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Walid Oueslati, Seraphim Alvanides, Guy Garrod

université angers

Granem
Groupe de Recherche ANgevin
en Economie et Management
UMR-MA n°49

13, allée François Mitterrand
BP 13633
49100 ANGERS Cedex 01
Tél. : +33 (0) 2 41 96 21 06

Web : http://www.univ-angers.fr/granem

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Walid Oueslati
GRANEM, Université d'Angers

Seraphim Alvanides
Geography and Built Environment, Northumbria University

Guy Garrod
Center for Rural Economy, University of Newcastle uponTyne

janvier 2014

Document de travail du GRANEM n° 2014-01-040

AGRO CAMPUS OUEST

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Classification JEL : H4, Q15, R1, R2, R5

Mots-clés : étalement urbain, villes européennes, échelle spatiale, modèle de ville monocentrique, fragmentation urbaine.
Keywords: urban sprawl, European cities, spatial scale, monocentric city model, urban scattering.

Résumé : Ce papier étudie les causes de l'étalement urbain dans le contexte européen. Sur la base d'un modèle de ville monocentrique, nous exploitons plusieurs sources de données portant sur 282 aires urbaines et trois périodes de références 1990, 2000 et 2006. Deux indicateurs de l'étalement ont été utilisés : la superficie artificialisée et fragmentation urbaine. Ces deux indicateurs ont été confrontés à un ensemble de variables économiques et géographiques. Afin de contrôler les corrélations possibles entre les variables explicatives et l'hétérogénéité des observations individuelles, nous avons utilisé à la fois une régression à la Hausman Taylor et une régression aléatoire. Bien que les principales conclusions du modèle monocentrique aient été confirmées, son pouvoir explicatif de la fragmentation est relativement faible.

Abstract: This paper provides empirical evidence that helps to answer several key questions relating to the extent and causes of urban sprawl in Europe. Building on the monocentric city model, this study uses existing data sources to derive a set of panel data for 282 European cities at three time points (1990, 2000 and 2006). Two indices of urban sprawl are calculated and respectively reflect changes in artificial area and the levels of urban fragementation for each city. These are supplemented by a set of data on various economic and geographical variables that might explain the variation of these indices. Estimating using a Hausman Taylor and random regressors to control the possible correlation between explanatory variables and unobservable city-level effects, we find that the fundamental conclusions of the standard monocentric model are valid in the European context for both indices. Although the variables generated by the monocentric model explain a large part of variation of artificial area, their explanatory power for the fragmentation is relatively low.

Walid Oueslati
Agrocampus Ouest
Université d'Angers
walid.oueslati@agrocampus-ouest.fr

Seraphim ALVANIDES
Geography and Built Environment
Université de Northumbria
s.alvanides@gmail.com

Guy GARROD
Center for Rural Economy
Université de Newcastle uponTyne
Guy.Garrod@ncl.ac.uk

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Walid Oueslati [a, 1], Seraphim Alvanides [b], Guy Garrod[c]

[a] *Granem, Agrocampus Ouest, France*
[b] *Geography and Built Environment, Northumbria University, Newcastle, UK*
[c] *CRE, University of Newcastle uponTyne, UK*

Abstract :

This paper provides empirical evidence that helps to answer several key questions relating to the extent and causes of urban sprawl in Europe. Building on the monocentric city model, this study uses existing data sources to derive a set of panel data for 282 European cities at three time points (1990, 2000 and 2006). Two indices of urban sprawl are calculated and respectively reflect changes in artificial area and the levels of urban fragementation for each city. These are supplemented by a set of data on various economic and geographical variables that might explain the variation of these indices. Estimating using a Hausman Taylor and random regressors to control the possible correlation between explanatory variables and unobservable city-level effects, we find that the fundamental conclusions of the standard monocentric model are valid in the European context for both indices. Although the variables generated by the monocentric model explain a large part of variation of artificial area, their explanatory power for the fragmentation is relatively low.

Key words : Urban sprawl, European cities, spatial scale, monocentric city model, urban scattering.

JEL Classification : H4, Q15, R1, R2, R5.

[1] Corresponding author: walid.oueslati@agrocampus-ouest.fr

1. Introduction

Europe has one of the world's highest densities of urban settlement, with over 75% of the population living in urban areas. Despite Europe's relatively low rate of population growth, there continues to be an uneven growth of urban areas across the continent. The size of many European cities is increasing at a much faster rate than their populations. This trend towards reduced population densities began in the early 1970s, most prominantly in medium-sized European cities. There is no sign that this trend is slowing down and as a result, the demand for land around cities is becoming a critical issue in many areas (EEA, 2006).

The phenonenon of increasingly large urban areas taking up a greater proportion of the available land area is often termed urban sprawl. Studies such as Czech *et al.* (2000), Johnson (2001) and Robinson *et al.* (2005) have documented the negative environmental impacts that can be associated with urban sprawl, while other studies (e.g. Hasse and Lathrop, 2003) have also documented the increased social costs involved in the provision of public infrastructure as cities increase in size. Such impacts can directly affect the quality of life for people living in European cities. For this reason, it is essential to gain a better understanding of urban sprawl and to gain some insights into what causes it. This paper, therefore, sets out to explore the determinants of urban sprawl in European cities and to compare its findings with those of the existing literature on this topic.

The literature on urban sprawl incorporates the work of economists, geographers and planners. Surveys of important issues underlying this research can be found in, among others, Anas et al. (1998), Brueckner (2000), Nechyba and Walsh (2004), Couch et al. (2007), and Anas and Pines (2008). Although there is some debate over the precise definition of urban sprawl, a general consensus seems to be emerging that characterises urban sprawl as a multidimensional phenomenon, typified by an unplanned and uneven pattern of urban development that is driven by a multitude of processes and which leads to inefficient utilisation of land resources. Urban sprawl is observed globally, though its characteristics and impacts vary. While early research in this area tended to focus on North American, several recent studies have discussed the accelleration of urban sprawl across Europe (e.g. EEA, 2006; Couch et al. 2007; Christiansen and Loftsgarden, 2011). Although differences in the nature and pattern of spawl have been observed between Europe and North America, there are also intra-European variations in urban sprawl reflecting the former's greater diversity in geography, land-use policy, economic conditions and urban culture.

Despite the increasing interest in urban sprawl in Europe, relatively few empirical studies have been undertaken at the continental scale. The heterogeneity of the European urban context and limits to the availability of data are probably the main reasons for this lack of interest. That is not to say that there has not been an effort to study the process of urban sprawl in Europe. Various studies, including Batty et al. (2003), Phelps and Parsons (2003), Holden and Norland (2005), Couch et al. (2007), Travisi et al. (2010) and Pirotte and Madre (2011), focus on urban sprawl within particular regions or cities. However, to the best of our knowledge, only Pattichani and Zenou (2009) and Arribas-Bel et al. (2011) consider a range of cities with the aim of giving a general overview of the phenomenon for Europe as a whole.

Pattichani and Zenou (2009) sought to contrast urban patterns in Europe and the United States, using data on a sample of European Cities[2]. They noted the lack of a standard definition of the city or metropolitan area in Europe and highlighted the difficulties inherent in attempting a systematic cross-national comparison of European cities owing to the limited availability of data. Despite these limitations, their study provided some evidence on the extent of urban sprawl in cities in the European Union. However, their study does not address the measurement of urbanized areas and instead concentrates on identifying the factors that influence population density. In their study, Arribas-Bel et al. (2011) used spatial data derived from the European Corine Land Cover database to consider the issue of urban sprawl from a multidimensional viewpoint. Using six dimensions to define the concept (i.e. connectivity, decentralisation, density, scattering, availability of open space, and land-use mix), they developed various indices of sprawl that were then calculated for a sample of 209 European cities for year 2000. Even though the study offered a new methodological approach using rich data sets to measure urban sprawl, it did not explicitly address the determinants of the phenomenon.

