Zoppi C., Lai S. (2015) Determinants of land take at the regional scale: a study concerning Sardinia (Italy). *Environmental Impact Assessment Review, 55 pp. 1–10*, ISSN: 0195-9255.
http://dx.doi.org/10.1016/j.eiar.2015.06.002

Determinants of land take at the regional scale: a study concerning Sardinia (Italy)

Abstract

In its “Roadmap to a Resource Efficient Europe” (Communication COM(2011) 571 of 20 September 2011), the European Commission (EC) established an ambitious goal for the European Union (EU), that of achieving no land take by 2050; towards this aim, a key milestone for the year 2020 was set, by stating that European policies in the programming period 2014–2020 ought to consider both their direct and their indirect impacts on land use in the EU. Within this framework, this paper builds upon the findings of a previous paper (Zoppi and Lai, 2014), in which we estimated the magnitude of land take over a short period of time (2003–2008) in Sardinia, an Italian NUTS2 region, and we assessed whether and how land take is related to a set of variables that are regarded as important determinants in the literature, such as parcel size, accessibility, and proximity to main cities and towns, to the coastline, or to protected areas. In this paper we study the land-taking process taking Sardinia as a case study, in two larger time periods, 1960– 1990 and 1990–2008.We assess if, and towhat extent, these factors reveal similar, or different, effects in the two periods, and try to identify consistencies concerning the determinants of land take.

1. Introduction

We define land take as the "Change of the amount of agriculture, forest and other semi-natural and natural land taken by urban and other artificial land development" (European Environment Agency, 2013a).

To assess the global relevance of land take is rather difficult, since only a few global land-cover datasets are currently available[1]. Among these, (i) a study carried out at the University of Maryland, which estimated that in 1992-1993 urban and built-up areas amounted to 0.18% of the world land area (Hansen et al., 2010:1350); (ii) the "Global Land Cover 2000" project (European Commission, Joint Research Centre, 2003), which assessed artificial land cover as 0.20% of the world land area in the year 2000; (iii) a series of maps produced by the European Spatial Agency (ESA Climate Change Initiative, 2014), which suggest that urban areas corresponded to approximately 0.54% of the world land area between 1998 and 2012; (iv) Chen et al. (2014), according to whom the artificial land surface in 2010 equaled approximately a 0.88% of the total land surface. These studies and datasets differ in many important aspects such as definition of land cover classes, data sources, classification methodologies, and spatial resolution; such differences make it quite problematic to compare land cover over time at the global scale so as to assess land take worldwide.

In the European Union (EU), where datasets on land cover were consistently produced by the European Environment Agency for the time period 1990-2006, annual land take has been assessed at approximately 1,000 km^2 per year between 1990 and 2000, slowly decreasing at about 920 km^2 between 2000 and 2006; artificial land has been estimated to amount to approximately 4% in 2006 (European Environment Agency, 2010:10), rather unevenly distributed.

[1] A list of available global land cover data sets, together with some information (e.g. year and resolution) is provided by Giri et al. (2013).

In Italy, land take shows a trend pattern similar to that of the EU in that, according to a recent report produced by the National Research Institute for the Protection of the Environment (ISPRA, 2015, p. 10), the rate at which land is being taken has slowly decreased from approximately 250 km^2 per year between 1989 and 1998 to about 200 km^2 per year between 1990 and 2014. The same report (ISPRA, 2015, p. 10) also estimates that in 2014 a 7.0% of the Italian land area was artificial.

Within this context, our analysis relates to Sardinia, one of the two major Italian islands and a NUTS2 region. Findings and discussion proposed in this paper build upon the results of a previous paper (Zoppi and Lai, 2014) in which we estimated the magnitude of land take over a short period of time (2003-2008) in Sardinia. Here, consistently with our previous paper, we do not consider land take in ethical terms; rather, we assess what factors influence land take by looking at a set of variables that are regarded as important determinants in the literature (such as parcel size, accessibility, proximity to main cities and towns, to the coastline, or to protected areas) and estimate their quantitative impacts.

In this paper we study the determinants of the dynamics of land-taking process taking Sardinia as a case study, in two larger time periods, 1960-1990 and 1990-2008, and assess these processes in terms of variables influencing land take. We therefore evaluate if, and to what extent, these factors reveal similar, or different, effects in the two time periods, and try to identify consistencies concerning the determinants of land take.

The identification of the most significant physical, socio-economic and planning-related determinants (among which parcel size, accessibility, population density and presence of nature conservation areas) is relevant in policy terms, since the European Commission (EC), in the “Roadmap to a Resource Efficient Europe” (Communication COM(2011) 571 of 20 September 2011), identifies no net land take as one of the objectives to be achieved by 2050, and sets a key milestone for the year 2020, by establishing that the EU 2014-2020 cohesion policy should consider both its direct and its indirect impacts on land use.

The second section starts by describing how we calculate land take and what set of factors we consider as determinants of Sardinian land take, and goes on to discuss the spatial representation and correlations of the land take variable and its covariates.

Findings from the implemented econometric model related to the correlations between land take and its determinants are presented in the third section, and qualitative and quantitative inferences are discussed. The paper concludes by proposing recommendations and suggestions concerning the definition and implementation of planning policies aimed at limiting or preventing land-taking processes, which may possibly be effective in addressing the EC recommendation on zero-land take by 2050.

2. Determinants of land-taking processes: data, correlations and spatial layouts

As of today, no detailed maps are available to describe, measure and compare land take over a large period of time in Italy. The European Environment Agency (EEA) does produce and make available land-cover maps but only from 1990 onwards[2]; moreover, the resolution of the maps is not fully appropriate at the regional scale. Therefore, because we aimed at studying the process at the regional scale and by looking at a much larger space of time, we chose to study land take by integrating various sources as follows:

i. two vector layers belonging to the dataset of the Sardinian Regional Landscape Plan (RLP) (produced in 2006 and available from the regional geoportal[3]) that respectively describe historic settlements, defined as artificial areas as of the end of the XIX century on the basis of the maps produced by the (then) Royal Geographic Italian Military Institute, and urban developments as of the end of the 1950's, which in Sardinia were usually built adjacent to the historic settlements, preserving their comparatively high density and compactedness together with the characteristics of older urban tissues and of the architectural features of the built environment;

ii. a vector layer produced by the EEA and describing Urban Morphologic Zones (UMZ) as of 1990[4]; these are defined by the EEA as "sets of urban areas laying less than 200m apart" and are identified on the basis of a selection of appropriate subclasses of the CLC class "artificial surfaces" that characterize the urban fabric and layout;

iii. the 2008 Corine Land Cover Map produced by the Regional administration of Sardinia and available from the regional geoportal[5]; this is a vector dataset from which we selected only polygons belonging to the first-level CLC class "artificial surfaces".

The three above datasets differ in aim and resolution and for this reason they were preprocessed to avoid inconsistencies. As Figure 1 shows, such inconsistencies were corrected by means of basic geoprocessing operations.

FIGURE 1

Hence, we use the Sardinian CLC-based land-cover maps for 2008, the EEA's UMZ for 1990, and the above mentioned layers of the RLP to detect artificial land cover and land take in 1960.

In the Corine Land Cover (CLC) taxonomy, first-level (that is, general and broad) land cover categories of non-artificial surfaces are as follows: i. agricultural areas; ii. forests and semi-natural areas; iii. wetlands; and, iv. waterbodies. We assume that land take occurs if an area changes its non-artificial condition, either in 1960, for the period 1960-1990, or in 1990, for the period 1990-2008, to the artificial land-cover class, either in 1990, for the period 1960-1990, or in 2008, for the period 1990-2008. Our analysis concerning Sardinia shows that artificial land increased from 0.54 percent in 1960 (13,090 hectares) to 1.59 percent in 1990 (38,182 hectares), to 3.25 percent in 2008 (78,379 hectares)[6].

We tentatively assume that land take, generated by demand for urbanization of non-artificial land (CRCS, 2012), depends on physical and planning rules-related factors, and on a social variable, that is residential density (Sklenicka et al., 2013; Huang et al., 2006).

We use the same covariates used by Zoppi and Lai (2014), classed in Table 1, which shows the definitions of the variables and the descriptive statistics concerning non-artificial and artificial land cover for all of the 377 Sardinian municipalities.

