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COMPARING URBAN SPRAWL PATTERNS WITH THE COSTS OF PROVIDING PUBLIC SERVICES: A TIME SERIES ANALYSIS

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L'obiettivo del paper è quello di dimostrare la relazione esistente tra le forme urbane e i costi pubblici e cioè se modelli urbani a bassa densità insediativi impongono costi pubblici maggiori di quelli imposti da forme urbane che presentano caratteri di maggior compattezza.

Le ricerche empiriche, realizzate soprattutto negli Stati Uniti, hanno evidenziato una correlazione tra la forma urbana e i costi relativi all'approvvigionamento delle infrastrutture pubbliche quali, ad esempio, strade, servizi igienico sanitari, reti idriche, scuole, ecc.

La nostra ricerca si inserisce in questo filone prendendo spunto da questi risultati e adattando le metodologie e gli indicatori utilizzati al contesto territoriale indagato.

L'area studio è quella centrale veneta, essa copre una porzione territoriale di circa 3.700 kmq ed è distribuita su 145 comuni e 4 provincie. È stata caratterizzata fin dagli anni '70 da fenomeni di dispersione insediativa peculiari – una sua porzione più ridotta è stata studiata nel dettaglio fin dalla fine degli anni '80 e riconosciuta come il modello territoriale della "città diffusa" – che seppur con modalità diverse, di maggiore o minore intensità, hanno accompagnato le trasformazioni avvenute nell'arco degli ultimi quarant'anni e tuttora presenti anche se manifeste con dinamiche diverse.

Il lavoro si propone di restituire le elaborazioni condotte in diverse soglie storiche dell'evoluzione dell'urbanizzato disperso e di comparare tali dati con i dati economici desunti dai bilanci comunali dei comuni dell'area studio, grazie ad una lettura e restituzione del territorio indagato attraverso strumenti di analisi automatica di immagini da satellite. L'analisi multitemporale è stata condotta integrando i risultati della classificazione di immagini Landsat, con i dati della Carta della Copertura del Suolo del Veneto edizione 2009. Per le elaborazioni sono stati utilizzati i software eCognition e MatLab. Al lavoro di individuazione e riconoscimento delle forme e dei pattern delle aree costruite, è stato associato il rilevamento dei valori dell'indice di vegetazione (NDVI). La combinazione di questi elementi di analisi ha reso possibile la determinazione di alcuni indicatori di crescita, serviti per mappare e stimare l'evoluzione del costruito e utilizzati poi nel modello di regressione lineare.

I dati dell'analisi economica desunti dai bilanci comunali dei singoli comuni degli anni compresi tra il 1998 ed il 2007 sono in particolare relativi ai costi dei principali servizi pubblici quali: il trasporto pubblico, la manutenzione stradale, la gestione di rifiuti, acqua e reflui.

Utilizzando l'analisi di regressione sono stati stimati gli impatti dello sprawl urbano sulla spesa corrente attraverso variabili quali le imposte locali e i trasferimenti da parte dello Stato.

I risultati fin qui ottenuti hanno dimostrato come lo sviluppo a bassa densità insediativa sia tendenzialmente più costoso di quello avvenuto in forma aggregata e compatta.

Tali risultati possono essere utili a mettere in evidenza le minacce che lo sviluppo urbano disperso impone sia relativamente ai costi legati ad una crescita squilibrata sia relativamente alle ricadute in termini di sostenibilità urbana. Questioni che dovrebbero suggerire di affrontare il problema attraverso l'implementazione di politiche urbanistiche volte al contenimento del consumo di suolo e alla riqualificazione del costruito esistente, attraverso un uso più articolato degli strumenti di pianificazione alle diverse scale di progetto, ma anche attraverso misure puntuali legate, ad esempio, ad una diversa fiscalità locale.

Parole chiave: dispersione urbana**,** costi pubblici**,** panel data

Abstract

The aims of this paper is to show the relationship between the dynamics of urban growth patterns and the public costs necessary to provide public services in order to find out if the different urban forms may affect local public spending.

The case study area is located in the central area of the Veneto Region, it covers an area of about 3,700 square km and it is composed by 145 municipalities, which are part of the administrative provincial territory of Padua, Treviso, Venice and Vicenza.

Our paper aims to compare the costs of public services coming from the annual balance sheets of the different municipalities included in our sample with urban growth dynamics based on two different temporal patterns (1998, 2007). Geographical elaborations are obtained with unsupervised analysis of satellite images; the multitemporal analysis integrates the data of Landsat images classification and of Cartographic land cover of the Veneto Region.

Keywords: urban sprawl**,** local public spending**,** panel data

1. Introduction and Motivation

Urban sprawl is characterized by low density, unlimited peripheral extension of new development, spatial segregation of different types of land uses through zoning regulations; leapfrog development, non centralized ownership of land or coordinated planning of development, private-car dependence, fragmentation of governance authority over land uses between many local governments, great variances in the fiscal capacity of local governments, and widespread commercial strip development along major roadways (Burchell et al., 1998).

It is commonly argued that low-density development patterns result in a higher cost of providing public infrastructure such as road, public transportation, water and sewage systems, solid waste collection and police protection, to mention just a few.

Given that previous empirical analysis on this issue are scarce and are generally focused on the US case studies, we want to contribute to the existing literature and provide evidences for the Italian situation.

The case study area covers an area of about 3,700 square km in Veneto Region and it includes 145 municipalities, which are part of the administrative provincial territory of Padua, Treviso, Venice and Vicenza. These four territorial areas are quite similar in social composition and economic growth and are recognized as part of the industrialized core of Italy.

The study area can be seen as an expansion of a polycentric metropolitan system and shows a tight functional integration among medium and small centres, as well as a strong dispersion of residential function. The area is characterized by low density development together with an homogeneous distribution of small-medium productive activities all over the territory, and commercial businesses that have acquired a new centrality, spread along the main transportation networks, well-served and easily reachable that make this area extremely fragmented and with high level of mixed-uses.

In the first part of our research we focus on the creation of a spatio-temporal geographic information system allowing the analysis and the comparison of the process of built up growth in different years and for the whole study area. To accomplish our goal, we have employed satellite images, ArcMap and new software technologies such as eCognition to better interpret the past phenomena and identifying and analyzing the actual urban changes. The results of this phase of work let us to create three different temporal threshold: 1984, 1998 and 2007.

In the second part of our research we analyze how urban forms, especially low-density urban pattern, affect the costs of public services provision. Generally, the increasing of built-up areas, together with rapid dynamics on population, raise the requirement for infrastructure investments, social services and other facilities to support the current and the projected needs; costs that are mostly borne by local government. If the urban development is poorly planned, scattered and disorganized these costs can be even higher creating troubles on the local spending capacity of municipalities. To carry out our analysis, we collect the municipalities' balance sheets for the 145 municipalities of the Veneto area in only two-years period 1998 and 2007 because, unfortunately, economic data for the year 1984 are still not available. In particular, we analyze the costs of the main public services sustained by the municipalities such as public transport, road and street maintenance, and environmental and land management.

This paper introduces empirical results obtained by implementing a two-waves panel data analysis. We estimate the impact of urban sprawl and density on different current expenditures, controlling for other variables such as local taxes paid by citizens, central government aids, and others. We find some evidences that low population density per ha of urbanized land determines more expenditures for public government than higher density, and that municipalities can realize economies of scale in more compacted areas, especially for investments in those infrastructure and services where it's possible to obtain monetary gains if the territory is contained around more densely settles places.

In the next Section we present an overview of the multi-temporal analysis and methodology implemented for analyzing the characteristics of the built environment. Next, we describe the characteristics of the study area, and in Section 4 we provide a brief literature review of sprawl costs. In Section 5 and 6 we describe the methodology to construct the density and sprawl indexes and the basic features of the data gathered and the construction of urban sprawl variables included in the regression equations. In Section 7 we present our empirical models and the main results obtained. Finally, in Section 8 we discuss the main conclusions.

2. Evolution of urban forms

2.1 The multi-temporal analysis

Satellite images, which in regional surveys of large areas are now tools of established use, elaborated the processing performed on the area. They provide more convincing results both in terms of specific disciplinary aspects of remote sensing and for the countless studies and research in various fields of application.

In recent years, satellite technologies have enabled us to acquire increasingly better images with spatial and spectral resolutions especially when used together, and to perform multi-temporal analysis of historical periods starting from about 1980: for this, Landsat images are necessary.

In our research the processing was based on three Landsat images acquired in the summer of 1984, 1998 and 2007 and the spatial and radiometric resolutions allow us to compare them even if acquired over a period of several years. We used these as primary sources for research with the aim of identifying the development of urban forms that occurred in the last thirty years.

Information relating to the current built environment (data of 2007) allows us to read past phenomena and the changes that took place over the period studied.

The first part of the investigation, therefore, is focused on finding a method of analysis that, once developed, tested and calibrated on the latest data[1], could be similarly reproduced on data from regarding 1984 and 1998. In this operation we have used specialized software: eCognition and Matlab to process satellite images, and ArcMap for the processing GIS oriented.

