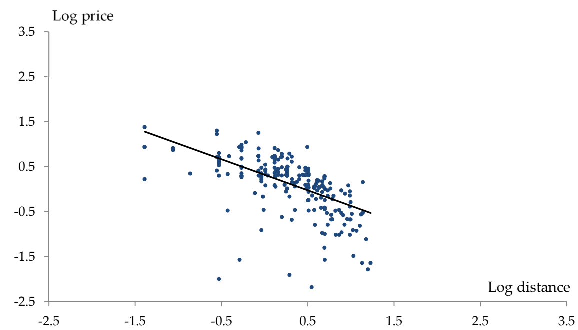
Panel (a.1): House prices in Paris



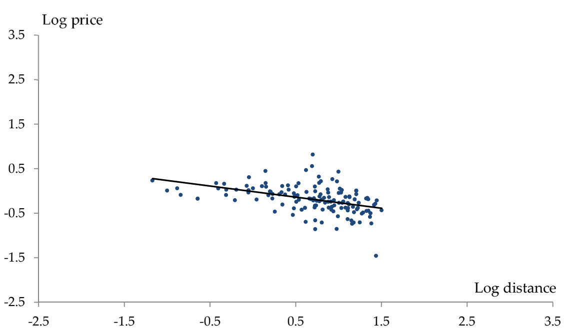
Panel (a.2): Land prices in Paris



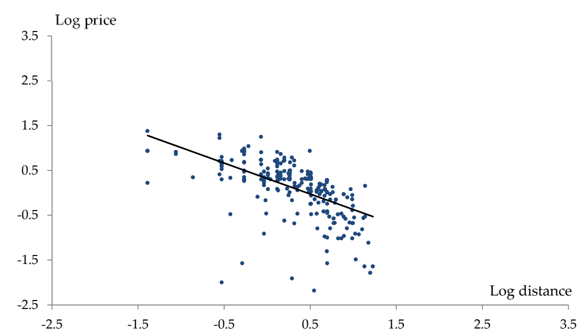
Panel (b.1): House prices in Toulouse



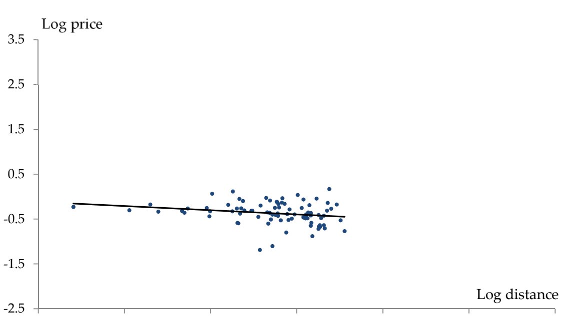
Panel (b.2): Land prices in Toulouse



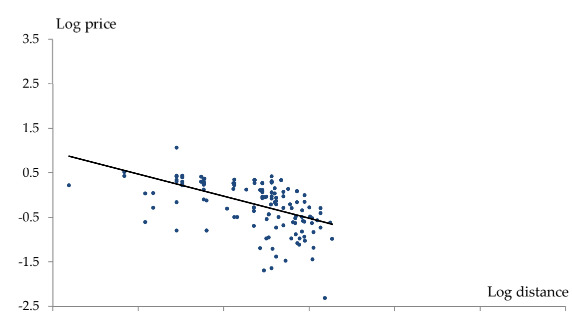
Panel (c.1): House prices in Dijon



Panel (c.2): Land prices in Dijon



Panel (d.1): House prices in Arras



Panel (d.2): Land prices in Arras

Notes: All panels represent 2012 data. The horizontal axis represents the log of the distance between a municipality centroid and the centre of its urban area. The vertical axis represents the log prices estimated from municipal means for house prices and from individual transactions for land prices. Both house and land prices condition out the same characteristics as in column 9 of table 3.

that no simple functional form is obviously better. We nonetheless verify that our results are not sensitive to this choice of a logarithmic form.

For house prices, we have an observation for each reported municipality. Because French municipalities are generally tiny, even for a small urban area like Arras, we can use data from more than 100 municipalities. For land parcels, we also note that we can observe transactions close to the centre, in close suburbs, and remote suburbs. This is because French land use regulations encourage in-filling and try to limit expansions of the urban fringe.[16] The plots for land are helpful to minimise the worry that parcels sold with a building permit form a highly selected sample of existing parcels in a urban area.

4. Estimating the elasticity of urban costs

To measure the elasticity of urban costs, we need to measure the elasticity of house prices and the share of housing in expenditure. In turn, the elasticity of house prices can be measured indirectly as the product of the elasticity of land prices and the share of land in housing.

Obtaining house and land prices that are comparable across urban areas

In line with predictions of models of urban structure and empirical evidence, we expect the cost of transportation to increase with city population as residents are located on average further away from the centre (see Duranton and Puga, 2015, for a review of the theoretical and empirical literature). In turn, accessibility should also be reflected in land and house prices. Then, to make meaningful comparisons across urban areas, we need to compare house and land prices for locations with the same (preferably low) cost of transportation. In absence of transportation data, we use land and house prices at the 'central point' for each city where the prices are highest and transportation costs are lowest. Because house and land transactions may be too sparse at central locations, we estimate land and house prices using information about all transactions in an urban area. For house prices, we estimate,

$$\log P_k = \ln P_{j(k)}(0) - \delta^P_{j(k)} \ln D_k + X_k \alpha^P + \nu^P_k \, , \tag{11}$$

[16] French municipalities need to produce a planning and development plan (*plan local d'urbanisme*) which is subject to national guidelines and requires approval from the central government. Existing guidelines for municipalities or groups of municipalities insist on the densification or re-development of already developed areas to save on the provision of new infrastructure (usually paid for by higher levels of government) relative to expansions of the urban fringe.

where $\log P_k$ is a (natural log) house price index for municipality k, $\log P_{j(k)}(0)$ – our variable of interest – is the intercept for the urban area j of municipality k, D_k is the distance of municipality k to the center of the urban area, $\delta^P_{j(k)}$ is a distance gradient for urban area j, and X_k are controls for amenities and socio-economic characteristics in municipality k. To keep the exposition simple, we ignore the time dimension in our exposition but note that we estimate an intercept for each urban area for each year of data and include the relevant year indicators. We also use the longitudinal dimension of the data below.

For land prices, the corresponding equation is,

$$\log R_i = \ln R_{j(i)}(0) - \delta^R_{j(i)} \ln D_{k(i)} + X_i \, \alpha^R + \nu^R_i \,, \tag{12}$$

where R_i is the unit land price for parcel i and $R_{j(i)}(0)$ is the unit price of land at the centre of urban area $j(i)$, where the municipality $k(i)$ is located.

The regressions described by equations (11) and (12) are standard specifications for urban gradients that have been estimated often since Clark (1951). These gradients regressions nonetheless raise a number of issues. The first is about functional forms. Equations (11) and (12) implicitly rely on the existence of a single centre with land and housing prices following a negative power function of the distance to this center. Ultimately, the appropriate functional form should depend on the shape of transportation costs, which we know little about. In the urban literature, besides power laws, exponential specifications leading regressions of log prices on distance instead of log distance are also popular.[17] A wide variety of controls could also be included as explanatory vairables. To deal with these functional form and specification concerns, we first verify that house and land prices in French urban areas decline monotonically with distance to the centre and that our log-log specification is reasonable. We then experiment with a wide variety of control variables for the local geography, geology, land use, socio-economic characteristics, and consumption amenities. In further robustness checks, we also estimate equations (11) and (12) with alternative functional forms for distance and alternative definitions for the city centre.

A second concern is that, in larger urban areas, housing may be of systematically higher (or lower) quality in more central locations or that more central parcels with a building permit may be of lower quality. Note first that this bias will affect our final results only to the extent that it varies systematically with city population. Then, recall that we estimate house price indices

[17] See Duranton and Puga (2015) for a review and a critical discussion of this large literature.

controlling for a range of house characteristics. For land parcels, we use individual observations directly but control for a number of parcel characteristics. In addition, we perform our estimations on subsamples of closer or more remote parcels or houses to verify the robustness of the results. Finally, we compare our results for housing and land prices.

Estimating the elasticity of house and land prices with respect to city population

Next, using the price of a house per square metre at the centre of city j estimated from equation (11), we estimate:

$$\log \hat{P}_j(0) = X_j\, \beta^P + \xi_j^P\,. \tag{13}$$

Using the price of a square metre of land at the centre of city j estimated from equation (12), we also estimate:

$$\log \hat{R}_j(0) = X_j\, \beta^R + \xi_j^R\,, \tag{14}$$

In both equations (13) and (14), the key explanatory variable of interest in X_j is the log of population of urban area j. That is, the estimation of equation (13) allows us to recover the elasticity of housing prices with respect to city population, ϵ_N^P while equation (14) estimates the elasticity of land prices with respect to city population, ϵ_N^R. Recall from above that we expect $\epsilon_N^P = s_h^L\, \epsilon_N^R$ where s_h^L is the share of land in construction.

Several issues arise in the estimation of equations (13) and (14). The main one is the possible simultaneity between house and land prices and city population. Unusually, let us start our discussion of the identification of these two elasticities by stating what the problem is not. To be clear, the issue is not that some characteristics of urban areas will make them have a large population and, as a result, this will make their land and houses more expensive. This is exactly the logic of the simple model in section 2. For instance, a better climate will increase city population and, as a result, increase the demand for land. Not including climate as an explanatory variable in equation (14) is not a problem, unless climate affects land prices through another channel beyond city population.

As we show below, we can easily rule out reverse-causation where house and land prices determine city population. Instead, we are concerned by potential missing variables that are correlated with population and may determine house and land prices 'directly'. The first possible confounding factor arises from the fact that house and land prices are asset values, not rental values. We expect house and land prices to capitalise future population growth and because future growth is correlated with past growth, it can also be correlated with population. Simply put, fast growing cities are going to be larger and face much higher prices. This concern is easy to address because we can include population growth among the explanatory variables of the regression.

The second set of confounding factors includes the determinants of the demand for housing and land. More attractive cities may not only attract more population but may also face a different demand for housing and land. To return to the example above, a warmer climate may draw more residents and these residents may want to enjoy larger gardens and bigger houses. This could be due to unobserved local characteristics that complement the consumption of housing or to unobserved households characteristics if, for instance, households with a stronger demand for housing sort into smaller urban areas where housing is cheaper.[18] The third set of confounding factor concerns the supply of housing. Some city characteristics such as a greater availability of developable land that make some cities larger may also make them particularly cheap for a given level of population.[19]

To avoid missing variables associated with the demand and supply of housing in French metropolitan areas, our first strategy is to include the main determinants of the demand and supply for land and housing in the regressions corresponding to equations (13) and (14). On the demand side, we include measures of income and other socio-economic characteristics of local residents such as education. We control for these local characteristics both at the municipal level when we estimate city prices in regressions (11) and (12) and at the urban area level when we subsequently estimate equations (13) and (14). At the first stage, municipal characteristics are centred relative to the mean of their urban area because we only want to condition out local effects and not urban-area effects that may be correlated with population.

Regarding the supply of land, we know the land area of French urban areas. This variable may not tell us much about the supply of land available for construction. This may be because

[18] We reckon nonetheless that this is unlikely to be a first-order problem because cheaper housing can be found at the periphery of most urban areas in France.

