The Costs of Agglomeration:

Land Prices in French Cities

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Objective:

Estimate the elasticity of urban costs with respect to city population

Preferred estimate: 0.041

Why it matters:

- First empirical assessment of '**the fundamental tradeoff of spatial economics**' (Fujita and Thisse, 2002)
  - Does it exist?
  - Does it matter?
- Implications for the city size debate and urban policies
- Intermediate output of interest:
  - Population elasticity of unit land prices
  - Distance gradient for land prices
- Evaluation of the monocentric model

What we do:

1. Build a simple urban model
2. Design a two-step empirical strategy

   Step 1: Estimate a land price equation at the parcel level

   Step 2: Estimate the population elasticity of land prices in city centres
3. Use this elasticity to compute the population elasticity of urban costs

Related literature

- Literature on urban costs: Tolley, Graves, and Gardner (1979), Thomas (1980), Richardson (1987), and Henderson (2002)
- Literature on urban gradients: Clark (1951), McMillen (1996)
- Literature on land values: Davis and Heathcote (2007), Davis and Palumbo (2008), Albouy and Ehrlich (2012)

Model: Geography

- Circular monocentric city
- City residents must commute to the CBD to receive a wage W
- City population:

$$N \equiv \int_0^{\overline{D}} N(D)dD = \int_0^{\overline{D}} \frac{H(D)}{h(D)} dD$$

$N(D)$: population density at distance D from the CBD

$\overline{D}$: urban fringe

$H(D)$: housing supply D

$h(D)$: individual housing demand at D

Preferences and housing demand

- Utility:

$$U(D) = \frac{M}{\beta^{\beta}(1-\beta)^{1-\beta}} \frac{h(D)^{\beta}\, x(D)^{1-\beta}}{v(D)}$$

M: consumption amenities
h: housing consumption
x: numéraire
$v(D)$: commuting

- Budget constraint:

$$Q(D)h(D) + x(D) = W$$

$Q(D)$: rental price of housing

$\Rightarrow$ Housing demand:

$$h(D) = \frac{\beta W}{Q(D)}$$

Housing price gradient

- Within city spatial equilibrium:

$$U(D) = U(0) \text{ for } 0 \leq D \leq \overline{D}$$

$\Rightarrow$ Distance gradient for the rental price of housing:

$$Q(D) = Q(0) \left[\frac{v(0)}{v(D)} \right]^{1/\beta}$$

Housing supply

- Competitive production of housing:

$$H = BK^{1-\alpha}L^{\alpha}$$

B: housing TFP
K: capital
L: land

- Profit of a builder at distance D:

$$\pi(D) = Q(D)\,H(D) - R(D)L(D) - r^K\,K(D)$$

r^K: user cost of capital

$R(D)$: land rental price

$L(D) = 2\pi\theta D$: available land (θ, share of developed land)

Housing price

- Housing supply:

$$H(D) = 2\pi\theta B \left[\frac{1-\alpha}{\alpha} \frac{R(D)}{r^K} \right]^{1-\alpha} D$$

- Housing price:

$$Q(D) = \frac{1}{B} \left(\frac{r^K}{1-\alpha} \right)^{1-\alpha} \left[\frac{R(D)}{\alpha} \right]^{\alpha}$$

Urban costs

- Expenditure function:

$$e(Q(D),U(D)) = \frac{Q(D)^{\beta}}{M}U(D) = \frac{Q(O)^{\beta}}{M}U(O).$$

$\Rightarrow$ Elasticity with respect to population:

$$\rho = \alpha\beta\phi,$$

ϕ: population elasticity of rental price of land

Equilibrium

Distance gradient for the price of housing and the price of housing as a function of the rental price of land:

$\Rightarrow$ Distance gradient for the rental price of land:

$$R(D) = R(0)\left(\frac{v(0)}{v(D)}\right)^{1/\alpha\beta}$$

Recall:

$$N \equiv \int_0^{\overline{D}} N(D)dD = \int_0^{\overline{D}} \frac{H(D)}{h(D)}dD$$

where

- $H(D)$ function of $R(D)$, itself function of $R(0)$
- $h(D)$ function of $Q(D)$, itself function of $R(D)$ and thus of $R(0)$

⇒ Land rent at the CBD

$$R(0) = \alpha\beta \frac{W N}{\theta T(\overline{D})} \qquad \text{with} \qquad T(\overline{D}) \equiv \int_0^{\overline{D}} 2\pi D \left(\frac{v(0)}{v(D)} \right)^{1/\alpha\beta} dD$$

1. Homogeneous of degree one in population
2. Similar result for $R(1)$, $R(5)$, etc
3. The accessibility term depends only on $\overline{D}$...
4. ...therefore on land area $S = \pi\theta\overline{D}^2$

Possible extensions

1. Urban decentralisation: urban areas expand beyond monocentric cities

$$N = \overline{N}^{\gamma} \quad \text{where} \quad \gamma < 1$$

   (makes the price of land less than proportional to population)

2. Wage is not exogenous:

$$W = A\overline{N}^{\sigma}$$

   A: city TFP

   (makes the price of land slightly more than proportional to population)

3. Inelastic supply of housing

   (makes the price of land much more than proportional to population)

4. Income elasticity of the demand for housing below unity

   (makes the price of land more than proportional to population)

5. Congestion externality for commuting

   (makes the price of land more than proportional to population)

We only retain 1. and 2.

Towards a specification

- We have:

$$R(0) = \alpha\beta \frac{A\,\overline{N}^{(1+\sigma)\gamma}}{\theta\, T(\overline{D})}$$

- Functional form assumption for disutility cost of commuting

$$v(D) = (a + D)^{\tau}$$

with a small

- Assume measurement error on the rental price of land

Main equations to be estimated

First stage: distance gradient for the rental price of land:

$$\ln R_i \approx \ln R_{j(i)}(0) - \frac{\tau}{\alpha\beta} \ln D_i + \epsilon_i$$

Second stage: equilibrium rental price of land at the CBD

$$\ln R_j(0) \approx C_1 + (1+\sigma)\gamma \ln \overline{N}_j - \left(1 - \frac{\tau}{2\alpha\beta}\right) \ln S_j + \eta_{1j}$$

with $\quad C_1 \equiv \ln(\alpha\beta - \tau/2) - \frac{\tau}{2\alpha\beta} \ln \pi \quad$ and $\quad \eta_{1j} \equiv \ln A_j - \frac{\tau}{2\alpha\beta} \ln \theta_j$