In this paper, we identify and gather existing data that can be used to identify the key determinants of urban sprawl across a large sample of European cities. We base our analysis on the well-known monocentric city model, which identifies population, income, transportation cost and the value of agricultural land as essential drivers of sprawl. In addition to these economic variables, other geographical, socio-cultural and climatic factors, highlighted by the literature, are also considered.
Our study makes two main contributions to the literature on urban sprawl. The first concerns the measurement of sprawl and makes some observations about the data that is available for this purpose. Two complementary indices of sprawl are used, the first reflecting the change in spatial scale and the second the fragmentation processes that are observed when large urban areas grow. By considering these two indices, we seek to ascertain whether the factors that lead to the expansion of urban areas are also responsible for discontinuities in its spatial configuration. Both indices are calculated using

[2] Pattichani and Zenou (2009) used data provided by the Urban Audit database.

Corine Land Cover data sets for three reference years (1990, 2000 and 2006). Moreover, we use a range of data sources to build a complete and consistent set of explanatory variables for a sample of 282 European cities. To our knowledge this is the first time that a study of this magnitude and scope has been conducted in the European context.

The second important contribution of this study is related to the econometric techniques used in the estimation of the indices. Unlike previous studies, a comprehensive analysis of panel data is conducted to account for unobservable individual heterogeneity and to determine the best estimation method for each index. Several tests were used to choose between alternative panel data estimators. Specifically, a modified random effects-type model (the Hausman–Taylor method) is used, which allows us to control for endogeneity bias while, simultaneously, identifying the estimates for the time-invariant regressor.

The remainder of this paper is structured as follows. Section 2 reviews the theoretical and empirical literature on sprawl and identifies its main determinants. Section 3 presents some methodological issues related to the measurement of sprawl and the associated data requirements, and goes on to discuss some characteristics of urban sprawl in Europe based on our indices. Section 4 presents the empirical model and results from a regression analysis. The final section concludes and makes some observations relevant to urban planning policy.

2. Determinants of urban sprawl

2.1. Theoretical background

The fundamental theory in urban economics relevant to urban expansion is the monocentric city model (Alonso 1994; Mills 1967; Muth 1969; and Wheaton 1974). Within this model it is assumed that all employment in the city takes place within a single Central Business District (CBD). The pattern of urban development is then shaped by the trade-off between afforable housing further away from the CBD and the associated commuting costs. Thus, to offset higher commuting costs, housing prices decline with distance away from the CBD. In the monocentric city framework, space is represented by a real line $X = (-\infty, +\infty)$ with the CBD at its origin. Let $\bar{x}$ be the boundary of the city, r denotes urban land rent and r_a is the agricultural land rent. Land being rented to the highest bidder, the city can then be represented by the set:

$$C = \{x < \bar{x} \mid r(\bar{x}, y, t, u) = r_a\} \quad (1)$$

where y and t are the household income and the commuting cost respectively. u is a common utility level enjoyed by all households in the metropolitan area. The urban area must be sufficient to provide

housing for all households who chosen to settle in the city. To formalize this condition, let ρ be the population density and θ equal the number of radians of land available for housing at each x, with $0<\theta\leq 2\pi$ (This means that the remaining land will be consumed by topographical irregularities). Multiplying the density by $\boldsymbol{\theta}$ gives the number of people fitting in a narrow ring and integrating out to $\bar{x}$ then yields the n households living in the city. The condition that the urban population n fits inside x may then be written :

$$\int_0^x \theta x \rho(x,y,t,u)dx = n \tag{2}$$

The interpretation of the urban equilibrium conditions (1) and (2) depends on whether the city is closed or open to migration. In a closed city, where n is fixed, the equilibrium conditions are given by (1) and (2), determining the utility level (u) in the urban area. In an open-city, where migration in and out is costless, urban residents are neither better of nor worse of than the rest of the population. In this case, the urban utility level is fixed exogenously, and population n becomes endogenous, adjusting to whatever value is consistent with the prevailing utility level.

The influence of these parameters on the city's spatial size can be derived by comparative static analysis of (1) and (2), as presented by Wheaton (1974) and Brueckner (1987). In the closed-city model, the exogenous parameters are n, y, t and r_a. Results of the comparative static analysis for $\bar{x}$ and ρ can be expressed as:

$$\frac{\partial \bar{x}}{\partial n} > 0, \frac{\partial \bar{x}}{\partial y} > 0, \frac{\partial \bar{x}}{\partial t} < 0, \frac{\partial \bar{x}}{\partial r_a} < 0 \tag{3}$$

$$\frac{\partial \rho}{\partial n} > 0, \frac{\partial \rho}{\partial y} < 0, \frac{\partial \rho}{\partial t} > 0, \frac{\partial \rho}{\partial r_a} > 0 \tag{4}$$

These results highlight the main predictions of the monocentric city model. First an increase in the urban population should increase the distance to the edge of the city and raise the population density since more people must be housed. Second, an increase in income increases housing demand and leads to an extended city with a lower population density. Third, an increase in commuting cost lowers disposable income at all locations, reducing housing demand and leading to a compact city with high population density. Fourth, increasing the agricultural rent raises the opportunity cost of urban land and makes the city smaller and denser.

In the open-city model, where the population (n) is endogenous and the utility level is exogenous the impact of changes in y, t and r_a on x and ρ follow immediately from (1) and (2). The results predict that a high-income city will have a larger and denser area than a low-income city. Moreover, high transportation costs in an open city leads to a smaller and less dense city. The comparative static

analysis also predicts that a high agricultural rent leads to a smaller city with a lower population, but at a given distance from the CBD the cities will be identical. More complicated comparative static analyses that includes multiple resident classes have been presented by Miyao (1975) and Hartwick *et al.* (1976).

The question that arises is whether cities in the real world are best viewed according to the open- or closed-city model. Several empirical studies suggest that the predictions of both models are partly borne out in reality. While the case of a closed city seems to be considered typical of advanced countries, the open city situation is more likely in developing country contexts (Wheaton,1974).

The basic version of the monocentric city model cannot explain scattered development, where parcels of land are left undeveloped while others farther away are built up. One direction that urban economists have followed to account for scattered development is to assign an amenity value to public open space so that individuals may be willing to incur the additional commuting costs associated with locating farther away from the city center in order to have open space near their home (Wu and Plantinga, 2003; Turner, 2005; Wu, 2006; Tajibaeva et al. 2008; Newbern and Berck, 2011). This is mainly due to the fact that the household bid-function is not necessarily monotonous with regards to the distance from the CBD. Following this line of research, Cavailhès et al. (2004) and Coisnon *et al.* (2014) show that the spatial heterogeneity of agricultural amenities can also lead to leapfrog development within a suburban area.

2.2. Empirical approaches

Several empirical studies have been undertaken to test the empirical validity of the monocentric city model. Brueckner and Fansler (1983) utilised cross-sectional data from 40 small metropolitan regions in the United States using linear and non-linear Box-Cox regressions. They found that income, population and agricultural rent were statistically significant determinants of urban land area. However, the coefficients of the variables measuring commuting costs were not significant. They used two proxies to measure the commuting cost: percentage of commuters using public transit and percentage of households owning one or more automobiles.

