Landscape metrics for determining landscape prices

Mohamed Hilal, Thierry Brossard, Jean Cavailhès, Daniel Joly, François-Pierre Tourneux, Pierre Wavresky

Landscape metrics for determining landscape prices

Mohamed Hilal*, Thierry Brossard†, Jean Cavailhès*, Daniel Joly†, François P. Tourneux†, Pierre Wavresky*

ABSTRACT: This paper reviews the landscape metrics used in economic valuations of farmland and forest landscapes. The diversity of landscape indicators used in the literature (land use, landscape composition, distance from landscape assets, seen landscapes: viewshed, objects, shapes) sometimes leads to divergent results. After reviewing the literature, we present a numerical model of the visible landscape, combining satellite images and digital elevation models. Associated with a hedonic model of price valuation, this geographical model offers the flexibility required to test several landscape metrics. The results show that although these have substantial effects on the estimation of the price of a particular landscape seen from a given house, the hedonic prices obtained have rather similar mean values.

1. INTRODUCTION

Urban sprawl extending out into peripheral rural areas is a familiar phenomenon in most developed countries (Caruso, 2002). 'Open space is often cited as a primary attractor of urban and suburban residents to exurban areas located just beyond the metropolitan fringe' (Irwin and Bockstael, 2001). In France, Le Jeannic (1997) speaks of the taste for 'living in a natural setting far from the bustle of cities, in spacious houses with gardens while holding on to the source of remuneration of a job in town'. The choice between living in the city or in the surrounding countryside involves striking a balance between better access to employment and to cultural and educational infrastructures that weigh on the urban side and to environmental and landscape amenities that weigh on the side of peripheral rural areas.

The management of urban and periurban amenities is a major ongoing concern for local public authorities (Clay and Daniel, 2000; Davodeau, 2005). For geographers, this research area is very well documented because of collaboration with ecologists, urbanists or public operators, giving rise to objectively-based criteria for evaluating landscapes. Economists too endeavour to evaluate landscape prices; they have an interest in integrating the results of the geographic approach, provided that it engenders the quantitative indices they need to construct their econometric models. To this end, geographical information systems (GISs) are

* INRA, UMR1041 CESAER, F-21000 Dijon, France.

† CNRS, UMR 6049 ThéMA, F-25000 Besançon, France.

the essential technical resource for characterising landscape using numerical data filed in ad hoc bases.

GISs can produce a large quantity of indices on various landscape properties; but their sheer abundance may cause confusion. This is why this paper proposes to review the landscape metrics used in economic evaluations of farmland and forest landscapes. Section 1 presents the main economic results derived from a review of the literature, arranged by the type of metric used. Section 2 looks at how GISs and the experimental capacities they provide can be used to construct a formal approach to landscapes providing insight into the diversity of landscape composition through quantitative indices. Section 3 tests how robust or how volatile the selected landscape measures are by using the hedonic price method and discusses the results.

2. INDICATORS USED IN ECONOMIC EVALUATIONS OF LANDSCAPE

In the literature on the economic value of farmland and forest landscapes, indicators of landscape attributes long remained rather crude. They were confined to three types of variable: distance from particular objects such as golf courses, parks, open spaces, forests, etc. insofar as the view of a landscape is dependent on such distance; land use (farming, forestry, etc.) analysed in two dimensions from maps, aerial photographs and satellite images; landscape composition indices that add shape variables to the foregoing. More recently, recourse to numerical geographic information means more elaborate landscape indicators can be constructed that measure what an observer at the ground level sees in three dimensions.

2.1. Distance from landscape objects

Economists have long included in hedonic price models landscape variables of the presence of an object that may be thought of as an amenity (golf courses, parks, open spaces) or a nuisance (waste disposal sites, electricity pylons, roads) or of distance of housing from such objects as measured on a map. This is a far cry, then, from landscapes, although it is sometimes the view of such objects that is under study.

