URBAN SPATIAL STRUCTURE
And
SUBURBANISATION.

the case of the Barcelona Metropolitan Region

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1. INTRODUCTION

The metropolitan spatial structure displays various patterns, sometimes monocentricity and sometimes multicentricity, which seems much more complicated than the exponential density function used in classic works such as Clark (1961), Muth (1969) or Mills (1973) among others, can effectively represent. It seems that a more flexible density function, such as cubic spline function (Anderson (1982), Zheng (1991), etc.) to describe the density-accessibility relationship is needed. Also, accessibility, the fundamental determinant of density variations, is only partly captured by the inclusion of distance to the city centre as an explanatory variable. Steen (1986) has proposed to correct that miss-especification by including an additional gradient for distance to the nearest transportation axis. In identifying the determinants of urban spatial structure in the context of inter-urban systems, some of the variables proposed by Muth (1969), Mills (1973) and Alperovich (1983) such as city age or population, make no sense in the case of a single urban system. All three criticism to the exponential density function and its determinants apply for the Barcelona Metropolitan Region, a polycentric conurbation structured on well defined transportation axes.

The paper is structured as follows. Section 2 presents the main criticisms of the exponential density function, its virtues and alternative proposals. Section 3 characterises the Barcelona Metropolitan Region. In section 4 the results of the diverse estimated functions are shown. Section 5 develops the dynamic framework to analyse employment and population decentralisation. Section 6 presents the results of the dynamic VCM for the case of population decentralisation and section 7 presents the results for the case of employment relocalisation. Finally, section 8 gives the conclusions of the research.

2. RESIDENTIAL DENSITY AND ACCESSIBILITY

The Exponential Density Function

One of the main conclusions of the Monocentric City Model is that the relationship between residential and employment density and accessibility is seen as a reflection of a more basic relationship between land rent and accessibility. Residential and employment density declines with distance to the city centre because bid rent declines to compensate for commuting costs.

Equation (1) represents the standard residential density function.

$$DEN(x) = D_0 e^{-\gamma x} \quad (1)$$

Where $DEN(x)$ is density at distance x from the city centre, D_0 is the theoretical density in the central district and γ is the density gradient. The population density gradient measures the proportional decline in density per unit of distance. The estimated exponential function enables the density level at any city centre distance to be predicted. The value of the gradient is in turn related to the suburbanisation level. The greater the level of suburbanisation the flatter the estimated gradient.

Among the criticisms of the suppositions of the Monocentric City Model, three of them directly apply for the exponential function.

Accessibility and distance to the city centre.

Accessibility seems to depend on distance to the city centre only when 1) the transportation system is radial and 2) it is organised on an infinite number of axes. In fact, cities extend on a limited number of transportation axes. According to Steen (1986), the bid-rent function- and therefore the density function- must include two gradients, one for distance to the city centre and another for the perpendicular distance to the nearest axis.

$$DEN(x) = D_0 e^{-\gamma_1 x - \gamma_2 Daxis} \quad (2)$$

The estimated value for this second gradient must be higher than the first one, since accessibility declines faster with the distance to the axis than with the distance to the city centre.

Although the following assumption is not highlighted by Steen (1986), it seems clear that in measuring distance in time, new cities, extended on private transportation axes, should present similar values for both estimated gradients, since time distance directly measures accessibility.

Subcentres, dense peripheries and green belts

The ideal Monocentric City expands like an oil slick over an empty space whose economic value depends solely on its accessibility. Far from following this pattern, the growth of Asian and European conurbations consisted of neighbourhoods of massive housing, space contention policies (green belts), rural spaces protection, and small and medium sized municipalities commuting integration. The European urban regions are characterised by their discontinuities and clots of density (Dieleman and Faludi (1998) and Lambooy (1998)).

In the case of the North American cities, the decentralisation of employment which followed the suburbanisation of the population generated edge cities as a result of a strategy designed to achieve greater efficiency in production (economies of scale) and in commuting trips (Garreau (1991), Giuliano and Small (1991), Mc Millen and Mc Donald (1998), Cervero and Wu (1997)).

The presence of dense peripheries, subcentres and green belts cannot be captured by an exponential function, so cubic-spline functions have been used in research applied to European cities (Goffette-Nagot and Schmitt (1999)), Asian cities (Zheng (1991)) and North American cities (Anderson (1982), McDonald (1989)).

$$DEN(x) = a + b(x_t - x_0) + c(x_t - x_0)^2 + d_1(x_t - x_0)^3 + \sum_{i=1}^{n-1}(d_{i+1} - d_i)(x_t - x_i)^3 Y_i \quad (3)$$

where x_t is the distance between municipality t and the city centre, x_i ($x_i<x_{i+1}$, $i=1,2, ...n-1$) are the knots dividing (x_0, x_b) into n segments; a, b, c and d_i are the parameters to be estimated, and Y_i is a dummy variable such that

$Y_i=1$ *if* $x_t \geq x_i$
$Y_i=0$ *otherwise*

The determinants of urban spatial structure

Muth (1969), Mills (1973), Johnson and Kau (1980) and Alperovich (1983) among others, have applied a varying-parameter model in which some fundamental explanatory variables (income, transportation cost, city size and so forth) are introduced in the exponential function to represent D_0 and the population density gradient.

$$D_0 = A(P_r) = a_0 + \sum_{r=1}^{n} a_r P_r \quad (4)$$

$$\gamma = B(P_r) = b_0 + \sum_{r=1}^{n} b_r P_r \quad (5)$$

Where P_r are the fundamental factors determining D_0 and γ.