[19] As we state in the previous paragraph, we are concerned with omitted variables that are "correlated" with population and determine house and land prices. We must draw a subtle distinction here. We are certainly very concerned with missing variables that cause both population and prices. Missing variables that are caused by population and determine prices are more ambiguous. To be concrete, think of restrictive land use regulations that may be imposed as a city grows. We are only concerned with these 'endogenous' regulations when we want to know what happens to house and land prices when population increases, all else equal. If the question is instead about what happens to land and house prices as a city gets larger, 'endogenous' regulations are no longer a concern. Then, an endogenous change in regulation is viewed as part of the effect of population on housing and land prices. We do not find that this distinction makes a detectable difference in our context.

of geographic constraints. This is why we include an extensive set of variables to describe the geography and geology of municipalities and urban areas in our regressions. The availability of land for construction may also be constrained by regulations. Unfortunately, there are, to our knowledge, no publicly available data on land use regulations for the entire country. However, the main instrument used to regulate the intensity of land development in France is a simple floor-to-area ratio and, in this country, land use regulations are national in scope. We can thus proxy for land use regulations by using a measure of the fraction of land that is built up and a measure of the mean floor to area ratio of buildings. Finally, we also use a variety of measures of relative location at a broad spatial scale such as the distance to the main coasts and borders to condition out regional trends in prices.

Despite using an exhaustive set of control variables for local socio-economic characteristics, land use, geography, and geology, there may still be some shocks that affect both population and prices directly. Our second strategy is then to use long term predictors of city population as instruments. These predictors of city population should be immune from reverse causation and from the effects of more recent shocks affecting both population and prices. The instruments we use are 1831 population and some summary measures of long term attractiveness of cities including temperatures in January, the number of hotels and particularly budget hotels (since higher-end hotels in France arguably cater predominantly to the needs of business travellers).[20] We also use a predictor of past growth which relies on the sectoral composition of economic activity in 1990 interacted with the national employment growth of sectors between 1990 and 1999. We expect cities that were specialised in sectors that grew in employment faster between 1990 and 1999 to be larger after 2000.

While we can make the case that these instruments are strong enough predictors of contemporaneous city population, they might still be correlated with land prices through some other channels. We first note that these instruments rely on different sources of variation in the data. Population in 1831, climate, tourism, and expected growth between 1990 and 2000 are arguably different predictor of contemporaneous population size. For instance, the correlation between January temperatures and other instruments is always below 0.20. Second, it is important to keep in mind that we control extensively for the characteristics of municipalities and urban areas.

[20]This is in the spirit of Carlino and Saiz (2008) who argue that tourism visits provide a summary proxy for all amenities in a city.

Hence, to invalidate our instruments, remaining missing variables should be uncorrelated with local socio-economic characteristics, land use, geography, and geology. We also note that because of the long-term nature of our instruments, any failure of the exclusion restriction should work through reasonably permanent unobserved characteristics of urban areas.[21]

Given this, our third strategy is to use only the time variation of prices and population within cities. Interestingly, using changes over time should address, at least partially, concerns regarding the sorting of residents across cities depending on their unobserved preferences for housing. Because we have only six years of data for land prices (and for two of these years, we are missing population data), we can only use this approach for house prices where our study period expands to 12 years. When using the longitudinal variation of house prices and population we can first use fluctuations that arise from the biannual frequency of our house price indices. The main limitation here is that population changes over two year periods may not be well measured. Hence, we can also restrict the estimation to the first and final year of data and use only these longer differences.

Just like population may be simultaneously determined with house prices, changes in population and changes in house prices may also be simultaneously determined, perhaps even more so. To address this, we can instrument population changes using the approach first developed by Bartik (1991) and used by much of the subsequent literature. In essence, we can predict the population growth of cities using the initial structure of sectoral employment of cities interacted with the national growth of sectoral employment. Loosely put, a city with a high fraction of employment in high-end services in 2000 is expected to enjoy more growth from 2000 to 2012 than a city with a high initial share of employment in traditional manufacturing which kept declining over the period. We also develop a parallel approach using the initial structure of employment by occupations and national changes in employment by occupation. This approach is described in greater details in Appendix A.

We note one important caveat. In many economic contexts, a cross-sectional regression and a 12-year difference may be expected to capture the same long-term effects. This is less obvious for housing. Given the long lags in construction and the low frequency at which changes in zoning designations and in the maximum intensity of development take place, we may not estimate exactly the same quantity in cross-section and using 12-year differences. Both estimates should

[21]It is of course always possible to imagine the existence of a missing variable correlated with 1831 population that suddenly started to affect city population after 2000. What such variable might be is less clear.

nonetheless be informative.

Our next issue is that we would like to control for the land area of French urban areas. First, this is likely to be a major determinant of the availability of land for housing. We also think that the relevant question about urban costs regards their increase following an increase in population, keeping land area constant. As already stated, French land use regulations make the expansion of urban boundaries extremely difficult. The problem is then that land area is potentially simultaneously determined with land prices. Given that land area is strongly correlated with urban population, this may affect the coefficient on population. In some specifications, we thus also instrument land area. Because of the high correlation between population and land area (and predictions from land use models that both land area and population should be tightly linked), a strong instrument for population should also be a strong instrument for land area. In additions to the instruments already mentioned, we also use measures of historical urban development, namely population density, that are based on the land area for the same year as for the historical populations.

The last issue is technical. For our second-step dependent variable, we use an estimator instead of its true value. This may affect the standard errors. It is possible to take into account the specific structure of the covariance matrix of error terms in second step using feasible generalised least squares (FGLS). Alternatively, we also computed weighted least squares (WLS) estimates. These two estimation techniques are briefly described in Appendix B.

Estimating the share of housing in expenditure

Recall that the share of housing in expenditure is a key input into the computation of the urban cost elasticity. Using data from a household expenditure survey, we can estimate the following regression,

$$\ln s_i^h = \bar{s}^h + X_{j(i)}\gamma + Y_i\alpha^h + \mu_i \,, \tag{15}$$

where the dependent variable is the share of housing in expenditure for household i, $\bar{s}^h$ is a constant (which represents the average share of housing in the sample provided the other explanatory variables are appropriately centered), $X_{j(i)}$ is a set of explanatory variables for the urban area j where household i lives, and Y_i is a set of household control variables. The main variable of interest among urban area explanatory variables is again log urban area population. Household control variables include demographic characteristics, income, and the distance of their residence to the city center. Standard errors are clustered at the urban area level to be robust to intra-area correlations.

Our most important worry when estimating equation (15) is that our explanatory variable of interest, population, might be determined simultaneously with the dependent variable, the share of housing in expenditure. This is essentially the same identification issue as with the elasticities of house and land prices as the share of housing in expenditure should be affected by house prices. As a result, we employ the same type of strategy as with the elasticties of house and land prices. We are nonetheless more constrained by the data at hand. With only two waves for 2006 and 2011, we cannot reliably use time variations in housing expenditure unlike what we do with house prices.

Finally, we expect housing decisions to be based on permanent income instead of current income. A lack of a measure of permanent income clearly leads to a biased estimate of the effect of income on housing expenditure as the true variable is missing and replaced by a noisy proxy. In turn, this imperfect measure of income may also affect the estimation of the coefficient on urban area population since urban area population and income are correlated given the existence of agglomeration effects. To obtain a better estimate of the sensitivity of the share of expenditure devoted to housing and preclude possible correlations with city population, we can instrument household income by education (or use education as a control to condition out permanent income directly).

5. Comparable house and land prices across French urban areas

The first part of our empirical analysis is to construct house and land prices that are directly comparable across French urban areas. This involves estimating these prices at a central location, controlling for the characteristics of houses or land parcels and for the characteristics of their location within their urban area.

Table 3 reports summary results regarding the estimation of equation (11) for house prices in panel A and equation (12) for land prices in panel B. Column 1 uses only house and parcel characteristics to explain their price per square metre. For houses, recall the we work with indices estimated at the municipal level. Individual house characteristics were already conditioned out to estimate these indices. Unsurprisingly, the explanatory power of variables like the mean municipality floorspace area is low.

For land parcels, we use individual transaction data. Interestingly, parcel area, its square, whether a parcel is serviced, and three indicator variables that relate to the type of intermediary through whom the parcel was purchased have a fairly high explanatory power, explaining about 47% of the variance of land prices per square metre. Although we do not report the details of the coefficients for parcel characteristics in table 3, some interesting features are to be noted. First and foremost, smaller parcels fetch a higher price per square metre. Then, a serviced parcel is more than 50% more expensive than a parcel with no access to basic utilities. Parcels sold by real estate agencies, builders, or other intermediaries are also significantly more expensive since real estate professionals are likely to specialise in the sale of more expensive parcels.

Column 2 of table 3 no longer includes house or parcel characteristics and estimates only fixed effects for urban areas. The urban area where a parcel is located explains about two thirds of the variance of our municipality house price index and more than half of the variance of the unit price of individual parcels. The R^2 is lower for land parcels given the more disaggregated nature of these data. It would be cumbersome to report 277 urban areas fixed effects over 7 years of data. We report instead summary statistics for their distributions after averaging across years. It is interesting to look at the interquartile range. Normalising the mean of all urban area fixed effects to zero, the bottom quartile is at -0.173 for house prices (about 16% below the mean) and at -0.469 for land prices (about 37% below the mean). For the top quartile, the fixed effect for house prices is 0.152 (about 16% above mean) and the fixed effect for land prices is 0.513 (about 67% above the mean). Put differently, the interquartile range is three times as large for land prices as for house prices. We return to this feature below.

Column 3 enriches the specification of column 2 with a distance effect specific to each urban area. Column 4 further includes house or parcel characteristics. While distance gradients appear to differ across urban areas, they are generally negative. Interestingly land price gradients are generally much steeper than house price gradients. For instance, in column 4, the median land price gradient is four times as large as the median house price gradient.

Columns 5 to 8 further include different sets of control variables that pertain to the geography and geology of municipalities (20 variables in total), to their socioeconomic characteristics (including log mean income, its standard deviation, and the share of university-educated residents), to their land use (including the share of land that is built and average height of building), and to

Table 3: Summary statistics from the first step estimation regressions, 277 urban areas

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. Log house prices per m^2									
Urban area effect									
1st quartile		-0.173	-0.207	-0.209	-0.206	-0.208	-0.204	-0.201	-0.201
3rd quartile		0.152	0.156	0.153	0.154	0.181	0.164	0.155	0.173
Log distance effect									
1st quartile			–0.0905	-0.0874	-0.0812	-0.0814	-0.0612	-0.0729	-0.0442
Median			-0.0374	-0.0370	-0.0378	-0.0400	-0.0141	-0.0261	-0.0104
3rd quartile			-0.0006	0.0016	0.0089	-0.0054	0.023	0.0145	0.0228
Observations	74,621	74,621	74,621	74,621	74,621	74,621	74,621	74,621	74,621
R^2	0.01	0.66	0.79	0.80	0.81	0.85	0.80	0.81	0.86
Panel B. Log land prices per m^2									
Urban area effect									
1st quartile		-0.469	-0.573	-0.506	-0.504	-0.453	-0.483	-0.487	-0.439
3rd quartile		0.513	0.489	0.355	0.355	0.386	0.382	0.373	0.414
Log distance effect									
1st quartile			-0.416	-0.239	-0.243	-0.218	-0.198	-0.236	-0.153
Median			-0.262	-0.148	-0.144	-0.143	-0.114	-0.144	-0.089
3rd quartile			-0.153	-0.067	-0.062	-0.083	-0.044	-0.069	-0.035
Observations	204,656	204,656	204,656	204,656	204,656	204,656	204,656	204,656	204,656
R^2	0.47	0.52	0.63	0.82	0.82	0.83	0.82	0.82	0.83
Controls									
House/Parcel charac.	Y			Y	Y	Y	Y	Y	Y
Geography and geology					Y				Y
Income, education						Y			Y
Land use							Y		Y
Consumption amenities								Y	Y

Notes: OLS regressions with year indicators in all columns. All reported R^2 are within-time. Reported distance and urban area effects are averaged over time weighting each year by its number of observations.
For house price indices, house characteristics include log mean area and its square for each municipality. For parcels, characteristics include log area and its square and indicator variables for whether the parcel is serviced and three types of intermediaries through whom the parcel may have been bought. Geography and geology characteristics for municipalities include maximum and minimum altitude, distance to each of the five main rivers (Seine, Loire, Garonne, Rhône, Rhin), distance to each neighbouring country (Spain, Italy, Swirtzerland, Germany, Belgium/Luxemburg), distance to each major body of water (British Channel , Atlantic Ocean, and Mediterranean Sea), four geology variables (erodability, hydrogeological class, dominant parent material for two main classes). Income and education variables of a municipality include: mean income, income standard deviation, share of university degree. Land use variables of a municipality include: share of land that is developed and average height of buildings. Consumption amenities for each municipality are all normalised per unit of population and include: restaurants, supermarkets, primary, secondary, and high schools, medical establishments, doctors, cardiologists, and cinemas. All municipal controls are centered relative to their urban area mean.

their consumption amenities (9 variables in total). These explanatory variables are all centered relative to their urban area mean in order to condition out only municipality effects. Column 9 is our preferred first-step specification. It includes all house/parcel and municipality controls at the same time. Relative to column 2 where only urban area fixed effects are included, the explanatory power is much higher, well above 80% for both house and land prices per square metre.