TABLE 1

i. Physical factors:
   a. average size, slope and distance from the nearest town of a municipality's non-artificial-land areas in 1960 or in 1990, which became artificial in 1990 or in 2008 (Sklenicka et al., 2013; Cheshire and Sheppard, 1995; Palmquist and Danielson, 1989);
   b. accessibility, that is (Stewart and Libby, 1998), (i) endowment of roads connecting towns and cities of regional importance, classed by the Italian Code concerning Road Regulation (Italian law enacted by Decree n. 1992/285) as "Highways", "Main extra-urban roads" and "Secondary extra-urban roads;" (ii) proximity to the city of Cagliari, the regional administrative capital center and the most prominent regional metropoli-

[6] Due to differences in data sources and methodology, these findings are only partly consistent with data on land take provided by ISPRA, the National Agency for Environmental Protection and available at http://www.isprambiente.gov.it/files/comunicati-stampa/2014/Tabelle_consumo_di_suolo.pdf/at_download/file [accessed March 12, 2015].

tan area; and, (iii) proximity to the closest city or town hosting the headquarters of intermediate tiers of government (that is, in the Italian system, provinces);

c. distance from the coast, since in Sardinia the-so called “coastal-strip” (CS) is considered a “strategic resource, vital for the achievement of sustainable development in Sardinia, that requires integrated planning and management” by art. 19 of the Planning Implementation Code (PIC) of the Regional Landscape Plan of Sardinia[7] (RLP); since the CS is subject to very strict conservative rules, a proximity effect related to land take could possibly be detected, as Dewi et al. (2013) put in evidence with reference to Asian and African protected forest areas.

ii. Planning-rules-related factors:

a. endowment of protected areas; it would be expected that conservative policies which entail the presence of great amounts of protected areas could possibly limit or mostly prevent land-taking processes;

b. areas classed as “landscape components with an environmental value, defined as natural and seminatural areas” and as “agricultural and forestry areas” by the PIC of the RLP; it would be expected that the change of the status of an area from non-artificial to artificial should be comparatively more difficult in such areas;

c. areas located in the CS; in these areas the change from non-artificial to artificial land cover should be particularly unlikely, as already discussed;

d. areas which were classed, before the RLP’s approval in 2006, as areas where transformation of land was not allowed; a positive influence of this variable on land take would be expected, at least in the 1990-2008 time period, because of the less conservative regime that took place in 2003, when the old RLPs were cancelled.

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[7] Available at: http://www.sardegnaterritorio.it/paesaggio/pianopaesaggistico.html [accessed March 12, 2015], which includes the PIC of the RLP, its cartography cartographical zoning classes and spatial dataset.

iii. population density; several studies put in evidence a positive agglomeration effect of this variable on land take (Sklenicka, 2013; Guiling et al., 2009; Forster, 2006).

TABLE 2

Finally, in the set of covariates we consider an autocorrelation-related spatially-lagged dependent variable defined through the methodology, proposed by Anselin (1988; 2003), implemented by Zoppi and Lai (2014).

Table 2 shows definitions and statistics of the variables related to land take.

Once three shapefiles describing artificial areas as of (i) 1960, (ii) 1990, and (iii) 2008 were obtained (as previously stated in Section 2, from the Sardinian CLC-based land-cover maps for 2008, the EEA's UMZ for 1990, and from selected layers of the RLP spatial dataset for the end of the 1950's), it was possible to derive two further shapefiles describing those parcels of land which became artificial in periods 1960-1990 and 1990-2008; this in turns made it possible to calculate, for each Sardinian municipality and in the two selected time periods, the magnitude of land-take (PLT6090, PLT9008), as well as the average size of parcels that had become artificial (PSIZ6090, PSIZ9008).

Through geoprocessing analyses or more advanced GIS techniques (e.g. to estimate the values of SLOP6090 and SLOP9008, PRS6090 and PRS9008, DISC6090 and DISC9008), a geographic dataset was developed and the value of each variable for each of the 377 Sardinian municipalities was calculated, which made it possible to analyze the spatial distribution of the variables.

The coefficients ρ, which measure the linear correlations between the dependent variables PLT6090 and PLT9008 (measuring the magnitude of land take in the two time periods taken into account) and their respective sets of factors, are reported in Table 3, which puts in evidence some significant positive correlations: PLT6090 is correlated to DENS1961 (ρ=0.7185) and to PSIZ6090 (ρ=0.5259), while PLT9008 is correlated to PSIZ9008 (ρ=0.6068) and to DENS1990 (ρ=0.4951). This indicates a positive correspondence between the magnitude of land take and the size of parcels which became artificial. Moreover, we observe that the larger the population at the beginning of the interval under examination, the larger the size of land take.

TABLE 3

Correlations between PLT6090 and COASTRIP, AGFO6090, NAT6090 are relevant and lower in size. The same observation holds for the correlation between PLT9008 and COASTRIP as well. This indicates that the magnitude of land take is larger in cities and towns whose territory overlaps the coastal strip as defined within the 2006 RLP, and that between 1960 and 1990 land take occurred in municipalities having larger areas that are classified under the provisions of the RLP as forestry, agricultural, seminatural or natural zones. As far as the negative values are concerned, the highest correlations can be found between PLT6090 and DISTNEAC and between PLT9008 and the variables DISTNEAC and DISC9008, although the linear correlation is not as relevant as the above mentioned positive ones (ρ takes values between -0.24 and -0.34).

Figure 2, where polygons represent cities and towns, shows a series of maps that describe the spatial configuration of the variables PLT6090, PLT9008 and of the two determinants with the highest correlations, i.e., respectively, PSIZ6090 and DENS1961 for the first, and PSIZ9008 and DENS1990 for the second.

FIGURE 2

3. Results

Our estimates are based on the implementation of an OLS (ordinary least squares) model, in order to detect correlations between land take and its determinants in the two periods 1960-1990 and 1990-2008. In the first place, we estimated two regression models for each period, using the levels and the logarithms of the covariates. We noticed that, although the estimated coefficients were consistent with each other, the goodness of fit was significantly higher in the case of linear OLS estimates than in the case of the log-linear estimates, since the values of adjusted Rs-squared related to the 1960-1990 period are about 80 percent and about 73 percent respectively, and the values of adjusted Rs-squared related to the 1990-2008 period are about 63 percent and about 55 percent respectively. Therefore, our discussion is based on the estimates of the linear OLS models. The results of the log-linear estimates are reported in Appendix 1.

Moreover, since determinants of land take can show geographic non-stationarity, we tried to estimate geographically-weighted regressions (GWRs) which could effectively address spatial heterogeneity (Sander and Zhao, 2015). The GWR approach estimates as many regressions as the land take-related observations, by considering, at each observation's location, as many observations related to land take and its determinants as the number of records belonging to a neighborhood defined through an optimal bandwidth identified by a kernel function which can be either fixed or identified on an ad hoc basis through the Akaike's criterion (Akaike, 1974) or through an algorithm that minimizes the sum of squares of the residuals (Fotheringham et al., 2002) of the estimated regressions at each observation's location. Through the Akaike's criterion or the minimization algorithm, local samples are identified which have constant sizes (Yu et al., 2007; Sander and Zhao, 2015). Unfortunately, estimates related to our dataset, implemented through either algorithm, since we do not have any priors on optimal bandwidth, are characterized by very large local samples (more than two thirds of the total number of observations, mostly three quarters) and results are very close to each other and to the global model's.

This finding does not exclude non stationarity, but it simply puts in evidence that non stationarity cannot be explored through our dataset. In order to estimate GWRs we would need a larger number of observations, namely several hundred observations[8], which would give room to small overlapping of observations belonging to optimal bandwidths. In the concluding section, this issue is stressed as an important future development of the application of the methodology proposed in this essay.

The estimates related to the 1960-1990 period, reported in Table 4, show significant correlations (p-values less than 0.1 percent) for: (i) the size of parcels that changed their status from non-artificial to artificial in the period 1960-1990 (PSIZ6090, positive); (ii) the components of landscape with an environmental value (agricultural and forestry areas) that change from the non-artificial to the artificial land cover (AGFO6090, negative); (iii) the size of a municipality's environmentally valuable landscape components (NAT6090, positive); (iv) the percentage of a municipality's area included in the CS (COASTRIP, positive); (v) the municipality's area classed in the planning code in force before 2006 as areas where land transformations and new developments were almost totally forbidden that became artificial between 1960 and 1990 (OLPL6090, positive); (vi) the residential density in 1961 (DENS1961, positive); and (vii) the spatially-lagged dependent variable (AUTC6090, positive).

Moreover, less significant estimates are reported for: (i) the distance of a municipality from the regional capital city (DISTCAPC, negative, p-value: 6 percent); (ii) the distance of a municipality from the closest province administrative center (DISTNEAC, positive, p-value: 7

[8] The chapter on "Geographically Weighted Regression (GWR) (Spatial Statistics)", based on Fotheringham et al. (2002), of *ArcGIS Resources – ArcGIS 10.1* indicates that "GWR should be applied to datasets with several hundred features for best results. It is not an appropriate method for small datasets." Available at: http://resources.arcgis.com/en/help/main/10.1/index.html#/Geographically_Weighted_Regression_GWR/005p00000021000000/ (accessed 31.05.15).

percent); (iii) the endowment of roads connecting regional town and city centers per unit of municipal land area (ACCESS, positive, p-value: 11 percent); (iv) the municipality’s total protected area; (v) the municipality’s weighted average distance from the closest urban center to areas classed as non-artificial in 1960 and artificial in 1990 (PRS6090, negative, p-value: 14 percent); (vi) the municipality’s weighted average distance from the shoreline to areas classed as non-artificial in 1960 and artificial in 1990 (DISC6090, positive, p-value: 20 percent).

Finally, the municipality’s weighted average slope of areas classed as non-artificial in 1960 and artificial in 1990 does not seem to influence land take in the period.

The estimates related to the 1990-2008 period, reported in Table 4 as well, are consistent with the 1960-1990 estimates for variables PSIZ9008, PRS9008, ACCESS, DISTNEAC, CONSAREA, COASTRIP, OLPL9008, DENS1990 and AUTC9008. Variables DISTCAPC, DISC9008, NAT9008 and AGFO9008 do not seem to impact on land take. SLOP9008 does not seem to influence land take in the 1990-2008 time period as well.