Using a panel data set for 33 United States metropolitan statistical areas, McGrath (2005) found similar results to Brueckner and Fansler (1983), except for the coefficient on the commuting costs variable[3], which was statistically significant. Both studies used different proxies for commuting costs. In order to capture the time-variant unobservable factors, McGrath (2005) included a time trend variable to control for the fact that the data covered five decades. Song and Zenou (2006), estimated a

[3] McGrath (2005) used average annual Consumer Price Index (CPI) for private transportation for each year, rescaled to each region using private transportation cost data.

model relating an urbanized area's size to the property tax rate and other control variables such as population, income, agricultural rent, and transportation expenditure. Their study covered 448 urban areas in the US. They found that higher property taxes result in smaller cities. For the other variable, they confirmed the predictions of the monocentric city model, except for the coefficient of the agricultural rent variable which was not significant. They explained this result by arguing that the constructed weighted average of agricultural land rent for the urbanized area did not reflect the actual agricultural land rent at the periphery of the urbanized area.

In addition to the key variables of the monocentric city model, Burchfield *et al.* (2006) included different environmental and geographical variables to account for differences between cities. Sprawl in their study is measured as the amount of undeveloped land surrounding an average urban dwelling. This involves capturing the extent to which urban development is scattered across undeveloped land. They concluded that sprawl in the United States between 1976 and 1992 was positively related to ground water availability, temperate climate, rugged terrain, decentralized employment, early public transport infrastructure, uncertainty about metropolitan growth, and low impact of public service financing on local taxpayers.

In the context of developing countries, Deng *et al.* (2008), and Shanzi *et al.* (2009) investigate the determinants of the spatial scale of Chinese cities using a consolidated monocentric city model. Consistent with a number of the key hypotheses generated by that model, their results demonstrate the crucial role that income growth has played in China's urban expansion. Similarly, while Deng *et al.* (2008) find that industrialisation and the rise of the service sector both appear to have influenced the growth of urban development, they conclude that the role of these factors was relatively minor compared to the direct effect of economic growth. In addition, Shanzi *et al.* (2009) illustrate that the urban spatial scale of Chinese cities is better understood by using a model that consolidates features of both closed and open city models. In another paper, Deng *et al.* (2010) estimated the elasticity of economic growth on urban land expansion in China by using spatial statistics. Using these techniques they filter out the effects associated with spatial dependencies that can distort the relationship between GDP growth and the size of the urban core.

All of these studies confirm that the monocentric city model is empirically robust. The economic variables identified by this literature explain the majority of spatial variation in the sizes of cities in different contexts. Moreover, many other geographical variables have also been found to play an important role in explaining urban expansion.

It should also be noted that some models have included variables that measure the ethnic composition of the population (e.g. Selod and Zenou, 2006) and crime rates (e.g. Freeman *et al.*, 1996). In the

American context, it was established that increases in the percentage of ethnic minority populations within cities and rising city centre crime rates both led to a growth in urban sprawl. The latter has been explained by the desire of many residents to improve their personal security by moving further away the central area of the city. In a European context, Patachini and Zenou (2009) confirm the positive impact of higher crime rates on sprawl, but observe the opposite effect for the impact of ethnic minority populations.

Although there is evidence that urban sprawl is a multidimensional issue that should be measured in a particular way (Arribas-Bel *et al.*, 2011), each of the previous empirical studies examines only a single dimension of sprawl, i.e. the urbanised area or population density. Chin (2002), however, identified four definitions of urban sprawl based upon: urban form; land use; impacts; and density. In definitions based around urban form, sprawl is positioned against the ideal of the compact city, any deviation away from which may be regarded as sprawl. By contrast, the land-use perspective tends to associate sprawl with spatial segregation and with the extensive mono-functional use of land. An alternative definition is based on the impacts of sprawl. Here it is suggested that sprawl can be defined as any development pattern leading to poor accessibility among related land uses (Ewing, 1994). Finally, the density approach considers the relationship between sprawl and the number of people living in a given land area and concentrates on the intensity of land use, i.e. where a decrease in the population density of an urban area can be an indicator of urban sprawl.

Chin (2002) also identifies three main dimensions of urban sprawl, respectively based around: urban spatial scale; population density decline; and scattered urbanisation. These are used to provide the rationale for the indicators used in this study.

3. Data

Based on the theoretical and empirical literature, we seek to explain differences in urban sprawl in Europe across space and time. Our approach is mainly based on the monocentric city framework and conceptually our empirical model is given by:

Sprawl index = f(income, population, agricultural land value, transportation costs, other socio-economic, climatic and geographic variables)

We consider the two indices of sprawl that best reflect both the spatial scale of cities and urban morphology. By considering these indices, we examine the extent to which the determinants of urban expansion can explain the fragmentation of urban areas. As independent variables, both indices will be estimated using the same explanatory variables. In this section we specify the sources and extent of the

data used in this study before discussing the methodological features of sprawl measurements and the choice of explanatory variables.

3.1. Data on urbanisation and sprawl measures

We focus on a sample of European cities obtained by combining various existing data sources. Our starting point was the complete set of 320 cities used in the Urban Audit database[4]. Here, all cities are defined at three scales: the Core city, which encompasses the administrative boundaries of the city; the Large Urban Zone (LUZ), which is an approximation of the functional urban region centred around the Core city; and the Sub-City District, which is a subdivision of the LUZ (Eurostat, 2004). We concentrate on the LUZ, because sprawl is observed around the fringes of cities from where it spreads out across the whole urban region. Therefore, the boundary of each LUZ defines the spatial units upon which this study is based.

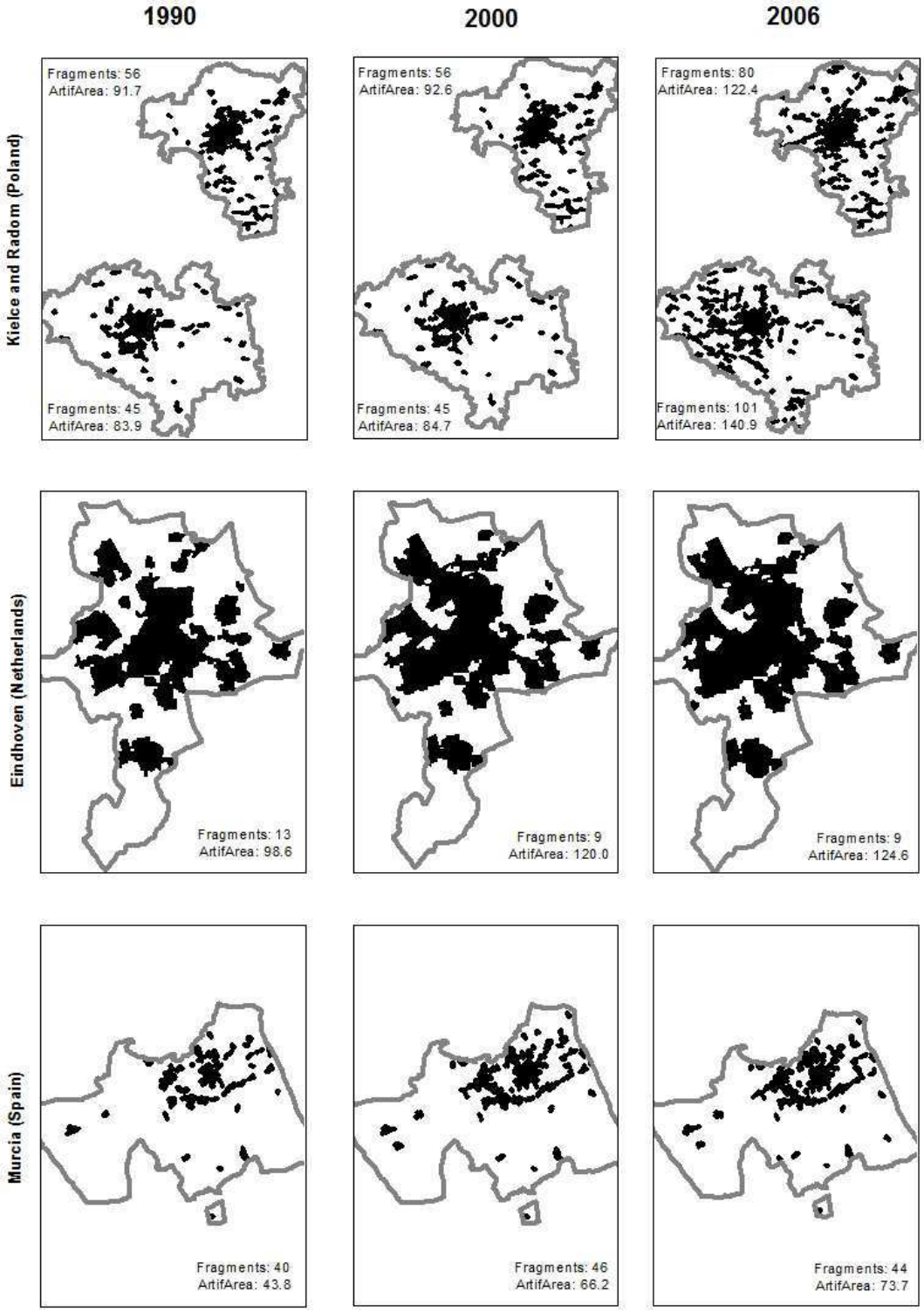
Urban Audit provides rather limited information on land-use, with poor coverage for many cities. As an alternative to this data set, we use data on Urban Morphological Zones (UMZ), compiled by the European Environment Agency (EEA), which contains spatial information for three years (1990, 2000 and 2006)[5]. Derived from Corine Land Cover, UMZ data covers the whole EU-27 at a 200m resolution for those urban areas that considered to contribute to urban tissue and function (Guerois et al., 2012). Geospatial data on land-use for each city is obtained by superimposing the LUZ boundaries and the UMZ spatial data, using a Geographical Information System (GIS). To illustrate this process and the nature of the spatial data, maps are provided created for four selected cities.