Closing the model (to understand endogeneity issues)

- Endogenous urban fringe:

$$R(\overline{D}) = \underline{R}$$

$\underline{R}$: agricultural land rent

$\Rightarrow$ Land area is endogenous and be substituted away:

$$\ln R_j(0) \approx C_2 + (1+\sigma)\gamma \frac{\tau}{2\alpha\beta} \ln \overline{N}_j + \eta_{2j}$$

$$\text{with } \; C2 \equiv \frac{\tau}{2\alpha\beta}(\ln(\alpha\beta - \tau/2) - \ln \pi) \; \text{ and } \; \eta_{2j} \equiv \frac{\tau}{2\alpha\beta}(\ln A_j - \ln \theta_j) + (1 - \frac{\tau}{2\alpha\beta}) \ln \underline{R}_j$$

- Free mobility with reservation utility $\underline{U}$.

$\Rightarrow$ Endogenous city population:

$$\ln \overline{N}_j \approx C_3 + \beta\, c \ln B_j + c \ln M_j - (\alpha\beta - \tau/2)\, c\; \ln \underline{R}_j + \eta_{3j}\,,$$

with $C3 \equiv f(\alpha, \beta, \tau, r^K, \underline{U})$, $c \equiv \dfrac{2}{\tau(1+\sigma)\gamma - 2\gamma\sigma}$, $\eta_{3j} \equiv (1{-}\tau/2)c \ln A_j {+} \tau/2\, c\; \ln \theta_j$

$\Rightarrow$ Endogenous city land area:

$$\ln S_j \approx \ln(\alpha\beta - \tau/2) + (1+\sigma)\gamma \ln \overline{N}_j + \ln A_j - \ln \underline{R}_j$$

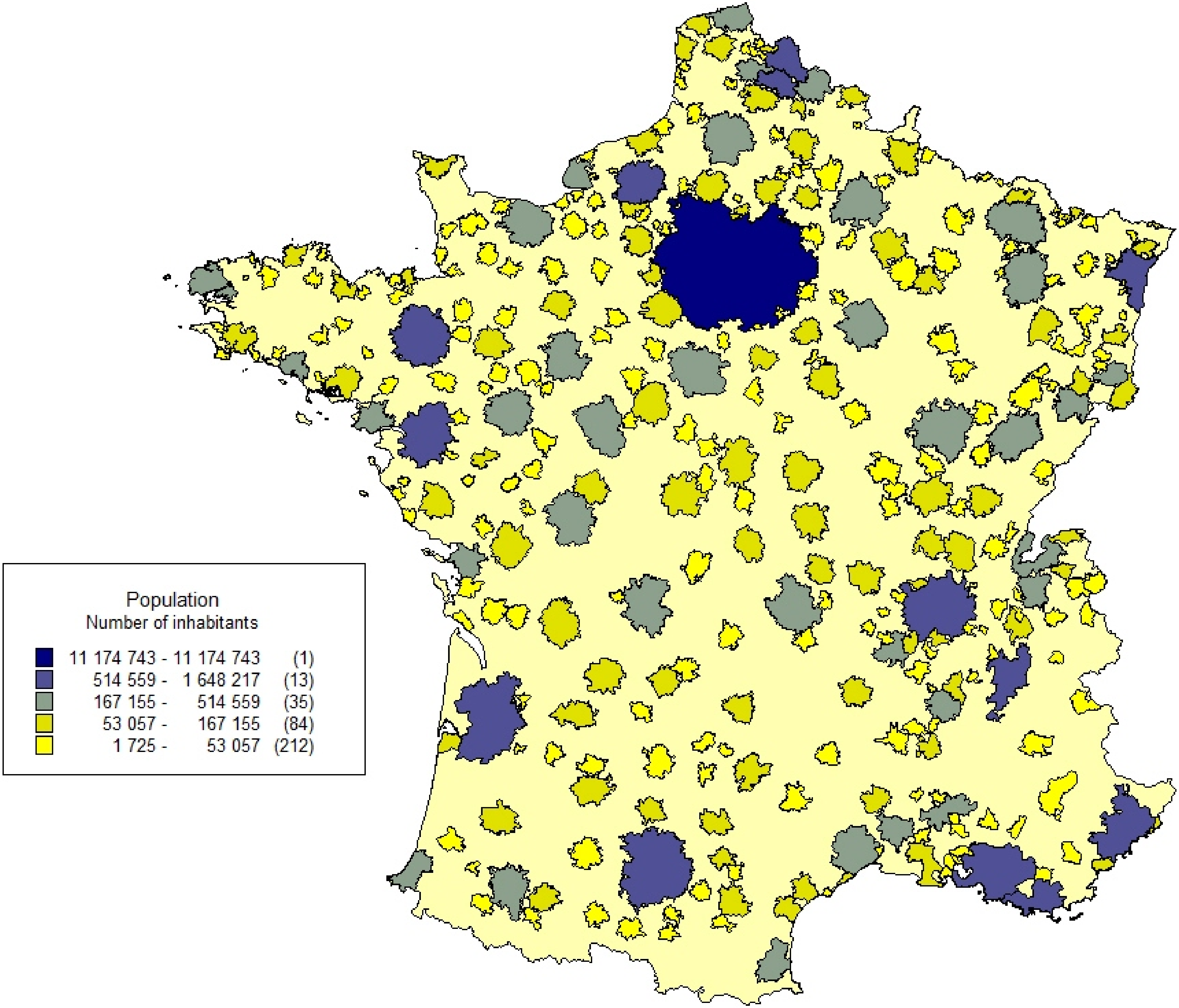
$\Rightarrow$ A_j and θ_j are part of the second-step error term and correlated with population/land area