4. Discussion and conclusion

We study Sardinian land take through OLS regression models in two time periods, 1960-1990 and 1990-2008. In our analyses, we identify the land take determinants as factors that the mainstream literature associates with land-taking processes. We tentatively consider covariates of land take related to location, physical status, and planning rules. The outcomes of our study suggest planning policies that are mostly consistent with a previous study (Zoppi and Lai, 2014) concerning Sardinian land-taking processes in the 2003-2008 period.

TABLE 4

The negative impact of variables PRS6090 and PRS9008 in both periods indicates that land-taking processes are more likely to occur in the vicinity of urban centers. This impact increases if the urban center is far from the provincial capital city, that is, the higher the impact the more isolated the closest urban center (variable DISTNEAC). This is fairly intuitive (Sklenicka et al., 2013), and that balanced urbanization processes would help reducing land take as well. Sardinian region is characterized by few urban centers and limited sprawl, which, in the light of the estimates related to variables PRS6090 and PRS9008, is effective in explaining the relatively lower Sardinian land take phenomenon compared to other Italian regions.

The positive impact of variable ACCESS in both periods is fairly intuitive as well (among many, Sklenicka et al., 2013; Cheshire and Sheppard, 1995; Stewart and Libby, 1998). A more balanced endowment of public roads among municipalities would help mitigating land-taking processes, while the Sardinian endowment is much more concentrated in few towns, mostly the provincial capitals.

The positive influence of variables PSIZ6090 and PSIZ9008 in both periods is consistent with Sklenicka et al. (2013) and puts in evidence a concentration effect, that is, the higher the parcel's concentration of land taken, the highest the total quantity of land taken. Moreover, since residential density has positive impacts on land take, planning low-density settlements and establishing rules that prevent urbanization of contiguous land parcels would help limit land-taking processes, which is consistent with the findings of Sklenicka et al. (2013). Under this perspective, Sardinian public planning policies should discourage developments of high-density settlements and project new developments in areas characterized by low residential densities, which are mostly located in the already-urbanized peripheral zones of Sardinian municipalities.

The positive impact of variable CONSAREA in both periods is fairly intuitive (among many, Cheshire and Sheppard, 1995; Palmquist and Danielson, 1989; Zoppi and Lai, 2014). Sardinian regional protected areas could increase in number and surface, were the provisions of Sardinian Law on the institution of regional protected areas (no. 1989/31) fully implemented, since only a small part of the potential protected areas identified by this law have been established so far. It would probably be appropriate to update Law no. 1989/31 through the approval of a new law which should take account of several legal and technical changes related to the establishment and management of protected areas. Among many, very important protected areas are the sites of the Natura 2000 network. Natura 2000 is a coherent network of areas established under Directive 92/43/EEC ("Habitats" Directive), which includes Sites of Community Interest (SCIs) and Special Areas of Conservation (SCAs) identified under the provisions of the Habitats Directive itself, as well as Special Protection Areas (SPAs), identified under the provisions of the "Birds" Directive (Directive 2009/147/EC). The network was established to protect biodiversity and species and habitats that are threatened with extinction, or deemed valuable, or typical within a certain biogeographic area. 87 SCIs, 31 SPAs and 6 SCIs/SPAs are established at present, with a total area of about 452,000 square kilometers, which corresponds to a 18.77% of the regional territory (Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2014).

The variables COASTRIP and OLPL6090 and OLPL9008 have positive impacts. These are planning-rules-related variables which concern a municipality's endowment of areas, mostly coastal areas, where, before 2006 (OLPL6090 and OLPL9008) or after 2006 (COASTRIP), land transformations and new developments were or are almost totally forbidden (Zoppi and Lai, 2014). We think that positive correlations between land taken and restrictive and conservative planning rules can be explained through the Dewi et al.'s argument, who observed that restrictive ruling regimes concerning protection of nature and natural resources in some areas may eventually increase land take in the neighboring marginal areas (Dewi et al., 2013). Under this perspective, it would be advisable to try to decrease the restrictive and conservative character of the provisions of the Sardinian Regional Landscape Plan, particularly in the coastal areas, and to promote a balanced and widespread approach to planning rules, which should integrate protection of nature and new development potentials.

Finally, we use GIS to propose a spatial representation of planning suggestions implied by our results. These representations can be easily exported to regions at the NUTS 2 level, and interpreted straightforwardly in terms of the spatial layout of the implied results as well.

A “what-if” scenario was simulated, based on the outcomes of the OSL models, that is, on the results reported in Table 4: for each town, we derived the magnitude of the effect either on the 1960-1990 or on the 1990-2008 land take (respectively, PLT6090 and PLT9008) that would have occurred had a covariate (DENS1961, PSIZ6090, ACCESS, CONSAREA for PLT6090, and DENS1990, PSIZ9008, ACCESS, CONSAREA for PLT9008, that is, the variables with the lowest p-values) increased by ten percentiles.

Figure 3 and Figure 4 present visually some of the results. As for the time period 1960-1990, the most important variation in artificial land cover is generated by policies that increase PSIZ6090, as up to 2.089 percent land take would have occurred in the period 1960-1990, had PSIZ6090 increased by ten percentiles (Figure 3, left-center). The maximum effect of DENS1961 is 1.559 percent (Figure 3, left), closely followed by the maximum effect of ACCESS, which can reach a 0.123 percent (Figure 3, right). Effects of CONSAREA are negative (Figure 3, right-center) and their peak is at 0.25 percent in absolute value.

With reference to the time period 1990-2008, the highest amount of land take is generated by policies aimed at increasing PSIZ9008, as up to 1.896 percent of the 1990 land take would have occurred, had a ten-percentile increase occurred (Figure 4, left-center). The effect of ACCESS amounts to 0.422 percent (Figure 4, right), closely followed by the impact of the variable DENS1990, which takes 0.397 percent as its maximum value (Figure 4, left). Effects of the variable CONSAREA are also negative (Figure 4, right-center) and their peak is at 0.426 percent in absolute value.

The maps also unveil evident clusters of towns that take the greatest effect values related to the factors DENS1961, ACCESS and CONSAREA (the latter, in absolute value) for the time period 1960-1990 (Figure 3) and with the variables DENS1990, ACCESS and CONSAREA (the latter, in absolute terms) for the time period 1990-2008 (Figure 4); moreover, these clusters show similar spatial patterns in the two time periods. Such a clear spatial agglomeration does not emerge, on the other hand, for municipalities having either the lowest impact values associated with PSIZ6090 (Figure 3) or the highest impact values associated with PSIZ9008 (Figure 4).

FIGURE 3

FIGURE 4

The methodology proposed in this essay is easily exportable to other Italian and European regional areas characterized by similar land-taking processes, even though the set of explanatory variables should be adapted to physical, geographical and planning-rules-related factors which characterize each different regional context.

The policy implications coming from the implementation of the methodology proposed in this paper have to be considered as tentative, since they could be improved in terms of their explanatory power were more detailed data available, as we put in evidence below. However, the results here obtained are effective and useful reference points for comparisons between land-taking processes and their determinants related to other Italian and European regional contexts, since the proposed methodological approach is exportable and replicable in other contexts.

An important issue concerning future research related to the application of the methodology implemented in this essay is the assessment of the possible non-stationarity of land taking processes. As we discussed above, we would need datasets larger than the 377-observation dataset we used for our analysis, which would imply the availability of data on land take at the under-municipal level, namely information concerning the single land parcel that changes its status from non-urbanized to urbanized. This is an important technical recommendation, which comes from our results, for the qualitative improvement of inferences on land take determinants. In this essay we have explored the global (regional) character of Sardinian land-taking processes but their local (geographically-weighted) nature is still to be assessed, which would add substantially to the effectiveness of the methodological approach proposed so far, both in terms of understanding the role of determinants of land take and of definition of mitigation policies.

References

Akaike, H., 1974. A new look at the statistical model identification. *IEEE Trans. Autom.Control* 19: 716–723.

Cheshire, P., and S. Sheppard. 1995. On the price of land and the value of amenities. *Economica - New Series* 62 (May): 247-267.

Chen J., A. Liao, L. Chen, H. Zhang., C. He, S. Peng., H. Wu, W. Zhang, R. Li, X. Zheng, Y. Mei, M. Lu, N. Lu, J. Liu, R. Kang, H. Xing, W. Zhu, L. Liu, G. Han, J. Wang, A. Yang, L. Sun, H. Song, W. Chen, X. Zhou, L. Xia, H. Jiang, J. Huo, Y. Zhang, W. Liu, Y. Li, L. Zhai, and H. Sang. 2014.*Global Artificial Land Surface Dataset in 30m Resolution (2010)*. Global Change Research Data Publishing & Repository, DOI:10.3974/geodb.2014.02.02.V1, Available on the Internet at http://www.geodoi.ac.cn/WebEn/doi.aspx?DOI=10.3974/geodb.2014.02.02.V1 [accessed June 01, 2015].

CRCS (Centro di Ricerca sui Consumi di Suolo [Research Center for Land-taking Processes]). 2012. *Rapporto 2012 [2012 Report]*. Rome, Italy: INU Edizioni.

Dewi, S., M. van Noordwijk, A. Ekadinata, and J.L. Pfund. 2013. Protected areas within multifunctional landscapes: Squeezing out intermediate land use intensities in the tropics?. *Land Use Policy* 30: 38-56.