Importantly, the values of the top and bottom quartiles of urban area fixed effects do not fluctuate much for neither house nor land prices. To show the robustness of these estimated fixed effects, we compute the Spearman rank correlation between the urban area fixed effects estimated in column 2 with no further controls and those estimated in column 9 with a full set of controls (house or parcel characteristics and 34 municipal controls). This rank correlation is 0.96 for house prices and 0.93 for land prices. The corresponding Pearson correlations are similarly high. These high correlations are suggestive that our estimates of prices at the centre of urban areas are insensitive to the exact manner we estimate them.

In further robustness checks, we verify that our results are robust to alternative specifications for the measure of distance to the centre, to an alternative definition of the urban area centre, to considering multiple centres, to ignoring observations that are close to the centre (as there may be some selection on the type of houses or land parcels), or even to ignoring the least expensive houses and land parcels (as they may be misreported for fiscal reasons). The correlations between the fixed effects of column 9 of table 4 for houses and those we estimate in these further robustness checks are also generally high.[22]

In results not reported here, we also consider a housing price index that applies to both houses and apartments. For the estimation of urban area fixed effects for the price of all dwellings with a full set of controls, we find that the Spearman rank correlation with the corresponding house price fixed effects from column 9 of table 4 is again a high 0.91.

We also compute the correlation between the urban area fixed effects we estimate for house prices and those we estimate for land prices. For column 2 with only urban area fixed effects in the regression, the Spearman rank correlation between the two is 0.83. For column 9 with a

[22]For instance, the correlation between the urban area fixed effects estimated in column 9 and panel A of table 4 have a correlation of 0.99 with those estimated from a similar specification which uses distance in levels instead of logs. They also have a similar correlation with fixed effects estimated from a specification which eliminates the 25% of municipalities with the lowest prices in an urban area. We nonetheless find a weaker correlations of 0.67 when using two centers instead of one or of 0.78 when eliminating the 25% municipalities closest to the centre of each urban area. We verify below that our second-step results are robust to these alternative estimates of urban areas.

complete set of controls, it is 0.88. Hence, not only is there a high correlation between house prices or between land prices at the centre of urban areas regardless of how we estimate them but there is also a high correlation between those two series of fixed effects. This is reassuring because the model we propose above (like most models of land development) tightly links the two.

6. The elasticity of unit house and land prices with respect to population

With house and land prices that are comparable across urban areas at hand, we now turn to the estimation of the elasticity of these prices with respect to city population. We start with OLS cross-sectional results before turning to results exploiting alternative sources of variation in the data.

Cross-section estimates

Table 4 reports results for a number of OLS regressions. Panel A uses the estimated price of houses per square meter of floorspace at the centre of urban areas as dependent variable while panel B uses the estimated price of land per square meter. The specifications are otherwise identical across both panels. Columns 1 to 3 use house and land prices recovered from the estimation reported in column 2 of table 3 in the first step as dependent variable. Aside from year effects, column 1 only includes log urban area population and log area as explanatory variables. This is a barebone specification for the second step of our estimation that uses the output of the simplest first-step estimation as dependent variable. The estimated elasticity with respect to population is 0.22 for house prices and 0.77 for land prices. Column 2 also includes population growth, log mean income, log standard deviation of income, and the share of university educated workers as explanatory variables. In both regressions, this slightly lowers the coefficient on log population, to 0.17 for house prices and to 0.70 for land prices. Column 3 enriches the regression further with 20 geography and geology variables and two important land use variables, the share of built up area and the log of the average height of buildings. The coefficient on population declines again modestly in both panels.

Columns 4 to 6 repeat the same pattern of estimation as columns 1 to 3 by gradually considering more complete specifications but use as dependent variable the fixed effects estimated from a more complete regression in the first step. More precisely, the fixed effects for the prices of houses and land parcels are estimated as per column 4 of table 3 using a specification which includes house

Table 4: The determinants of unit house prices and land values at the centre, OLS regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
First-step	Only fixed effects			Basic controls			Full set of controls		
Controls	N	Y	Ext.	N	Y	Ext.	N	Y	Ext.
Panel A. Houses									
Log population	0.217[a]	0.173[a]	0.141[a]	0.259[a]	0.212[a]	0.193[a]	0.255[a]	0.207[a]	0.208[a]
	(0.00712)	(0.00617)	(0.00910)	(0.00830)	(0.00715)	(0.0110)	(0.00799)	(0.00674)	(0.0103)
Log land area	-0.151[a]	-0.176[a]	-0.162[a]	-0.114[a]	-0.142[a]	-0.149[a]	-0.144[a]	-0.172[a]	-0.195[a]
	(0.00817)	(0.00679)	(0.00910)	(0.00952)	(0.00787)	(0.0110)	(0.00916)	(0.00742)	(0.0103)
R^2	0.35	0.56	0.67	0.44	0.62	0.69	0.41	0.62	0.69
Observation	1937	1937	1937	1937	1937	1937	1937	1937	1937
Panel B. Land parcels									
Log population	0.774[a]	0.698[a]	0.664[a]	0.678[a]	0.597[a]	0.597[a]	0.665[a]	0.594[a]	0.624[a]
	(0.0163)	(0.0162)	(0.0259)	(0.0140)	(0.0127)	(0.0205)	(0.0130)	(0.0120)	(0.0193)
Log land area	-0.676[a]	-0.708[a]	-0.713[a]	-0.345[a]	-0.388[a]	-0.430[a]	-0.436[a]	-0.473[a]	-0.537[a]
	(0.0187)	(0.0177)	(0.0259)	(0.0161)	(0.0139)	(0.0204)	(0.0150)	(0.0132)	(0.0192)
R^2	0.54	0.60	0.66	0.63	0.73	0.77	0.61	0.71	0.75
Observation	1933	1933	1933	1933	1933	1933	1933	1933	1933

Notes: The dependent variable is an urban area-year fixed effect estimated in the first step. Columns 1 to 3 use the output of column 2 of table 3. Columns 4 to 6 use the output of column 4 of table 3. Columns 7 to 9 use the output of column 9 of table 3. All reported R^2 are within-time. The superscripts *a*, *b*, and *c* indicate significance at 1%, 5%, and 10% respectively. Standard errors are between brackets. All regressions include year effects. For second-step controls, N, Y, and Ext. stand for no further explanatory variables beyond population, land area, and year effects, a set of explanatory variables, and a full set, respectively. Second-step controls include population growth of the urban area, income and education variables for the urban area (log mean income, log standard deviation, and share of university degrees). Extended controls additionally include the urban-area means of the same 20 geography and geology controls as in table 3 and the same two land use variables (share of built up land and average height of buildings) used in the same table.

or parcel characteristics and a distance effect specific to each urban area in addition to urban area fixed effects and year fixed effects. Columns 7 to 9 repeat again the same pattern of estimation using this time the output of the most complete first step regression from column 9 of table 3. In these three columns, the urban area fixed effects are estimated conditional on house or parcel characteristics and 34 municipality characteristics, including their socioeconomic composition, geography, geology, land use, and amenities. Our preferred OLS estimates are in column 9. They suggest an elasticity of house prices with respect to city population of 0.21 and an elasticity of land prices with respect to city population of 0.62.

As already noted, house and land prices vary with distance to the center. As we will confirm in the next section, income is an important component of the demand for housing. Although we do not report the coefficients on all the control variables in the table, the coefficient on log mean income is always significant and equal to 1.53 in column 9. Once distance to the centre in the first step and income in the second step are included in the regressions, little else appears to affect the coefficient on population. This is not because the coefficients on the other explanatory variables are not significant. Many are. Most notably, a one percentage point of population growth is typically associated with about 10% higher prices for houses. Despite this large effect, including population growth does not affect the coefficient on population because population and population growth are only weakly correlated, in keeping with Gibrat's law. As could be expected, we also find lower prices in urban areas where a greater proportion of the land is built up and where the average height of building is lower.[23] Many of our geographic controls including the distance to the main rivers and various borders have a significant effect. They capture broad trends in land and housing prices in France. We also find that altitude is positively associated with higher prices, arguably because mountains reduce the supply of land. Finally, urban areas with a greater share of more fragile soils (unconsolidated and eolian deposits) have higher land and housing prices for probably similar reasons.

We also note that despite the price of houses or land parcels in the center of urban areas being estimated (with error) in the first step, the R^2 at the second step is high. Regardless of how the first step is estimated, population and land area alone explain between 54 and 63% of the variation of land prices and between 35 and 44% of the variation of house prices. The full set of explanatory variables in column 9 explains 75% of the variation of land prices and 69% of the variation of house prices.

In column 9, the elasticity of land prices is about three times as high as the elasticity of house prices with respect to population. This was to be expected given our findings above that the interquartile range for land prices at the centre is about three times as large as the interquartile range for house prices at the center and that the price of housing at the center of cities is highly correlated with the price of land at the same location.

Recall also that equation (10) above indicates that the elasticity of house prices with respect to population should be equal to the product of the elasticity of land prices with respect to population and the share of land in housing. Hence, the relative magnitude of these two elasticities suggests a

[23] These are urban areas with a more abundant supply of land for housing. Then cheaper land leads to lower constructions.

share of land in housing of about one third. For the new houses built on the land parcels we study here, Combes *et al.* (2016) document a share of land in total construction costs of about 40%.[24] Finding that new housing is slightly more land intensive is perhaps unsurprising. Many older houses in French urban areas were built on small parcels in close suburbs before municipalities started to impose minimum lot size regulations which subsequently became prevalent in France (Comby and Renard, 1996).