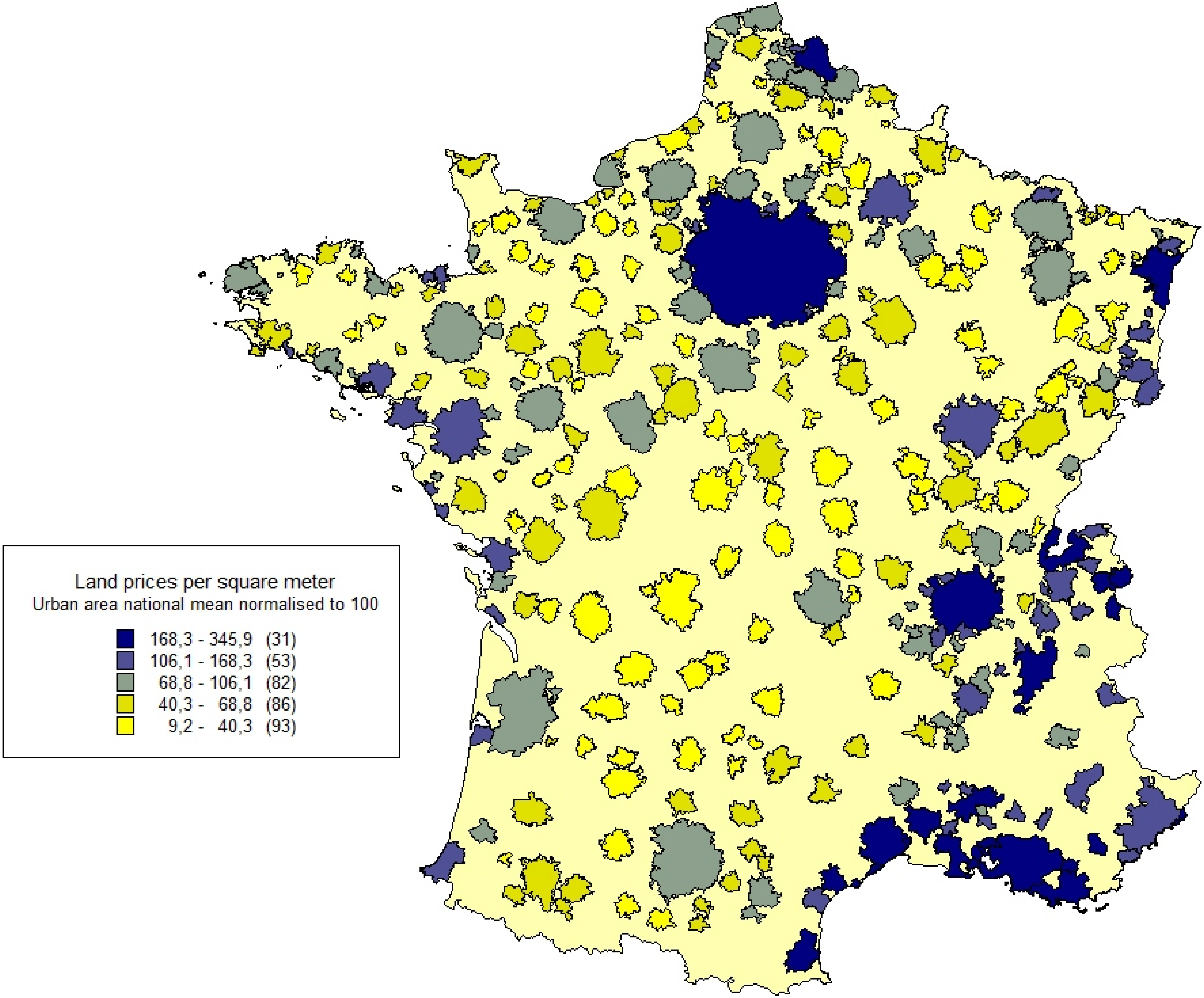
$\Rightarrow$ Direction of bias is ambiguous

$\Rightarrow$ Possible 'internal' instruments with M, B, and R

Data

- French Survey of Developable Land Prices (2008)
  - Parcels sold with a building permit for an individual house
  - Large scale random sample of land transactions:
    52,113 observations, around 60% of the universe
  - Prices of the parcel and construction
    Location at municipality level (36,000 units)
    Characteristics: area, shape, seller's type, access to utilities
  - We work on 27,854 land sales in 345 urban areas
- 1999 and 2007 census: population, occupations, sectors, education
- European soil database (soil and terrain characteristics)
- Climate and tourism data
- Land cover data, municipal inventories, fiscal data


Population
Number of inhabitants
11 174 743 - 11 174 743 (1)
514 559 - 1 648 217 (13)
167 155 - 514 559 (35)
53 057 - 167 155 (84)
1 725 - 53 057 (212)


Land prices per square meter
Urban area national mean normalised to 100
168,3 - 345,9 (31)
106,1 - 168,3 (53)
68,8 - 106,1 (82)
40,3 - 68,8 (86)
9,2 - 40,3 (93)