Including equations (4) and (5) in equation (1) and taking logarithms,

$$LnDEN(x) = Ln(a_0 + \sum_{r=1}^{n} a_r P_r) - x\left(b_0 + \sum_{r=1}^{n} b_r P_r\right) \quad (6)$$

3. CHARACTERIZATION OF THE BARCELONA METROPOLITAN REGION

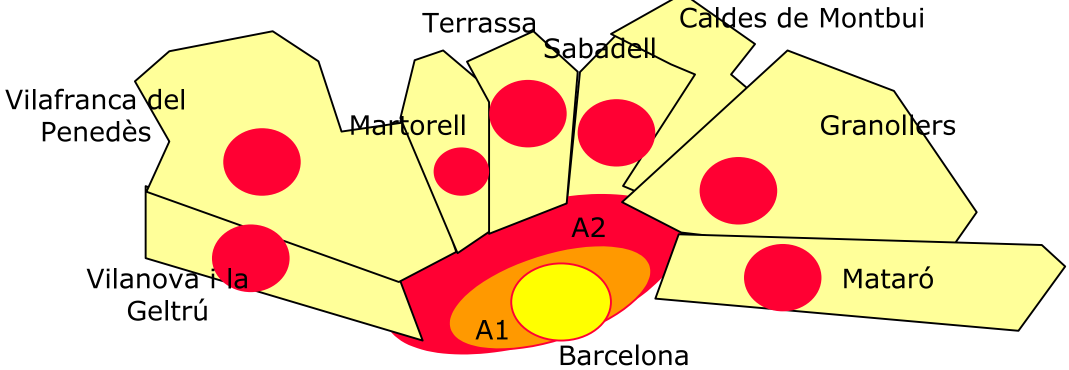
The Metropolitan Region of Barcelona (BMR) is a conurbation with a large, diverse and compact centre (the municipality of Barcelona), an extremely dense first metropolitan ring urbanised by massive housing blocks, discontinuities in the form of agricultural land and metropolitan parks, seven activity and residential subcentres and an extensive area that combines rural and low density residential uses.

The transportation network is radial. All subcentres and corridors are connected to the city centre through diverse railroad lines and Metropolitan highways. The BMR is a complex, diverse, discontinuous, polycentric and also partly dispersed metropolitan region. A city of cities with more than 160 municipalities that occupies nearly 4000 km2 in a radius of approximately 45 km. (**Table 1**)

Table 1
The Barcelona Metropolitan Region

METROPOLITAN RINGS	NUMBER OF MUNICIPALITIES	MEDIUM DISTANCE FROM THE CITY CENTRE	NET DENSITY RESIDENTIAL LEVELS (POPULATION/HA)	PER CAPITA RESIDENTIAL ENERGY CONSUMPTION (KWH)	PERCENTAGE OF PUBLIC TRANSPORT COMMUTING TRAVELS	PERCENTAGE OF RESIDENTIAL UNITS IN BUILDINGS WITH MORE THAN 3 FLOORS	MEDIUM POPULATION
Barcelona	1	2,5	366	0.77	41	94	1,6 millions
First ring	10	12,2	378	0.55	29	86	88230
Second ring	23	20,3	241	0.70	19	69	23289
Subcentres	7	38,1	169	0.71	15	68	85283
Subcentres commuting area	20	41,3	54	0.93	13	33	5391
Metropolitan Corridors	101	41,2	69	1.01	16	46	5830

Figure1
The Barcelona Metropolitan Region



Source: Pacte Industrial Metropolità (2000)

4. RESIDENTIAL DENSITY FUNCTION ESTIMATES

The data

The urban residential land data comes from the BMR Map of Land Uses (1992). One of the problems involved in working with municipal data is that the municipality of Barcelona, a single observation, is extremely large in comparison with the rest, so we have decided to break it up into ten districts in population density estimates. The "distance to the axis" variable has been defined as the shortest distance between the centre of the municipality i and its nearest rail axis. Employment data comes from PIM[1]. Finally, socioeconomic data comes from population census. Population density is measured by population per hectare of residential land (net density), while employment density is measured by the number of jobs per hectare (gross density).

Residential density functions

The estimated parameters for each axis and for the total of the region appear in **Table 2a** and their graphic representation in **Figure 2**. The results corresponding to the total of the BMR (first column) indicate that the extended with distance to the axis exponential function presents the better adjustment. However, the estimates for each one of the axes indicate that in some cases the cubic-spline function adjusts better than the others (in four of the six axes it presents the smallest standard error and another combination offers the best results for the R^2 value).