To assess the robustness of these OLS results for the cross-section of French urban areas, we duplicate panel A of table 4 for housing prices that pertain to all dwellings instead of only houses. The results are reported in table 10 in Appendix C. This table estimates elasticities of the price of central dwellings with respect to city population which are generally lower than in table 4. This is arguably caused by the lower land intensity of apartments relative to houses. With an elasticity of the price of all dwellings as low as 0.1 instead of 0.2 for houses, the implicit share of land implied by our model is thus half of what it was for houses: one sixth instead of a third. While our companion paper (Combes *et al.*, 2016) can only estimate the share of land for houses and not for all dwellings, these proportions do not strike us as implausible.[25]

In table 10 in Appendix C, we report results for a number of variants of our preferred OLS specification from column 9 of table 4. As dependent variable, we use the urban area fixed effects from alternative first-step specifications that use as explanatory variable the distance to the center in level (instead of in log), the log of distance and its square, an alternative definition of the centre for urban areas, or allow urban areas to have two centres instead of one. The estimated elasticity of house prices with respect to city population remains between 0.19 and 0.28 instead of 0.21 with our preferred OLS. Ignoring the 25% cheapest municipalities or the 25% closest municipalities also implies estimates of the elasticity of house prices in the same range. Because we rely in our second step on a dependent variable that is estimated (with error) in a first step, we also use FGLS and WLS

[24]Combes *et al.* (2016) estimate a share of land in the production of housing services of 20% after correcting for the difference in user costs between land and structure. Land essentially appreciates over time whereas structures depreciate. Combes *et al.* (2016) apply user costs of 3% for land and 6% for structure to account for 2% appreciation for land and a 1% depreciation for structures. These numbers are roughly in line with the 1.5% depreciation rate used by Davis and Heathcote (2005) and the 3% appreciation rate of Davis and Heathcote (2007) for the US. This user cost correction would not be consistent here because house prices are inclusive of the value of land and structure. Ignoring this correction implies a share of land in the value of houses of 40% in France. This share is moderately larger in larger urban areas.

[25]With about 50% of apartments and 50% of single family homes in French urban areas (CGDD, 2011), a coefficient for all dwellings that is half the size of the same elasticity for houses would require apartments to be about one quarter as land intensive as single-family houses for equation (10) to be satisfied. This would occur if multi-family buildings were to offer four times as much floorspace as houses per unit of land and if the more expensive land on which apartments are built (raising measured land intensity) were to offset the higher building costs (raising capital intensity).

Table 5: The determinants of unit house prices and land values at the centre, Within and 2000-2012 difference regressions

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Within area				2000-2012 difference			
First-step	Only fixed effects		Full set of controls		Only fixed effects		Full set of controls	
Controls	N	Ext.	N	Ext.	N	Ext.	N	Ext.
Log population	0.400^{a}	0.324^{a}	0.409^{a}	0.342^{a}	0.681^{a}	0.742^{a}	0.704^{a}	0.780^{a}
	(0.0680)	(0.0987)	(0.0674)	(0.0978)	(0.113)	(0.183)	(0.114)	(0.175)
Within R^2	1937	1937	1937	1937	275	275	275	275
Observations	0.02	0.03	0.02	0.03	0.11	0.12	0.12	0.14

Notes: The dependent variable is an urban area-time fixed effect estimated in the first step. Columns 1, 2 and 5 and 6 use the output of column 2 of table 3. Columns 3, 4 and 7 and 8 use the output of column 9 of table 3. Columns 1 to 4 are within area estimates on time detrended variables, and the R^2 are also within area. Columns 5 to 8 are 2000-2012 difference estimates on time detrended variables and robust standard errors are reported between brackets. The superscripts *a*, *b*, and *c* indicate significance at 1%, 5%, and 10% respectively.

techniques to explicitly account for this measurement error. We remain again in the same range. Instead of using a two step procedure, we can also estimate everything in one step. This last specification estimates an elasticity of house prices with respect to city population of 0.23 instead of 0.21. The difference is again small.

Within and difference estimates

Table 5 reports results for a series of estimations exploiting the variation in house prices and in urban area population over time. We do not use land price data here because they are only available for a short time period (2006-2012) instead of 2000-2012 for house price data.

Column 1 of table 5 adds city fixed effects to the specification of column 1 of table 4. Column 2 further includes the time-varying explanatory variables among those used in column 3 of table 4. These explanatory variables are population growth, log mean municipal income, its standard deviation, and the share of university graduates. Columns 3 and 4 of table 5 duplicate columns 1 and 2 of the same table but use urban area fixed effects estimated from the more complete estimation of column 9 of table 3 as dependent variable.

The estimated house price elasticity is about 0.4 in column 1 and 3 and about 0.3 in columns 2 and 4 with time-varying controls. The estimate of 0.34 in column 4 of table 5 is larger than the corresponding cross-sectional estimate of 0.21. At the same time, the standard error associated with the within estimate is about 0.10 so that the difference between these two coefficients is insignificant at the 10% confidence level.

Columns 5 to 8 of table 5 also estimate the elasticity of house prices with respect to population but use only the 2000-2012 difference. The specifications in these four columns otherwise mirror those of columns 1 to 4 of the same table. The coefficient on population now ranges from 0.69 in column 5 to 0.78 in column 8. This is much larger than previously. This said, the standard errors are also larger since this estimation relies only on 275 observations corresponding each to one 2000-2012 difference. But even with a standard error of 0.18, the elasticity of 0.78 estimated in column 8 is both larger than the corresponding within elasticity of 0.34 in column 4 of the same table and larger than the cross-section elasticity of 0.21 from column 9 of table 4. We attribute the difference in the estimated elasticity of house price with respect to population between the first and second half of table 5 to measurement error for population over two-year intervals or to the fact that tensions on the housing market may start occurring before population starts to increase.

The larger numbers we estimate for the 2000-2012 change relative to the cross-section estimates of table 4 are most likely due to the fact that housing supply is slow to adjust since a change in demand may take time to be perceived by house builders, obtaining a building permit takes time, and building a house also takes time. Beyond this, new housing often requires a change in the zoning designation (conversion from agricultural to residential or from commercial/manufacturing to residential). These changes are infrequent in France.[26]

Instrumental-variable estimates

Table 6 reports results for a series of IV regressions using a number of instruments for population and land area. We estimate all our IV regressions with limited information maximum likelihood (LIML) instead of two-stage least squares (TSLS) because the one-stage LIML procedure provides more reliable point estimates and test statistics with weak instruments. Weak instruments is not an issue in table 6 but it occurs below. As illustrated by the results reported in table 6, there is some variability in the coefficient we estimate for instrumented log population. It ranges from 0.12 in column 6 to 0.40 in column 4. We note that the estimates in column 1, 2, and 5 are very close to

[26]For instance, a consultation regarding a new urban master plan for Lyon and 58 surrounding municipalities in the same urban area was launched early 2012 and is not expected to end before late 2017 for this plan to become effective after 2020. (`http://blogs.grandlyon.com/mavilleavenir/download/3127/`, consulted on 2 June 2016.)

Table 6: The determinants of unit house prices at the centre, IV estimations

	(1)	(2)	(3)	(4)	(5)	(6)
First-step controls	Yes	Yes	Yes	Yes	Yes	No
Second-step controls	Yes	Yes	Yes	No	No	Yes
Log population	0.198[a]	0.213[a]	0.404[a]	0.405[a]	0.214[a]	0.119[a]
	(0.0384)	(0.0279)	(0.0314)	(0.0407)	(0.0107)	(0.0242)
Log land area	-0.149[a]	-0.139[a]	-0.364[a]	-0.290[a]	-0.0866[a]	-0.0935[a]
	(0.0401)	(0.0311)	(0.0318)	(0.0514)	(0.0114)	(0.0269)
First-stage statistic	58.7	143.8	122.4	24.9	822.9	143.9
Overidentification p-value	0.05	0.07	0.52	0.33	0.12	0.18
1st Shea part. R2, population	0.12	0.22	0.16	0.05	0.56	0.22
1st part. Fisher, population	803	726	960	1,827	1,490	726
1st Shea part. R2, land area	0.11	0.19	0.17	0.04	0.66	0.19
1st part. Fisher, land area	740	526	1,046	1,009	2,955	526
Instruments						
January temperature	Y	Y	N	Y	Y	Y
Number of hotel rooms	Y	N	Y	Y	N	N
Share of one-star hotel rooms	Y	N	Y	Y	N	Y
Number of movie-theaters	Y	N	N	N	N	N
Urban population in 1831	N	Y	N	N	Y	Y
Urban population density in 1881	N	N	Y	N	Y	N
Bartik industry 1990-1999	N	Y	N	N	N	Y
Observations	1,937	1,937	1,937	1,937	1,937	1,937

Notes: [a]: significant at 1% level; [b]: significant at 5% level; [c]: significant at 10% level. All estimations are performed with LIML. The first-step controls are the same as in column 9 of table 3. The second-step controls correspond to the extended controls used in columns 3, 6, and 9 of table 4.

their OLS counterparts at around 0.20. From these estimates and many others we did not report here, it appears that the IV estimates are on average about 20 to 30% larger than their OLS. This difference would be consistent with the idea that population growth takes place in urban areas where housing is cheaper.

A similar patterns appears for land prices in the first two columns of table 7 where we estimate the elasticity of land prices with respect to population to be about 0.8 instead of 0.6 in OLS. Again, we estimate IV coefficients that are on average about 20 to 30% larger than the corresponding OLS coefficients.

Finally, the last four columns of table 7 report results for which the 2000-2012 change in population is instrumented using predicted changes in employment that arise from the initial structure of employment by occupation or by sectors of urban areas interacted with national

Table 7: The determinants of unit property prices and land values at the centre, IV estimations for land prices and houses prices in difference

	(1)	(2)	(3)	(4)	(5)	(6)
Dwelling type	Land	Land	Houses	Houses	Houses	Houses
First-step controls	Yes	Yes	Yes	No	Yes	No
Second-step controls	Yes	No	No	No	Yes	Yes
Log population	0.781^a	0.801^a	0.947^a	0.956^a	1.936^a	1.993^a
	(0.0406)	(0.0458)	(0.284)	(0.290)	(0.721)	(0.745)
Log land area	-0.626^a	-0.546^a				
	(0.0381)	(0.0567)				
First-stage statistic	223.6	55.1	15.9	15.9	9.1	9.1
Overidentification p-value	0.05	0.07	0.10	0.11	0.90	0.88
1st Shea part. R2, population	0.38	0.15	0.19	0.19	0.06	0.06
1st part. Fisher, population	515	1057	15.9	15.9	9.1	9.1
1st Shea part. R2, Land area	0.42	0.13				
1st part. Fisher, Land area	647	657				
Instruments						
Number of hotel rooms	Y	Y	Y	Y	N	N
Share of one-star hotel rooms	Y	Y	N	N	N	N
Urban population in 1831	N	N	Y	Y	N	N
Urban population density in 1831	N	Y	N	N	N	N
Urban population density in 1881	Y	N	N	N	N	N
Bartik industry 1999-2011	N	N	Y	Y	Y	Y
Bartik occupation 2006-2011	N	N	Y	Y	Y	Y
Observations	1,933	1,933	275	275	275	275

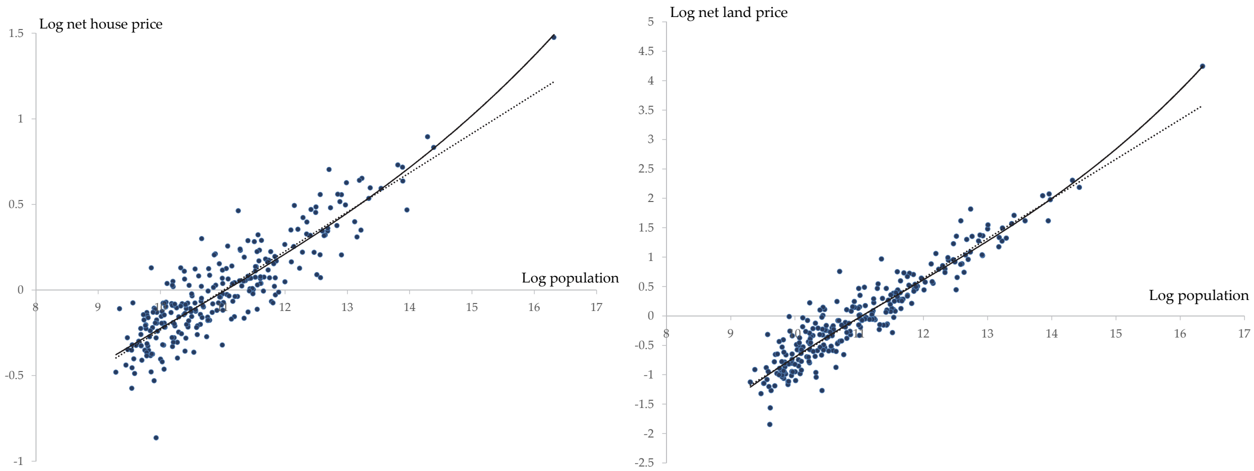
Notes: ^{a}: significant at 1% level; ^{b}: significant at 5% level; ^{c}: significant at 10% level. All LIML estimations The first-step controls are the same as in column 9 of table 3. The second-step controls correspond to the extended controls used in columns 3, 6, and 9 of table 4.

changes in employment by sector or occupation (see Appendix A for details). Depending on the exact specification, we estimate coefficients that are about the same as for the 2000-2012 differences or between two and three times as large. We note nonetheless that the instruments are marginally weak for these specifications and the standard errors are much larger. Hence, despite different point estimates in some specifications, we do not reject that the IV estimates in the last four columns of table 7 are equal to our preferred uninstrumented estimate of 0.78 in column 8 of table 5.