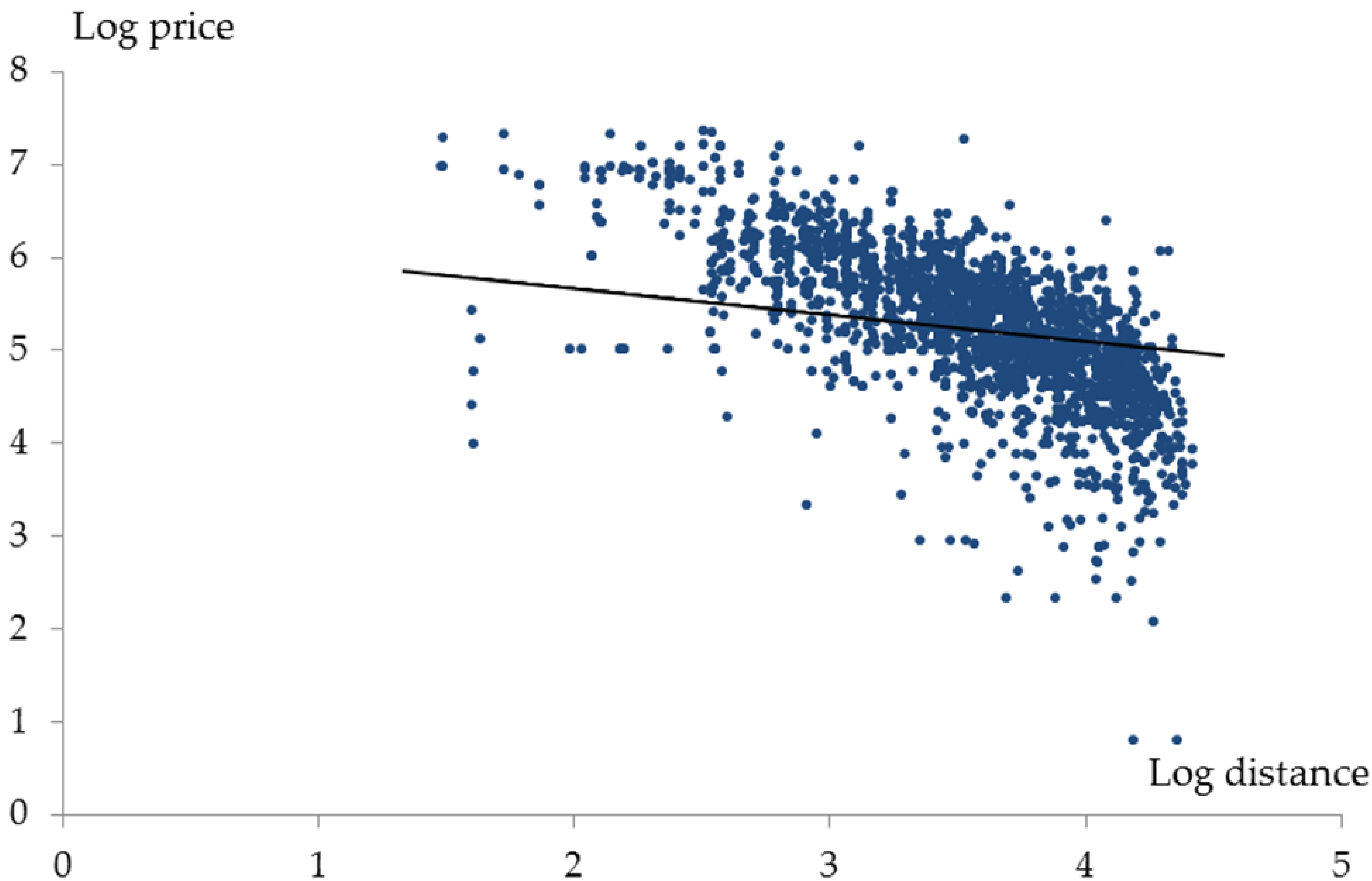


Figure 1. **Paris**

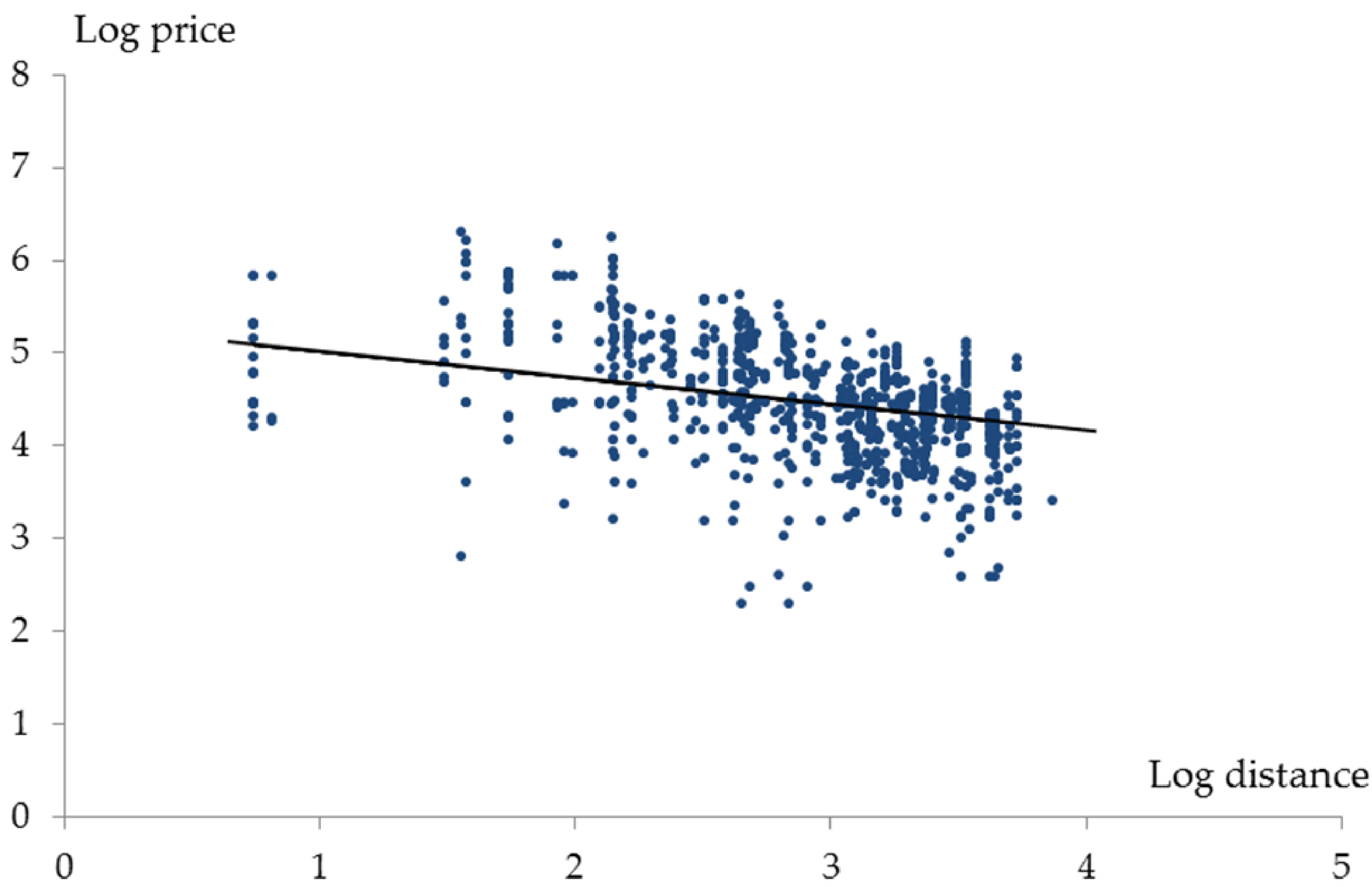


Figure 2. **Bordeaux**

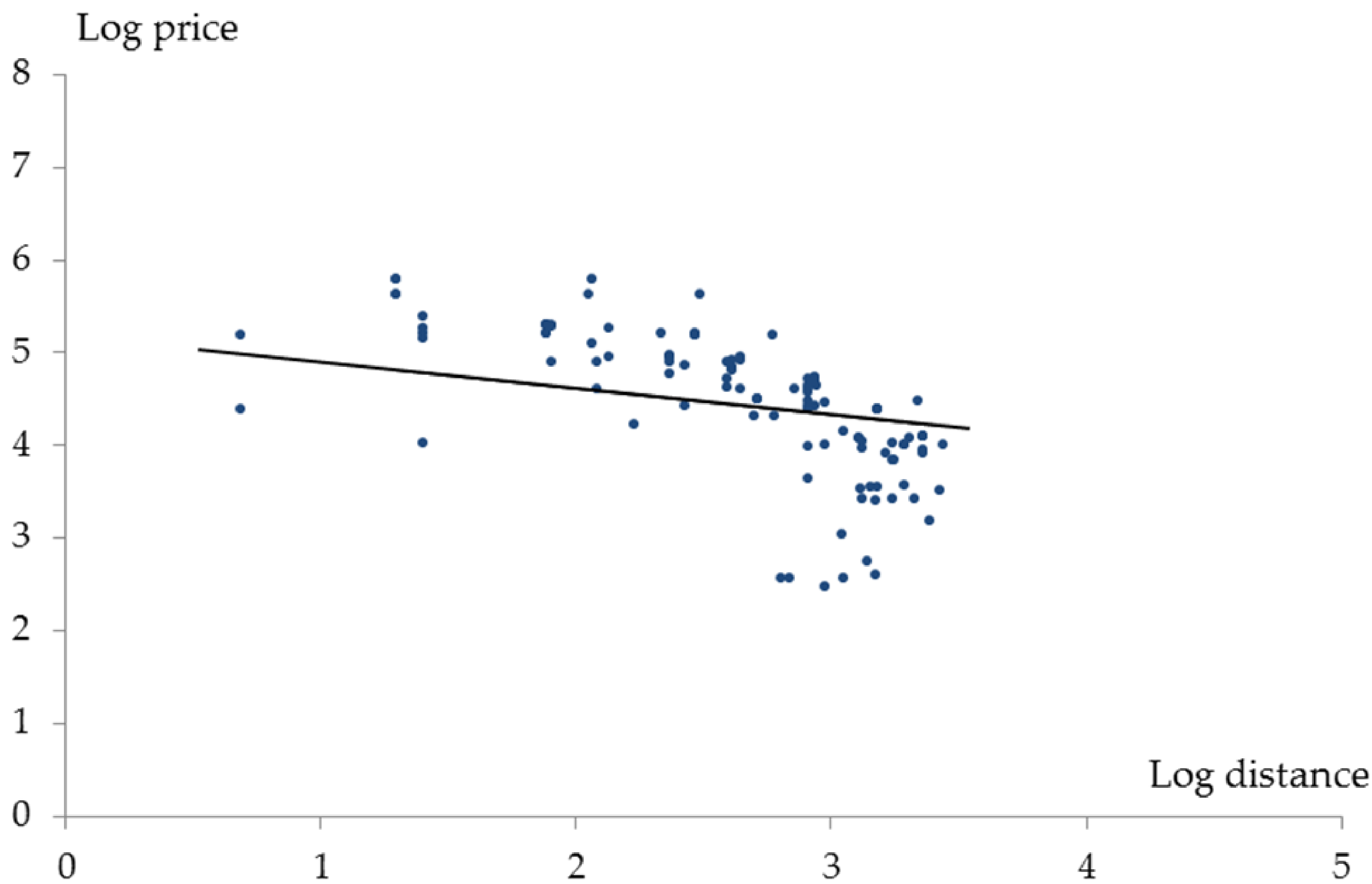


Figure 3. **Dijon**

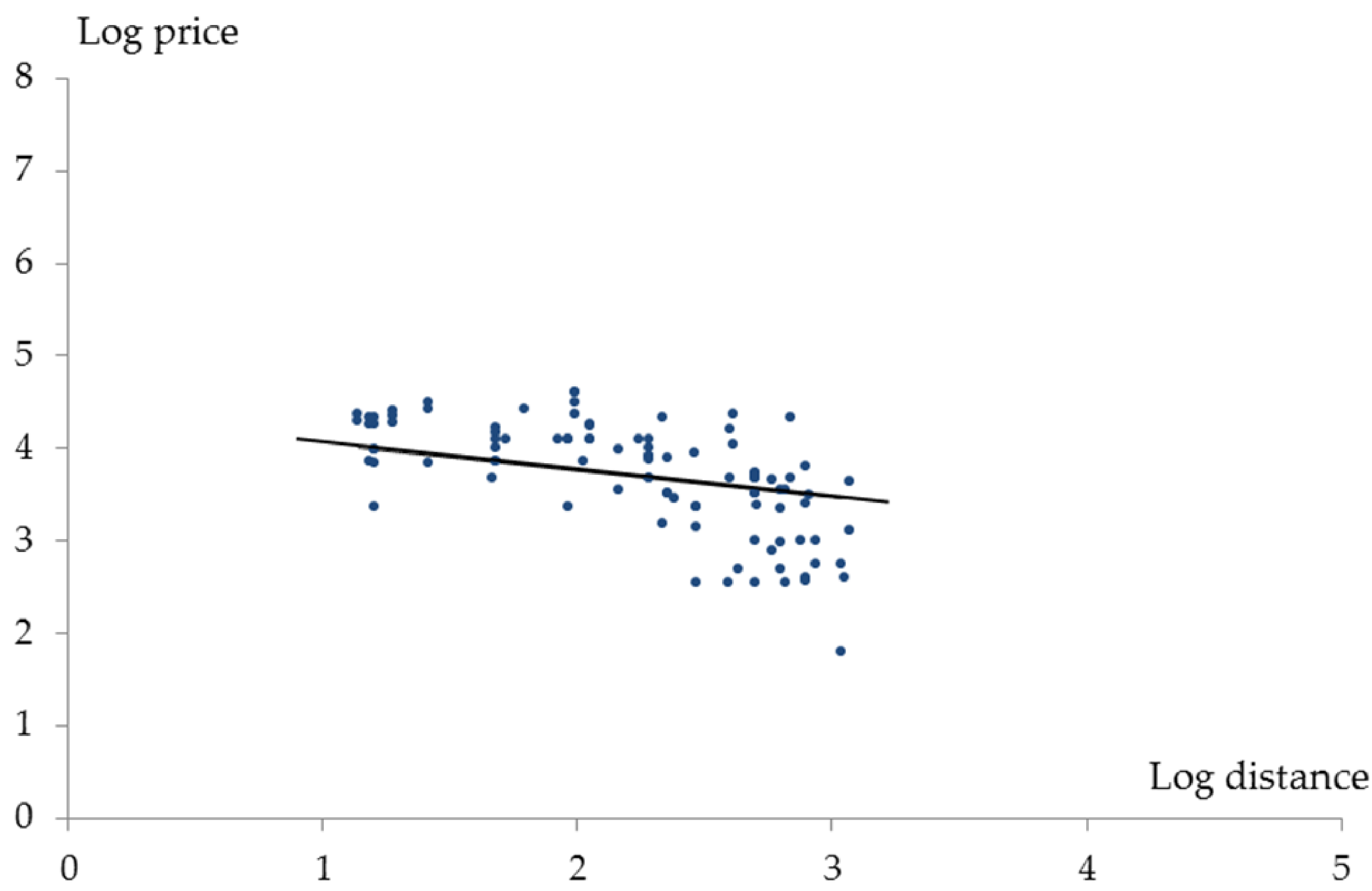


Figure 4. **Chalon-sur-Saône**

Descriptive statistics

Variable	Mean	St. Error	1st decile	Median	9th decile
Price (€ per m^2)	101.8	121.9	21.6	78.7	202.5
Price of construction (€ per m^2 of land)	169.8	137.4	62.6	150.0	293.2
Parcel area (m^2)	1103	1200	477	838	2000
Road frontage / square-root area	0.68	0.50	0.23	0.68	1.07
Serviced parcel	0.64	0.62	0	1	1
Prior Building	0.05	0.29	0	0	0
Prior building to be demolished	0.02	0.20	0	0	0
Bought through an agency	0.24	0.55	0	0	1
Bought through a builder	0.17	0.49	0	0	1
Bought through another intermediary	0.17	0.49	0	0	1
Population (urban area, '000, 2007)	1,049	3,617	28	186	1,164
Land area (urban area, km^2)	2,042	4,360	198	859	3,875
Population growth (urban area, %, 1999-2007)	5.9	6.1	0.0	5.9	11.6
Distance to the barycentre (km)	13.0	14.7	2.8	10.1	25.9
Distance to the closest centre (km)	11.9	14.4	2.5	8.6	24.6

Estimation issues: Step 1

$$\ln P_i = \ln P_{j(i)}(0) - \delta \ln D_{k(i)} + T_i b + \epsilon_i$$

- Prices vs. rents?

  Not worried for now, goes into the fixed effect