Employment density functions

The estimated parameters for each axis and for the total of the region appear in **Table 2b**. The results corresponding to the total of the BMR (first column) indicate that the extended with distance to the axis exponential function presents the better adjustment. The same pattern is found in all axes except for the case of Vilanova.

Comparing total BMR results of **Tables 2a** and **2b**, we find that the gradient for distance to the city centre in employment density functions is more than twice the gradient for residential density functions, which means that proportional reduction in employment density in moving away from the city centre is two times the proportional reduction in residential density per km. A stylised pattern of our results is that the difference in distance to axis gradients presents the same proportion.

[1] *Pacte Industrial Metropolità* Municipal Data base

Table 2a

Residential Density Functions (1996)

DENSITY FUNCTION		BMR total	MATARO	GRANOLLERS	TERRASSA-SABADELL	MARTORELL	VILAFRANCA	VILANOVA
EXPONENTIAL (I)	D_0	**411.86 *** (15.42)	**411.92 *** (7.57)	**481.04 *** (10.96)	**394.45 *** (7.69)	**433.46 *** (8.04)	**459.7 *** (10.92)	**276.67 *** (4.83)
	γ_1	**-0.0518 *** (12.78)	**-0.0496 *** (5.52)	**-0.063 *** (8.71)	**-0.0472 *** (4.68)	**-0.0438 *** (4.63)	**-0.0573 *** (8.1)	**-0.0331 *** (2.7)
	R^2	0.57	0.56	0.7	0.52	0.51	0.75	0.44
	S.E.	**75.83**	**84.19**	**74.72**	**92.08**	**93.31**	**69.12**	**84.02**
EXTENDED EXPONENTIAL	D_0	**394.55 *** (17.05)	**420.96 *** (10.5)	**461.4 *** (12.37)	**387.2 *** (7.28)	**432.14 *** (7.81)	**446.16 *** (10.83)	**277 *** (5.94)
	γ_1	**-0.0398 *** (10.47)	**-0.0354 *** (5.94)	**-0.0468 *** (6.87)	**-0.0436 *** (3.64)	**-0.0429 *** (4.09)	**-0.049 *** (6.07)	**-0.0226** (2.32)
	γ_2	**-0.1570 *** (4.66)	**-0.2305 *** (3.32)	**-0.2525 *** (2.86)	**-0.0283** (0.48)	**-0.0137** (0.2)	**-0.1153** (1.35)	**-0.1651** (1.51)
	R^2	0.65	0.73	0.77	0.53	0.51	0.76	0.62
	S.E.	**69.22**	**67.47**	**66.17**	**93.45**	**96.23**	**67.71**	**71.83**
CUBIC-SPLINE	No. segments	**4**	**5**	**4**	**4**	**5**	**4**	**5**
	R^2	0.57	0.67	0.72	0.65	0.61	0.8	0.75
	S.E.	**75.71**	**80.72**	**75.64**	**88.08**	**96.34**	**66.48**	**76.21**
	No. OBS.	**172**	**35**	**50**	**26**	**26**	**39**	**15**

Statistic "t" in parenthesis.
(*) Statistically significant variable.
S.E.: Regresión standard error.
R^2: Determination Coefficient.

Table 2b

Employment Density Functions (1996)

DENSITY FUNCTION		BMR total	MATARO	GRANOLLERS	TERRASSA-SABADELL	MARTORELL	VILAFRANCA	VILANOVA
EXPONENTIAL	D_0	**68.685 *** (16.35)	**66.089 *** (13.20)	**66.311 *** (20.96)	**67.131 *** (18.75)	**71.961 *** (9.71)	**67.009 *** (58.04)	**66.769 *** (27.73)
	γ_1	**-0.1144 *** (-20.48)	**-0.1237 *** (-10.51)	**-0.1246 *** (-15.97)	**-0.0975 *** (-15.38)	**-0.1028 *** (-8.60)	**-0.0948 *** (-23.18)	**-0.1612 *** (-12.30)
	R^2	0.71	0.83	0.91	0.93	0.80	0.99	0.98
	S.E.	**4.66**	**5.21**	**3.17**	**3.59**	**7.69**	**1.16**	**2.41**
EXTENDED EXPONENTIAL	D_0	**66.63 *** (17.27)	**62.43 *** (15.54)	**66.13 *** (20.74)	**66.96 *** (17.40)	**72.36 *** (10.29)	**66.99 *** (111.79)	**66.69 *** (28.04)
	γ_1	**-01028*** (19.55)	**-0.0947 *** (10.64)	**-0.1208 *** (13.54)	**-0.0964 *** (13.13)	**-0.097 *** (8.70)	**-0.112 *** (11.10)	**-0.155*** (12.26)
	γ_2	**-0.3270*** (3.01)	**-0.5940** (1.65)	**-0.0733** (0.57)	**-0.043** (0.439)	**-0.392** (1.19)	**0.060** (1.73)	**-0.203** (0.51)
	R^2	0.75	0.89	0.91	0.94	0.83	0.998	0.984
	S.E.	**4.33**	**4.27**	**3.19**	**3.86**	**7.30**	**0.59**	**2.38**
CUBIC-SPLINE	No. Segments	**2**	**2**	**5**	**2**	**2**	**2**	**3**
	R^2	0.72	0.84	0.91	0.93	0.80	0.99	0.98
	S.E.	**4.61**	**5.21**	**3.06**	**3.84**	**7.58**	**1.18**	**2.24**
	No. OBS.	**162**	**34**	**44**	**21**	**24**	**29**	**14**

Statistic "t" in parenthesis.