Non-constant elasticities

Given that we are interested in how the elasticity of urban costs varies with city population, we worry whether it is appropriate to estimate a constant elasticity of house or land prices with respect

Figure 3: Log house and land prices (component plus residual) and log city population



Panel (a): House prices

Panel (b): Land prices

Notes: The horizontal axis in both panels represents log urban area population. The vertical axis represents the residual of the regression of column 9 of table 4 plus log urban area population multiplied by its estimated coefficient. The dependent variable is house prices at the center of urban areas in panel (a) and the corresponding land prices in panel (b). The plain continuous curve is a cubic trend line. The dotted line is a linear trend. Mean prices across all urban areas are normalised to zero in both panels.

to city population as we have done so far. In panel A of figure 3, we provide a 'component plus residual' plot where we represent the price of housing after conditioning out explanatory variables other than population on the vertical axis and log urban area population on the horizontal axis.[27] In panel B of figure 3, we provide a similar 'component plus residual' plot for land prices. Each plots also contains two trend lines: a linear and a cubic.

In panel A, for log population below 14, which corresponds to 1.2 million inhabitants, the two trend lines are extremely close but they diverge for extremely large cities because Paris is unusually expensive for its population relative to a log linear trend. A similar but milder concavity is also apparent for land prices.

To explore this issue further, table 12 in Appendix C reports results for a series of regressions where we introduce terms of higher order for log population. These terms are usually significant. For the OLS specification of column 4 where log population is also included with a quadratic term, we estimate an elasticity of house prices with respect to city population of 0.21 for a city with 100,000 inhabitants, an elasticity of 0.26 for a city with a million inhabitants, and 0.32 for a city

[27]For the preferred OLS specification of column 9 of table 4, we compute the sum of the residual and log population multiplied by its estimated coefficient.

with the same population as Paris. The other specifications yield roughly similar estimates for the first two cities. There is some variability for a city with the same population as Paris given that Paris is a population outlier in France.

To summarise our findings, our cross-sectional estimates of the elasticity of house prices at the centre of urban areas with respect to population are mostly in a 0.17-0.27 range with a preferred estimate at 0.21. We also find that this elasticity may increase with city population ranging from about 0.21 for a small urban area of 100,000 inhabitants to 0.32 for Paris. Instrumental variable estimates tend to vary more but they are on average larger by 20 to 30%. We find larger estimates for the elasticity of house prices when using the time dimension. Our preferred estimate for the 2000-2012 difference is 0.78, which reflects the slow adjustment in the supply of housing in France.

7. The share of housing in expenditure

We now turn to the estimation of the share of housing in household expenditure. Davis and Ortalo-Magné (2011) estimate the share of housing relative to income to be constant across cities at about 0.24 for renters in US metropolitan areas.[28] We want to estimate the same relationship for the expenditure share of housing in French urban areas.

Housing represents a constant share of expenditure across cities of different sizes when the price elasticity of housing demand is equal to minus one. While a unit price elasticity of demand may be a reasonable approximation for many purposes, small deviations from it can have a sizeable effect on our estimates of urban costs as we show below.

Table 8 reports results for the pooled sample of homeowners and renters in the French household expenditure surveys for 2006 and 2011. Column 1 regresses the share of housing in expenditure on household demographic characteristics, (log) household income, and (log) urban area population. We estimate a coefficient on city population of 0.028. Column 2 also includes distance to the city centre. Columns 3 and 4 further enrich the regression by including log land area, population growth, and a number of further controls to take into account urban area geographic characteristics and municipality geology, land use, and amenities. The coefficient on population

[28] A replication of this exercise by CGDD (2011) estimates a share of 0.23 of GDP devoted to housing for French urban areas.

Table 8: The share of housing in expenditure for homeowners and renters

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log population	0.028[a]	0.031[a]	0.037[a]	0.039[a]	0.036[a]	0.047[a]	0.067[a]	0.048[a]
	(0.001)	(0.001)	(0.005)	(0.007)	(0.007)	(0.011)	(0.010)	(0.008)
Log land area			-0.011	-0.017[b]	-0.020[a]	-0.025[b]	-0.043[a]	-0.025[a]
			(0.007)	(0.007)	(0.006)	(0.010)	(0.010)	(0.008)
Population growth			2.767[a]	2.694[a]	2.503[a]	2.521[a]	2.121[a]	2.502[a]
			(0.562)	(0.640)	(0.679)	(0.665)	(0.692)	(0.649)
Log distance to city centre		-0.008[c]	-0.008	-0.006[b]	-0.003	-0.008[a]	-0.013[a]	-0.008[a]
		(0.005)	(0.005)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Log income	-0.282[a]	-0.284[a]	-0.283[a]	-0.286[a]	-0.170[a]	-0.286[a]	-0.286[a]	-0.286[a]
	(0.013)	(0.012)	(0.012)	(0.011)	(0.012)	(0.011)	(0.011)	(0.011)
First-stage statistic					158.0	112.5	6.6	17.2
Overidentification p-value					0.09		0.03	0.00
1st Shea part. R2, income					0.15			
1st part. Fisher, income					158.0			
1st Shea part. R2, population						0.39	0.33	0.52
1st part. Fisher, population						112.5	10.0	21.5
Instruments								
Degree					X			
Urban population in 1831						X		X
Consumption amenities							X	X
Local controls	No	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.56	0.56	0.56	0.57				

Note [a]: significant at 1% level; [b]: significant at 5% level; [a]: significant at 10% level. All R^2 are within time. 8,446 observations in each regression corresponding to 197 urban areas. All variables are centered and the estimated constant, which corresponds to the expenditure share in a city of average size (2.99 million inhabitants), takes the value 0.325 in all specifications. Regressions are weighted with sampling weights and include: age and indicator variables for year 2011 (ref. 2006) and homeowner (ref. renter), living in couple within the dwelling (ref. single), one child, two children, three children and more (ref. no child). Standard errors are robust to intra-area correlations. Local controls include the same geography variables for urban areas as in table 4 and the same geology, land use, and amenity variables at the municipality level as in table 3 and they are centered with respect to their urban area mean. The instruments are the same as in table 6. The education instruments are five indicator variables corresponding to PhD and elite institution degree,master, lower university degree, high school and technical degree, lower technical degree, and primary school (reference). All instrumented regressions estimated with limited information maximum likelihood (LIML).

increases slightly to 0.039.[29]

As already mentioned, we expect housing decisions to be based on permanent income instead of current income. This may affect our results because income and urban area population are correlated. Column 5 duplicates column 4 but instruments for income using five indicator variables for educational achievement. This lowers the magnitude of the coefficient on income but does not

[29]Most of the change in the coefficient on city population between columns 2 and 3 of table 8 is due to the inclusion of land area into the regression. Recall that land area is strongly positively correlated with city population.

appear to affect the rest of the regression.[30] In particular, the coefficient on population in column 5 only marginally differs from its counterpart in column 4.

Column 6 of table 8 instruments contemporaneous urban area population by urban area population in 1831. The point estimate on population modestly rises from 0.039 with OLS in column 4 to 0.047. These two coefficients are only about one standard deviation apart. Column 7 instruments population using urban area amenities as previously using the overall number of hotels and the number of low-end hotel rooms per population.[31] This leads to a slightly higher coefficient on city population of 0.067. While this larger coefficient does not really affect our conclusions as we show below, we should keep in mind that the instruments are somewhat weak in that case.[32] Finally, column 8 uses both amenities and past population as instruments to estimate a coefficient of 0.048 for population.

These small variations in the coefficient for urban area population make no economically meaningful difference to our final results. With a mean share of housing in expenditure of 0.325 for a mean urban area of 2.99 million inhabitants, our preferred coefficient of 0.048 from column 8 implies a share of housing in expenditure of 39.2% for a city with the same population as Paris and a share of 16.2% for an urban area with only 100,000 inhabitant. Retaining a population coefficient of 0.028 as in column 1 rather than 0.048 implies a share of housing in expenditure of 36.4% for a city with the same population as Paris. At the other extreme, a population coefficient of 0.067 as in column 7 implies a housing share of 41.9% for a city with the same population as Paris. These predicted shares of housing for a large urban area with a population slightly above 12 million differ by no more than 6 percentage points or about 15% of their value. Focusing on large urban areas is important because we are interested in the elasticity of urban costs when cities get large.

We may also worry that these results for the joint sample of homeowners and renters may mask some important heterogeneity between the two groups. To gain insight into this issue, we duplicate the results of table 8 separately for homeowners and renters in the two panels of table 13 in Appendix C. We first note that, unsurprisingly, renters are more prevalent than homeowners

[30] The overidentification test rejects that all the indicator variables we use for educational achievement yield the same answer. This is not a preoccupation here given that our focus is on the population coefficient. This rejection is due to the strong power of these instruments. Transforming these indicators of educational achievement into an equivalent number of years of education would obviously make this issue disappear.

[31] When using amenities as instruments at the urban area level, we include a measure of the same variables at the municipal level as explanatory variables in the regression. All our explanatory variables are centred relative their urban area means to condition out only for municipal effects.