- Adds parcel characteristics (endogenous?)

  Replicate results without

- No difficult disentangling between structure and land

- Parcel selection

  None?

- Distance to the CBD: great circle distance between the centroid of the parcel's municipality and the weighted (2007 employment) barycentre of its city

  Experiment with alternatives including linear distance, alternative definition of centres, multiple centres

Summary statistics from the first step estimation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Parcel log-area	−0.61[a]				0.93[a]	1.22[a]	0.99[a]	1.23[a]
Parcel squared log-area	−0.03[a]				−0.12[a]	−0.14[a]	−0.12[a]	−0.14[a]
Other parcel charac. signif. (max=8)	6			8	7	6	6	6
Mean urban area fixed effect		4.3	4.9	4.4	3.8	3.0	3.7	2.6
First decile		3.3	3.9	3.4	3.0	1.9	2.9	1.7
Last decile		5.1	5.9	5.4	4.7	4.2	4.6	3.5
% above mean (signif.)		47.6	48.1	46.8	22.0	24.1	22.1	22.1
% below mean (signif.)		39.4	41.7	41.3	20.5	33.4	22.8	25.3
Distance effect			−0.28[a]	−0.26[a]	−0.18[a]		−0.26[a]	−0.03[a]
Mean distance effect by urban area						−0.26		
First decile						−0.48		
Last decile						−0.01		
% above mean (signif.)						32.1		
% below mean (signif.)						31.4		
R^2	0.48	0.52	0.57	0.62	0.79	0.81	0.80	0.81