In 2007, the different typologies of urban areas were only identified using the appropriate classes of Land Use Charter. In particular, the categories were selected corresponding to level 3 of the original classification[2] and after the data was appropriately geo-referred it was possible to

1. The calibration of the model for recognizing built-up areas was made on the image of 2007, using a file in vector format (shape) from the DB section of Land use Charter of the Veneto Region (1:10,000 scale; 2009 edition, with data referring to the year 2007, Veneto Region, UP, SIT and cartography), as the basis for identifying the typologies.

2. That is: 111 – The city center with mixed functions, continuous very dense urban fabric; 112 - Medium discontinuous urban fabric, primarily residential (30%-50% of built environment); 113 – Particular types of urban forms and isolated residential structures; 121 - Industrial areas, public services, etc.

select from the Landsat images the only portions of land classified as built environment in the database of the Land Use Charter. Thus, it was possible to obtain a database of reference for assessing the accuracy of the results obtained during the processing. This preliminary step has allowed us to compare the configuration of the built areas identified on the 2007 Landsat image with similar areas defined on the Land Use Charter.

In addition to a classical interpretation of the spectral bands, the authors have tried to classify five different typologies of built environment, defined on the basis of the size and shape of the different areas of built environment and the vicinity to main streets[3].

The results of this first classification were then applied to the 145 municipalities of the area, in order to recognize the different typologies of built environment present.

2.2. The built environment in Landsat images

The Landsat images were processed to obtain for every pixel the value of vegetation index NDVI (Normalized Difference Vegetation Index): more vegetated areas have a high NDVI value, and areas with sparse vegetation have low values and are potentially built up. Obviously, to properly identify these areas, the vegetation index is not sufficient, and it is necessary to improve the investigation method and parameters.

The eCognition software has proved extremely useful for this goal, because it implements a sophisticated technology based on algorithms that let us create sequences of rules to properly guide and govern the processes of geospatial analysis. In particular, the software is based on segmentation techniques that allow us to divide the image into elementary units with similar radiometric characteristics. Starting from this basic processing, it is possible to have a set of very complex rules (geometrical and topological criteria, information from data in vector format, etc. may be taken into account) and using processing models that implement different logic approaches (object-oriented, fuzzy, etc.), a classification of images that accurately follows the researchers' specifications can be obtained.

Initially, we processed the Landsat image using the multi-resolution space technique, suitably parameterized to obtain the fragmentation of the image in homogeneous micro-zones in terms of size, shape and radiometric values. Each micro-area has been subsequently linked to the information of the corresponding class of built environment and a similar operation was carried out to assign the NDVI value to the micro-area. After these operations, it was possible to classify the case study area according to criteria of belonging to the built-up areas classified by the Land Use Charter. For areas so identified it was necessary to further classify sub-areas by the density of built environment established by the NDVI index.

The product of this processing is a raster image, similar in size to the original Landsat image, in which each pixel is associated with the class value "built environment" to which it belongs. This result provided the database on which further processing and analysis were elaborated. In particular, after determining a first classification level of individual pixels, we focused on drawing a "grid" for dividing the built environment that is, to identify the criteria to adopt in

3. In order to improve the level of accuracy in identifying the level of isolation of the built environment, we used an evaluation standard of the distance from the road network, using as reference the road graph provided by the Veneto Region (UP, and Geographic Information System cartography). Municipal boundaries weere identified using the CTR of the Veneto.

order to aggregate each pixel to recognize the different levels of built-up density of the case study area.

The pixels were organized in groups (squares of the grid) of dimensions that made it possible to recognize the built-up areas' density and form in order to determine the relations among the different built-up areas. For this purpose a few attempts were made using squares of differing dimensions (3x3, 4x4 e 6x6 pixels) and considering the real size of the Landsat image (30 meters), these squares correspond respectively to 90x90, 120x120 e 180x180 meters we decided to chose the 4x4 model as the one most suitable for reading and representing our research.

Each of these square portions of the image was examined by evaluating the "density" (calculated as the average density of each pixel in every square of the grid) of the built environment and then ranked according to percentage of total built-up area of the square.

As a result of the processing we produced a new raster file that has the same size as the original Landsat image, but whose grid dimension is 120x120 meters. Each pixel in this new image is associated with a value that corresponds to the percentage of built environment and the classes of density are: built higher than 80%; between 60% and 80%; between 40% and 60%; between 20% and 40 %; for values below 20% the areas are considered undeveloped.

2.3. Identification of urban clusters

The identification of the built environment allowed us to identify the urban clusters – the set of areas of high building density (defined above) connect to lower density areas, which together create a continuous urban form – which are different from the urban areas and characterized by urban sprawl.

We began by using multi-resolution spatial techniques implemented in the software eCognition. Then we identified the homogeneous areas in each municipality classified according to the types of density in an elaboration of topological overlay of the vector layer of administrative boundaries involved in the analysis. It was thus possible to define areas of high density of built environment (above 80%) and areas with lower density (not less than 40%) interspersed within the first ones, as connection areas.

Some typologies of urban centers were also cataloged on the basis of their size and, in particular:

- Large urban clusters, an area greater than 18 Sqkm,
- Medium urban clusters, an area from 2,7 to 18 Sqkm.
- Small urban clusters, an area less that 2,7 Sqkm.

Areas of "urban sprawl" have been identified: these are built up areas not contiguous to the urban clusters and are located about 300 meters away from them.

Finally, the last typology, identified as "spread built environment", defined all the areas excluded from the others identified classes. So all the areas classified as built environment are included in this class but they are not part of the urban clusters of large, medium or small size.

The results obtained from the processing of identification of urban clusters performed on raster data were exported in vector format, so these data can be processed with the usual tools of topological analysis of GIS applications.

To refine the analysis of raster data, we tried to correlate the presence of built-up areas with their proximity to roadways that have been highlighted on Landsat images through the road graph of the Veneto Region and ranked according to their administrative class (national road, provincial road, etc.). Then, the criteria established for being part of the "spread built environment" class was verified using the distance between the built environment and streets.

This elaboration defines, through the density values listed above, five new classes summarized as follows:

- Large urban cluster (dim1): aggregates areas with density higher than 80%, between 60% and 80% and between 40% and 60% that covered an area of 18 Sqkm,
- Medium urban cluster (dim2): aggregates areas with density higher than 80%, between 60% and 80% and between 40% and 60% that covered an area between 2.7 and 18 Sqkm,
- Small urban cluster (dim3): aggregates areas with density higher than 80%, between 60% and 80% and between 40% and 60% that covered an area between 0.72 and 2.7 Sqkm,
- Urban sprawl (dim4): includes the urbanized areas with density higher than 80%, between 60% and 80%, between 40% and 60% and between 40% and 20% that have no borders in common with the three classes of urban cluster above, and are located at a distance of about 300 meters from them,
- Spread built environment (dim5): includes the urbanized areas with density higher than 80%, between 60% and 80%, between 40% and 60% and the sprawled built-up areas that are not included in the classes described above.

Once this phase of analysis and processing was finished, by using ESRI ArcMap a topological overlay (union) made it possible to map the different categories of built environment and define the percentage of covered area for each class size for all the municipalities in the case study area. Comparing the results of the three time periods studied, even by means of an immediate visual assessment, it was possible to recognize the transformations of the built-up areas that occurred over the past thirty years.

3. The characteristics of the study area

Research and studies were conducted on the case study area and on different sections of it, at first the central portion of the area called "città diffusa"[4] (Indovina et al., 1990) was taken into consideration and then on the entire study area. Some different processing has highlighted how the initial characteristics of the central portion of the area are now outside of that perimeter.

This processing has described a phenomenon of progressive land consumption due to an intense process of urbanization, as noted above that began in the 1970s and has remained constant, albeit, with varying degrees of intensity, over the 1980s and early 1990s. The latest

4. Since the late 80s at the Department of Economic and Social Analysis of the territory of the IUAV, began a series of searches on a portion of the area, known as urban sprawl, which constitute the starting point for reflections and analysis that the authors of this paper are not made in this paper.

phase, from about the 1995 to the present shows forms of clustering around the compact urban centers even if phenomena of fragmentation of the built environment and sprawled growth continue to be present.

This territorial system was completely supported by the regional policies of the 1970s and 1980s. The Veneto Region welcomes and endorses the requests of municipalities and business operators, and it promotes policies that favor the strengthening of the services and infrastructure allocation in the different urban centers that acquired importance and functions though an "urbanity" quality and character that is unusual for areas that still maintain a rural character.

The planning tools of the municipalities facilitated generous expansions by identifying new industrial and residential areas, in the wake of a housing market that promotes an image of rural and semi-rural communities and the opportunity for families to buy an affordable home in a low density residential subdivision with open space. To this trend is added the development of traditional rural buildings now restored, renovated, expanded often completely or partially self-constructed, located on privately owned agricultural land not equipped with services and infrastructures but only connected to a network of, often modest, roads.

In the last processing conducted (1984, 1998 and 2007) with the analysis techniques and tools of representation described above, the dynamics of growth that have characterized the study area are highlighted and confirmed on the basis of previously made elaborations (Fregolent, 2005). In the period 1984-1998 the increase of built environment registered the variation of 38.10% with a variation of population of only +0.83%, and in the period 1998-2007, of 27.04% with a population increase of 10.05%. We can see that even if the increase in the first step is higher than in the second, we have a continuing trend of significant growth and land consumption (Fig. 1 in Appendix). We will describe the characteristics of the areas as outlined in the three elaborated maps (Fig. 5, 6 and 7 in Appendix).