(*) Statistically significant variable.

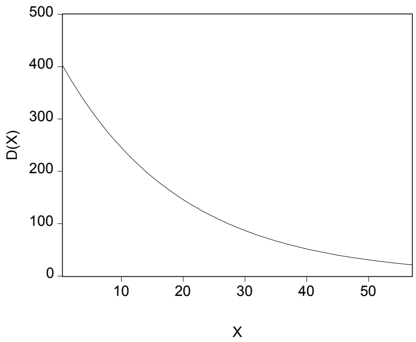
S.E.: Regresión standard error.

R^2: Determination Coefficient.

Figure 2.a.

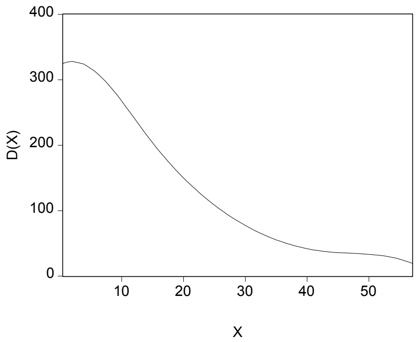
Net Density Functions. Total BMR.

EXPONENTIAL (I)



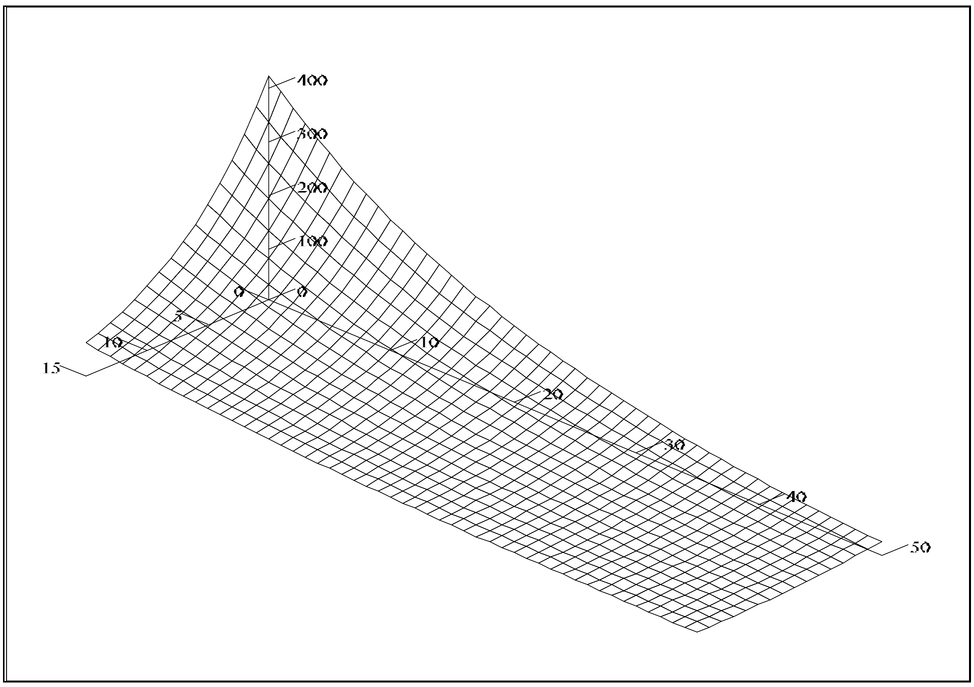
dist. Centre gradient: -0.0518

CUBIC-SPLINE



EXTENDED

EXPONENTIAL (II)

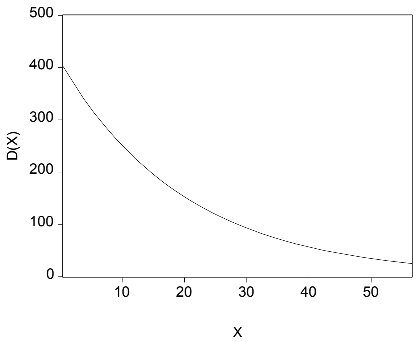


dist. Centre gradient: -0.0398

dist. Axis gradient: -0.1570

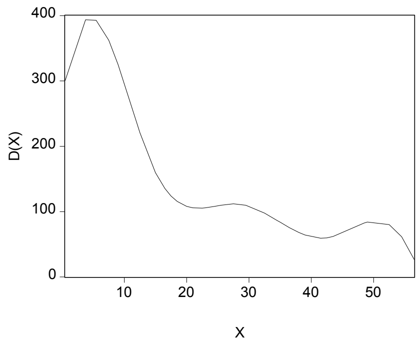
Figure 2.b.
Net Residential Density Functions
Mataró Axis.