Figure 1 shows the example of the urban regions of Kielce and Radom (Poland), Eindhoven (Netherlands) and Murcia (Spain), observed for the three reference years (1990, 2000 and 2006). As shown in Figure 1, the external boundary (in grey) representing each LUZ remains stationary through time. However, the fragments of urbanised land represented by the black patches vary in both their size and numbers. The cities in Figure 1 were selected to illustrate different urban dynamics. For Kielce and Radom, both the number of fragments and the artificial area increased significantly in a relatively short period of time (between 2000 and 2006). In Eindhoven the artificial area increased while the number of fragments decreased over the three reference years. Finally, Murcia experienced a major urban development (as evidenced by the increase in artificial area), but the number of fragments remained relatively steady over time, for example compared to Kielce and Radom.

[4] The Urban audit database arises from a project coordinated by Eurostat that aims to provide a wide range of indicators of socio-economic and environmental issues. These indicators are measured across four periods: 1989-1993, 1994-1998, 1999-2002, 2003-2006. For futher details, refer to :
http://epp.eurostat.ec.europa.eu/portal/page/portal/region_cities/city_urban

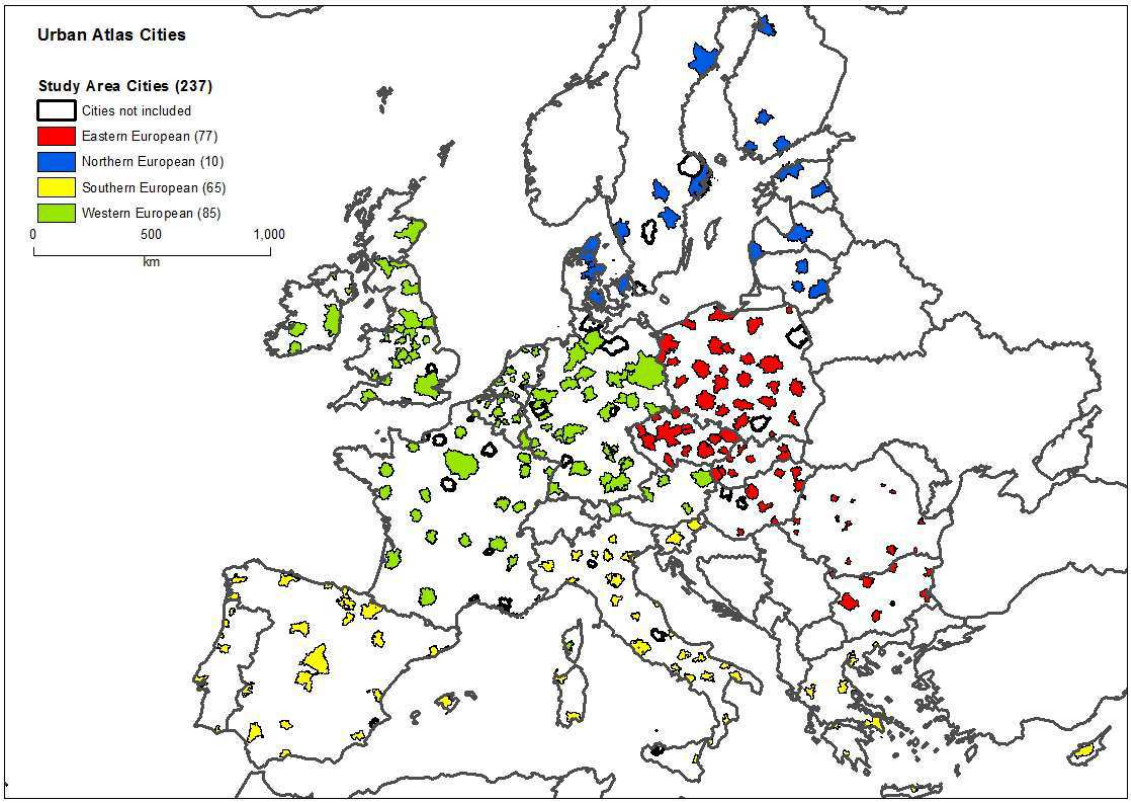
[5] For further details, refer to : http://eea.europa.eu/

Figure 1: *UMZ boundaries (in grey) and Artificial urban areas (in black) for selected cities*



Although the urban audit database covers 320 cities, the publicly available UMZ does not include data for a number of countries for 1990 (UK, Cyprus and Finland) and for 2006 (Greece and Cyprus). The sample used in this study contains the 282 LUZ, for which we have a complete information on artificial areas, the number of urban fragments, population and GDP for the three reference periods 1990, 2000 and 2006. Figure 2 shows the extent of the sample and cities are identified by four colours, depending on their supra-national region group[6].

Figure 2: *Study area with Urban Atlas Cities for supra-national regions*



The data collected on urbanization, allow two indices of urban sprawl to be constructed. The first index aims to measure the spatial scale of each city. The total artificial area in square kilometers (ArtifArea) is then considered as a proxy for all urbanised land in each LUZ. These areas were obtained directly from the spatial UMZ data according to Corine Land Cover nomenclature. This simple measure reflects the evolution of urban land cover in a given area without any prejudgment on internal composition or urban morphology, i.e. the scattered nature of the urban area.

The second index reflects urban morphology, and the spatial patterns of residential land development, in particular, whether residential development is scattered or compact. A simple scattering index is

[6] The supra-national regions are defined as follows : Southern European cities (Cyprus, Portugal, Spain, Italy, Malte, Slovenia), West European cities (Austria, Germany, Belguim, France, Ireland, Luxembourg, Netherlands, UK). Northern European cities (Danmark, Sweden, Finland, Estonia, Latvia, Lithuania) and Eastern European cities (Poland, Romania, Slovakia, Hungary, Czech Republic, Bulgaria).

adopted, measuring the degree to which urban development is spread across land in different fragments. We use the following expression:

$$Scatt = \frac{Frag}{ArtifArea} \quad (5)$$

where *Frag* represents the number of urban fragments (i.e. individual patches) within a specific LUZ. This index reflects how scattered the urban development is across the whole urban region. Sprawl is then identified as a high number of different fragments. We divide here by the artificial area within each LUZ to correct for the size effect, since we expect that larger urbanised areas will have more fragments.