ESA Climate Change Initiative. 2014. *Climate Research Data Package (CRDP)*. Available on the Internet at http://www.esa-landcover-cci.org/?q=node/158 [accessed June 01, 2015].

European Commission. 2011. *Report on best practices for limiting soil sealing and mitigating its effects. 2011*. Available on the Internet at http://ec.europa.eu/environment/archives/soil/pdf/sealing/Soil%20sealing%20-%20Final%20Report.pdf [accessed March 12, 2015].

European Commission, EUROSTAT. 2010. *Land cover/use statistics (LUCAS)*. Available on the Internet at http://ec.europa.eu/eurostat/web/lucas [accessed March 12, 2015].

European Commission, Joint Research Centre. 2003. *Global Land Cover 2000 database*. Available on the Internet at http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php [accessed June 01, 2015].

European Environment Agency. 2010. *The European environment state and outlook 2010 - land use*. Available on the Internet at http://www.eea.europa.eu/soer/europe/land-use/at_download/file [accessed June 01, 2015].

European Environment Agency. 2013a. *Land take*. Available on the Internet at http://www.eea.europa.eu/data-and-maps/indicators/land-take-2/ [accessed March 12, 2015].

European Environment Agency. 2013b. *CORINE Land Cover*. Available on the Internet at http://www.eea.europa.eu/publications/COR0-landcover [accessed March 12, 2015].

Forster, D.L. 2006. An overview of U.S. farm real estate markets. *Working Papers of the Department of Agricultural, Environmental and Development Economics, Ohio State University*. AEDE-WP-0042-06. Available on the Internet at http://ageconsearch.umn.edu/bitstream/28319/1/wp060042.pdf [accessed March 12, 2015].

Fotheringham, A.S., C. Brunsdon, and M.E. Charlton. 2002. Geographically Weighted Regression: The Analysis of Spatially Varying Relationships. John Wiley and Sons, West Sussex, England, pp. 284.

Giri C., B. Pengra, J. Long, and T.R. Loveland. 2013. Next generation of global land cover characterization, mapping, and monitoring. *International Journal of Applied Earth Observation and Geoinformation* 25:30-37.

Guiling, P., B.W. Brorsen, and D. Doye. 2009. Effect of urban proximity on agricultural land values. *Land Economics* 85: 252-264.

Hansen, M.C., R.S. Defries, J.R.G. Townshend, and R. Sohlberg 2000. Global land cover classification at 1 km spatial resolution using a classification tree approach. *International Journal of Remote Sensing*, 21:1331-1364.

Huang, H., Y. Miller, B.J. Sherrick, and M.I. Gòmez. 2006. Factors influencing Illinois farmland values. *American Journal of Agricultural Economics* 88: 458-470.

ISPRA. 2015. *Il consumo di suolo in Italia [Land take in Italy]*. Available on the Internet at http://www.isprambiente.gov.it/files/pubblicazioni/rapporti/Rapporto_218_15.pdf [accessed June 01, 2015].

Ministero dell'Ambiente e della Tutela del Territorio e del Mare [Italian Ministry of the Environment and of Territorial and Sea Protection]. 2014. SIC, ZSC e ZPS in Italia [SCIs, SCAs and SPAs in Italy]. Available on the Internet at http://www.minambiente.it/pagina/sic-zsc-e-zps-italia [accessed March 12, 2015].

Moran, P.A.P. 1950. Notes on continuous stochastic phenomena. *Biometrika* 37: 17–33.

Palmquist, R.B., and L.E. Danielson. 1989. A hedonic study of the effects of erosion control and drainage on farmland values. *American Journal of Agricultural Economics* 71: 55-62.

Sander, H.A., and C. Zhao. 2015. Urban green and blue: Who values what and where?. *Land Use Policy* 42: 194-209.

Sklenicka, P., K. Molnarova, K.C. Pixova, and M.E. Salek. 2013. Factors affecting farmlands in the Czech Republic. *Land Use Policy* 30: 130-136.

Stewart, P.A., and L.W. Libby. 1998. Determinants of farmland value: the case of DeKalb County, Illinois. *Review of Agricultural Economics* 20: 80-95.

Tobler W. 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography* 46: 234-240.

Yu, D., Y.D. Wei, and C. Wu. 2007. Modeling spatial dimensions of housing prices in Milwaukee, WI. *Environment and Planning B: Plan. Des.* 34: 1085–1102

Zoppi, C., and S. Lai. 2014. Land-taking processes: An interpretive study concerning an Italian region. *Land Use Policy* 36: 369-380.

FIGURES (ONLINE VERSION)

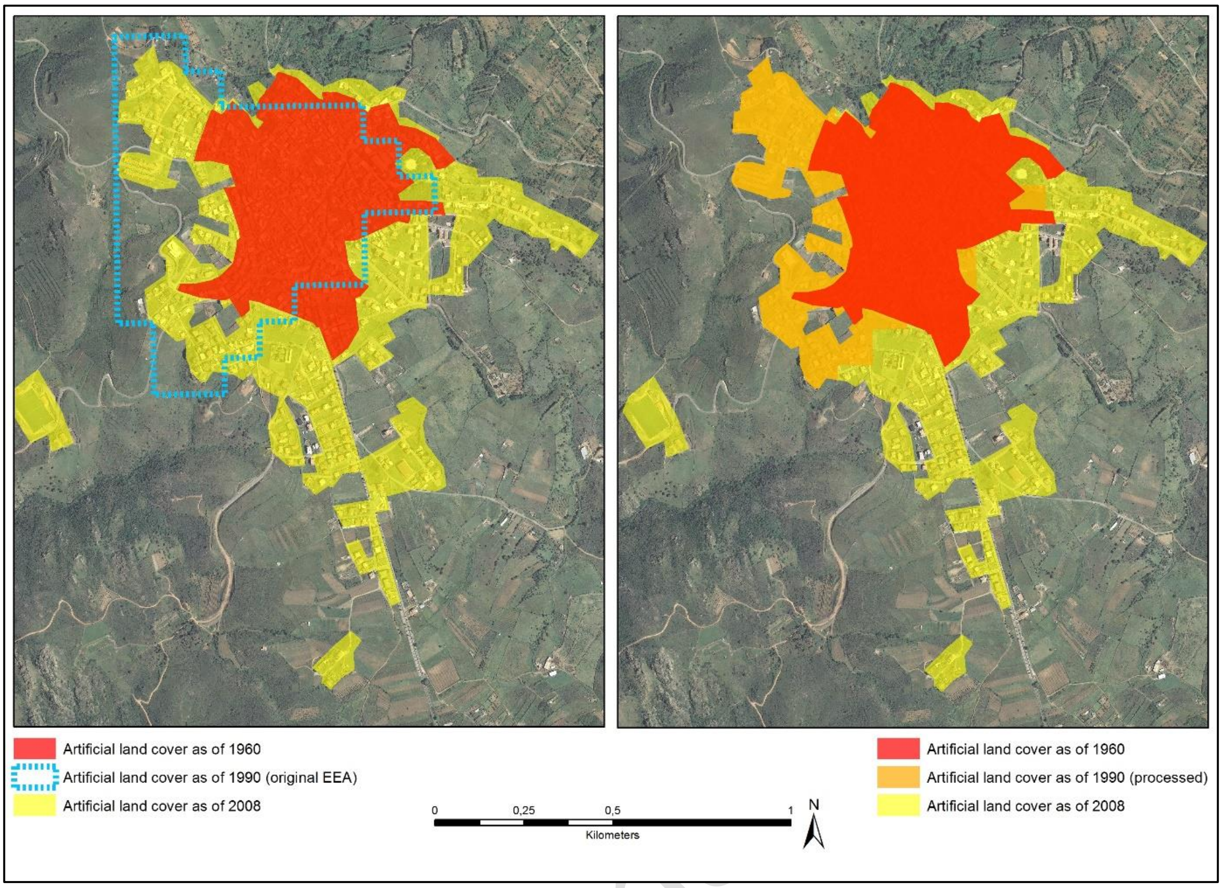


Figure 1. Analysis of changes in artificial land cover between 1960 and 2008: an example showing correction of inconsistencies due to differences in map resolutions.