EXPONENTIAL (I)



dist. Centre radient: -0.0496

CUBIC-SPLINE



The estimates for the standard and enlarged exponential functions of **Tables 2a** and **2b** show that, in incorporating the distance to the axis as an additional regressor, the value and statistical significance of the gradient for the city centre distance decreases. On the other hand, as Steen highlighted (1986), the value of the gradient for distance to the axis is higher than the one for distance to the city centre, confirming that accessibility declines more in moving away from the axis than from the city centre. The gradient for distance to the axis estimated value is on average more than three times the gradient of the distance to the centre estimated value.

One of the criticisms of the standard density function is that the fundamental explanatory variable is not distance, but car accessibility, so it would be better to measure distance in car travel time. We have tested that relationship taking as explanatory variables distance to the port and distance to the nearest highway measured in time finding results shown in **Table 3**.

The estimated time-distance regression indicates that the explanatory power overall measured by the R2 statistic is poorer and the statistical significance of the estimated coefficients is lower, specially for time distance to the highway gradient. This result seems to indicate that density variation is better explained by physical distance than time distance. Our intuition is that the weight of history is still very important. Another result that supports this idea is that time distance to the axis gradient is lower than distance to the port gradient. Modern cities, where density variation is explained by car time accessibility, must have very similar time distance gradients. The fact that time distance to the axis is lower than time distance to the centre is picking up an older density pattern. Again, we find results supporting the idea that history still determines density variations.

Table 3
Time-distance exponential and extended exponential density functions
Total BMR, 1996

	DEPENDENT VARIABLE	
	Residential Density	**Employment Density**
γ_1 **(Distance in minutes to the Port)**	**-0.063*** (7.9)	**-0.127*** (5.28)
γ_2 **(Distance in minutes to the nearest highway)**	-0.0016 (0.93)	-0.009 (1.4)
R^2	0.54	0.43

Statistic "t" in parenthesis.
(*) Statistically significant variable.
R^2: Determination Coefficient.

5. VCM: DETERMINANTS OF THE URBAN SPATIAL STRUCTURE

Measuring population and employment suburbanisation

Figures 3a and **3b** shows the estimated exponential density variation between 1991 and 1996 for population and employment. In both cases the gradient value decreases. Density near the area centre has declined while far away from the centre has increased. This implies the suburbanisation of employment and population in all directions.

Figure 3.a
Residential exponential density functions 1991 and 1996

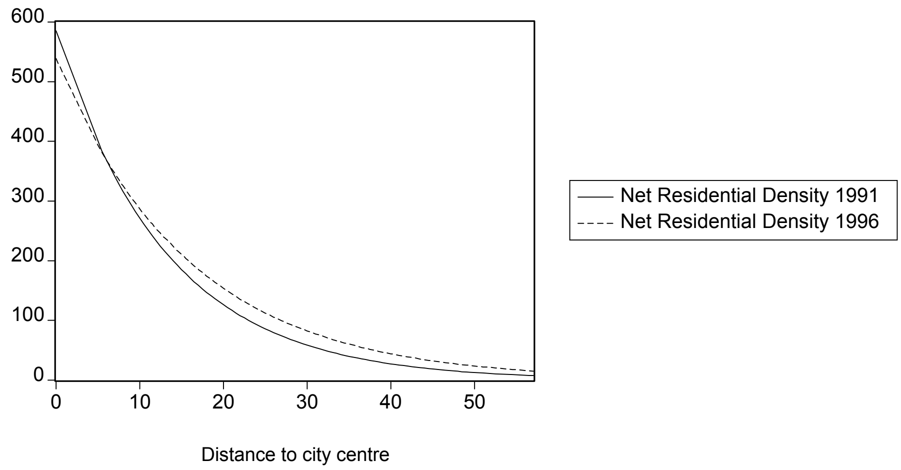
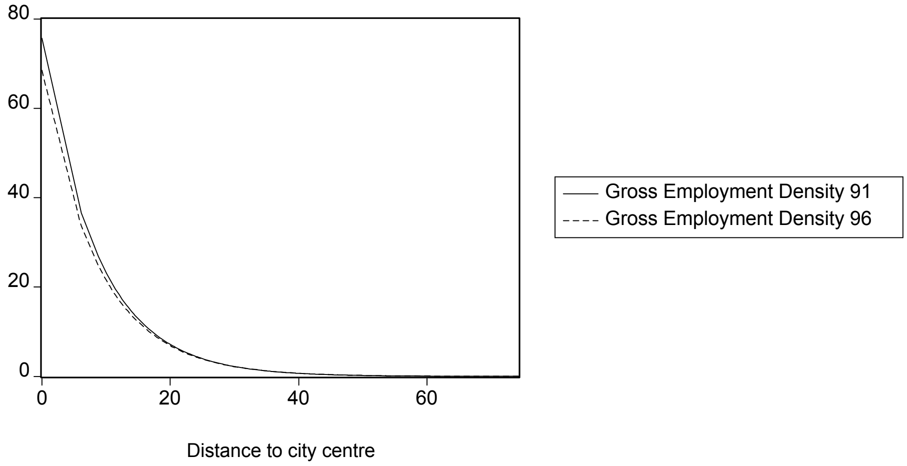


Figure 3.b
Employment exponential density functions 1991 and 1996



The dynamic VCM Model

The varying parameter density gradient model developed by Johnson-Kau (1980) and Alperovich (1983) consists in introducing socio-economic variables to explain inter- and intra-urban variations in the distance-density relationship. The most common variables proposed to capture inter-metropolitan variations are medium income, transportation costs, city size and city edge. The individual city varying parameter density gradient model allows D_0 and γ to be conditioned on tract or municipal specific variables.