3.2. Data on explanatory variables

The Urban audit database provides a wide range of variables, including those used in the monocentric city model (urban area, population, revenue, transport). However, data are missing for different cities and at different periods, which makes their use unfeasible. Therefore, the Urban Audit data is supplemented using data obtained from the European Observation Network, Territorial Development and Cohesion (ESPON)[7]. When combined, these data sources provide a set of explanatory variables covering a broad sample of European cities for three periods 1990, 2000 and 2006.

The ESPON database provides comprehensive data for each LUZ on Gross Domestic Product (GDP) adjusted for Purchasing Power Standards[8] and total population (POP)[9]. We use GDP per capita (GDPcap) as a proxy for income. All of these variables are defined for the three reference years (1990, 2000 and 2006) for 282 cities across Europe. However, no direct measures of transport costs or agricultural land rents exist for the whole of Europe over the relevant time periods. Similarly, there are no European data sets relating to agricultral land markets or transport costs at the city level. Based on the empirical studies cited earlier, proxies are identified that provide adequate measurements of these variables. First, to account for agricultural land rent, we calculate the ratio of agricultural land value to the area of agricultural land (Agriprox). Data on agricultural added value was available from ESPON, and the relevant data for agricultural land area for each LUZ was calculated from the other available data sets. The rationale for including this proxy is that the ratio could explain different levels of agricultural productivity. Normally, higher agricultural productivity should be capitalised into land rent. Similarly, highway density (Highway) data from the Eurostat regional data set was used as a

[7] ESPON is a European research programme, which provides pan-European evidence and knowledge about European territorial structures, trends, perspectives and policy impacts which enables comparisons amongst regions and cities. For further details, see : http://database.espon.eu/

[8] Purchasing Power Standards (PPS) reflect the price ratios between the countries and are at the same time expressed in a single currency. They thus eliminate from gross domestic products both the differences in currency expression and the differences in the prices levels between the countries.

[9] Total population represents all residents who have their residence within the LUZ

proxy for transport costs. The implicit assumption here, is that investments in highways make traveling faster and more convenient, which reduces the time and the costs of commuting.

Following Burchfield *et al.* (2006) and Deng *et al.* (2008), a set of climatic and environmental data was collected from the Urban Audit. The former include the number of days of rain per year (Rain) and the average temperature of the warmest months on the year (Temperature). The latter includes the annual average concentration of NO2 (*NO2*) as a good indicator of air pollution in the cities. A terrain variable, median city centre altitude above sea level (MedAlt), is also included. This variable is a partial indicator for the ruggednes of the LUZ's terrain which may have an impact on the potential for urban growth.

In addition to the economic and geographical variables of interest, various other social and cultural variables are considered. First, data on recorded crime (Crime) from the Urban Audit is used to account for the security situation in the central city. As mentioned previously, Patachini and Zenou (2009) find that higher crime rates increase sprawl. Second, we include the number of cinema seats (Cinema) as a proxy for the cultural attractiveness of the central city. A vibrant central city would be expected to discourage decentralisation, thus reducing sprawl and resulting in more compact urban areas. Despite some of these variables having missing data for certain cities, they were used to estimate the differentiating factors between different LUZs our sample. Table 1 provides a statistical summary of the panel data used in this study.

Table 1 : Statistical summary of explanatory variables

Variables *unit /(source)* [(c)]	Obs.[(a)]	Missing Obs.[(b)]	Mean	Min	Max	St. dev.
ArtifArea *Km2(UMZ)*	801	45	211.41	9.64	2876.50	293.54
Scatt *fragmenst/Km (UMZ)*	801	45	0.472	0.017	1.438	0.275
POP [(a)] *1000 inhabitants (ES)*	846	0	939.8	26.7	12961	1255.7
GDPcap [(a)] *Euros (ES)*	846	0	19935.6	1152	149681	12288.2
Agriprox *Euros per ha (ES and U)*	240	42	5761.9	36.2	90364.2	10415.2
Highway *km per km2(ER)*	282	0	28.6	0.1	289.0	36.4
Crime per *1000 inhabitants (UA)*	228	54	79.1	0.9	233.0	45.4
Rain *Number of days of rain per year (UA)*	282	0	157.3	32.0	266.0	49.6
Temperature *°C (UA)*	282	0	21.2	14.6	35.5	4.0
AccessAir *EU=100(U A)*	248	34	94.6	26.0	187.0	34.4
NO2 *Annual average concentration (UA)*	210	72	27.6	8.7	64.8	10.3

CineSeats *per1000 inhabitants (UA)*	250	32	17.3	0.8	51.9	9.8
MedAlt *m (UA)*	282	0	132.2	2	746	142.5

(a) The sample is consisted of 282 cities observed in 1990, 2000 and 2006. (b) Missing data includes cities in the UK and Greece for 1990, and Cyprus, Finland, Greece, Sweden for 2006. (c). Data sources : ER: Eurosatat Regional data; ES: ESPON; U: UMZ and UA:Urban Audit.

3.3. Variations in urban sprawl across Europe

Preliminary analysis of the data shows that on average over the period 1990-2000, the urbanized area increased by 18.4%, while population density fell by 9.07 % and the Scattering index decreased by 9.43% (Table 3). In general, European cities became larger, less dense and more compact over this period. Obviously these averages conceal a wide variation across countries and regions. To observe the evolution of sprawl indices at the regional level, we subdivide the sample into four supra-national regions that are close geographically, as shown in Figure 2. Table 3 shows that the Southern European cities achieve the highest urban growth (32.02 %), but with less fragmentation of urban areas (-4.53%). Despite low growth in urban areas, the Eastern cities are denser and more scattered. The Western European cities experience a high urban growth (15.29%), a small decrease in density (-3.8%) and a decrease in scattering close to the sample mean. Northern European cities show a low urban growth (7.98%) but a sharp decline in density (-11.91%) and scattering (-8.08).

In summary, sprawl shows different trends depending on the index used and the region within which cities are located. Southern cities have the fastest growth of urbanization and the highest decrease in density, but their morphology tends to be more compact. Despite their relatively low levels of urban growth, northern cities experienced a relatively large decline in both density and scattering. From this it can be deduced that rapid urbanisation is not necessarily accompanied by a decrease in density. Also urban areas within cities with declining density are not necessarily more scattered.

Table 2 : Growth rates of sprawl indices, population and GDP between 1990 and 2006 according to different supra-national region groups

Sprawl indices in growth rate *1990-2006 (percent)*	Obs.[a]	*ArtifArea*	Scatt	Density
All cities	237	18.40	- 9.07	- 9.43
Southern European cities	65	32.02	-13.98	-14.53
Western European cities	85	15.29	-9.62	-3.80
Eastern European cities	77	11.68	-4.36	-11.01
Northern European cities	10	7.98	-8.08	-11.91

(a). We consider only the cities for which we have urbanization data for 1990 and 2006.

To illustrate the interdependence between these three indices of urban sprawl and the time-varying explanatory variables (Population and GDP per capita), we divide our sample of LUZ into two groups depending on the growth rate of each index. The first group corresponds to the bottom quartile (relatively slow growth). The second group corresponds to the top quartile (relatively high growth). Table 2 summarises changes across these groups. Inspection of Table 2 shows that GDP per capita growth is lower for cities where growth is relatively slow, compared to those that were growing at a much faster rate. However, GDP per capita growth is inversely related to density and the growth of scattering. It should also be noted that population growth is lower for cities having a slow growth of urbanisation and density, but is higher for cities with a slow growth of scattering.