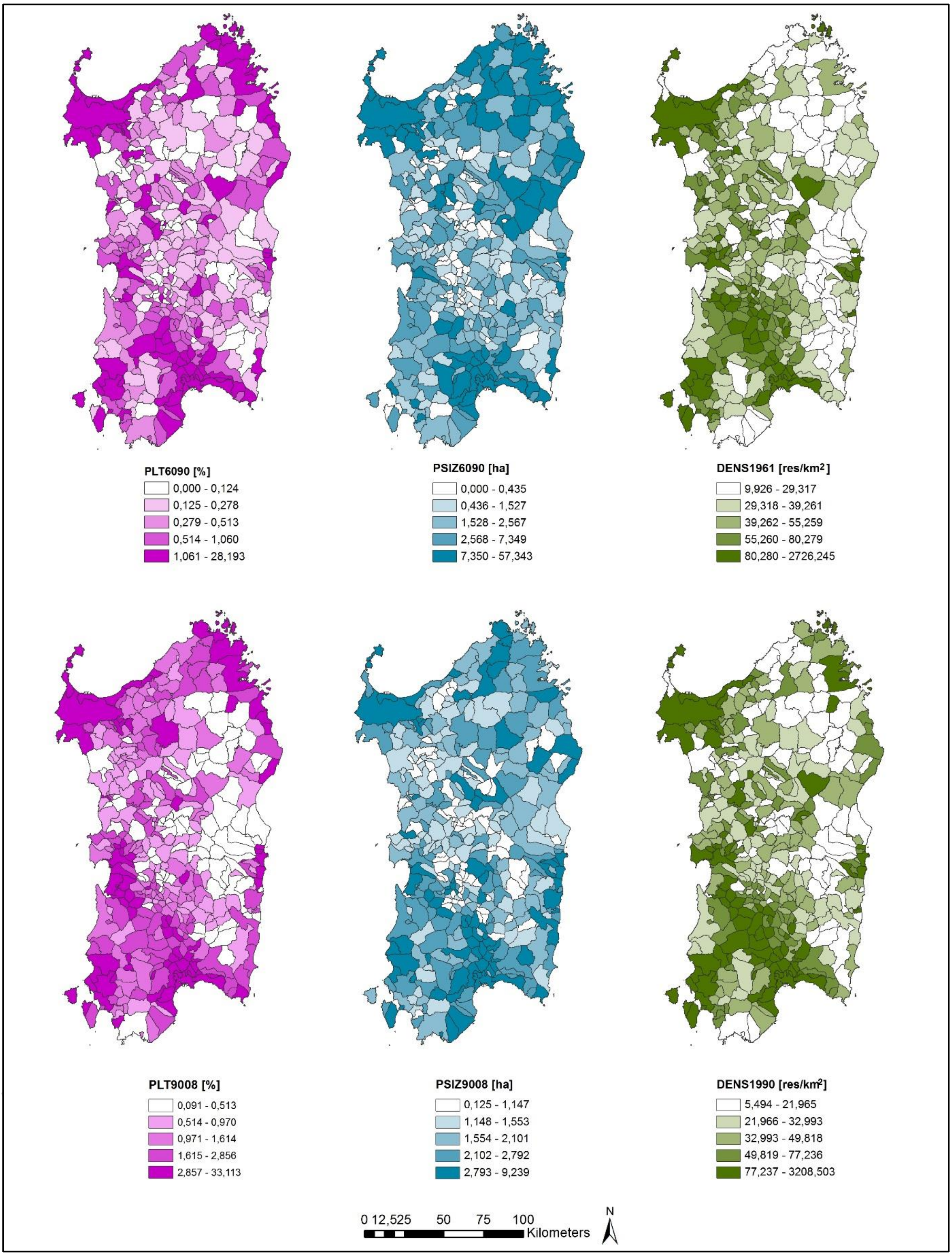


Figure 2. Spatial distribution of the variables PLT6090, PSIZ6090 and DENS1961 (top) and PLT9008, PSIZ9008 and DENS1990 (bottom) (quantiles). Polygons represent municipalities.

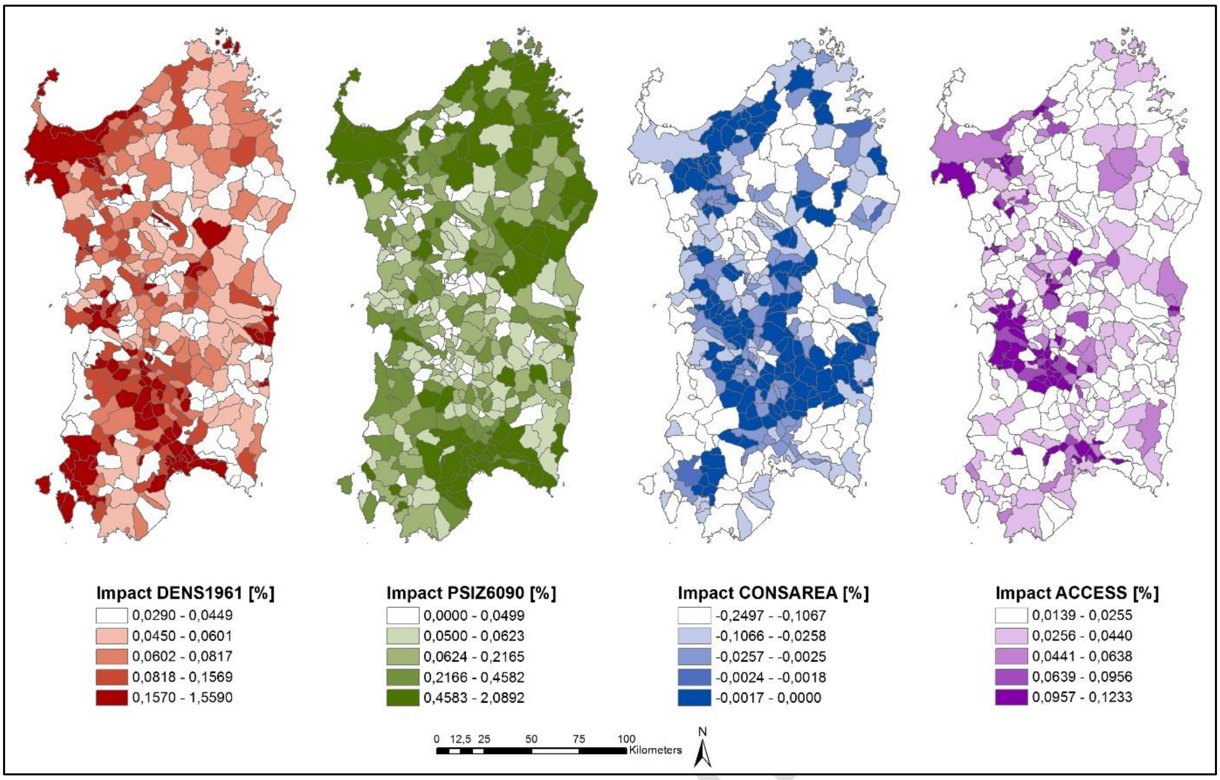


Figure 3. Spatial distribution of policy implications: impacts on land-cover change (from non-artificial to artificial in the 1960-1990 time period stemming from policies that increase: residential density in 1961 (left); or average size of areas whose land cover changes from non-artificial to artificial between 1960 and 1990 (left-center); or a municipality's total protected area (right-center); or its endowment of roads connecting regional town and city centers per unit of municipal land area (right) (all quantiles). Polygons represent municipalities.