We shall develop a *dynamic varying-parameter mode*l to test the diverse theories of employment and population suburbanisation.

Employment and population suburbanisation is captured by the decline of the estimated gradient and theoretical D_0

$$|\gamma_{t+1}| < |\gamma_t|$$
$$D_{0,t+1} < D_{o,t}$$

From equation (6) we know that

$$LnDEN_{t+1}(x) - LnDEN_t(x) = LnD_{0t+1}, - LnD_{0,t} - x(\gamma_{t+1} - \gamma_t)$$

so

$$LnDEN_{t+1}(x) - LnDEN_t(x) = Ln(a_r \sum_{r=1}^{n}(P_{r,t+1} - P_{r,t}) - xb_r(\sum_{r=1}^{n}(P_{r,t+1} - P_{r,t}) \quad (7)$$

in case that the fundamental parameters remain constant.

Following equation (6), parameters a_r and b_r captures the municipal determinants of urban spatial structure, while following equation (7) the same parameters capture the static effect of each r variable on suburbanisation. We can also determine the dynamic or inertial effect of such variables by considering that:

$$D_{0\,t+1} - D_{0t} = F'(P_r) = a'_0 + \sum_{r=1}^{n} a'_r \, P_{r\,t} \quad (8)$$

$$\gamma_{t+1} - \gamma_t = G'(P_r) = b'_0 + \sum_{r=1}^{n} b'_r \, P_{rt} \quad (9)$$

Including equations (8) and (9) in equation (7) by considering both static and dynamic factors, we find

$$\begin{aligned} &LnDEN_{t+1}(x) - LnDEN_t(x) = \\ &Ln(a_r \sum_{r=1}^{n} (P_{r,t+1} - P_{r,t}) + Ln(a'_\gamma \sum_{\gamma=1}^{n} (P_{\gamma,t})) - xb_r (\sum_{r=1}^{n} (P_{r,t+1} - P_{r,t})) - xb'_\gamma (\sum_{\gamma=1}^{n} (P_{\gamma t})) \end{aligned} \quad (10)$$

In the single city case, Richardson (1978) and Lahiri and Numrich (1983) have noted that while suburbanization entails a decline in $|\gamma|$, D_0 remains nearly the same. We have tested diverse specifications and in all cases the dependent variables for LnD_0 are not statistically significant, so next we present only regressions with γ conditioned on municipal specific variables.

$$LnDEN_{t+1}(x) - LnDEN_t(x) = -xb_\gamma \sum_{\gamma=1}^{n} (P_{r,t+1} - P_{r,t})) - xb'_\gamma (\sum_{\gamma=1}^{n} (P_{rt})) \quad (11)$$

6. RESIDENTIAL DENSITY DYNAMIC VCM

Suburbanisation theories

In identifying the variables of urban spatial structure, or the static effects of suburbanisation, we have not followed the works of Muth (1969), Johnson and Kau (1980) or Lahiri and Numrich (1983) among others, where inter-urban variations in the distance-density relationship are explained by income, transportation cost, city size and city age differences. The reason is that in the case of a single city, age or municipal size differentials are irrelevant. The criteria followed was to introduce variables related to the main theories of suburbanisation.

Mieszkowski and Mills (1993) propose grouping all approaches under two main theories, the Natural Evolution Theory -or the Urban Filtering Approach- and the Externalities Theory. The former explains the tendency of the middle class to live in suburbs since new housing is built on the periphery. Older, smaller, and centrally located residential units filter down to lower income groups. This theory emphasises the effect of rising real income over time, the demand of new housing and land, and the heterogeneity of housing stock (Mieszkowski and Mills (1993)). In contrast, the latter approach stresses social problems of central cities such as low quality public schools, racial tension, crime and congestion. These problems lead medium and high income families to migrate to the suburbs. Both theories emphasise the effect of urban transportation innovations as the factor that reinforced the process of migration to the suburbs.

Variables

To capture the dynamic effect of urban filtering we have chosen *HABNOU91*, the number of new housing of municipality i between 1991-1992 over the housing stock of the municipality in 1991, as explanatory variable, while for testing the static effect of urban filtering we included as an additional variable *DIFHANOU*, the difference between *HABNOU96*, the number of new housing between 1996 and 1997 over the housing stock in 1996, and *HABNOU91*. To capture the dynamic effect of externalities between different educational groups we have included *SUP91*, the percentage of graduate population over total population of municipality i in 1991. The static effect is captured by *DIFSUP*, the difference between 1996 and 1991 in the same variable. To test the static effect of technology innovation and infrastructure improvement in private transportation, we take as explanatory variable *PTR91*, the percentage of private transport commuters in 1991. The static effect is captured by *DIFPTR*, the difference in private transport commuters between 1991 an 1996.