Built environment in 1984

The urban structure in 1984 (Fig. 2 and Fig. 5 in Appendix) mapped and recognized five types of urban forms articulated in the compact city of Padua and the hinterland part of Venice (Mestre) (dim1), followed by – with classes of different densities (dim2) – the other two main cities of the Region: Treviso and Vicenza, but also the smaller cities of Bassano, Thiene, Castelfranco, Mogliano Veneto, Montebelluna Cittadella. This network of cities and towns forms the polycentric structure that has deeply marked the region and to which must be added now – in the same density class –the smaller towns particularly those closer to the main cities.

We observe, in fact, the Padua built environment stretches to the south-west beyond the municipal boundaries in the municipalities of the first and (in part) the second belt (Rubano, Abano Terme and Montegrotto Terme); Venice continues towards north-west in the small town of Spinea, which becomes part of Mestre, the hinterland part of Venice; Vicenza that stretches along the State road (SS 53) that crosses the city and continues in the near town Creazzo and finally, Treviso, where some towns in the south-east, Silea and Casier, are becoming suburbs of Treviso.

The distinct polycentric structure that appeared during the 1980s in the main and medium cities had in the nodes of an infrastructure network that supports the territorial system and along which small towns grow and had, in the later period, a significant increase of built-up areas that also would affect the smallest settlements of the minor roads network.

In the 1980s, the "città diffusa" manifested phenomena of intense growth and fragmentation of the built environment (Indovina and Savino, 1999) while the municipalities north and west of the boundaries of the "città diffusa" area[5] begin to show urban sprawl starting at the same time. That means that the entire study area has some homogeneity in terms of morphological evolution of the built environment and urban sprawl, but these changes occurred at different times.

Between 1984 and 1992 we can observe an intensification of growth of built environment in the municipalities close to the boundaries of the area studied that have the most significant increases in their built-up area with percentages from 50% to more than 200%. These municipalities are also affected by significant growth of industrial areas.

The population is growing, although not with the intensity of growth manifested by the increase of built environment, but this happens in almost all municipalities of the area except in the major cities that instead register a loss of residents who abandon the cities for smaller municipalities (Fig. 1 in Appendix).

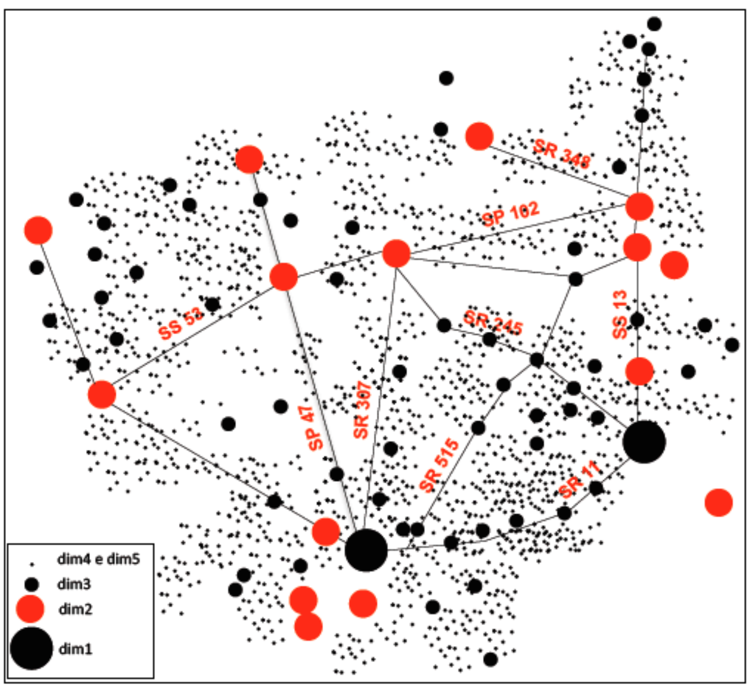

Fig. 1 – Built environment in 1984

Built environment in 1998

The urban structure in 1998 (Fig. 3 and Fig. 6 in Appendix) consolidates and thickens around the urban centers but also around the built-up area of medium and small size centers that are progressively assuming a more consolidated form. According to the typological classification given above, a significant number of urban areas classified as small urban cluster (dim3),

5. North of the Regional Road (SR) n. 53 (Postumia) and west of SR n. 307 (Strada del Santo).

previously classified as urban sprawl or spread built environment (dim4 and dim5), increased especially along the main roads connecting the principal centers of the area studied.

The phenomenon of thickening along the Venice-Padua line is evident and in the next threshold (Fig. 7) it is possible to recognize a continuous urban area connecting the two cities. Along this root – we are on the Riviera of the Brenta (SR 11), location to one of the most important manufacturing districts of the region – there are processes of intensive built-up development. The municipalities of the first urban belt, especially around Padua, but also around Vicenza, Treviso and Venice, become part of the urban fabric of the cities.

The intensification of construction activity and the evident densification of the urban growth is parallel to an intensive increase of the sprawled areas along the secondary roads because there are two different processes underway in the entire area: the first one of densification and compactness of urban form, and the second of progressive sprawled development. The data can be found in the processing carried out: in the overall trend of the built-up areas between 1984 and 1998 there is, in fact, a significant increase of areas classified as “dim4” (139.80%) and an increase, although smaller, of areas classified as “dim5” (15.37%). In this second phase we can observe a uniform trend of growth in most of the municipalities that increase from 0 to 50%, except for a group of small towns located along the Treviso-Vicenza line that increase from 50 to 100% (Figure 1 in Appendix). These are municipalities that in the previous phase had the same growth trend of building construction. They are in a favorable geographical position, close to mobility infrastructures – such as the SR 53, the new “Strada del Santo” (SR 308) and the new line of the motorway A4 opened to traffic in 2009 – and are also municipalities that at this stage showed great expansion of industrial areas.

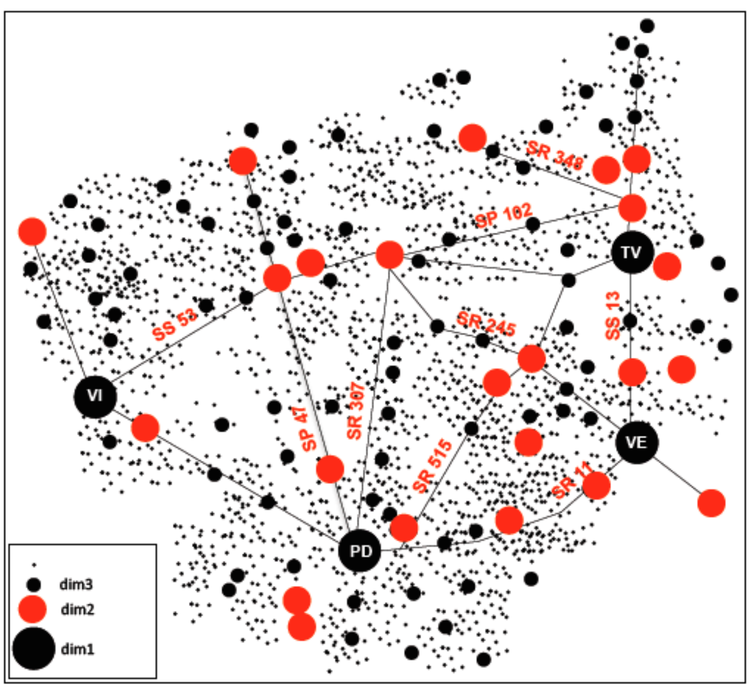

Fig. 2 – Built environment in 1998

Built environment in 2007

In the last step considered, the elaboration in 2007 (Fig. 4 and Fig. 7 in Appendix) the process of densification continued. It the continuous urban development is evident along SR 53 from Treviso to Vicenza: the municipalities of the first and second belt of Treviso have just become part of this city and this new conurbation is gradually consolidating and involves medium and small size municipalities located along the SR 53 up to the junction with the SP 47, and then continues along the SP 47 north to Bassano.

There is a similar trend along SR 11 (Riviera del Brenta). It was already evident in the previous phase but it is now intensified with certain evidence, not only around the main centers where there is a process of thickening, but in general along the area crossed by this road. Even if we have not the same trend of growth of the previous phase, we can observe an intense building activity, in particular , in industrial areas.

It should be recalled that in 2005 many municipalities in the Veneto to the Region's administrative office presented 1,276 variations of general or partial plans. These variations were drawn up under the old legislation and before the enforcement of the new Regional planning law (n. 11/2004), with the aim of increasing the building surfaces and volumes.

Comparing the three different historical thresholds we see a gradual strengthening of a polycentric metropolitan system through the identification of new urban functions in the peripheral belt of the main urban centers, and a consequent and progressive densification around the main centers and along the main roads that cross the area. We can verify this phenomenon by observing what happened in the classes defined previously – urban sprawl (dim4) and Spread built environment – where there was a significant decrease of urban structures because between 1998 to 2007 there was a decrease of spread built-up environment of -3.86% for the class "dim4" and -7.82% for the class "dim5".