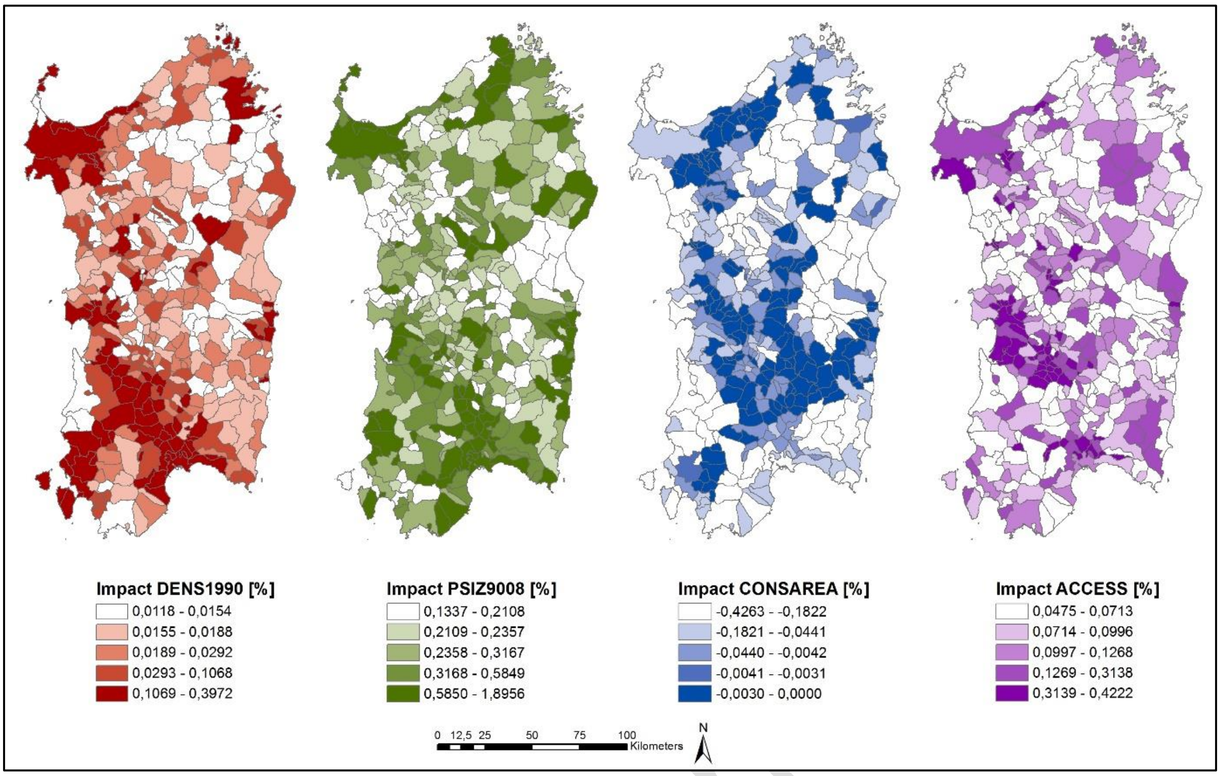
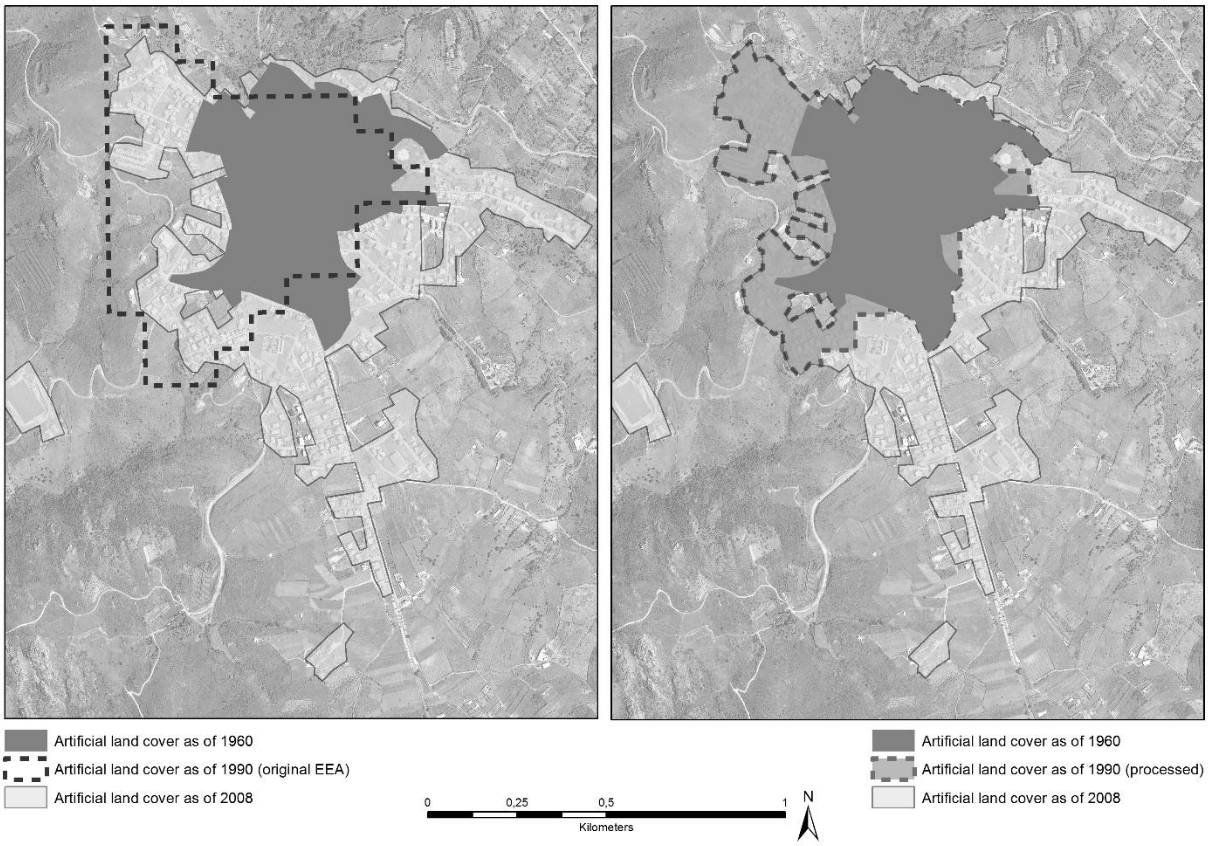


Figure 4. Spatial distribution of policy implications: impacts on land-cover change (from non-artificial to artificial) in the 1990-2008 time period stemming from policies that increase: residential density in 1990 (left); or average size of areas whose land cover changes from non-artificial to artificial between 1990 and 2008 (left-center); or a municipality's total protected area (right-center); or its endowment of roads connecting regional town and city centers per unit of municipal land area (right) (all quantiles). Polygons represent municipalities.

FIGURES (PRINT VERSION)



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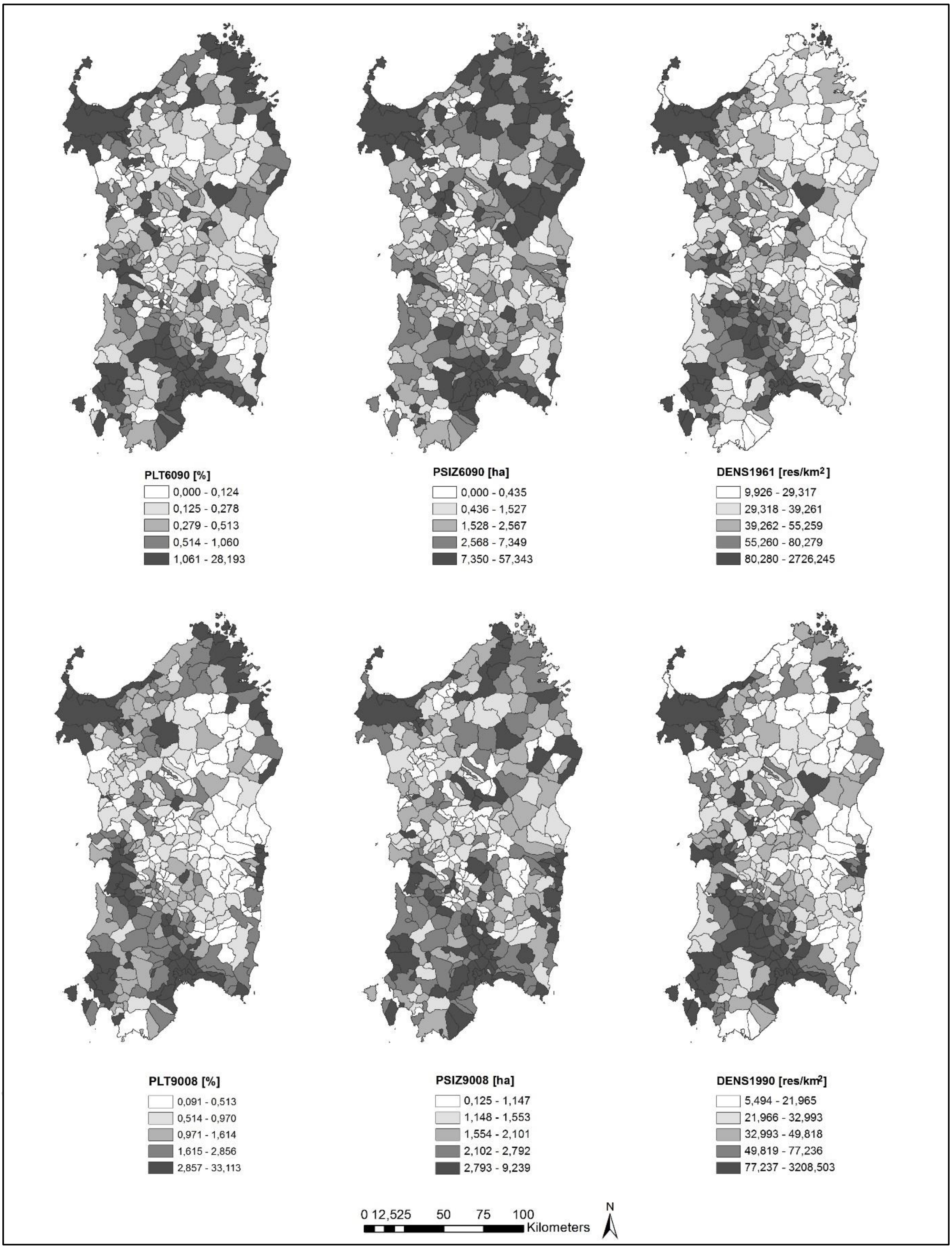

Figure 2. Spatial distribution of the variables PLT6090, PSIZ6090 and DENS1961 (top) and PLT9008, PSIZ9008 and DENS1990 (bottom) (quantiles). Polygons represent municipalities.