Table 3 : The growth rate of sprawl indices between 1990 and 2006 according to the change of population and GDP per capita

Items	***Population Growth*** *(percent)*	***GDPcap Growth*** *(percent)*
Relatively slow *ArtifArea* growth [a]	- 0.50	10.26
Relatively high *ArtifArea* growth [b]	70.92	77.11
Relatively slow density growth [a]	2.05	77.55
Relatively high density growth [b]	8.77	56.06
Relatively slow scatt growth[a]	7.44	78.44
Relatively high scatt growth[b]	1.20	68.16

(a) Relatively slow growth is associated with the cities that are in the lowest quartile. (b) Relatively high growth is associated with cities that are in the highest quartile.

All changes in urban areas and density are moving in the direction that is predicted by the monocentric city model. Furthermore, the growth of population and GDP per capita are negatively corrolated to the evolution of scattering.

4. Empirical model and regression results

4.1. Estimation strategy

The panel data analysis is adopted to deal with observations from multiple cities over three periods. Given the variables discused above, the estimating equation of sprawl indices is given by

$$\log(SI_{it}) = \alpha_i + \beta_{it}\log(POP_{it}) + \mu_{it}\log(GDPcap_{it}) + \gamma_i D_i + \varepsilon_{it} \quad (5)$$

where *i* and *t* stand for cities and time periods respectively. The dependant variable SI_{it} represents urban sprawl indices (*ArtifArea* or *Scatt*)[10]. We have two time-varying regressors including Population

[10] As there is a strong correlation between ArtiArea and density, we get similar results for both dependent variables (except for the sign of some coefficient, see equations (3) and (4)).

(*POP*) and GDP per capita (*GDPcap*). D_i is a vector of time-invariant variables. α_i is specified as random or fixed effects. ε_{it} is the error term.

Eq. (5) may be estimated using OLS, pooling observations across cities and over time. However, OLS does not take into account the panel nature of the data and can yield invalid inferences (Baltagi, 2005). Instead of OLS, the more relevant models are the random effects and the fixed effects models, which are the two estimators most commonly applied to panel data. Unobservable individual heterogeneity is taken into account by both models. The distinction between the two models is whether the individual-specific time-invariant effects are correlated with the regressors or not. The fixed effects model offers consistent estimators but does not allow us to estimate time-invariant variables since it is based on the within operator (it subtracts from the variables their mean over time, so time-invariant variables have a mean equal to their value and the within estimator leads to a null value of the within transformation of these variables). The random-effects model increases the efficiency of estimations but imposes a strong assumption that individual effects are not correlated with explanatory variables.

Furthermore, in order to improve on some of the shortcomings of these two models, the Hausman-Taylor instrumental variable estimator might also be applied (Hausman and Taylor. 1981). The Hausman-Taylor model combines the fixed and random effects models to deal with the null correlation between the specific effects and the covariates by allowing some variables to be considered as endogenous, i.e. correlated with individual effects. The variance matrix of the composite errors maintains the random structure but the variables suspected of being correlated with the individual effects are instrumented by their within transformation (Wooldrige. 2002).

Our model selection process follows Baltagi *et al*. (2003) in using the Hausman test to select between alternative panel data estimators (Hausman. 1978). First, we perform a Hausman test comparing the fixed and random effects estimators. If the null hypothesis of no systematic differences is not rejected, the random effects model is preferred since it yields the most efficient estimator under the assumption of no correlation between the explanatory variables and the errors. However, if the Hausman test between fixed and random effects is rejected, then a second Hausman test is performed comparing the Hausman-Taylor estimator and the fixed effects estimator. Failure to reject this second Hausman test implies the use of the more-efficient Hausman-Taylor estimator, while rejection implies the use of the fixed model[11].

The Hausman and Taylor method can be represented in its most general form as follows:

$$Y_{it} = X_{1,it}\beta_1 + X_{2,it}\beta_2 + Z_{1,i}\gamma_1 + Z_{2,i}\gamma_2 + v_i + \varepsilon_{it} \qquad (6)$$

[11] For more details see Hausman and Taylor (1981), Wooldridge (2002) and Baltagi et al. (2003).

where $X_{1.it}$ and $X_{2.it}$ are time-varying variables, whereas $Z_{1.i}$ and $Z_{2.i}$ are individual time-invariant regressors. v_i is iid(0. σ_v^2) $and\ \varepsilon_{it}$ is idd(0. σ_ε^2) and both are independent of each other. The X_1 and Z_1 are assumed to be exogenous and not correlated with v_i and ε_{it}. while the X_2 and Z_2 are endogenous due to their correction with v_i but not with v_i. Thus, the endogeneity arises from the potential correlation with individual fixed effects. Hausman and Taylor (1981) suggest an instrumental variables estimator which premultiplies expression (6) by $1/\sqrt{\Delta}$ (where Δ is the variance-covariance term of the error component $v_i+\varepsilon_{it}$) and then performs 2SLS using as instruments [Q. X_1. Z_1], where Q is the within transformation matrix with $X_{it}^*= c - \bar{X}_i$ and $\bar{X}_i$ the individual mean. Thus we run 2SLS with [$X^*.\bar{X}_1$ .Z_1] as the set of instruments (Baltage et al..2003). If the model is identified in the sense that there are at least as many time-varying exogenous regressors X_1 as there are individual time-invariant endogenous regressors Z_2 then this Hausman-Taylor estimator is more efficient than the fixed effects estimator. How should the endogenous and exogenous variables be defined? The Hausman-Taylor estimator should produce estimations close to the fixed-effect estimator for time-varying variables. Thus, a Hausman test between the fixed-effects model and the Hausman-Taylor model allows the best specification to be chosen.

4.2. Results

We performed a Hausman test to discriminate between fixed and random effects approaches. Under the null hypothesis of the Hausman test, the estimators from the random effects model are not systematically different from those from the fixed effects model. If the null hypothesis cannot be rejected (probability of the test higher than 10%), we consider the estimators from the random effects model to be consistent. Otherwise, if the null hypothesis is rejected (probability lower than 10%). only the fixed-effects model is consistent and unbiased. In the case of our model, Hausman test results show that the random effects hypothesis is rejected in favour of the fixed effect estimator when ArtifArea idex is the dependent variable. However, when the Scatt index is considered as the dependent variable, the random effect regressor is consistent. The results of the Hausman test are reported in the bottom of tables 4 and 5[12].

Some qualifications need to be made regarding the use of the Hausman-Taylor estimator, in the case of the *ArtifArea* index. Although the fixed effects estimator is not an option in our study, since it does not allow the estimation of the coefficients of the time-invariant regressors, it is still useful in order to test the strict exogeneity of the regressors that are used as instruments in the Hausman–Taylor estimation. Thus, when strict exogeneity for a set of regressors is rejected, others must be considered in the

[12] All estimates presented in this paper are obtained using the Plm package of R . For details see Croissant and Millo (2008).

estimation to act as instruments. Once the second Hausman test has identified which regressors are strictly exogenous, they are subsequently used as instruments in the Hausman–Taylor estimation.

After testing several configurations, we retain *POP* as endogenous, while *GDPcap* and all time-invariant variables are exogenous. Only this configuration allowed us to obtain estimates close to the fixed-effects for time-varying variables. In addition, the Hausman test confirms the consistency of the Hausman-Taylor estimator (see the bottom of Table 4).

Table 4 reports the results of a regression for the *ArtifArea* index obtained using the Hausman–Taylor estimator. We present two configurations of our model. The first includes only the main variables of the monocentric city model, i.e. populatio, GDP per capita, agricultral rent proxy and transportation costs proxy (columns (1) and (2)). The second configuration adds all the explanatory variables selected in our study (columns (3) and (4)). Furthermore, year dummies are used to control for time-specific changes in the sprawl indices caused by other factors.