Distance provides an understanding that most landscape goods have a double status (Correll et al., 1978; Lee and Fujita, 1997). A green belt is both a pure public good by the view one has of it and an impure public goods since, because of remoteness, some consumers can be excluded from it. Distance also makes it possible to analyse the effect on house prices of proximity to objects such as open areas, when the scale is very large (Hobden et al., 2004; Mooney and Eisgruber, 2001; Thorsnes, 2002). Distance also lends itself to studies of the decreasing effect on property prices when an object is moved away, which also applies to nuisances (Garrod and Willis, 1998; Hamilton and Schwann, 1995) or to amenities such as wetlands (Mahan et al., 2000), green areas (Bolitzer and Netusil, 2000; Morancho, 2003; Smith et al., 2002) or woodlands (Tyrvainen and Miettinen, 2000).

These few examples are just a small fraction of the very many studies of economic evaluation using distance variables. The results are fairly homogeneous from one study to another. These works show in particular that the effects of distance are generally very localised: sometimes one has to be adjacent to the object in question or with a few tens of metres of it at most, to perceive its positive (open spaces) or negative (electricity pylons) effects. Beyond a few tens of metres, or one or two hundred metres at most, consumers seem indifferent to the presence of this sort of object.

2.2. Land use without shape variables

Economic evaluations of the price of land use by different types of land cover (forests, farmland, gardens, roads, etc.) are very plentiful. The method consists first in delimiting a perimeter around a house, usually a circle or an administrative unit and then measuring the presence, the proximity or the proportion of land-use categories within that perimeter. The number of categories varies with studies. For example, Kestens et al. (2001) use four categories of land use (trees, lawns, wasteland and artificialised ground) whereas Des Rosiers et al. (2002) use 31 categories (trees located in front of or behind property, ranked by size, species, distinctions in floral compositions, hedges, laid-out pavements, the presence of a patio, balcony arrangements, etc.). Classifications are usually made on the basis of maps, aerial photographs or satellite images. The method therefore provides complete cover of a study region so it can be mapped and each house located in its two-dimensional landscape setting so that it can be examined whether or not prices incorporate landscape attributes. The landscape analysed is greatly simplified since no measure of shape is involved, although this is essential for characterising landscape.

Studies based on land use generally conclude that the presence of farmland, woodland or forests command positive hedonic prices. Thus, among others, Des Rosiers et al. (2002) show that, near Quebec (Canada), the presence of landscape attributes (forests, landscaped gardens, hedges) raises house prices. Other workers, however, report contrasting results, as is the case of Garrod and Willis (1994), Irwin (2002), Palmer (2003), Smith et al. (2002) and Dumas et al. (2005). The results for farmland are also ambiguous as they differ from one study to another. Roe et al. (2004) report a positive hedonic price, contrary to Smith et al. (2002), while for Paterson and Boyle (2002) the effect is not significant either way.

2.3. Landscape ecology indices

Beyond land use measured by the presence, proximity and proportion of the different types of land cover, shape analysis has come under study as it makes it possible to get closer to what a landscape is through the analysis of the number of patches of each type, their shape, the complexity or the uniformity of the compositions arising from them, etc. (Gustafson, 1998). Here we look at works using land-use data and landscape-ecology indices and ignore those based on photographs (Palmer 2003).

Geoghegan et al. (1997), in a multidisciplinary programme of landscape economics and ecology, use landscape-ecology indices which they integrate in a hedonic model. The study area is a watershed of 1000 square miles in Maryland, near to Washington D.C. Acharya and Bennett (2001) conduct similar work to estimate the value of identical or similar attributes in a watershed in Connecticut.

Geoghegan et al. (1997) define eight types of land use and introduce into the regression a land-use diversity index and a fragmentation index calculated within a 400-m circle around the house (supposedly corresponding to the field of view) and with a 1-km circle (walking range). Acharya and Bennett (2001) also define two circles, of 800 m and 1.6 km that similarly are supposed to correspond to the viewshed and to the walking range; to these indices they add richness, measured by the number of categories of land use found in each circle relative to the maximum possible number of categories and an interaction between richness and population density in order to distinguish between the richness of rural and urban landscapes.