[32] Moreover, the regressions of table 8 can exploit data from only 197 urban areas instead of 277 previously when estimating the elasticity of house and land prices with respect to population.

in larger urban areas. The difference is nonetheless modest as mean urban area population is 2.94 million for homeowners instead of 3.12 million for renters. A comparison of the two samples of renters and homeowners also indicates that renters devote a slightly larger share of their income to housing than homeowners.[33]

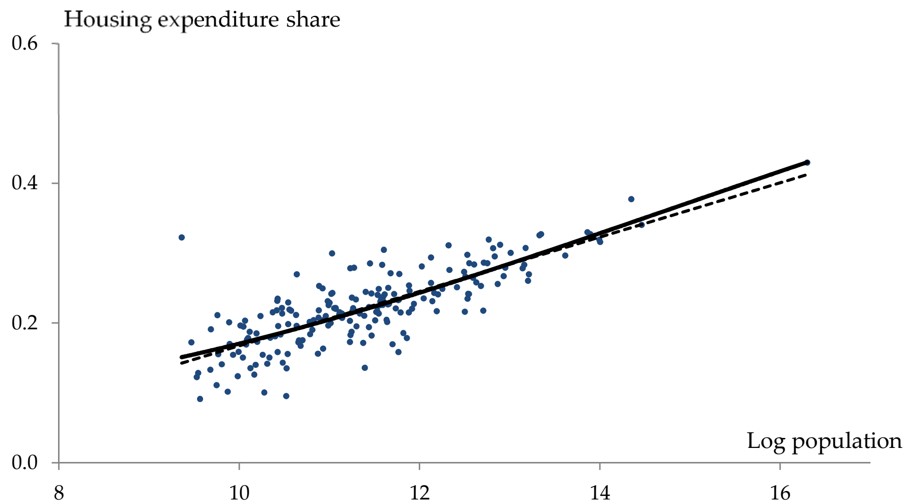
Turning to the coefficients on city population, we find that they are very close for renters and homeowners in most OLS specifications. Modest differences arise when we instrument for population. We estimate coefficients of 0.055 for homeowners and 0.034 for renters instead of 0.048 for the pooled sample of column 8 of table 8. While the coefficients for renters and homeowners differ, they are less than two standard deviations apart. They are also included in the same range of coefficients that we estimate for the pooled sample across the different specifications of table 8.

In results not reported here, we also experimented with instrumenting for land area using 1881 population density in addition to population. This does not affect our results in any major way. For instance, we estimate a coefficient on city population of 0.039 for city population instead of 0.048 in column 8 of table 8 when also instrumenting for land area. We also experimented with including education directly as a control variable to condition out elements of permanent income instead of instrumenting. This does not affect the coefficient on urban area population. Using education as a control variable to the specification of column 4 of table 8 leads to a coefficient 0.033 for population instead of 0.036 in column 5 where it is used as instrument.

Our last worry is that when we regress a share (of expenditure) on a log (population) we may not capture well the increase in housing expenditure associated with a larger city population. In figure 4, we provide a 'component plus residual' plot where we represent the share of housing in expenditure after controlling for other controls on the vertical axis and log urban area population on the horizontal axis. The figure also contains two trend lines, linear and cubic. As made clear by the figure, the two trends are virtually undistinguishable except for the very top of the distribution. More specifically, it is only for Paris that we observe a small deviation from linearity. The difference between the linear and cubic trends is just 2 percentage points. The second largest difference is for Lyon but it is already below 1 percentage point. Consistent with this, the difference in explanatory power between the cubic and linear trends is small. We have an R^2 of 63.1% for the

[33]This difference remains somewhat modest at about 4 percentage points after we account for the difference in mean city population. This difference even flips signs if we also account for income differences across both groups. Overall, these results suggest small differences between the two groups.

Figure 4: Share of housing in household expenditure and log city population



Notes: The horizontal axis represents log urban area population. The vertical axis represents the urban area median of the residual of column 4 of table 8 plus log urban area population multiplied by its estimated coefficient. The plain continuous curve is a cubic trend line. The dotted line is a linear trend.

cubic instead of 62.8% for the linear trend line. Hence, we conclude that our log linear specification provides an accurate first-order description of the relationship between housing expenditure and city population, except for Paris that deviates modestly.

8. The elasticity of urban costs with respect to population

Recall that we define urban costs as the increase in the cost of living in a given city when its population increases keeping utility constant. In section 2, we show that after making two empirically plausible simplifications, the elasticity of urban costs with respect to city population can be written at the spatial equilibrium within the city as the product of the elasticity of the price of housing at the center and the share of housing in expenditure.[34] Importantly, this result holds regardless of how housing enters the utility function provided some basic regularity conditions are satisfied to ensure that the consumer problem is well behaved.

Our results regarding the share of housing in expenditure are reasonably straightforward. At the sample mean, the share of housing in expenditure is 0.325. This corresponds to a city of 2.99 million inhabitants. Using the share of household expenditure devoted to housing as dependent

[34]The two simplifications are that the price of goods is constant across cities and travel costs at the centre of cities can be neglected. Should these two simplifications be unwarranted despite extent evidence, we would measure a more partial aspect of urban costs.

Table 9: The elasticity of urban costs

	City 1 (pop. 100,000)			City 2 (pop. 1m)			City 3 (pop. Paris)		
Slope of the housing share	0.030	0.047	0.06	0.030	0.047	0.06	0.030	0.047	0.06
Panel A. Housing share									
Share of housing in expenditure	0.223	0.165	0.121	0.292	0.274	0.259	0.367	0.391	0.409
Panel B. Urban costs elasticity									
Allowing for urban expansion	0.016	0.011	0.008	0.020	0.019	0.018	0.026	0.027	0.028
Constant boundaries, OLS	0.046	0.034	0.025	0.061	0.057	0.054	0.076	0.081	0.085
Constant boundaries, IV	0.058	0.043	0.031	0.076	0.071	0.067	0.095	0.102	0.106
Constant boundaries, non-linear	0.048	0.035	0.026	0.077	0.072	0.068	0.116	0.123	0.129
12-year adjustment	0.174	0.129	0.094	0.228	0.213	0.202	0.286	0.305	0.319

variable, our preferred estimate for the coefficient on log city population is 0.047. For our computations of urban costs, we also consider a lower estimate of 0.03 and a higher estimate of 0.06. This conservative range accounts for our findings that the coefficient on population is lower for renters and when using OLS and higher for homeowners and with IV.

We consider three cities. A small city with 100,000 inhabitants, a larger city with a million inhabitants, and a large city with a population equal to that of Paris, slightly above 12 million. The predicted share of housing in expenditure for these three cities associated with the three scenarios described above are reported in panel A of table 9. Regarding a city like Paris or a city with a million inhabitants, the predicted share of housing in expenditure is only modestly affected by the value we consider for the population slope. Differences are larger for a city with 100,000 inhabitants.

Turning to the elasticity of house prices with respect to city population, we consider five different situations. First, we allow cities to increase their land area when population grows. Recall that our preferred OLS coefficients from column 9 of table 4 are 0.21 for log population and -0.20 for log land area. As cities grow in population, their land area does not grow proportionately. Consistent with the predictions of standard urban models, cities with a greater population are also denser cities. In our data, regressing log land area on log population estimates a coefficient of 0.71. Hence, a 1% increase in population should lead to a $(0.21 - 0.71 \times 0.20)\% = 0.07\%$ increase in house prices.

The second situation corresponds to an increase in population without urban expansion. We think this is empirically a better approximation of the current situation in France where planning regulations strongly favour densification and in-filling relative to the expansion of urban boundaries. For this second situation, we retain our preferred OLS estimate from column 9 of table 4 of 0.21 for log population. Our third situation assumes a stronger effect of city population on house prices. In line with the average of our IV results, we consider an effect 25% larger. Our fourth situation allows for some log convexity in the relationship between log house prices and log population. We use our preferred estimates from a regression with a quadratic term in log population where we use log 1831 population and its square as instrument. This specification implies an elasticity of house prices with respect to population of 0.21 for a city with 100,000 inhabitants, an elasticity of 0.26 for a city with a million inhabitants, and 0.32 for a city with the same population as Paris. Finally, the last situation we consider is a shorter-term situation where we do not allow housing supply to fully adjust. We use the higher elasticity of housing prices with respect to population of 0.78 estimated using the twelve-year variation in house prices and population from column 8 of table 5.

The urban costs elasticities implied by the various scenarios we consider for the elasticity of urban costs with respect to population are reported in panel B of table 9. Because our results are not sensitive to the exact manner we estimate how the share of housing in expenditure depends on population, we concentrate our comments on the other two dimensions, the population size of cities and the elasticity of house prices with respect to city population.

Our first finding is that the elasticity of urban costs increases with population size. This is true for all rows of panel B of table 9. This finding is primarily driven by the increase in the housing expenditure share as we consider larger cities. Even with a slope of the housing share relative to log population as low as 0.03, the housing share in a city like Paris is 50% larger than in a city with 100,000 inhabitants. With our preferred slope of 0.047, this ratio is above two. With an even steeper slope of 0.06, this ratio is just above three. In row 4 of panel B, the higher urban costs elasticity in larger cities is also explained by the log convexity of the relationship between the prices of houses and population, which we uncovered some evidence of.

This evidence of rising urban costs with city population is consistent with the 'fundamental tradeoff of spatial economics' (Fujita and Thisse, 2002). Extent literature about agglomeration effects usually regresses log wages or other productivity outcomes on log city population or density and never highlighted much evidence of a deviation from log linearity (Combes and Gobillon, 2015). This is in particular the case for the estimation of agglomeration effects in France (Combes *et al.*, 2008, 2010). Some convexity for urban costs is thus consistent with an inverse U-shape where agglomeration effects may initially dominate but eventually get trumped by urban costs.

We now turn to the differences across rows in panel B of table 9. While the elasticities reported in this panel appear to differ greatly, we must keep in mind that they reflect three different thought experiments. The first row allows for a full adjustment of cities to population growth including a physical expansion. The next three rows consider the effect of an increase in population keeping land area constant. Finally, the last row considers a '12-year effect' over which housing supply may not fully adjust.

Starting with the first row, the elasticity of urban costs with respect to city population is about 0.01 for a city with 100,000 inhabitants, 0.02 for a city with a million inhabitants, and slightly below 0.03 for a city of the size of Paris. These figures indicate that in the long run and if cities can adjust their physical footprint, the costs of urban expansion are low. With an elasticity of wages with respect to city population of about 0.025 (Combes *et al.*, 2008), our results indicate that in the long run the inverse U-shape associated with the fundamental tradeoff of spatial economics is extremely flat. Cities appear to operate close to constant returns in the long run when they can adjust their land area. A flat inverse U-shape also suggests that this long-run tradeoff will be empirically weak to explain the growth of cities. Finally, having most cities facing an elasticity of urban costs below their agglomeration elasticity is also suggestive that the vast majority of cities may be undersized relative to the population size that would maximise their productive efficiency.

If we take seriously the notion of a spatial equilibrium across cities as described by equation (6), the difference between the urban cost elasticity and the agglomeration elasticity should be equal to the change in willingness to pay for amenities as city population increases. This difference is negative for small cities and becomes positive for a cities with a size between Lyon and Paris. In a spatial equilibrium framework, we should interpret our results as indicating that amenities are getting mildly worse as cities of a larger size are considered (as wages increase faster than urban costs) with a reversal between Lyon and Paris (as urban costs start increasing faster than wages). The key is nonetheless the small size of these effects, an interpretation consistent with the results of Albouy (2008, **?**) for US cities.

We turn next to the urban costs elasticities associated with an increase in population for given land area, which is an increase in density. While we obtained a variety of estimates for the underlying house price elasticity and share of housing in expenditure, the results are fairly consistent. For a small city with 100,000 inhabitants, the urban cost elasticity is between 0.03 and 0.06. For a city with a million inhabitants, the urban cost elasticity is between 0.05 and 0.08. Finally, for a city with the same population as Paris, the urban cost elasticity is between 0.08 and 0.13. Preventing cities to adjust spatially and constraining population growth to take place only through densification makes urban costs larger by a factor of three to four. These higher urban costs are also suggestive that population in most cities is too large if they cannot expand their footprint. This is because the urban costs elasticities associated with higher densities tend to be larger than extant estimates of the elasticity of wages with respect to population density of about 0.03 (Combes *et al.*, 2010). A net cost of rising density would in turn suggest that amenities are getting modestly better with population density at the spatial equilibrium.