Estimates

Table (5) reports our basic ordinary least squares estimates of equation (12).

$$LnDEN_{96}(x) - LnDEN_{91}(x) = -x(b_1 DIFHABNOU + b_2 DIFSUP + b_3 DIFPTR + b'_1 HABNOU91 + b'_2 SUP91 + b'_3 PTR91) \quad (12)$$

A negative sign of the estimated coefficient implies a direct negative effect of the variable on the absolute value of the gradient, which implies a positive effect on suburbanisation. The estimates indicate that:

a) the static or simultaneous effect of the percentage of graduate population is positive and statistically significant. This result reveals that high income and graduate families have a proportionally greater presence in central areas. Such a tendency is quite common in the case of European cities, whereas it only happen in older North East American cities (Glaeser et al (2000)) (figure 4). The dynamic effect is negative, suggesting that externalities between different educational groups is driving suburbanisation. The inertial or dynamic effect counteracts the static weight of historical central localisation of high income families.

b) The static effect of urban filtering is negative, but not significant, while the dynamic effect is negative and significant. This result probably reflects that those municipalities which in 1991 were building proportionally more housing, have received more population than the rest, but between 1991 and 1996 the response of the construction sector has been to build proportionally more in the first and second rings of the region.

c) Private transport commuting has a static and a dynamic effect on suburbanisation. Both parameters are negative and significant.

Figure 4
Medium Income (thousand ptas 1996) and Distance to urban centre. Cubic-Spline function

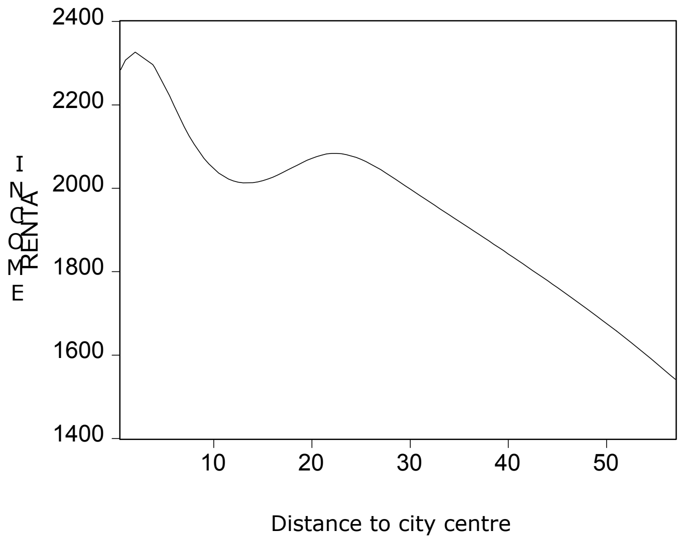


Table 4
Equation (12) estimates

	DEPENDENT VARIABLE $LnDEN(X)_{1995} - LnDEN(X)_{1990}$
-DIFHABNOU*X	-0.002 (0.2)
-DIFSUP*X	**0.19*** (10)
-DIFPTR*X	**-0.04*** (2.1)
-HABNOU91*X	**-0.05*** (2.5)
-SUP91*X	**-0.15*** (5.6)
-PTR91*X	**-0.028*** (3.07)
R^2	0.46

Statistic "t" in parenthesis.
(*) Statistically significant variable.
R^2: Determination Coefficient.

7. EMPLOYMENT DENSITY DYNAMIC VCM

Theories of employment Suburbanisation

Industry has changed its localisation pattern from being strongly concentrated to present a dispersed distribution. The theories that pretend to explain this tendency are:

a) *Urban Planning theory*: Competition for the use of the central land has tended to favour service and the residential uses at the expense of industry, due to environmental incompatibilities (McDonald (1997))

b) *City Life Cycles Theory*: Industry employment is spatially concentrated in the first stages, when the industry needs the incubator effect of central city, and begin to disperse once processes are standardised, and the need for cheap land and accessibility to the main transport axes becomes stronger (Norton (1979)).

c) *Local taxes*. Pay lower taxes on the periphery can decisively influence the localisation decision (Tiebout (1966)).

d) *Pecuniary externalities*. If demand creates supply, industrial and services activities for the end consumer can locate in a dispersed way to minimise consumer transportation costs. In this sense, activity may spread because population spreads (Krugman (1989)).

e*) New suburban agglomeration economies*. New agglomeration economies can give way to new suburban activity centres such as the industrial and service corridors along freeways, office centres, high tech industry corridors, etc., as well as reinforcing old industrial districts localised in medium cities within the urban system. These agglomeration economies can in turn exercise a static or a dynamic effect (Stanback (1991)).

f) *Network economies and transport infrastructures improvement*. Transport improvements allow agglomeration economies to have a bigger impact radius.

g) *Segmentation theory:* More flexible organisation structures attempt to seek greater production efficiency. The main predictions of this theory is that big firms tend to segment and localise in a more disperse way (Scott (1988)).