In the last twenty years a process of urban densification around the centers of the polycentric system has appeared, accompanied in the last ten years by a process of filling the open spaces, gradually making the study area more similar to a low-density city.

The analysis of urbanization processes helps us to recognize the different forms of urbanization and to follow their evolution. The area is more dense and compact around the main cities and surrounding areas and along the mobility infrastructure; the ribbon sprawl along the secondary roads has been strengthened and created small urban clusters; the compact centers have expanded and incorporated previously isolated urban portions; the urban sprawl, so evident in the first threshold analyzed, decreases and becomes small peripheral clusters. In addition, even if new centrality such as "street-markets", large infrastructure nodes, areas of shopping malls that characterized the sprawling system have not become the main polarities of the urbanization processes, they have become nonetheless "catalysts" for mobility and family activities, leading to practices of social life and causing substantial changes in land use and in traditional public spaces.

In summary, the process of urban explosion and sprawled urbanization in agricultural areas that characterized the 1970s and 1980s was followed, starting in 1990s, by dynamic densification due to several factors. The expansive planning policies that have affected urban centers, partly have promoted redevelopment projects and requalification of large and medium-sized historic centers –the economic effect is the increase of building values, in particular in the cities of Vicenza, Padua and Treviso – and have partly promoted new residential or industrial areas as the planning policies of small communities.

Large and small cities and communities are experiencing an economic crisis that has progressively reduced the financial transfers from the central State. This situation has certainly led the Local authorities to promote more construction.

In conclusion, we must say that the densification in reality is nothing but constant increase of the built environment and loss of open space.

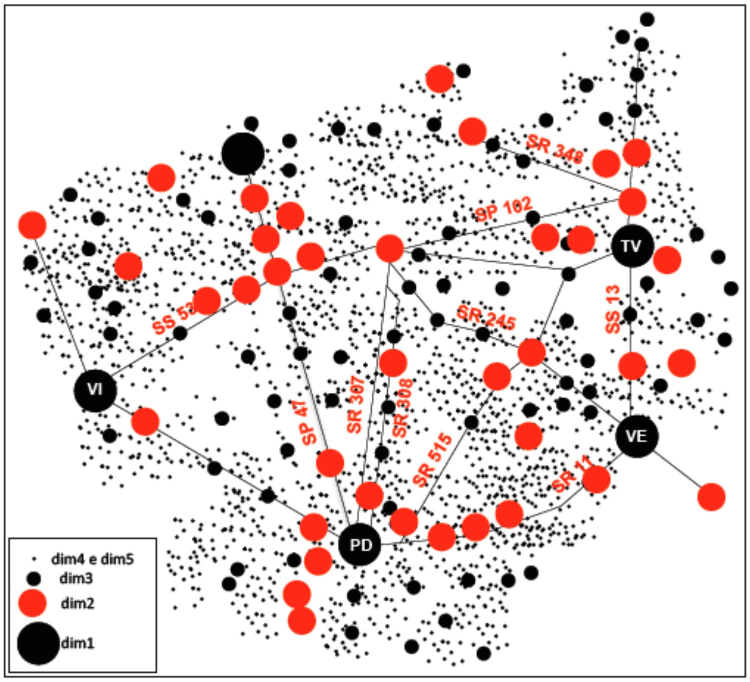

Fig. 3 – Built environment in 2007

4. Previous literature on the cost of sprawl

The analysis of the impact of sprawl on local spending is still limited and only few examples have been developed (see for example Carruthers and Ulfarsson, 2003, 2006; Ladd, 1992; Hortas-Rico and Solè-Ollè, 2010).

To this extent, this paper aims to contribute to the empirical literature that examines the impact of urban development on local government budget, considering two different temporal thresholds: 1998 and 2007.

Previously, scholars have adopted theoretical or engineering approaches to investigate how alternative urban development patterns affect the cost of providing services and infrastructures. Most of them find that low-density developments are expensive. For example, the most famous of these studies is certainly that of the Real Estate Research Corporation (RERC, 1974). This study aims to calculate the different costs applied to different development patterns, and it indicates whether the costs are incurred publicly or privately. The research is an investigation of "prototype development patterns, not of actual developments, although many of the data were obtained from empirical studies" (RERC, 1974). This research shows that providing the infrastructure to high-density planned development costs about half as much as the cost necessary to develop low-density sprawl ($5,167 in 1973 dollars vs $9,776) (Muro and Puentes, 2004).

Later, based on RERC's research and due to many criticisms towards that study, different updates and new studies were proposed, some of them offering a future cost projection for the year 2025.

Burchell et al. (1998; 2002) review the RERC study and calculate that sprawl would result in $227 billion in additional costs for uncontrolled vs controlled growth. Uncontrolled growth leads to greater costs for land consumption and physical infrastructure and creates fiscal costs that exceed revenue. Moreover, the auto dependence of sprawl development increases the private travel costs, both in economic terms and time consumed.

All the engineering-type studies (see also Speir and Stephenson, 2010), though very well designed, estimate costs for hypothetical developments of differing densities and other characteristics without considering the actual costs sustained by local governments. Moreover, uncertainties exist regarding the appropriate use of cost concepts and measures, and regarding the quality level and technology considered when estimating the different situations.

Another different set of studies has adopted regression analysis approach for investigating the relationship between sprawl or population and urban density, and public sector costs. One of the first studies to our knowledge is Ladd (1992). She finds that population density follows a U-shaped impact on current account spending. Population exerts two different opposite forces. On the one hand, higher density could abating per capita costs because of economy of scale, or economies of density in the production of certain public services; on the other hand, the higher density is likely to increase per capita spending as more services must be provided by public rather than by private sector.

More recently, Carruthers and Ulfarsson (2003) analyze how characteristics of urban development affect twelve categories of public expenditure in a cross section of 283 metropolitan US counties during the period 1982 – 1992. The analysis evaluates how density, spatial extent of urbanized land area, property value, and political fragmentation affect the cost of services. Contrary to the work of Ladd, their empirical analysis show that the per capita cost of most services declines with density and rises with the spatial extent of urbanized land area, indicating that urban sprawl undermines cost effective provision of public service and contributes to support planned growth management or smart growth strategies. Similarly, Cox and Utt (2004) examine the actual data on municipal expenditures deriving from the database of the United States Bureau of the Census for the year 2000 for more than 700 municipalities. They estimate a regression model for explaining the relationship between local expenditures and some explanatory variables such as population density, crime rate, total of state and federal aid per capita, property values, etc. Results of their analysis demonstrate that the "actual data indicate that the lowest expenditures per capita tend to be in medium- and lower-density municipalities; medium- and faster-growing municipalities; and newer municipalities".

In Europe, to our knowledge, very few examples of this kind of analysis exist. For example, in Italy, Camagni et al. (2002) and Travisi et al. (2009) have provided an estimate of collective costs of sprawl investigating the impact of different urban forms on land consumption and on urban mobility. The results of the analysis prove that low density, recent urbanization development and residential specialization are associated to higher environmental impact of mobility.

Analogous to our research objective, Hortas-Rico and Solè-Ollè (2010), investigate the impact of urban sprawl on the costs of providing local public services in Spain. They estimate a series of different aggregate and disaggregate local public spending functions that can be more influenced by urban sprawl, regressed to a set of accurate exploratory variables. Their results indicate a non linear impact of low-density pattern on the costs of providing public services. Moreover, economies of scale for certain public services are not realized by more spatially extensive urban development.

5. Data and Methods for measuring urban sprawl

In this Section we will describe the methods with which we obtain the main variables used for our econometric analysis and related to urban sprawl and urban density.

5.1. Density variables

We have used several variables of density because we think that a single one does not fully capture the full value of the density concept, but instead each measure reflects a different dimension. Thus, we have calculated *population density* as population/total surface area of the municipality, *urban density* as population/built up area, *total urban density* for taking into account different uses of land (residential and employment uses) and computed as the ratio between the sum of residents and workers on the built up area, and finally we have constructed the *built up area ratio* (built up area/total amount of area). All these measures can better explain the relationships between population and urbanized land area: population has grown at a slower rate, while built up area has radically increased over time. The net effect of these indicators on the per capita current expenditure of municipalities is not certain, in fact increased density may affect per capita public spending in two opposite ways. On the one hand, higher density may increase per capita current expenditure as more service have to be provided by public sector, on the other hand, higher density may realize economies of scale in the provision of certain public services and infrastructure (see for example, Ladd 1992).

Clearly, given the similarities among these density measures, we have to expect high collinearity between them, losing explanatory power in regression analysis. Table 1A on the appendix shows the Pearson correlation results and reveals significant multi-collinearity. In order to improve the results of our regressions, we have employed principal component analysis (PCA) to construct one combined density measure. PCA is used to reduce the dimensionality of data by transforming the original set of correlated variables into a smaller and more understandable set of uncorrelated variables (Jolliffe, 2002).

The component explaining the majority of the variance in the four density variables has positive loadings on all four measures, and thus can be considered as the "density" component (see Table 2A in appendix). After that, we have created a combined density index by linearly combining the four density measures, weighted by the component loadings. This variable will be used in our regression analysis (*density*).