Table 4 : Estimation of the determinants of ArtifArea index (Hausman-Taylor)

	Dependent variable : Ln(ArtifArea)			
	(1)	(2)	(3)	(4)
Constant	7.051	8.264	6.9171	6.231
	(4.40)***	(3.05)***	(2.99)**	(2.80)**
Ln(POP)	0.223	0.272	0.153	0.184
	(5.01)***	(5.46)***	(2.63)**	(3.24)***
Ln(GDPcap)	0.134	0.243	0.191	0.277
	(4.71)***	(17.30)***	(4.32)***	(15.08)***
Ln(Agriprox)	-0.655	-0.971	-0.302	-0.302
	(3.45)***	(2.89)**	(6.16)***	(6.37)***
Ln(Highway)	0.105	0.077	0.059	0.054
	(2.93)**	(2.44)**	(1.79)*	(1.69)*
Ln(Crime)			0.273	0.261
			(2.46)**	(2.44)**
Ln(Rain)			-0.586	-0.583
			(2.91)**	(2.99)**
Ln*(Temperature)*			-1.306	-1.284
			(2.94)**	(2.98)**
L(AccessAir)			0.714	0.662
			(3.39)***	(3.27)***
Ln(NO2)			0.229	0.200
			(1.45)	(1.31)
Ln(CineSeats)			-0.199	-0.215
			(2.14)**	(2.40)**
Ln(MedAlt)			-0.04	-0.039
			(1.06)	(0.99)
Year dummies	Yes	No	Yes	No
Obs.	677	677	466	466
Hausman FE-RE	171.91	95.85	93.35	91.08
(p-value)	(0..000)	(0.000)	(0.000)	(0.000)
Hausman FE-HT	0.207	0.101	2.128	1.085
(p-value)	(0.999)	(0.999)	(0.712)	(0.581)

Notes : Absolute values of t-statistics in parentheses. * significant at 10 per cent; ** significant at 5 percent; *** significant at 1 percent. Hausman FE-RE is the Chi-squared of the Hausman test comparing the fixed effects and random effects estimator. Hausman FE-HT is the Chi-squared of the Hausman test comparing the fixed effects and Hausman-Taylor estimator. p-value is the p-value of this test.

All the coefficients of the main independent variables emerge as significant with the expected signs (columns (1) and (2)). Population coefficient is significant and positive, ranging between 0.223 and 0.272. GDP per capita coefficient is also significant with a positive sign, varying between 0.134 and 0.243. The sign on the coefficient of the Agriprox, our proxy for agricultural land values, is negative and is in accordance with the monocentric model prediction. The higher the agricultural land value, the slower the expansion of artificial area. The coefficient on transportation cost proxy (Highway) is positive which is also as expected. When transportation networks are dense, the cost of transportation is low and the artificial area is relatively large. As we add other explanatory variables, the main variables of the monocentric model remain significant with the expected signs. This is still true with or without the dummies for years.

Interstingly, this study highlights the importance of agricultural productivity in limiting the expansion of urban areas. Unlike previous studies, a relatively high coefficient is observed for the agricultral rent proxy, ranging from -0.302 to -0.971. This means that agricultural productivity can be a genuine barrier to urban sprawl in Europe. This reflects the fact that in Europe, agriculture at the urban fringe is often highly intensive and offering relatively high yields and profits.

The coefficient on the variable *Crime* is significant and positive varying between 0.273 and 0.261. A high crime rate in the central city would promote urban expansion, encouraging households to settle in suburban areas. The climatic variables (*Rain* and *Temperature*) have a significant and negative effect, which reflects the tendency towards urban sprawl in temperate climates. The connectivity of cities to the rest of world, measured through the relative importance of the nearest airport (*AccessAir*), is also significant and positive. Generally, cities with a major airport attract significant economic activity and therefore grow. The cultural attractiveness of the city, approximated by the number of cinema seats, is significant and negative, suggesting that attractive cultural amenities in the centre of the urban area discourage outward sprawl that makes those amenities less accessible. The coefficients of the variables *NO2* and *MedAlt* are not significant, but show the expected signs. Thus, pollution recorded in the central city tends to encourage households to move to suburban areas, promoting sprawl. We also note that, as might be expected, increasing altitude acts as a brake to the expansion of cities.

Returning to the *Scatt* index, where the Hausman test rejects the fixed effects estimator in favour of the random effects model. Table 5 reports the results of the regression and various statistical tests. Again, two configurations, with and without year dummies, are considered. Columns (1) and (2)

includes the main variables of the monocentric city model, while Columns (3) and (4) add the other explanatory variables.

The Breusch-Pagan test (Lagrange-Multiplier test) is used to test for the existence of individual heterogeneity, i.e. testing whether or not the pooled OLS is an appropriate model (Breusch and Pagan, 1980). The OLS hypothesis is unsurprisingly rejected in favour of the random effects estimator for all configurations. Moreover, the Hausman test clearly rejects the fixed effects model in favour of a random effects estimator.

Table 5 : Estimation of the determinants of Urban sprawl indices (GLS Random effects)

	Dependent variables : Ln(Scatt)			
	(1)	(2)	(3)	(4)
Constant	3.300	3.640	1.490	2.224
	(6.03)***	(8.97)***	(0.66)	(0.94)
Ln(POP)	-0.307	-0.309	-0.226	-0.243
	(7.54)***	(7.54)***	(4.80)***	(5.20)***
Ln(GDPcap)	-0.158	-0.194	-0.031	-0.164
	(3.96)***	(11.02)***	(8.20)***	(8.20)***
Ln(Agriprox)	-0.093	-0.094	-0.059	-0.059
	(2.96)**	(2.85)**	(2.17)**	(2.17)**
Ln(Highway)	-0.017	-0.011	-0.056	-0.049
	(1.85)*	(1.58)*	(1.75)*	(1.73)*
Ln(Crime)			0.149	0.175
			(1.39)	(1.43)
Ln(Rain)			-0.19	-0.183
			(0.98)	(0.85)
Ln(Temperature)			0.464	0.486
			(1.08)	(1.02)
L(AccessAir)			- 0.157	- 0.103
			(0.78)	(0.48)
Ln(NO2)			- 0.428	- 0.398
			(2.79)**	(2.45)**
Ln(CineSeats)			0.003	0.027
			(0.035)	(0.28)
Ln(MedAlt)			0.229	0.226
			(5.72)***	(5.30)***
Year dummies	Yes	No	Yes	No
Obs.	654	654	433	433
Adj. R-squard	0.38	0.30	0.38	0.36
LM test	455.31	453.75	293.89	287.03
(p-value)	(0.000)	(0.000)	(0.000)	(0.000)
Hausman FE-RE	1.748	0.518	11.61	1.259
(p-value)	(0.782)	(0.771)	(0.020)	(0.532)

Notes : Absolute values of t-statistics in parentheses. * significant at 10 per cent; ** significant at 5 percent; *** significant at 1 percent. LM test is the Chi-squared of the Breusch-Pagan test comparing the pooling and random effects estimators. Hausman FE-RE is the Chi-squared of the Hausman test comparing the fixed effects and random effects estimator. p-value is the p-value of tests.

Results reported in columns (5) to (8) are consistent. The low adjusted R-squared values and non-significance of several variables, shows that fragmentation is not necessarily influenced by the same set of variables that determines spatial scale. In all cases, we observe that the coefficients for

Population and *GDP per capita,* are negative and significant. suggesting that larger populations and higher income levels in an urban area are associated with lower rates of fragmentation. Therefore increases in population and per capita income are likely to result in cities that are both larger and more compact. This reflects the strong demand for land in more affluent LUZs and the associated levels of population growth. Such demand may lead to a reduction in the number of urban fragments, as discrete settlements start to expand and merge with each other, or with the central city. Such phenomena can be influenced by urban planning policies, which may be designed to encourage development within these interstitial spaces rather than around the fringes of the LUZ.