Variables

The static effects are captured by the following variables:

DIFPOB: 1996 and 1991 population difference
DIFINC: 1996 and 1991 medium income difference
DIFVEH: 1996 and 1991 number of vehicles per employed difference.
DIFVAR: 1996 and 1991 HH index that measures the lack of diversity difference
DIFCL: 1996 and 1991 localisation coefficient difference.
DIFSIZE: 1996 and 1991 number of employed per establishment diferrence

The dynamic or inertial effects are captured by means of:

POB91: 1991 Population
INC91: 1991 medium income
VEH91: Number of vehicles per worker in 1991
VAR91: Lack of diversity index in 1991
CL91: Localisation coefficient in 1991
TK: Kilometres of highways (constant in the period considered period)
IAE: economic activity taxes (only available for one year)
SIZE: Number of employed per establishment

Population and income seek to simultaneously capture demand attraction (pecuniary externalities) or expulsion (urban planning theory); the number of vehicles per employed and the kilometres of highway of the municipality, the costs of transport; IAE, the effects of local taxes; the difference of diversity and localisation coefficients, the static effects of urbanisation and localisation economies respectively; 1991 localisation and diversity coefficient, the dynamic effects of agglomeration economies; and finally, the variable “size” seeks to capture the effects of the product cycle.

Estimates:

Table 5 reports our basic ordinary least squares estimates of equation (13).

$$
\begin{aligned}
& LnEmpDEN_{96}(x) - LnEmpDEN_{91}(x) = \\
& -x(b_1 DIFPOP + b_2 DIFINC + b_3 DIFVEH + B_4 DIFVAR + b_5 DIFCL + b_6 DIFSIZE \qquad (13) \\
& + b'_1 POP91 + b'_2 INC91 + b'_3 VEH91 + b'_4 VAR91 + b'_5 CL91 + b'_6 SIZE91 + b'_7 TK + b'_8 IAE)
\end{aligned}
$$

The estimated coefficients for all the sectors and just for manufacturing sectors indicate that Population, Income, Localisation Coefficient and firm size have an statistically significant static suburbanisation effect, while Income, the number of vehicles per unit of labour and the localisation coefficient have a dynamic suburbanisation effect.

The explanatory power of Income is lower for manufacturing sectors indicating that industrial and residential uses are not as compatible in high income municipalities as service sectors. Another interesting result is that the value of the localisation coefficient is negative for the static specification while is positive for the dynamic or inertial specification. It seems to indicate that historically there has been a product cycle process, but that at present there is a tendency towards segmentation. There is not evidence in favour of dynamic or static Jacobs externalities, and taxation has not generated a trend towards employment sprawl.

Table 6
Equation 13 Estimates

	DEPENENT VARIABLE: $LnEmpDEN96 - LnEmpDEN91$	
	All sectors	**Industry**
-DIFPOP*X	-7.3* (2.7)	-9.4* (2.2)
-DIFINC*X	$-1.8e^{-6*}$ (2.3)	$-8.1\ e^{-6}$ (0.6)
-DIFVEH*X	$1.8e^{-6*}$ (2.9)	$2.4\ e^{-6*}$ (2.3)
-DIFVAR*X	-0.01 (0.4)	0.02 (0.57)
-DIFCL*X	-0.009* (21.2)	-0.009* (17.2)
-DIFSIZE*X	-0.0001* (8.9)	-0.0001* (7.3)
-POP91*X	$-5.11\ e^{-8}$ (1.5)	$-6.8\ e^{-8}$ (1.3)
-INC91*X	$3.5\ e^{-6}$ (1.5)	-2 e-6* (2.4)
-VEH91*X	-8.6 e-7 (1.7)	$-1.7\ e^{-6*}$ (2)
-VAR91*X	-0.01 (0.8)	-0.007 (0.34)
-CL91*X	-0.0009* (3.5)	-0.0018* (5.3)
-SIZE91*X	0.0001* (9.6)	0.0001* (7)
-TK*X	$3.6\ e^{-5}$ (0.9)	$6.9\ e^{-6}$ (0.1)
-IAE*X	0.005* (3)	0.005* (2)
R^2	0.25	0.28

Statistic "t" in parenthesis.
(*) Statistically significant variable.
R^2: Determination Coefficient.

8. CONCLUDING REMARKS

We have estimated exponential, extended exponential with distance to axis, and cubic-spline population and employment density functions. We have also tested a dynamic VCM to explore which factors are driving suburbanisation in the case of the Barcelona Metropolitan Region. The main findings are:

1) The extended exponential function and the cubic-spline function explain population and employment variations better than the standard exponential density function.

2) The estimated density gradient variation between 1991 and 1996 suggest that suburbanisation is taking place, population suburbanisation being a more intensive process than employment suburbanisation.

3) One of the reasons than explain the poor overall explanatory power of the exponential function is that the Monocentric City Model only partly applies in the Barcelona Metropolitan Region, an old conurbation were history is still very present.

4) Dynamic externalities and urban filtering, as well as private transportation improvements are driving population suburbanisation, while in the case of employment, the main static factors seems to be Population, Income, Localisation Coefficient and firm size. Income, the number of vehicles per worker and the localisation coefficient seem to exercise a dynamic suburbanisation effect.

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