5.2. Urban sprawl variables

There is no consensus about the variable that better than others describes urban sprawl, even if population density still remains the most widely used indicator of sprawl because of its simplicity (Hortas-Rico and Solè-Ollè, 2010). There exists a remarkable body of literature dealing with sprawl indicators (see for example Galster et al., 2001; Ewing et al., 2002; Tsai, 2005; Frenkel et al., 2008), but quite difficult to replicate because of the available information and data. For this reason we have tried to construct a different indicator for mapping the characteristics of Veneto Region urban area, as explained in Section 2.

After having designed the five territorial dimensions (dim1-dim5) in which subdivided the urbanized area of each municipality, we have employed cluster analysis to create homogeneous groups of municipalities that are similar internally and different between the other groups. Among the various clustering methods, the technique employed by Ward (1963) is chosen as it generates a classification hierarchy while minimizing the variance within each of the groups. Before applying cluster analysis, the five territorial dimensions have been standardized and the analysis is performed separately for the three year period (1984-1998-2007), even if only the 2 recent years have been later used in regression analysis. Three clusters emerge from the statistical analysis and three different groups of municipalities have been identified: compact areas, minor centers and sprawl areas[6]. Later, we use the same groups to create three different dummy variables and each municipalities is correctly assigned to one of this variable.

Table 1 – Distribution of municipalities across the final clusters

	Percentage of municipalities		
	1984	**1998**	**2007**
Compact area	18.98	41.38	54.48
Minor centers	30.00	35.86	31.03
Sprawl area	51.03	22.76	14.48
Total	**100**	**100**	**100**

6. A descriptive analysis of data

The empirical analysis aims to trace the effects of certain variables on the local public spending. We collect data on different public costs functions for 145 municipalities of the central area of the Veneto Region (representing about the 22% of the whole region) for the years 1998 and 2007. Data come from annual balance sheet of each municipality. In addition to information to current expenditures, we also collect data on capital outlays but we decide to focus only on the current operations because capital expenditures represent not the annual costs of using capital but rather the amount of investment in public sector infrastructure planned for both current and future residents.

We use municipalities' accountability system because they are in charge of managing a certain number of services that are directly influenced by a low-density urban development pattern. In fact, municipalities must produce important services to the citizenry, including public transport, solid waste collection, street cleaning, urban planning, local policy, waterworks, school lunches and transport, the management of public green areas, day nurseries, and the management of nursing homes for the elderly. These services are provided partly free of charge and partly against payment of a sum, which is usually lower than production cost (Caperchione, 2003).

Municipalities are allowed to (1) increase local taxes and (2) charge tariffs for the services they provide, but a large percentage of their inflows (about 30%) is still represented by transfers from higher levels of government.

6. Detailed information on the cluster analysis is available from the authors upon request.

In our case study, the average total current expenditure for the 145 municipalities is about 599.66 euro per capita in 1998, and 512.58 euro in 2007. A significant decreasing is registered for all the budget items considered for this analysis, consequence of the small population size of the municipalities belonging to our sample area. In fact only 3% of the sample is formed by municipalities with more than 40000 residents[7]. Similarly, the average total amount of transfers (State plus Region) is about 196 euro per capita in 1998 and 138 euro in 2007. The average total amount of local taxes paid by citizens is about 330,00 euro per person in 1997 and 318 euro in 2007, comprising the municipality property tax (Imposta Comunale sugli Immobili, ICI), tax on waste collection (TARSU), income tax on resident (IRPEF), use tax, license and permits.

Municipalities in our sample range from very small towns of a thousand of inhabitants to other like Venice and Padua with more than 200,000 inhabitants, so the average population of the sample is around 13,000 people in 1998 and it increases to an average of 14,500 in 2007, with a mean population density of 4,44 people per hectare and 5,25 respectively in 1998 and 2007. The average built-up area is calculated in about 500 ha in 1998 and about 630 in 2008, thus with an overall increment of about 27%.

In particular, if we go into more depth, we find that between 1998 and 2007, the average population of the whole area has grown by about 10% while the total amount of developed land has grown by about 27% (Fig. 8 in Appendix). These numbers show that in about ten years population is increased relatively slowly, while the total developed land is increased nearly three times the rate of population growth. But, if we look at the same statistics referred to the temporal threshold 1984-2007, and especially at the distribution of the developed land, we can see that there has been a sort of urban compactness. This fact can be also basically highlighted looking at the sprawl index calculated as the natural logarithm of the ratio between urbanized land in the more recent year and urbanized land in the previous period. For example the average sprawl index of the period 1998/1984 is 0.40 versus the ratio 2007/1998 that is 0.28.

Table 2 – Variables: descriptive statistics of selected variables (145 municipalities)

Variables	**Description of main exploratory variables**	**Wave**	
		1998	**2007**
		Mean (st. dev)	Mean (st. dev)
Popolution	Average population of the municipality	13239.51 (32393.5)	14570.17 (29697.79)
Supurbha	Total number of hectars of built-up area	498.78 (704.80)	632.93 (784.66)
denspopha	Average number of people per ha	4.44 (3.05)	5.25 (3.21)
densurbha	Average number of built-up area per ha	0.20 (0.09)	0.26 (0.10)
denspopurbha	Average number of people per ha of built-up area	21.78 (6.54)	19.71 (5.45)
densurbtotha	Average number of people and employee per ha of built-up area	27.75 (8.37)	25.66 (7.60)
sprawlindex	Index for measuring sprawl calculating as the ratio between urbanized land in the recent year and urbanized land in the previous period	0.40 (0.37)	0.28 (0.13)
ptransfer	Total public transfers (State and Regional aid) per person	194.80 (44.53)	137.95 (55.88)

7. To give an example, we have found that municipalities with more than 40000 residents show an average current expenditures of 1074.40 euro in 1998 and 1148.89 euro in 2007, whereas municipalities with less than 40000 have an inverted trend showing an average current expenditure of. 586.19 euro and 489.86 euro respectively for 1998 and 2008.

poneriurb	urban fee, per person	57.58 (34.66)	65.68 (48.09)
ptax	Total value of local tax paid by citizens per person	331.10 (96.07)	317.50 (102.45)
pcorrenti	Average spending on current operations	599.66 (156.44)	512.58 (171.79)

7. Empirical model and results

In this study, a two-wave (t=2) and balanced panel dataset is used to understand if urban built up environment can influence the current expenditure of Veneto municipalities (i=municipalities=145); the explanatory variables and the dependent variables are better described in Table 1.

The basic model is the following:

$y_{it}=\alpha_i+x_{it}+\varepsilon_{it}$

where y_{it} is per capita total current expenditure of municipality i in year t, x_{it} is a vector of explanatory variables, α_i are random individual-specific effects, and ε_{it} is the error term.

We first use a pooled OLS regression, then a random effect model (RE) and fixed effect model (FE). Later, we will implement the Hausman specification test for helping to decide whether it is the random effects model or the fixed effects one that is more appropriate and efficient to be used.

The basic models are displayed in Table 3. The dependent variable is the Municipality's total current expenditure per capita.

Table 3 – Results of the models

	Pooled OLS (a)	**RE model (b)**	**FE model (c)**
Dependent variable	**pcorrenti**	**pcorrenti**	**pcorrenti**
Independent variables			
Const	-75.09*** (22.26)	-65.73*** (26.28)	129.71* (73.59)
ptransfer	1.34*** (0.09)	1.32*** (0.10)	1.26*** (0.14)
poneriurb	0.35*** (0.09)	0.32*** (0.11)	0.17 (0.16)
ptributi	1.04*** (0.06)	1.02*** (0.06)	0.74*** (0.12)
density	-1.28 (1.00)	-1.40 (1.07)	1.52 (2.42)
compatto	38.81** (11,75)	38.27*** (14.74)	-9.32 (39.75)
centrimin	15.97* (9.62)	16.12 (14.32)	-1.27 (29.32)
Number of obs:	290 F-test=245.94*** R-squared= 0.79	290 Wald chi2 =943.92*** R-squared: 0,79	290 F-test= 32.18*** R-squared=0.75

Note:
1. Standard errors are given in parentheses
2. Significance is indicated by ***, ** and * for the 1, 5 and 10 percent level, respectively.

All models, the pooled OLS regression with cluster-robust standard errors, the random effect (RE) and the fixed effect (FE), are significant. Based on the Hausman test we cannot reject the null hypothesis that there is no correlation between individual effects and the explanatory variables and so, given such results, the preferred model is the RE[8].

The coefficient of *ptributi* (total local taxes paid by citizens) and *ptransfer* (total monetary aid from higher government level) are both significant and positive, meaning that per capita total current expenditure is a function of municipality revenues. Greater transfers from central governments imply greater willingness for local spending. Also the parameter estimate for urban fee (*poneriurb*) influences positively the per capita total current expenditures, more revenues from urban land development increases the capacity of spending of municipalities.

The coefficient related to density measures, calculated as explained in Section 5, is negative but not statistically significant. However, even if not significant, the negative effect suggests that higher density might create economies of scale: the per capita cost decreases as density intensifies, with the greatest savings realized in areas with elevated densities.