Observations	26,177	26,177	26,177	26,177	26,177	26,177	26,177	26,177

Estimation issues: Step 2

$$\ln \hat{P_j}(0) = X_j \varphi + \xi_j$$

- Endogeneity of population and land area: IV
  - *Internal instruments: climate, tourism (Carlino and Saiz, 2008)*
  - *External instruments: long demographic lags (Combes, Duranton, Gobillon, and Roux, 2010)*
  - *External instruments: Sectoral and occupational structure (Bartik, 1991, Henderson, 1974, Duranton and Puga, 2005)*
- Land prices vs. land rents

  City population growth as control, itself endogenous Bartik (1991). In any case, mostly orthogonal
- First-step gradient may be a function of population and land area

  We provide evidence that it is not

The determinants of unit land values at the centre, OLS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.310[a]	0.650[a]	0.613[a]	0.601[a]	0.616[a]	0.629[a]	0.583[a]	0.579[a]
	(0.024)	(0.030)	(0.027)	(0.029)	(0.030)	(0.028)	(0.031)	(0.034)
Land area		−0.466[a]	−0.440[a]	−0.427[a]	−0.449[a]	−0.467[a]	−0.399[a]	−0.415[a]
		(0.032)	(0.029)	(0.031)	(0.030)	(0.032)	(0.029)	(0.035)
Population growth			3.254[a]	3.079[a]	3.135[a]	3.350[a]	3.744[a]	3.322[a]
			(0.394)	(0.415)	(0.443)	(0.394)	(0.395)	(0.447)
Controls	no	no	no	geog.	econ.	urb.	geol.	all
R^2	0.38	0.65	0.72	0.72	0.72	0.72	0.75	0.76