Furthermore, the coefficient of the agricultural land value proxy is also negative but not always significant. As might be expected, high agricultural land productiviy should constrain urban fragmentation by limiting the amount of land available for development. The opposite might be expected for less productive land provided that other factors (e.g. topography, drainage) are favourable to development. The results reported here, suggest some level of heterogeneity in the agricultural activities within each LUZ, resulting in complex land use patterns specific to each area. The transport cost proxy also had a negative coefficent, and again this was not always significant. Of the other explanatory variables, only *NO2* and *MedAlt* were significant in the models. The pollution proxy has a negative impact on scattering, reflecting a tendency towards greater fragmentation in cities experiencing higher levels of air pollution. However, the effect of altitude is positive; cities located in urban areas at higher altitudes are likely to be more fragmented, possibly as a result of the local terrain.

4.3. Investigating the effects of variables that vary over time

The relative importance of variables that vary over time (*Population* and *GDP per capita*) in explaining changes in the sprawl index, can be ranked according to the magnitude of their elasticities. However, this criteria can be misleading, because the total effect of one factor on another over time, depends on both the magnitude of the elasticity and the change in the variable.

Decomposition analysis is used to help understand the effect of these time-varying variables on the dependent variables. This approach accounts for both the size of the marginal effects and the magnitude of the change in the explanatory variables. Table 6 reports the results of the decomposition analysis for both *ArtifArea* and *Scatt* index[13]. *GDP per capita* is the most important factor affecting change in artificial area. Nearly 70% of the growth of urban areas between 1990 and 2006 is explained by increases in income per capita. However, population growth explains only 4.45% of urban area

[13] Estimated parameters for *ArtifArea* correspond to those obtained in Table 4 column 3. Estimated parameters for *Scatt* correspond to those reported in Table 5 column 3. Considering estimated parameters without year dummies does not change the conclusions drawn from the decomposition analysis.

growth. Other explanatory variables explain another 24.9% of variation in the expansion of urban ares. By contrast, 13.3% of the decline in scattering is explained by population growth and 23% by growth in income per capita.

The significance of this decomposition analysis is twofold. First, we show that income growth is by far the most important cause of urban expansion. Second, we find that other factors are more important than changes in income and population in explaining the fragmentation of urban areas within LUZs.

Table 6: Decomposition analysis of sources of urban sprawl indices [(a)]

Variables		Ln(ArtifArea)			Ln(Scatt)		
	(1) Changes in variables (percent)	(2) Estimatied parameter	(3) Impact on ArtifArea	(4) Contribution (percent)	(5) Estimatied parameter	(6) Impact on Scatt	(7) Contribution (percent)
Ln(POP)	5.36	0.153	0.82	4.45	-0.226	-1.21	13.34
Ln(GDPcap)	68.00	0.191	12.98	70.58	-0.031	-2.10	23.24
Residual				24.96			63.41
ArtifArea	18.40			100			
Scatt	-9.07						100

(a) The decomposition analysis follows three steps. First. the percentage change of each variable between 1990 and 2000 is calculated (column 1). Then column 1 is multiplied by parameters estimated for each index (columns 2 and 5) to obtain the impact of each time-varying variable on both indices respectively (column 3 and 6). Finally. the impact of each variable is divided by the percentage change in *ArtifArea* (18.4%) and Scatt (-9.07%) to obtain the contribution of each variable to changes in *ArtifArea* (column 4) and *Scatt* (colimn 7).

5. Conclusions

Using the framework of the monocentric city model, this paper has empirically investigated the determinants that influence urban sprawl across a large set of European cities. The phenomenon of sprawl was examined both as an increase in the spatial scale of urban areas and as a process of fragmentation, where the urban area is shown to be characterised by a number of discrete parcels of urban settlement scattered around the central city. For each city in our sample, data on these two dimensions of urban sprawl were accurately measured using GIS software. Based on the literature on the causes of urban sprawl, a set of potential explanatory variables was drawn up and appropriate data collected from a range of existing sources (e.g. Eurostat, Urban Audit, ESPON). Where data on potential explanatory variables was not available, a suitable proxy variable was constructed.

Data was obtained for these variables over three reference years. The use of panel data allows unobservable individual heterogeneity to be controlled but also means that a simple OLS estimator is unlikely to be suitable, as this would not account for such unobservable heterogeneity across cities.

Several different estimators were considered and statistical tests were performed to determine the ability of each to account for the specific structure of the panel data for the two aspects of sprawl measured by the study. The Hausman-Taylor estimator was used in the case where sprawl is measured in terms of changes to the urban (artificial) area, but where the dependent variable is an index of fragmentation (i.e. scattering) a random effects estimator was adopted.

Our results are robust and when urban sprawl is approximated by the spatial scale, i.e. changes to the artificial area within the LUZ, they clearly confirm the predictions of the monocentric city model. Thus, the coefficients of the main explanatory variables in the model are significant, with the expected signs. In addition, the significance of these variables does not change when other explanatory variables are introduced. While increasing income per capita and population growth are clear drivers of the expansion of urban areas, the models reported in this paper highlight the importance of the productivity of adjacent agricultural land as a factor discouraging the outward growth of cities. High productivity maintains or increases land values and makes development on the urban fringe more expensive and therefore less atractive. This economic restriction to the supply of available land may be supported by planning regulations, which limit the availability of land in the urban fringe for development.

In terms of explaining the fragmentation of urban areas, the growth of income and population are far less important. A few other factors, such as altitude or terrain, are shown in the model to increase the tendency towards fragmentation but much of the variation is left unexplained. It is suggested that urban planning policies and land availabity may be particularly influential in determining the level of fragmentation, along with any other factors that reduce the outward growth of cities and therefore encourage in-fill development in the interstices between fragments.

Some limits of our study must be acknowledged, such as our current inability to include variables relating to important political and institutional factors, such as land supply and zoning, that are likely to affect both urban scale and fragmentation. The model also omits information on some specific geographical features therefore limiting our ability to explore the variation in urban sprawl indices more deeply. It is also possible that there may be complex interactions between some environmental factors (such as coastal and mountain amenities) and urban sprawl, that are not accounted for in our model.

Although we have not accounted explicitly for the role of land use policies (mainly due to the lack of data), our study can provide some insights into the design of policies seeking to control sprawl. While environmental and landscape protection are important aims, such policies should not ignore the important economic mechanisms that can drive urban sprawl. This research confirms that in many

cities, urban sprawl is associated with increasing wealth. Therefore policies that limit the expansion of urban areas may risk restricting economic growth, as house prices within the LUZ increase, development land becomes scarce and individuals and businesses decide to relocate to cities where there is still room for new development on the periphary.

Policy makers reluctant to place regulatory restrictions on sprawl but who are concerned about the loss of environmental quality or amenity from the development of the urban fringe, may wish to consider other policies that use the market to discourage the outward expansion of cities. Our results suggest that agricultural productivity, and by extension profits, can restrict development by driving up land prices around cities. Therefore the adoption of policies that have a positive impact on farm incomes on the urban periphary can have a direct impact on reducing the likelihood of outward sprawl, while at the same time potentially encouraging the development of non-urban areas within the LUZ boundary, therefore reducing urban fragmentation and making the city more compact. Within such compact cities, achieving low crime rates and maintaining a vibrant cultural life appear to be key considerations when encouraging residents to live close to the city centre rather than in the outer suburbs. These conclusions appear to offer some support for those who argue that planners should implement policies that encourage an urban morphology that maximises the quality of life for residents, while at the same time minimizing the environmental impacts of urban growth.

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