The coefficients of the parameters describing if the municipalities are "compact" or "small centers" have positive sign, but only the first variable "*compatto*" is statistically significant. The term "compact" is used to identify those municipalities in which urban growth is around existing population centers and where the population density per urbanized ha is high. This result is quite surprising, but not unreasonable. In fact, within this category, all the bigger towns of our sample are included (i.e. Padua, Venice, Treviso, Vicenza) where urban congestion phenomena such as excess pressure for the use of urban infrastructure or higher resident's demand for municipalities services in general might have increased the per capita current total expenditure of municipalities. Furthermore, another reasonable explanation might be the quality diversity of infrastructures and services in the different municipalities but information about that are not available. Finally, in the period 1998 and 2007, all the small municipalities have experienced a per capita reduction in their local budgets, on the contrary, for towns with more than 40,000 residents we have found just the opposite, as explained in Section 6.

To better isolated the role of the pure density measure – namely people per ha of urbanized land – on the capita current expenditure, we have run three simple models for each subsamples related to the different type of municipalities, as we have identified in the previous section: compact, minor centers and sprawl area. The density measure is a dummy variable that differs according to the range of population density (dens15 if density is less than 15 people per urbanized ha; dens20 if density is comprised between 16 and 20 people per urbanized ha; and densup20 if density is higher than 20 people per urbanized ha). Results are reported in Table 4.

Table 4 – Results of regression models for distinct groups of municipalities

	Compact area	**Minor center**	**Sprawl area**
Dependent variable	**pcorrenti**	**pcorrenti**	**pcorrenti**
Independent variables			
constant	-29.23 (21.26)	109.81 (36.57)	74.72*** (108.65)
ptransfer	1.48*** (10.42)	1.01*** (0.11)	1.04*** (0.20)
ptributi	0.34***	0.77***	0.85***

8. Results of Breusch and Pagan Lagrangian multiplier test for random effects is chibar2 =5.38**

	(0.14)	(0.08)	(0.31)
poneriurb	1.06*** (0.09)	0.17 (0.15)	0.35*** (0.12)
dens15	2.84 (27.36)	1.90 (15.97)	1.53 (23.62)
dens20	-26.70* (14.64)	-7.81 (10.50)	-39.34** (15.04)
Number of obs:	139 F-test=231.92*** R-squared=0.81	97 F-test=32.68*** R-squared=0.66	54 F-test=8.04*** R-squared=0.57

Note:
1. Standard errors are given in parentheses
2. Significance is indicated by ***, ** and * for the 1, 5 and 10 percent level, respectively.

Results of the different models are quite convincing, the only weak outcome is that obtained for the minor centers: it seems that density measures have not explanatory power in the model. In fact, all the three density dummies (with the higher density "*densup20*" assumed as base) are not statistically significant, even if the signs are in line with our expectations.

Briefly, results show that the coefficient for low density (dens15) is always positive in the three models, but unfortunately not significant so we cannot draw conclusions supported by strong statistical evidences. We can only assume that for each type of municipalities very low density increase public spending. On the contrary, because the coefficient for the higher density is always negative and statistically significant we can say that higher density in compact and sprawling municipalities is able to reach economies of scale.

To conclude, we have also run other models in which the dependent variable is now the per capita current expenditure for roadways and transport, and the environmental and land management spending function, whose main results are reported in Table 5 below[9]. Our goal is to find more evidences that the sign of the variable describing the less or more sprawling communities depends on the different public spending functions which have diverse behaviour and policy objectives.

Table 5 – Results of the empirical models

	Roadways and transport (1)	**Environmental and land management (2)**
Independent variables:		
constant	13.08* (7.91)	-7.67*** (2.97)
ptransfer	0.11*** (0.02)	0.03*** (0.01)
poneriurb	0.05* (0.03)	0.04*** (0.01)
ptributi	0.09*** (0.01)	0.01* (0.006)
density	-0.59*** (0.19)	-0.07 (0.12)
compatto	-6.02* (3.63)	6.94*** (1.70)
centrimin	-1.26 (3.51)	4.44*** (1.55)

9. Other estimates were attempted but results were not satisfactory, but if interested are available from the authors upon requests.

veicoli	-0.04*** (0.01)	
Number of obs:	290 Wald chi^2=197.16*** R-squared=0.44	290 Wald chi^2=45.95*** R-squared=0.16

Note:
1. Standard errors are given in parentheses
2. Significance is indicated by ***, ** and * for the 1, 5 and 10 percent level, respectively.

Results of different models confirm that coefficients related to the amount of local taxes and the other fiscal impositions paid by citizens are positive and significant, meaning that higher revenues favour local public spending in services and infrastructures. Moreover, also the parameter state and regional aid is positive and significant for all the equations. The greater the monetary transfers from higher governmental levels, the greater the per capita spending in transportation, and environmental and land management by local government within each municipality.

The parameter estimates for *density* are negative, even if not statistically significant in the second models, suggesting it might create economy of scale for public spending on transportation.

In the first model we have added a new exploratory variable that describes the total motor vehicles per 1000 inhabitants (*veicoli*) in each municipalities because we deem that this parameter is a proxy for measuring urban expansion, accessibility and centrality. Car has radically reshaped cities allowing people to live and work far from their respective houses and jobs. Results of our models show that the coefficient of *veicoli* is negative and statistically significant for roadways and transport expenditure. We assume that, *ceteris paribus*, increasing the number of private cars decreases the need to offer public transport to residents, reducing its cost.

Per capita development impact fees (*poneriurb*) are intended to transfer a fraction of the capital cost for new infrastructure from the public to the private sector. Both models are positively and significantly influenced by *poneriurb*. We speculate that greater impact fee revenues lead to better provision of infrastructure and consequently higher investments and higher expenditures supported by municipalities.

The coefficient related to the parameter *compatto* is negative and significant for the equation related to the roadway and transport expenditure function meaning that the less sprawling areas are able to reduce the costs of providing road networks and public transportation infrastructures. The same parameter is conversely positive and strongly statistically significant for per capita spending on environmental and land management, confirming the result that in more densely populated areas the costs of providing services such as water networks, waste collection and other territorial public services are higher because of higher residents' demand and possible inefficiencies caused by congestion. The same conclusion can be reached also in the case of the minor centres, whose coefficient is positive and significant.

8. Discussion and conclusions

The Central Veneto area has experienced a rapid growth in suburban development not supported by a comparable population growth in the last 30 years and the effect of this change has a price in terms of efficiency and cost effectiveness. In addition to regression analysis, we have used landsat images and software application specialized in image segmentation and classification such as eCognition in order to mapping land development in three different time period: years 1984, 1998 and 2007. We have observed that although the population of the area of study grew by 11% from 1984 to 2007, urbanized land increased by 65.40% during the same period. However, in the period 1998-2007 we have noticed some phenomena of new urbanizations around the existent urbanized area, especially if you look at the location and distribution of the new developed land. In particular, in the last twenty years a process of urban densification around the centers of the polycentric system has appeared, accompanied in the last ten years by a process of filling the open spaces, gradually making the study area more similar to a low-density city

A second step of our research has analyzed and estimated the role of urban forms, together with the more traditional indicators of urban and population density, in the management and public spending capacity of municipalities. We have collected the municipalities' balance sheets for the 145 municipalities of the Veneto area. In particular, we have analyzed the aggregate total current expenditures of municipalities and some other public spending functions such as public transport, road and street maintenance, and environmental and land management services.

Results of our models show that in general the per capita current expenditures of the municipalities is negatively influenced by our density variable, that we have defined as a compound index obtained from four different density measures through factor analysis. Unfortunately, this effect is not supported by strong statistically evidence, meaning that other independent variables may have a better explanatory power.

Because urban sprawl is one name for different situations (Galster et al., 2001) we have tried to create our dimension distinguishing compactness from sprawl urban areas applying the cluster analysis, having quantifying before five different dimensions of urban forms according different levels of built-up densities (large, medium and small urban areas, sprawl urban area and isolated or spread built area). The outcomes of our elaboration allow to create three different groups of municipalities: those where compact built up areas are predominant (compact area), those where the small and minors centres are numerous (minor centre) and those representing the most sprawling area (sprawl area).

We find some interesting results that need to be more elaborated in the future. In general, in the basic models (a and b in Table 3), the compact areas seem to determining more higher public expenditures; but if we better isolate the effect of the more traditional population density index, we find that there is a clear distinction within the same group of compact urban area. In fact, higher densities are able to realize economy of scale in the aggregate public current expenditures of municipalities, as well some savings are able to be obtained in some areas of public spending such as road and transport costs. We can conclude that the role of compact areas in determining public costs depends on the particular function of public spending and on the effect of population density on congestion and demand for public services and infrastructures. Scholars have already found that population density exerts a U-shaped impact on current account spending. At very low levels of density, lower than 250 people per square mile, population density shows a decrease in public safety spending. But at higher levels, the costs show an increase (Ladd, 1992).

Stable results are found for the coefficients describing the role of total local taxes paid by citizens and the total monetary aid from higher government level, that are both statistically significant and positive in all models estimated. This fact means that per capita public spending is a function of municipality revenues. Greater transfers from central governments imply greater willingness for local spending.