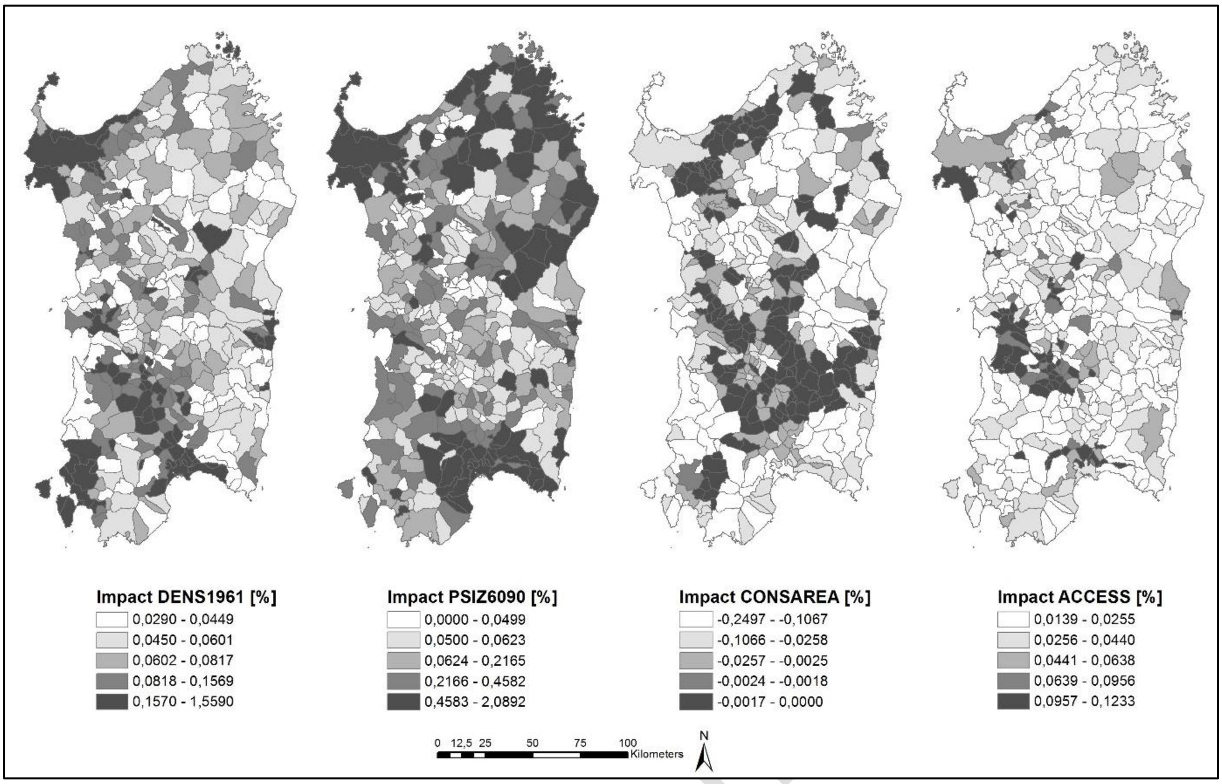

Figure 3. Spatial distribution of policy implications: impacts on land-cover change (from non-artificial to artificial in the 1960-1990 time period stemming from policies that increase: residential density in 1961 (left); or average size of areas whose land cover changes from non-artificial to artificial between 1960 and 1990 (left-center); or a municipality's total protected area (right-center); or its endowment of roads connecting regional town and city centers per unit of municipal land area (right) (all quantiles). Polygons represent municipalities.

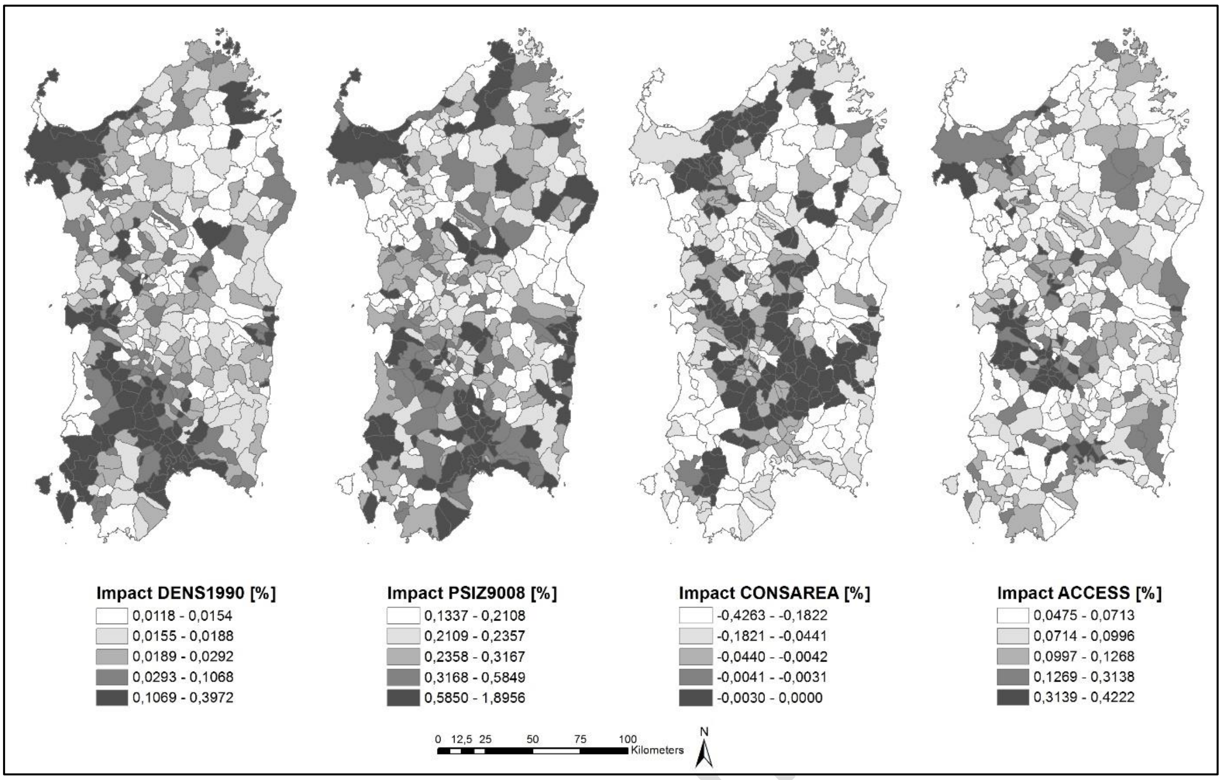

Figure 4. Spatial distribution of policy implications: impacts on land-cover change (from non-artificial to artificial) in the 1990-2008 time period stemming from policies that increase: residential density in 1990 (left); or average size of areas whose land cover changes from non-artificial to artificial between 1990 and 2008 (left-center); or a municipality's total protected area (right-center); or its endowment of roads connecting regional town and city centers per unit of municipal land area (right) (all quantiles). Polygons represent municipalities.

TABLES

Variable	Definition	Unit	Source(s)[9]	Mean	St.dev.
NURB1960	Municipality's non-artificial areas in 1960	ha	RLP, SDRGISS[10]	6,353.51	6,157.73
NURB1990	Municipality's non-artificial areas in 1990	ha	CLC1990, SDRGISS	6,286.95	6,081.00
NURB2008	Municipality's non-artificial areas in 2008	ha	CLCMS08, SDRGISS	6,180.33	5,963.59
PLT6090	Percentage of municipal area whose land cover changed from non-artificial to artificial between 1960 and 1990	%		1.05	2.58
PLT9008	Percentage of municipal area whose land cover changed from non-artificial to artificial between 1990 and 2008	%		1.89	2.35

Table 1. Definition of land-cover variables and descriptive statistics.

[9] CLC1990: European Corine Land Cover Map, 1990 release, Urban Morphological Zones; CLCMS08: Corine Land Cover Map of Sardinia, 2008 release, Level 1; RLP: Regional Landscape Plan; SDRGISS: Spatial Dataset of the Regional Geographic Information System of Sardinia.

[10] Available from the Regional Geoportal, http://www.sardegnageoportale.it/index.html [accessed March 12, 2015].

Variable	Definition	Motivation	Unit	Source(s)	Time period	Mean	St.dev.
PSIZ6090	Municipality's average size of areas classed as non-artificial in 1960 and artificial in 1990	Sklenicka et al., 2013	ha	RLP, CLC1990	1960-'90	4.60	7.18
PSIZ9008	Municipality's average size of areas classed as non-artificial in 1990 and artificial in 2008		ha	CLC1990, CLCMS08	1990-'08	2.07	1.25
SLOP6090	Municipality's weighted average slope of areas classed as non-artificial in 1960 and artificial in 1990; weight = area size	Sklenicka et al., 2013; Cheshire and Sheppard, 1995; Stewart and Libby, 1998	%	RLP, CLC1990, Sardinian DTM[11]	1960-'90	6.99	7.08
SLOP9008	Municipality's weighted average slope of areas classed as non-artificial in 1990 and artificial in 2008; weight = area size		%	CLC1990, CLCMS08, Sardinian DTM	1990-'08	9.56	6.19
PRS6090	Municipality's weighted average distance from the closest urban center to areas classed as non-artificial in 1960 and artificial in 1990; weight = area size		km	RLP, CLC1990, SDRGISS	1960-'90	0.96	1.54
PRS9008	Municipality's weighted average distance from the closest urban center to areas classed as non-artificial in 1990 and artificial in 2008; weight = area size		km	CLC1990, CLCMS08, SDRGISS	1990-'08	2.43	1.51
ACCESS	Endowment of roads connecting regional town and city centers per unit of municipal land area		km/km^2	SDRGISS	1960-'90 1990-'08	0.96	0.47
DISTCAPC	Distance of a municipality from the regional capital city, Cagliari	Sklenicka et al., 2013	km	Google Maps	1960-'90 1990-'08	126.46	71.27
DISTNEAC	Distance of a municipality from the closest province administrative center	Sklenicka et al., 2013	km	Google Maps	1960-'90 1990-'08	30.99	16.70
DISC6090	Municipality's weighted average distance from the shoreline to areas classed as non-artificial in 1960 and artificial in 1990; weight = area size	Dewi et al., 2013; xxx, yyy, zzzz	km	RLP, CLC1990, SDRGISS	1960-'90	17.23	14.98
DISC9008	Municipality's weighted average distance from the shoreline to areas classed as non-artificial in 1990 and artificial in 2008; weight = area size		km	CLC1990, CLCMS08, SDRGISS	1990-'08	21.05	13.91
CONSAREA	Municipality's total protected area: parks, reserves, etc.	Cheshire and Sheppard, 1995; Palmquist and Danielson, 1989; xxx, yyy, zzzz	ha	SDRGISS	1960-'90 1990-'08	1,342.74	2636.12
NAT6090	Municipality's landscape components with environmental value, defined in the Sardinian RLP as natural and seminatural areas, that change from non-artificial to artificial between 1960 and 1990	The Sardinian RLP sets highly conservative rules for these areas; therefore, they are expected to preserve their non-artificial land cover.	ha	RLP, CLC1990	1960-'90	2.73	13.45
NAT9008	Municipality's landscape components with environmental value, defined in the Sardinian RLP as natural and seminatural areas, that change from non-artificial to artificial between 1990 and 2008		ha	RLP, CLC1990, CLCMS08	1990-'08	10.79	22.16
AGFO6090	Municipality's landscape components with environmental value, defined in the Sardinian RLP as agricultural and forestry areas, that change from non-artificial to artificial between 1960 and 1990	The Sardinian RLP sets less conservative rules for these areas than for the natural and semi-natural ones; therefore, these areas might be more prone to become artificial.	ha	RLP, CLC1990	1960-'90	3.12	11.25
AGFO9008	Municipality's landscape components with environmental value, defined in the Sardinian RLP as agricultural and forestry areas, that change from non-artificial to artificial between 1990 and 2008		ha	RLP, CLC1990, CLCMS08	1990-'08	24.11	47.93
COASTRIP	Percentage of a municipality's area included in the CS	Dewi et al., 2013; xxx, yyy, zzzz	ha	RLP, SDRGISS	1960-'90 1990-'08	1.22	2.41
OLPL6090	Municipality's area classed in the planning code in force before 2006 as areas where	Dewi et al., 2013	ha	RLP, CLC1990,	1960-'90	20.35	87.46