The results show that in Maryland, near Washington, the immediate proximity of open spaces slightly raises land values, but that the effect becomes negative for more distant open spaces. Fragmentation and landscape diversity around the house have a negative effect on land values, except very close to and very far from Washington. In the Connecticut watershed studied by Acharya and Bennett, the diversity and richness have a negative hedonic price and the interaction between richness and density has a slightly positive price. The negative effect of diversity is consistent with zoning policies which are designed to segregate the different types of land use spatially. The positive effect of the interaction supposedly reflects a positive price of richness in an urban environment (habitat, gardens, shops) and a negative price of low richness in rural settings (uniform landscapes). The proportion of open spaces in the circles has a positive effect on price, with a parabolic shape.

The introduction of landscape composition variables or shape variables marks a significant advance in the economic evaluation of landscapes. Landscape ecology indices are generally used, since this is the discipline that provided the statistical indicators and tools for using them such as Fragstats (McGarigal and Marks 1995). It may be that the pioneering paper by Geoghegan et al. (1997) also helped to direct research along these lines.

However, the use of such indices must be discussed for three reasons. First, it assumes that people obey the same determinants as other animal species, as expressed by Geoghegan et al. (1997); yet, the aesthetic preferences of human beings are not of the same nature as the search for specific ecosystems and biotopes of other animal species. Secondly, the landscape-ecology variables have no connection with those used previously by urban planners, landscape architects, sociologists and economists and that sought to reflect aesthetic, psychological or cultural notions. Thirdly, landscape ecology can be used to produce variables seen from above and not seen from the ground: landscapes seen by an observer from the ground are very different from those seen from above. For example, where there may be a forest seen from above, someone in the forest will only see the few trees immediately around them.

2.4. The view of landscape

The view of a landscape is a much more complicated variable to compute than the attributes that have been analysed so far. It was long impossible to reconstruct the view from a large number of observation points. That is why, until recently, photographs of landscapes were used in survey protocols where respondents were asked to attribute scores to them or to evaluate them. In recent years, new approaches have made it possible to reconstruct views of landscapes from any point in space through suitable numerical modelling of landscape.

Preference analysis from photographs

Many studies investigate consumer preferences for landscapes from photographs. The method generally used involves explaining, on the basis of several sets of variables, a score given by respondents to a photograph.

For example, Kaplan et al. (1989) compare the role of four sets of variables in explaining a score given by students to landscape photographs in a rural area of Michigan: physical attributes (slope, relief, edge contrast, diversity, etc.); land use (arable land, grassland, brush, wasteland, etc.); landscape understanding and discovery variables (coherence, order, readability, complexity, mystery) and perception variables (field of view, texture). The authors conclude expressing some surprise because of the low predictive effect of the physical or land-use variables that are used in most studies of this type. It may be that an analysis of photographs by landscape architects and rated by psychology students introduces a bias, since these are not ordinary consumers of landscapes.

Recently, Kaplan and Austin (2004) have shown that, for people from a rural area near Detroit (USA), having a view of a 'natural landscape' from home is more important than having space (plot size, living area). Other works of this type have distinctive methods, such as the work of Johnston et al. (2002) that analyses the development of a housing project on Rhode Island (USA) by presenting plans and models to future residents. They show that households prefer a continuous, low-density project with fragmented plots separated by hedges.

The price of the landscape seen

New approaches mean that the view of landscape can now be reconstructed from any point in space by suitable numerical modelling of landscape. In these recent approaches, the actual view is introduced in the two-dimensional world described by a land-use layer, as presented earlier, by including the third dimension in the analysis through topography. Here what is investigated is the effect of the viewshed and, within the viewshed and depending on the different studies, the effect of the areas seen and put to various uses, the effect of the view of objects and of their composition, of topographical shapes, depending on the distance between the observer and the components of the field of view.