The possibility to save public money in some areas of public spending is particularly attractive today because of the lack of financial and monetary funds available at local government scale. If local governments are aware that some development patterns cost more than others, they have to act consequently and provide new rules and economic instruments to avoid or limit the waste of land. To this extent, it's even more urgent the implementation of land use policies that aim at a more sustainable use of land, such as growth management policies that try to direct growth to certain areas and away from others. However, critics of this kind of policy state that it reduces the supply of land available for development which may result in an increase in the price of land throughout the urban area, an increase in residential density, and an increase in the concentration of commercial development in the central city (McGuire and Sjoquist, 2002).

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Appendix

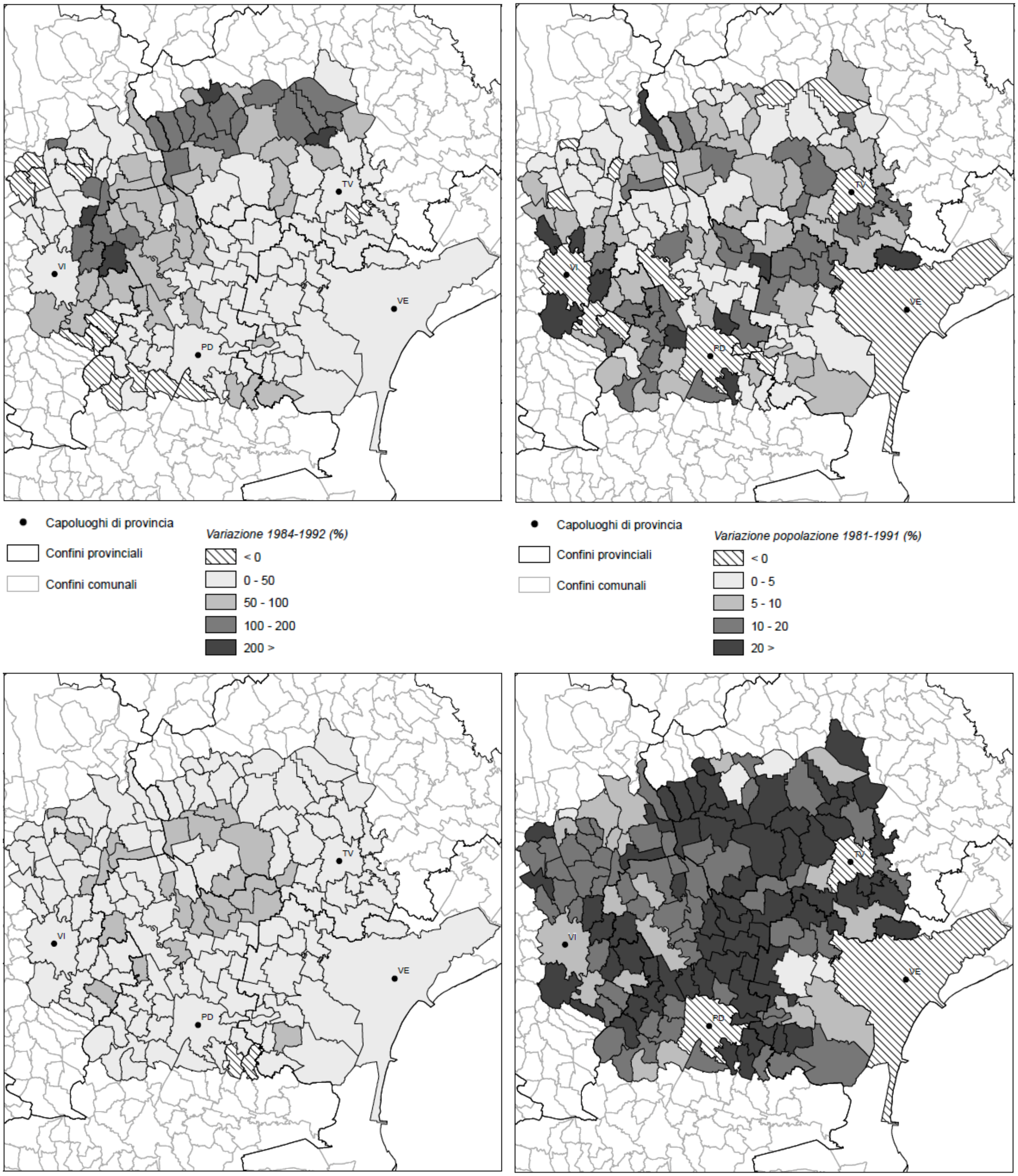

Figure 1 – Variation of built environment in 1984-1998 and variation of population 1981-1991; variation of built environment in 1998-2007 and variation of population in 1991-2007. Elaborations: Davide Martinucci.