Unit land values at the centre, IV

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.721^a	0.673^a	0.614^a	0.680^a	0.683^a	0.702^a	0.673^a	0.685^a
	(0.076)	(0.064)	(0.089)	(0.063)	(0.064)	(0.063)	(0.062)	(0.066)
Land Area	-0.563^a	-0.504^a	-0.425^a	-0.499^a	-0.502^a	-0.538^a	-0.501^a	-0.504^a
	(0.096)	(0.083)	(0.183)	(0.083)	(0.083)	(0.083)	(0.082)	(0.087)
Population Growth	3.017^a	3.117^a	3.238^a	3.090^a	3.083^a	3.055^a	3.115^a	3.080^a
	(0.430)	(0.412)	(0.428)	(0.412)	(0.413)	(0.416)	(0.510)	(0.414)
Overidentification p-value	0.68	0.26	0.36	0.76	0.99	0.84	0.27	0.95
First-stage statistic	9.8	13.3	6.4	13.2	13.0	13.4	10.2	11.8
Endogeneity p-value	0.13	0.24	0.41	0.02	0.01	0.05	0.10	0.01
Number of hotel rooms	Y	Y	Y	N	N	Y	Y	N
Share of 1-star rooms	Y	Y	N	N	N	N	N	N
Temperature in January	Y	N	Y	N	N	Y	N	Y
Bartik Occupations 1999	N	Y	N	N	N	N	Y	N
Bartik Industry 1999	N	N	Y	N	N	N	N	N
Urban Population 1831	N	N	N	Y	Y	N	N	Y
Urban density 1881	N	N	N	Y	N	N	N	N
Henderson Industry 1999	N	N	N	Y	Y	Y	Y	N
Henderson Occupations 1999	N	N	N	N	Y	N	N	Y

Unit land values at the centre, IV regressions with controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.758^a	0.674^a	0.634^a	0.709^a	0.699^a	0.694^a	0.656^a	0.712^a
	(0.087)	(0.081)	(0.091)	(0.066)	(0.060)	(0.059)	(0.060)	(0.057)
Land Area	-0.583^a	-0.477^a	-0.425^a	-0.421^a	-0.413^a	-0.494^a	-0.448^a	-0.438^a
	(0.111)	(0.111)	(0.123)	(0.093)	(0.093)	(0.071)	(0.079)	(0.085)
Population Growth	3.432^a	3.426^a	3.428^a	3.603^a	3.595^a	3.443^a	3.438^a	3.582^a
	(0.465)	(0.446)	(0.442)	(0.464)	(0.415)	(0.449)	(0.444)	(0.464)
Overidentification p-value	0.44	0.08	0.05	0.95	0.72	0.77	0.22	0.47
First-stage statistic	10.4	10.5	8.7	14.7	14.1	27.9	18.2	16.5
Endogeneity p-value	0.02	0.12	0.23	0.01	0.01	0.02	0.09	0.01
Number of hotel rooms	Y	Y	Y	N	Y	Y	Y	N
Share of 1-star rooms	Y	Y	N	N	Y	N	N	N
Temperature in January	Y	N	Y	N	Y	Y	N	Y
Bartik Occupations 1999	N	Y	N	N	N	N	Y	N
Bartik Industry 1999	N	N	Y	N	N	N	N	N
Urban Population 1831	N	N	N	Y	Y	N	N	Y
Urban density 1881	N	N	N	Y	N	N	N	N
Henderson Industry 1999	N	N	N	Y	Y	Y	Y	N
Henderson Occupations 1999	N	N	N	N	Y	N	N	Y

Unit land values at the centre, IV growth instrumented

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.607[a]	0.610[a]	0.607[a]	0.598[a]	0.688[a]	0.657[a]	0.661[a]	0.662[a]
	(0.028)	(0.029)	(0.028)	(0.029)	(0.060)	(0.058)	(0.060)	(0.058)
Land Area	−0.436[a]	−0.438[a]	−0.436[a]	−0.429[a]	−0.532[a]	−0.469[a]	−0.483[a]	−0.484[a]
	(0.030)	(0.030)	(0.030)	(0.031)	(0.084)	(0.076)	(0.079)	(0.076)
Population Growth	3.780[a]	3.512[a]	3.743[a]	4.581[a]	3.825[a]	3.473[a]	3.417[a]	3.449[a]
	(0.821)	(1.106)	(0.811)	(0.970)	(0.832)	(0.708)	(0.728)	(0.711)
Overidentification p-value	–	–	0.76	0.06	0.50	0.44	0.44	0.43
First-stage statistic	81.0	39.2	41.6	29.9	7.5	8.0	9.1	7.3
Number of hotel rooms	N	N	N	N	Y	N	N	Y
Temperature in January	N	N	N	N	Y	Y	Y	Y
Bartik Occupations 1999	N	Y	Y	N	N	N	N	N
Bartik Industry 1999	Y	N	Y	N	Y	Y	Y	Y
Bartik Occupations 1990	N	N	N	Y	N	N	N	N
Bartik Industry 1990	N	N	N	Y	N	N	N	N
Urban Population 1831	N	N	N	N	N	Y	Y	Y
Henderson Industry 1999	N	N	N	N	Y	N	Y	N
Henderson Occupations 1999	N	N	N	N	N	Y	N	Y

Unit land values at the centre, effect of first-stage specification

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Population	0.573[a]	0.712[a]	0.783[a]	0.766[a]	0.613[a]	0.644[a]	0.614[a]	0.636[a]
	(0.040)	(0.038)	(0.038)	(0.036)	(0.027)	(0.049)	(0.028)	(0.027)
Land area	−0.526[a]	−0.613[a]	−0.539[a]	−0.545[a]	−0.440[a]	−0.336[a]	−0.408[a]	−0.457[a]
	(0.049)	(0.041)	(0.041)	(0.038)	(0.029)	(0.053)	(0.030)	(0.029)
Population growth	3.210	3.900[a]	3.645[a]	3.520[a]	3.254[a]	3.503[a]	3.400[a]	3.437[a]
	(0.439)	(0.553)	(0.552)	(0.517)	(0.394)	(0.710)	(0.402)	(0.391)
R^2	0.69	0.63	0.67	0.69	0.72	0.51	0.72	0.74
Observations	26,177	278	278	278	278	278	278	278

Unit land values at the centre, econometric variants

	(1) OLS	(2) One-step OLS	(3) FGLS	(4) WLS	(5) OLS	(6) One-step OLS	(7) FGLS	(8) WLS
Population	0.611[a]	0.614[a]	0.616[a]	0.617[a]	0.568[a]	0.611[a]	0.579[a]	0.580[a]
	(0.029)	(0.040)	(0.027)	(0.026)	(0.036)	(0.040)	(0.034)	(0.034)
Land area	−0.460[a]	−0.487[a]	−0.444[a]	−0.445[a]	−0.393[a]	−0.478[a]	−0.415[a]	−0.416[a]
	(0.028)	(0.049)	(0.030)	(0.029)	(0.034)	(0.041)	(0.036)	(0.036)
Population growth	3.804[a]	3.126[a]	3.187[a]	3.168[a]	3.405[a]	2.325[a]	3.222[a]	3.211[a]
	(0.378)	(0.437)	(0.393)	(0.387)	(0.432)	(0.473)	(0.449)	(0.440)
Controls	no	no	no	no	all	all	all	all
R^2	0.65	0.71	0.74	0.73	0.69	0.74	0.78	0.77
Observations	345	26,177	278	278	345	26,177	278	278