Finally, the last row reports urban costs elasticities that rely on the 2000-2012 variations in house prices and population. The much higher point estimates for the elasticity of house prices with respect to population lead to much higher estimates for the urban costs elasticity: 0.09-0.17 for a city with 100,000 inhabitants, 0.20-0.23 for a city with a million inhabitants, and 0.29-0.32 for a city with the same population as Paris. Although we should keep in mind the large standard errors around the estimated elasticity of house prices using time differences, these figures are suggestive of large urban costs before the supply of housing can adjust which may take many years in the French context. While these effects appear large, we note that they are consistent with the large coefficients we estimate when we use annual population growth as an explanatory variable for house prices. All else equal, a city that grows by one percentage point more has houses that are about 10% more expensive.[35]

Again, these large elasticities of urban costs in the 'short run' should be taken with caution given the large standard errors of the underlying estimates. They are nonetheless indicative of potentially extremely large frictions in the housing market. As a result, population will take extremely long to adjust following the economic shocks that affect cities. Workers may end up residing where housing is affordable and not where they are the most economically productive or where amenities are the highest.

[35]Using a simple asset pricing model where the price of a house is the discounted sum of future rents, this figure should reflect both the contemporaneous increase of rents as well as the net present value of future increases in rents. In the extreme situation of no adjustment of the housing stock and a discount rate of 5%, a 10% more expensive house capitalises an annual increase in rents of 0.5% in perpetuity. That is a 1% increase in population is associated with a 0.5% increase in housing costs. This points to an implicit elasticity of house prices with respect to city population consistent with our 2000-2012 difference estimates.

9. Conclusion

This paper develops a new methodology to estimate the elasticity of urban costs with respect to city population. Our model derives this elasticity as the product of two terms: the share of housing in consumer expenditure and the elasticity of the price of houses at the centre of cities with respect to city population. In turn, this elasticity is also the product of the share of land in housing and the elasticity of the price of land in the centre of cities with respect to city population.

Using data for French urban areas, we estimate that the elasticity of house prices with respect to city population is between 0.2 and 0.3 in cross section and it is perhaps higher for larger urban areas than for smaller urban areas. We also estimate that the elasticity of land prices with respect to city population is between 0.6 and 0.8, consistent with a share of land in housing of about a third (Combes *et al.*, 2016). Finally, we estimate that the share of housing in expenditure varies from around 0.2 or less in small urban areas with 100,000 inhabitants to about 0.40 in a city with more than 12 million inhabitants like Paris.

These findings imply elasticities of urban costs from about 0.04 for an urban area with 100,000 inhabitants to 0.10 for an urban area of the size of Paris. These figures refer to an increase in population, keeping land area constant (i.e., higher density). We think these are the relevant magnitudes to consider in France during our study period as planning regulations strongly discourage urban expansions. Allowing land area to adjust following population increases in cities leads to urban costs elasticities which are smaller by a factor of three to four. Looking at changes within cities over time leads instead to much larger estimates of the urban cost elasticity as housing supply takes long to adjust.

Given the existence of agglomeration benefits with a constant elasticity of urban incomes with to city population, higher elasticities of urban costs in larger cities are consistent with the 'fundamental tradeoff of spatial economics' according to which cities face a region of increasing returns where agglomeration gains dominate urban costs followed by a region of decreasing returns as we consider larger population sizes. This tradeoff may play nonetheless a minor role in explaining the evolution of cities. In the short run, the adjustment of housing supply is expected to play a major role. This is consistent with what we know about urban growth (Duranton and Puga, 2014). In the long run, the inverse U-shape of urban efficiency as a function of population is extremely flat so that cities may deviate greatly from their efficient size without leading to large economic losses.

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Appendix A. Data description

Notary database. As mentioned in the main text, the floor area is missing for 25.7% of dwellings that appear in the data. It can be imputed from the FILOCOM repository, which is constructed from property and income tax records. This repository contains information about all buildings in France. For dwellings with missing floor area, our imputation attributes the average floor area of all dwellings with the same number of rooms in FILOCOM and in the same cadastral section which were involved in a transaction during the same year. This imputation is conducted separately for houses and apartments. It reduces the number of observations with missing floor area to 5.1% (but not to zero as the match with FILOCOM is not perfect). Dwellings for which the floor area cannot be recovered are dropped from the sample. With about 270,000 cadastral sections in France, this imputation is fairly accurate. We can assess this formally by imputing a floor area to all dwellings, including those for which this quantity is observed. Comparing actual and imputed floor areas, the average error is around 5%, and the R^2 of the regression of actual floor areas on imputed ones is about 0.75. Note that accuracy is higher for houses than for apartments since the average error is 2% for the former and 15% for the latter.

Enquête sur le Prix des Terrains à Bâtir (EPTB). While the data is put together by the French Ministry of Sustainable Development, the sample is composed of land parcels originally drawn from Sitadel, the official registry which covers the universe of all building permits for a detached house. Houses must include only one dwelling. Permits for extensions to existing houses are excluded.

Over the 2006-2009 period, parcels are drawn randomly from each municipal strata (about 3,700 of them) which corresponds to a group of municipalities (about 36,000 in France). Overall, two thirds of the permits are surveyed. Some French regions paid for an exhaustive survey: Alsace, Champagne-Ardennes, Île-de-France, Poitou-Charentes and Pays de la Loire (for Loire-Atlantique and Vendée départements). From 2010 onwards, the survey is exhaustive for the entire country.

Population. We have access to data on population at the municipality level for the 1982, 1990, and 1999 general censuses. For every other year from 2000 to 2012, we use the FILOCOM repository that is managed by the *Direction Générale des Finances Publiques* of the French Ministry of Finance. This repository contains a record of all housing units and their occupants. This is a better source of 'high-frequency' population data than the permanent rotating census of population, which replaced the general census in 2004 and surveys 20% of the population of large municipalities every year and smaller municipalities every five years.

Labour force administrative records. We use detailed information from the 1/4 sample of the 1990 census and the 1/20 sample of the 1999 census to construct measures of employment (by municipality of residence) by 4-digit occupational category and by 4-digit sector for each urban area (weighting by survey rates for the data to be representative of the whole population of occupied workers). The resulting aggregates are used to construct Bartik instruments.

Bartik instruments. To ease the exposition, we index the final year by t and the initial year by $t-1$. Denote N_{jst} employment in urban area j in the four-digit sector s, N_{jt} employment in urban area j, and N_{st} employment in sector s. The Bartik sectoral instrument that predict growth in urban area j between $t-1$ and t is:

$$B_{jt}^{sec} = \sum_{s} \left(\frac{N_{st}}{N_{st-1}} \right) \frac{N_{sjt-1}}{N_{jt-1}} \tag{A1}$$

A similar computation is applied to construct the Bartik occupation instrument that relies on changes in the four-digit occupational structure of national employment interacted with initial shares of occupations in urban areas.

Income. Mean household income and its standard deviation by municipality and urban area can be constructed using information from each cadastral section (about 100 housing units on average) contained in the FILOCOM repository, which is matched to income tax records.

Land use. We compute the fraction of land that is built up in each municipality and the average height of buildings from the *BD Topo* (version 2.1) from the French National Geographical Institute.

This data set is originally produced using satellite imagery combined with the French land registry. It reports information for more than 95% of buildings in the country including their footprint, height, and use (residential, production, commerce, public sector, religious, etc) with an accuracy of one metre.

Amenity data. We use data from the *French Permanent Census of Equipments* aggregated and maintained by the French Institute of Statistics. The original sources are: the French Ministry for Education for primary, middle, and high schools, the French Ministry of Health for medical doctors, hospitals and other medical services, the registry of establishments (*siren*) for retail establishments, restaurants, and movie theaters, and various other administrative sources. We use data from the 2000 census to construct our 2000 and 2002 data, data from the 2006 census for our 2004, 2006 and 2008 data, and data from the 2010 census for our 2008, 2010, and 2012 data.

Historical population data. We use a file containing some information on population by municipality for 27 censuses covering the 1831-1982 period (Guérin-Pace and Pumain, 1990). Over 1831-1910, the data contain only information on "urban municipalities" which are defined as municipalities with at least 2,500 inhabitants. The population of municipalities varies over time. Municipalities appear in the file when their population goes above the threshold and disappear from the file when their population goes below the threshold. Data are aggregated at the urban area level to construct our historical instruments.

Tourism data. These data at the municipality level are constructed by the French Institute of Statistics (INSEE) since 2002 from the census and a survey of hotels. It contains some information on the number of hotels depending on their quality (from zero star to four stars) and the number of rooms in these hotels. We construct our instruments, the number of hotel rooms and the share of 1-star rooms, by aggregating the data for 2006 at the urban area level.

Climate measures The original data come from the ATEAM European project as a high-resolution grid of cells of 10 minutes (18.6 km) per 10 minutes. These data came to us aggregated at the département level. The value of a climate variable for a département was computed as the average of the cells whose centroid is located in that département. The climate variables include the average monthly precipitation (in mm), the temperature (in C), the cloudiness (in % time) and the potential evapotranspiration (in hPa) for January and July. We attribute to each municipality the value of its département. The value of an urban area is computed as the average of its municipalities, weighting by the area.

Soil variables We use the European Soil Database compiled by the European Soil Data Centre. The data originally come as a raster data file with cells of 1 km per 1 km. We aggregated it at the level of each municipality and urban area. We refer to Combes *et al.* (2010) for further description of these data.

Appendix B. FGLS and WLS estimators

In this appendix, we explain how we construct weighted least squares (WLS) and feasible general least squares (FGLS) estimators used in some second-stage regressions. The model is of the form:

$$P = X\varphi + \zeta + \eta\,, \tag{B1}$$

where P is a $J \times 1$ vector stacking the fixed effects capturing unit land prices at the centre, $\ln P_j(0)$, with J the number of urban areas, X is a $J \times K$ matrix stacking the observations for urban area variables (area, population, population growth, etc.), ζ is a $J \times 1$ vector of error terms supposed to be independently and identically distributed with variance σ^2, and η is a $J \times 1$ vector of sampling errors with known covariance matrix V.

It is possible to construct a consistent FGLS estimator of φ as:

$$\widehat{\varphi}_{FGLS} = \left(X'\widehat{\Omega}^{-1}X\right)^{-1} X'\widehat{\Omega}^{-1}P\,, \tag{B2}$$

where $\widehat{\Omega}$ is a consistent estimator of the covariance matrix of $\zeta + \eta$, $\Omega = \sigma^2 I + V$. To compute this estimator, we use an unbiased and consistent estimator of σ^2 which can be computed from the residuals of an OLS residuals of equation (B1) and denoted $\widehat{\zeta + \eta}$:

$$\widehat{\sigma}^2 = \frac{1}{N-K}\left[\widehat{\zeta + \eta}'\widehat{\zeta + \eta} - tr\left(M_X V\right)\right]\,, \tag{B3}$$

where $M_X = I - X\left(X'X\right)^{-1}X'$ is the projection orthogonally to X. We thus use $\widehat{\Omega} = \widehat{\sigma}^2 I + V$ in the computation of (B2). A consistent estimator of the covariance matrix of the FGLS estimator is:

$$\widehat{V}\left(\widehat{\varphi}_{FGLS}\right) = \left(X'\widehat{\Omega}^{-1}X\right)^{-1}\,. \tag{B4}$$