[11]DTM: Digital Terrain Model; available at: http://www.sardegnageoportale.it/ [accessed March 12, 2015].

Variable	Definition	Motivation	Unit	Source(s)	Time period	Mean	St.dev.
	land transformations and new developments were almost totally forbidden, that changes from non-artificial to artificial between 1960 and 1990			SDRGISS			
OLPL9008	Municipality's area classed in the planning code in force before 2006 as areas where land transformations and new developments were almost totally forbidden, that changes from non-artificial to artificial between 1990 and 2008		ha	CLC1990, CLCMS08, SDRGISS	1990-'08	36.04	90.98
DENS1961	Municipality's population density in 1961	Sklenicka, 2013; Guiling et al., 2009; Forster, 2006	people/ km^2	http://www.comuni-italiani.it/	1960-'90	70.02	170.80
DENS1990	Municipality's population density in 1990		people/ km^2	http://demo.istat.it/dat81-91/COMUNI/ind_pro.htm	1990-'08	74.73	213.84
AUTC6090	Municipality's spatially lagged dependent variable 1960-1990	Tobler, 1970	%		1960-'90	0.99	1.56
AUTC9008	Municipality's spatially lagged dependent variable 1990-'08		%		1990-'08	1.82	1.27

Table 2. Land-cover covariates: definitions, reasons for their inclusion in this study, units of measurement, data sources, time periods and descriptive statistics.

Dependent variable: PLT6090				**Dependent variable: PLT9008**			
	ρ		**ρ**		**ρ**		**ρ**
PSIZ6090	0.5259	*CONSAREA*	0.0405	*PSIZ9008*	0.6068	*CONSAREA*	-0.0704
SLOP6090	-0.1316	*NAT6090*	0.3361	*SLOP9008*	-0.3039	*NAT9008*	0.1846
PRS6090	0.2664	*AGFO6090*	0.3955	*PRS9008*	0.0884	*AGFO9008*	0.2476
ACCESS	0.1442	*COASTRIP*	0.4328	*ACCESS*	0.2869	*COASTRIP*	0.3823
DISTCAPC	-0.1464	*OLPL6090*	0.2904	*DISTCAPC*	-0.1901	*OLPL9008*	0.1972
DISTNEAC	-0.2438	*DENS1961*	0.7185	*DISTNEAC*	-0.3402	*DENS1990*	0.4951
DISC6090	-0.1827			*DISC9008*	-0.3408		

Table 3. Pearson product-moment correlation coefficients between the two dependent variables (PLT6090 and PLT9008) and all of their covariates listed in Table 2.

1960-1990 period				
Variable	**Coefficient$_i$**	**Stand.error**	**t-statistic**	**Hypothesis test: coefficient=0**
Constant	-0.9315	0.2730	-3.413	0.0007
PSIZ6090	0.1122	0.0106	10.627	0.0000
SLOP6090	0.0018	0.0101	0.174	0.8621
PRS6090	-0.0740	0.0495	-1.494	0.1361
ACCESS	0.2315	0.1431	1.618	0.1065
DISTCAPC	-0.0018	0.0009	-1.944	0.0527
DISTNEAC	0.0073	0.0039	1.867	0.0627
DISC6090	0.0066	0.0051	1.299	0.1947
CONSAREA	-4.1E-05	2.5E-05	-1.624	0.1053
NAT6090	0.0337	0.0063	5.359	0.0000
AGFO6090	-0.0290	0.0082	-3.517	0.0005
COASTRIP	0.1483	0.0330	4.499	0.0000
OLPL6090	0.0037	0.0008	4.397	0.0000
DENS1961	0.0075	0.0004	17.616	0.0000
AUTC6090	0.4777	0.0547	8.727	0.0000
Adjusted R-squared = 0.8024				
1990-2008 period				
Constant	-1.7298	0.4922	-3.514	0.0005
PSIZ9008	0.8553	0.0679	12.588	0.0000
SLOP9008	-0.0150	0.0139	-1.073	0.2839
PRS9008	-0.0232	0.0691	-0.336	0.7372
ACCESS	0.7924	0.1869	4.239	0.0000
DISTCAPC	0.0011	0.0012	0.890	0.3741
DISTNEAC	0.0050	0.0054	0.917	0.3596
DISC9008	-0.0023	0.0076	-0.302	0.7626
CONSAREA	-7.0E-05	3.2E-05	-2.189	0.0293
NAT9008	-0.0024	0.0053	-0.450	0.6532
AGFO9008	0.0018	0.0021	0.841	0.4011
COASTRIP	0.1201	0.0443	2.712	0.0070
OLPL9008	0.0006	0.0013	0.447	0.6553
DENS1990	0.0026	0.0004	6.261	0.0000
AUTC9008	0.4222	0.0941	4.489	0.0000
Adjusted R-squared = 0.6289				

Table 4. OLS results, dependent variables PLT6090 (1960-1990 period) and PLT9008 (1990-2008 period): the regression models include the covariates of Table 2.

Appendix 1

Variable	Coefficient$_i$	Stand.error	t-statistic	Hypothesis test: coefficient=0
1960-1990 period				
Constant	-3.4086	0.2359	-14.450	0.0000
Log(PSIZ6090)	0.5897	0.0276	21.367	0.0000
Log(SLOP6090)	0.0965	0.0337	2.865	0.0044
Log(PRS6090)	-0.2855	0.0366	-7.811	0.0000
Log(ACCESS)	0.4509	0.0751	6.005	0.0000
Log(DISTCAPC)	-7.6E-05	6.2E-05	-1.228	0.2202
Log(DISTNEAC)	1.4E-05	1.8E-05	0.791	0.4293
Log(DISC6090)	0.0282	0.0366	0.770	0.4416
Log(CONSAREA)	-9.9E-06	6.1E-06	-1.623	0.1056
Log(NAT6090)	9.0E-06	7.3E-06	1.224	0.2218
Log(AGFO6090)	-7.8E-06	9.3E-06	-0.832	0.4062
Log(COASTRIP)	1.8E-05	1.1E-05	1.638	0.1023
Log(OLPL6090)	1.1E-05	8.6E-06	1.264	0.2072
Log(DENS1961)	0.5705	0.0582	9.807	0.0000
AUTC6090	0.0619	0.0239	2.594	0.0099
Adjusted R-squared = 0.6343				
1990-2008 period				
Constant	-0.6534	0.2045	-3.196	0.0015
Log(PSIZ9008)	0.7355	0.0458	16.071	0.0000
Log(SLOP9008)	-0.0973	0.0344	-2.828	0.0049
Log(PRS9008)	0.0532	0.0453	1.174	0.2412
Log(ACCESS)	0.5526	0.0618	8.938	0.0000
Log(DISTCAPC)	0.0002	5.0E-05	3.312	0.0010
Log(DISTNEAC)	2.5E-05	1.5E-05	1.680	0.0939
Log(DISC9008)	-0.17197	0.0437	-3.936	0.0001
Log(CONSAREA)	-9.0E-06	5.0E-06	-1.807	0.0716
Log(NAT9008)	-6.9E-06	7.9E-06	-0.879	0.3800
Log(AGFO9008)	2.4E-05	1.7E-05	1.427	0.1543
Log(COASTRIP)	6.6E-06	9.9E-06	0.666	0.5058
Log(OLPL9008)	8.0E-06	6.1E-06	1.295	0.1960
Log(DENS1990)	0.2062	0.0422	4.891	0.0000
AUTC9008	0.1443	0.0274	5.261	0.0000
Adjusted R-squared = 0.5487				

Table 5. OLS results, dependent variables Log(PLT6090) (1960-1990 period) and Log(PLT9008) (1990-2008 period): the regression models include the logarithms of the covariates of Table 2.