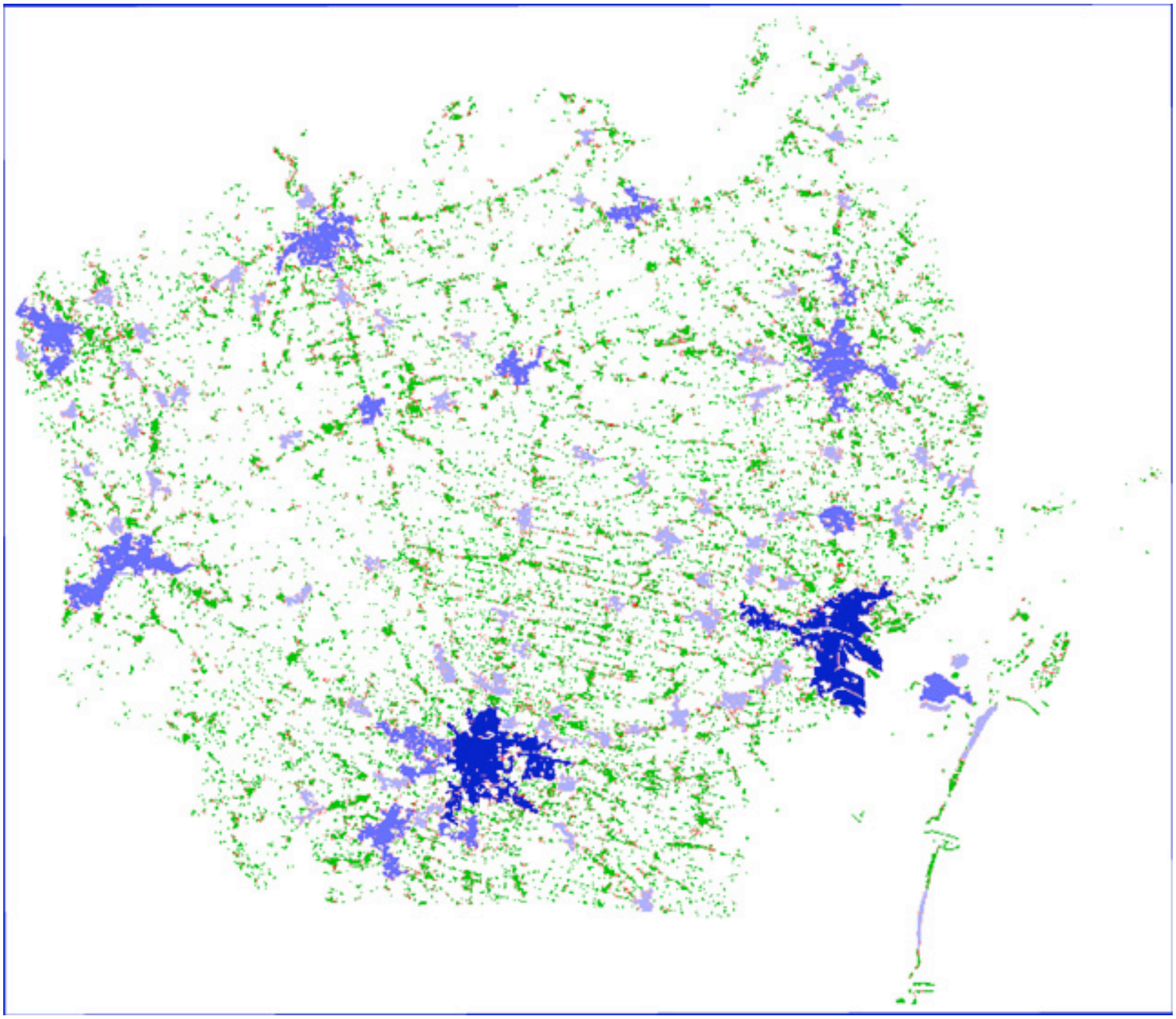

Figure 5 – Built environment in 1984

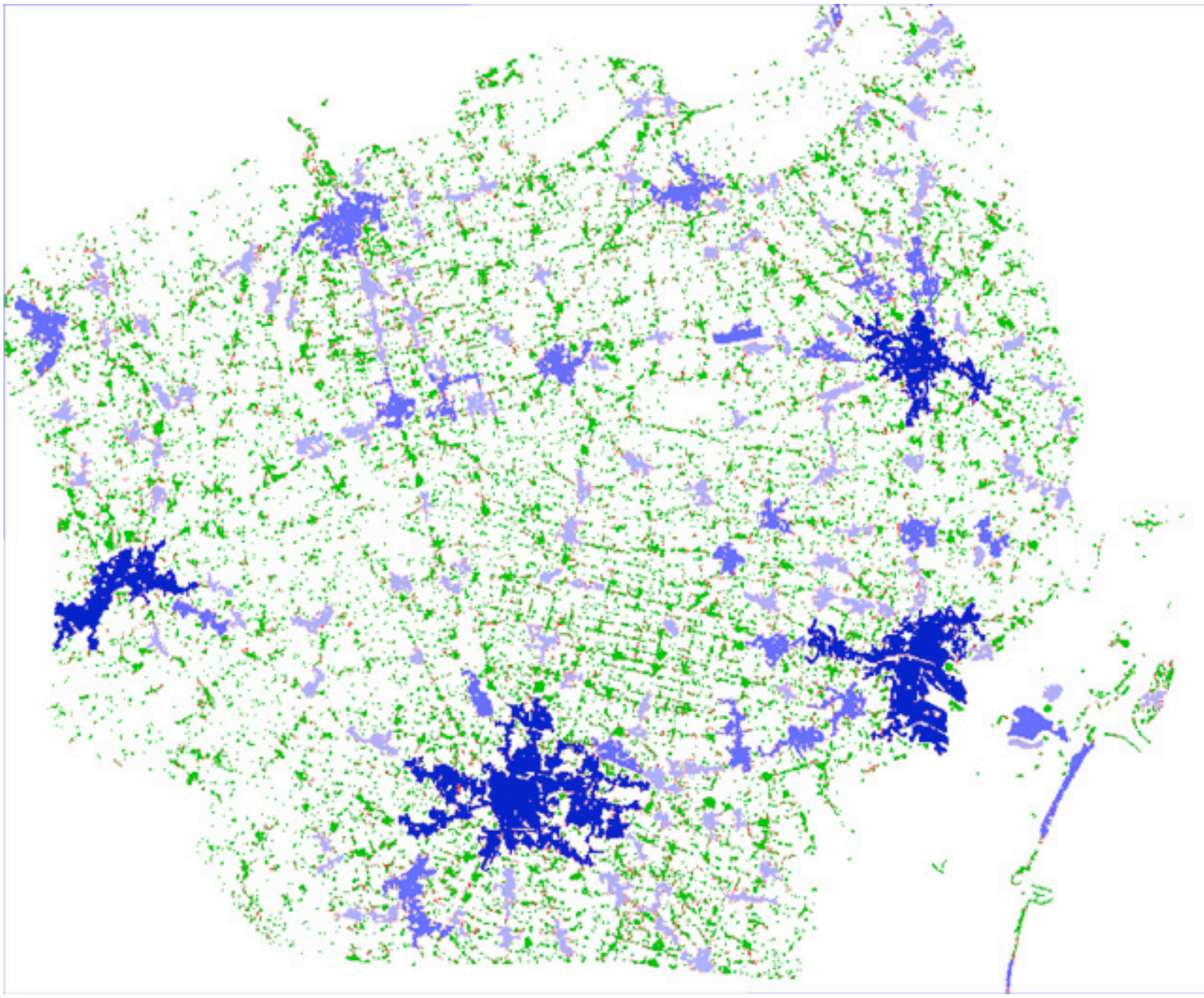

Figure 6 – Built environment in 1998

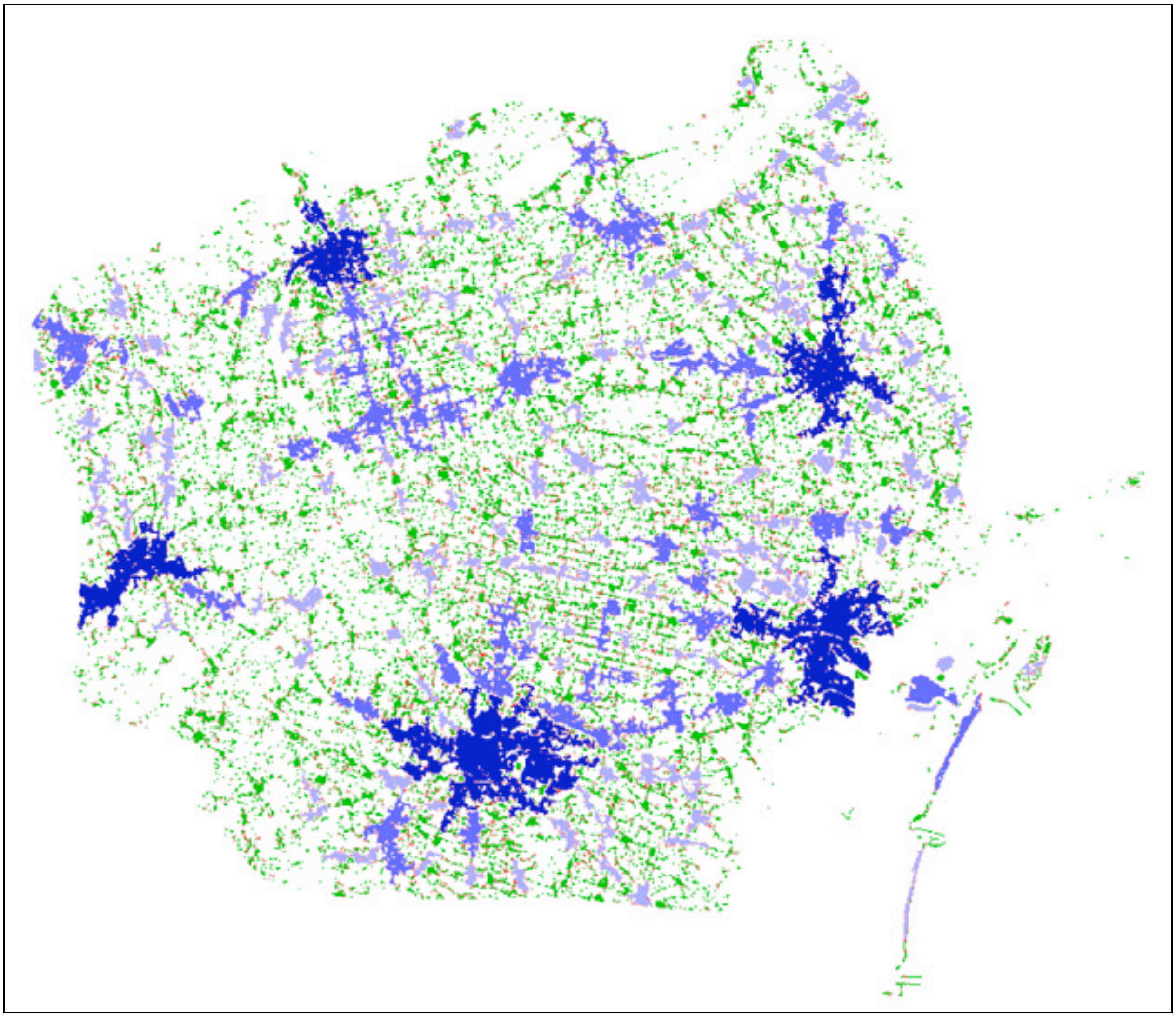

Figure 7 – Built environment in 2007

Figure 8 – Rates of growth in population and built-up from 1998–2007

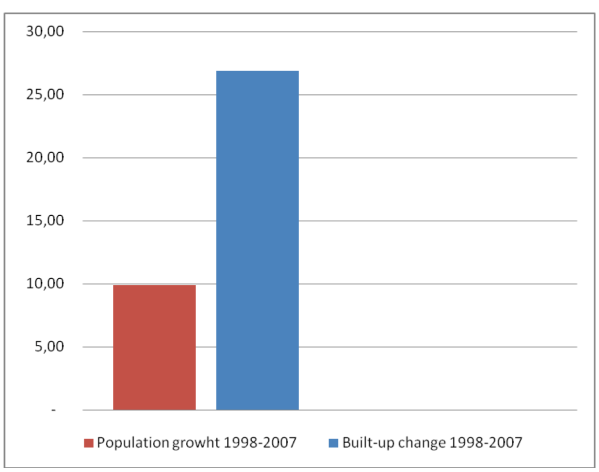

Table 1A – Pearson and Spearman correlation

	d~surbha	dens~pha	d~purbha	densurbtotha
densurbha	1.0000			
denspopha	0.8490	1.0000		
	0.0000			
denspopurbha	0.1977	0.6250	1.0000	
	0.0007	0.0000		
densurbtotha	0.2677	0.6658	0.9644	1.0000
	0.0000	0.0000	0.0000	

Table 2A – Principal component analysis

Principal components/correlation — Number of obs = 290; Number of comp. = 4; Trace = 4

Rotation: (unrotated = principal) — Rho = 1.0000

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	2.82172	1.71423	0.7054	0.7054
Comp2	1.10748	1.06485	0.2769	0.9823
Comp3	.0426372	.0144761	0.0107	0.9930
Comp4	.0281611	.	0.0070	1.0000

Principal components (eigenvectors)

Variable	Comp1	Comp2	Comp3	Comp4	Unexplained
denspopha	0.5515	0.3286	-0.6284	-0.4393	0
denspopurbha	0.5122	-0.4695	-0.2637	0.6691	0
densurbtotha	0.5301	-0.4107	0.5767	-0.4667	0
densurbha	0.3905	0.7092	0.4505	0.3762	0