Determinants of the distance gradients for land prices, OLS and IV regressions

	(1) OLS	(2) OLS	(3) OLS	(4) IV	(5) IV	(6) IV	(7) IV	(8) IV
Population	0.022	0.040	0.033	−0.050	−0.013	0.005	0.001	0.006
	(0.028)	(0.038)	(0.041)	(0.066)	(0.069)	(0.077)	(0.060)	(0.082)
Land Area	−0.102[a]	−0.096[b]	−0.090[b]	−0.005	−0.065	−0.042	−0.085	−0.093
	(0.031)	(0.039)	(0.041)	(0.087)	(0.090)	(0.086)	(0.079)	(0.102)
Population Growth	−0.051	−0.197	−0.203	0.094	0.028	0.180	0.017	−0.498
	(0.413)	(0.498)	(0.498)	(0.435)	(0.431)	(0.490)	(0.738)	(1.243)
Controls	no	all	all+gini	no	no	all+gini	no	all+gini
R^2	0.03	0.12	0.12	-	-	-	-	-
Overidentification p-value	-	-	-	0.94	0.70	0.89	0.57	0.49
First-stage statistic	-	-	-	13.4	11.8	21.9	8.0	7.9
Number of hotel rooms	-	-	-	Y	N	Y	N	N
Temperature in January	-	-	-	Y	Y	Y	Y	Y
Bartik Industry 1999	-	-	-	N	N	N	Y	Y
Urban Population 1831	-	-	-	N	Y	N	Y	Y
Henderson Industries 1999	-	-	-	Y	N	Y	N	N
Henderson Occupations 1999	-	-	-	N	Y	N	Y	Y

Unit land values at the centre, regressions without land area

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	OLS	OLS	IV	IV	IV	IV	IV	IV
Population	0.288[a]	0.346[a]	0.286[a]	0.360[a]	0.278[a]	0.422[a]	0.296[a]	0.370[a]
	(0.022)	(0.034)	(0.024)	(0.094)	(0.027)	(0.067)	(0.025)	(0.047)
Population Growth	3.903[a]	3.526[a]	3.912[a]	3.557[a]	3.934[a]	3.698[a]	3.305[a]	3.322[b]
	(0.528)	(0.551)	(0.526)	(0.527)	(0.779)	(0.556)	(1.035)	(1.359)
Controls	no	all	no	all	no	all	no	all
R^2	0.48	0.64	-	-	-	-	-	-
Overidentification p-value	-	-	0.52	0.53	0.66	0.75	0.11	0.30
First-stage statistic	-	-	629.9	145.8	267.8.1	47.5	25.3	12.7
Number of hotel rooms	-	-	Y	Y	N	N	Y	Y
Bartik Industry 1999	-	-	N	N	Y	Y	Y	Y
Urban Population 1831	-	-	Y	Y	Y	Y	Y	Y
Urban Density 1831	-	-	N	N	N	N	Y	Y

'Overidentification tests'

- Land price elasticity: $(1+\sigma)\gamma = 0.72$
  Estimates of σ: 0.015-0.03 (Combes *et al.*, 2010) $\Rightarrow \gamma \approx 0.70 - 0.71$
  Estimating $N = \overline{N}^{\gamma}$ yields $\gamma = 0.796$ (0.726 with controls)
- Alternative estimate of $(1+\sigma)\gamma$ from
  $\ln S_j \approx \ln(\alpha\beta - \tau/2) + (1+\sigma)\gamma \ln \overline{N}_j + \ln A_j - \ln \underline{R}_j$.
  We get $(1+\sigma)\gamma = 0.795$ (0.695 with controls)
- Without land area, land price coefficient is $(1+\sigma)\gamma\ \tau/(2\alpha\beta) = 0.286$.
  With $(1+\sigma)\gamma = 0.72 \Rightarrow \tau/(2\alpha\beta) = 0.397$.
  Coefficient on land area: $-1 + \tau/(2\alpha\beta) = -0.563 \Rightarrow \tau/(2\alpha\beta) = 0.437$
- Direct and indirect estimates of $(1+\sigma)\gamma\ \tau/(2\alpha\beta)$ are also close
- Less precision with $\tau/(\alpha\beta)$ from first stage

Computing urban costs

Recall: elasticity of urban costs with respect to population:

$$\rho = \alpha\beta\phi$$

α: share of land in housing production
β: share of housing in expenditure
ϕ: land rent elasticity with respect to city size

Preferred estimate for ϕ is 0.72

Share of housing in expenditure, β

From Commissariat Général au Développement Durable (2011):

we take $\beta = 0.23$

Davis and Ortalo-Magné (2011): 0.24 in the us.

Share of land in production, α

First-order conditions for profit maximisation in building:

$$\frac{\alpha}{1-\alpha} = \frac{r\,L}{r^K\,K}$$

- From our data, $L/K \approx 0.66$
- r^K, user cost of capital = interest rate + housing depreciation

  $r^K = 0.05 + 0.01 = 0.06$

  Davis and Heathcote (2005) take 0.015 for us depreciation
- r: user cost of land = interest rate - land rent appreciation

  $r = 0.05 - 0.02 = 0.03$

  Davis and Heathcote (2007) take 0.03 for us rent appreciation

$\Rightarrow \ \alpha = 0.25$

Implied urban costs

$\phi = 0.72$, $\alpha = 0.25$, and $\beta = 0.23 \quad \Rightarrow \rho = 0.041$

Recall: population elasticity of productivity (agglomeration gains):
$0.015 - 0.03$, very similar magnitude

Conclusions

- Population elasticities of unit land prices not far from simple theoretical predictions
- Population elasticity of urban costs is low, of the same magnitude as agglomeration economies
- Cities operate close to constant returns in aggregates
- 'The fundamental tradeoff of spatial economics' exists
- But we expect a limited ability to predict the size of cities

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