As the FGLS is said not to be always robust, we also compute a WLS estimator in line with Card and Krueger (1992), using the diagonal matrix of inverse of first-stage variances as weights, denoted Δ. The estimator is given by:

$$\widehat{\varphi}_{WLS} = \left(X'\Delta X\right)^{-1} X'\Delta P\,, \tag{B5}$$

with a consistent estimator of the covariance matrix given by:

$$\widehat{V}\left(\widehat{\varphi}_{WLS}\right) = \left(X'\Delta X\right)^{-1} X'\Delta\widehat{\Omega}_w\Delta X \left(X'\Delta X\right)^{-1} ,$$

where $\widehat{\Omega}_w = \widehat{\sigma}_w^2 I + V$ with $\widehat{\sigma}_w^2$ a consistent estimator of σ^2 based on the residuals of WLS denoted $\widehat{\Delta^{1/2}(\zeta+\eta)}$ and given by:

$$\widehat{\sigma}_w^2 = \frac{1}{tr\left(\Delta^{1/2} M_{\Delta^{1/2}X} \Delta^{1/2}\right)} \left[\widehat{\Delta^{1/2}(\zeta+\eta)}' \widehat{\Delta^{1/2}(\zeta+\eta)} - tr\left(\Delta^{1/2} M_{\Delta^{1/2}X} \Delta^{1/2} V\right)\right] . \tag{B6}$$

Appendix C. Supplementary results

Supplementary results regarding the elasticity of house prices with respect to population

Table 10: The determinants of unit property prices at the centre, OLS regressions for all dwellings

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
First-step	Only fixed effects			Basic controls			Full set of controls		
Controls	N	Y	Ext.	N	Y	Ext.	N	Y	Ext.
Log population	0.200[a]	0.163[a]	0.113[a]	0.222[a]	0.184[a]	0.148[a]	0.183[a]	0.152[a]	0.113[a]
	(0.00684)	(0.00523)	(0.00802)	(0.00827)	(0.00684)	(0.0110)	(0.00703)	(0.00576)	(0.00920)
Log land area	-0.129[a]	-0.130[a]	-0.0983[a]	-0.0998[a]	-0.104[a]	-0.0886[a]	-0.115[a]	-0.118[a]	-0.0930[a]
	(0.00784)	(0.00584)	(0.00792)	(0.00949)	(0.00764)	(0.0108)	(0.00806)	(0.00644)	(0.00909)
R^2	0.34	0.66	0.72	0.36	0.61	0.66	0.30	0.57	0.63
Observation	1937	1937	1937	1937	1937	1937	1937	1937	1937

Notes: [a]: significant at 1% level; [b]: significant at 5% level; [c]: significant at 10% level. All R^2 are within time. The dependent variable is an urban area-time fixed effect estimated in the first step using municipal prices for all dwellings instead of only houses. Otherwise, this table is similar to panel A of table 4.

Table 11: The determinants of unit house prices, robustness checks (specification)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log population	0.199[a]	0.266[a]	0.192[a]	0.277[a]	0.292[a]	0.218[a]	0.269[a]	0.264[a]	0.234[a]
	(0.00975)	(0.0154)	(0.0123)	(0.0277)	(0.0196)	(0.00969)	(0.00827)	(0.00026)	(0.00875)
Log land area	-0.186[a]	-0.211[a]	-0.194[a]	-0.172[a]	-0.237[a]	-0.190[a]	-0.120[a]	-0.110[a]	-0.212[a]
	(0.00963)	(0.0152)	(0.0121)	(0.0273)	(0.0194)	(0.00957)	(0.00953)	(0.00027)	(0.00903)
R^2	0.68	0.52	0.56	0.29	0.45	0.71	0.43	0.47	0.82
Observation	1,937	1,937	1,937	1,937	1,937	1,937	1,937	1,937	74,621

Notes: [a]: significant at 1% level; [b]: significant at 5% level; [c]: significant at 10% level. All R^2 are within time. All OLS regressions except columns 7 and 8. Each column is a variant of the estimation reported in column 9 of table 4. As explanatory variables, column 1 includes the distance to the centre of the urban area in level instead of its log. Column 2 includes log distance and its square (estimating a specific coefficient for each urban area for both variables). Column 3 defines the centre of an urban area as the centroid of the municipality with the highest residential density. Column 4 measures the distance to the centre as the distance to the two municipalities with the highest population in the urban area. Column 5 drops the 25% of observation closest to the center in each urban area. Column 6 drops the 25% of observations with the lowest price per square metre in each urban area. Column 7 estimates the regression using feasible generalised least squares (FGLS) as described in Appendix B. Column 8 estimates the regression using weighted least squares (WLS) as described in Appendix B. Column 9 estimates the elasticity of house prices with respect to population in one step instead of two separate steps.

Table 12: Non-linear effects of population on house and land prices

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
First step controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Second step controls	No	Yes	No	Yes	Yes	No	Yes	Yes
Panel A. House prices								
Log population	0.0370	0.326^a	-0.329^a	0.0621	1.418^a	-0.640^a	-0.0326	1.025
	(0.0571)	(0.0423)	(0.0628)	(0.0485)	(0.421)	(0.0953)	(0.0706)	(0.700)
Log population squared	0.00774^a	-0.00430^b	0.0250^a	0.0106^a	-0.102^a	0.0356^a	0.0107^a	-0.0754
	(0.00243)	(0.00174)	(0.00268)	(0.00200)	(0.0347)	(0.00388)	(0.00258)	(0.0562)
Log population cubed					0.00306^a			0.00231
					(0.00094)			(0.0015)
Log land area	-0.150^a	-0.228^a	-0.140^a	-0.273^a	-0.276^a	-0.0703^a	-0.148^a	-0.150^a
	(0.00816)	(0.0113)	(0.00897)	(0.0130)	(0.0130)	(0.0116)	(0.0301)	(0.0301)
First-stage statistic						255.0	113.6	90.5
Overidentification p-value						0.18	0.91	0.94
Observations	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933
R^2	0.35	0.72	0.43	0.74	0.74	-	-	-
Panel B. land prices								
Log population	1.111^a	1.795^a	-0.234^b	0.385^a	5.109^a	-1.300^a	-0.209	3.860
	(0.131)	(0.118)	(0.103)	(0.0898)	(0.765)	(0.186)	(0.145)	(2.867)
Log population square	-0.0144^a	-0.0373^a	0.0385^a	0.0167^a	-0.374^a	0.0710^a	0.0261^a	-0.258
	(0.00556)	(0.00482)	(0.00437)	(0.00365)	(0.0630)	(0.00714)	(0.00496)	(0.224)
Log population cube					0.0106^a			0.00744
					(0.0017)			(0.0059)
Log land area	-0.678^a	-0.951^a	-0.430^a	-0.650^a	-0.656^a	-0.0415	-0.195^a	-0.757^a
	(0.0187)	(0.0335)	(0.0147)	(0.0253)	(0.0251)	(0.0585)	(0.0713)	(0.219)
First-stage statistic						46.0	81.6	3.6
Overidentification p-value						0.19	0.57	0.38
Observations	1,933	1,933	1,933	1,933	1,933	1,933	1,933	1,933
R^2	0.54	0.71	0.63	0.78	0.78	-	-	-

Note ^{a}: significant at 1% level; ^{b}: significant at 5% level; ^{c}: significant at 10% level. All R^2 are within time. OLS regressions in column 1 to 5 and LIML regressions in column 6 to 8. The fixed effects for house and land prices are as estimated in column 2 of table 3 (no first-step controls) or as column 9 of the same table (with first-step controls). The second-step controls are either only year effects (no second-step controls) or the full set of controls used in column 9 of table 4 (second-step controls). Instruments include: January temperature, 1831 (log) urban population, and its square, column 6-8 of panel A. Column 6 additionally includes 1881 population density. Column 7 additionally includes a Bartik industry employment growth predictor for 1990-1999. Column 8 additionally includes the same Bartik variable and the cub of 1831 population. In panel B, column 6-8 include 1831 (log) urban population, and its square. Columns 6 and 7 additionally include the log number of movie theaters and a Bartik predictor. Column 8 additionally includes January temperature and the cube of log 1831 population.

Supplementary results regarding the share of housing in expenditure

Table 13: The share of housing in expenditure for homeowners and private renters

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Homeowners								
Log population	0.027^{a}	0.029^{a}	0.041^{a}	0.045^{a}	0.044^{a}	0.055^{a}	0.076^{a}	0.055^{a}
	(0.001)	(0.002)	(0.005)	(0.008)	(0.008)	(0.014)	(0.013)	(0.012)
Log land area			-0.020	-0.028^{a}	-0.033^{a}	-0.038^{a}	-0.057^{a}	-0.038^{a}
			(0.007)	(0.008)	(0.007)	(0.013)	(0.012)	(0.011)
Population growth			2.593^{b}	2.662^{a}	2.443^{a}	2.470^{a}	2.084^{a}	2.471^{a}
			(0.610)	(0.727)	(0.743)	(0.763)	(0.780)	(0.740)
Log distance to city centre		-0.005	-0.004	-0.006^{c}	-0.002	-0.008^{b}	-0.013^{a}	-0.008^{b}
		(0.005)	(0.005)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)
Log income	-0.252^{a}	-0.253^{a}	-0.253^{a}	-0.256^{a}	-0.168^{a}	-0.256^{a}	-0.257^{a}	-0.256^{a}
	(0.012)	(0.011)	(0.011)	(0.010)	(0.013)	(0.009)	(0.009)	(0.009)
First-stage statistic					253.2	97.0	5.8	14.9
Overidentification p-value					0.33		0.26	0.05
Instruments								
Degree					X			
Urban population in 1831						X		X
Consumption amenities							X	X
Local controls	No	No	No	Yes	Yes	Yes	Yes	Yes
R^2	0.53	0.53	0.54	0.55				
Panel B. Renters								
Log population	0.030^{a}	0.033^{a}	0.038^{a}	0.028^{a}	0.021^{a}	0.028^{c}	0.056^{a}	0.034^{a}
	(0.002)	(0.002)	(0.009)	(0.009)	(0.008)	(0.014)	(0.017)	(0.012)
Log land area			-0.008	0.005	0.009	0.005	-0.021	-0.001
			(0.013)	(0.012)	(0.011)	(0.018)	(0.019)	(0.016)
Population growth			2.775^{b}	3.950^{a}	4.205^{a}	3.957^{a}	3.277^{b}	3.806^{a}
			(1.262)	(1.116)	(1.184)	(1.256)	(1.273)	(1.217)
Log distance to city centre		-0.009^{b}	-0.009^{b}	-0.005	-0.003	-0.005	-0.011^{b}	-0.006
		(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.005)
Log income	-0.342^{a}	-0.342^{a}	-0.341^{a}	-0.343^{a}	-0.184^{a}	-0.343^{a}	-0.343^{a}	-0.343^{a}
	(0.023)	(0.023)	(0.023)	(0.022)	(0.033)	(0.022)	(0.022)	(0.022)
First-stage statistic					31.6	157.4	8.1	22.0
Overidentification p-value					0.03		0.03	0.01
R^2	0.58	0.58	0.58	0.59				

Notes: [a]: significant at 1% level; [b]: significant at 5% level; [c]: significant at 10% level. All R^2 are within time. The same regressions are estimated in both panels. 5,984 observations in each regression of panel A corresponding to 177 urban areas. 2,464 observations in each regression of panel B corresponding to 177 urban areas (20 of which differ from the previous sample). All variables are centered and the estimated constant, which corresponds to the expenditure share in a city of average size (2.94 million inhabitants in panel A and 3.12 million in panel B), takes the value 0.314 in all specifications of panel A and 0.352 in all specifications of panel B. Regressions are weighted with sampling weights and include: age and dummies for year 2011 (ref. 2006), living in couple within the dwelling (ref. single), one child, two children, three children and more (ref. no child). Standard errors are robust to intra-area correlations. Local controls include the same geography variables for urban areas as in table 4 and the same geology, land use, and amenity variables as in table 3. The instruments are the same as in table 6. The education instruments are five indicator variables corresponding to PhD and elite institution degree,master, lower university degree, high school and technical degree, lower technical degree, and primary school (reference). All instrumented regressions estimated with limited information maximum likelihood (LIML).