The study made of the value of view in the Rocky Mountains (Wyoming, USA) by Bastian et al. (2002) was the first to combine a method for reconstructing the view of the landscape with a hedonic price estimation. The environment of 158 plots is characterised from satellite images (25-m pixels) allowing 10 classes of land cover to be defined and from a 30-m digital elevation model. The combination of the two layers of geographic information allows the landscape to be reconstructed and landscape variables calculated: viewshed, relief, land use, diversity, break lines. The authors conclude that few of these variables are significant except for landscape diversity, which is greatly appreciated.

Paterson and Boyle (2002) also use satellite images and a digital elevation model to analyse landscape seen in a rural region of Connecticut (USA). They obtain results that they differ with the type of variable (satellite view or ground view).

Cavailhès et al. (2006, 2008, 2009) and Brossard et al. (2008a, 2008b) study the hedonic price of landscapes seen in periurban areas around Dijon and Besançon (France) using a method for modelling the view from the ground (Joly et al., 2009). They show that beyond a few tens or hundreds of metres, the planes of view and the objects in them do not significantly influence house prices. However, trees or fields in view close to houses have positive hedonic prices and roads negative hedonic prices. The view itself matters in that nearby trees that are hidden from view have a lower hedonic price than trees that are in view. Landscape ecology indices indicate positive prices for complex landscape shapes (mosaics, non-connectedness, etc.). In this paper, we extend these works by introducing new landscape measures.

2.5. What should be remembered from this overview of the literature?

First, that what is visible must be finely considered in landscape evaluation models. Admittedly analysis based on an overhead view of land use and topography is useful for defining the actual layout of the landscape in the geographical area, but it leads to approximations when attempting to bring out the criteria that underpin the value of the landscape. The mental processes by which a value is attributed to landscape is driven by many sensory experiences where the view from the ground is decisive. So by formalising the rules of visual composition of the landscape this reality can be approached objectively and the preferred features of the landscape identified. In this exercise, spatial and thematic precision of information is of great importance, because it must distinguish between close-up views and fine landscape objects that greatly structure the view from the ground. It is understandable that this requirement of precision implies designing state-of-the-art methods and using suitable instruments. Accordingly we are now seeing the emergence of principles for a coherent approach combining numerical data, quantitative methods, instrumentation by information systems and proceeding from conceptual thinking on measurement in respect of landscapes.

3. CALCULATING LANDSCAPE METRICS FROM A NUMERISED LANDSCAPE

3.1. Landscape modelling

Our landscape analysis method is based on a geographic information system (GIS) that manages multi-source data, including satellite pictures and a digital elevation model (DEM). We synthesise several approaches that are required to produce landscape indicators (see Joly et al. 2009 for a full description of the method):

(i) We formalise the reversibility relations between an observer and the landscape to be seen. We thus show the difference between the ‘view from above’, such as that in an aerial photograph, and the ‘view from within’, seen from the ground, where it is blocked by relief or tall objects that bring in the horizon. The ‘view from within’ is analysed by coupling it with the DEM, which describes the relief, and with satellite images, which are used for defining land use and the height of associated objects.

(ii) A landscape is arranged into grounds[1], from near to far. An object, such as a tree, is not the same for an observer depending on whether it is nearby (it is then a single object) or far

[1] For land cover, we use the term ‘buffer’ for a ring around transactions. For viewshed we

away (it becomes a part of a forest). We allow for this property by using multiple-scale methods that vary the nature of objects with distance.

(iii) The view of a landscape may be an amenity, but the possibility of being seen by others (passers-by on a road, the next-door neighbour) may be a nuisance. But the first view, or active view, is not symmetrical with the second, or passive view because of masks (a forest may be seen from far off, but someone walking in it sees only a small patch of undergrowth).

Numerical modelling of landscape allows us to measure the area seen by an observer virtually positioned at each point in the space in question and turning through 360° (active view). The same operation is repeated for each pixel and a symmetrical approach can be taken for the passive view.

In this way, the visual reality of the landscape is decomposed and may be translated into numerical indices. A virtual landscape is thus obtained for each pixel in the study area. The georeferencing of points where houses are located provides knowledge of the landscape around them, such as it is perceived by the householders moving around their plot.

3.2. Presence and abundance of seen and unseen objects on field depth

The model allows us to make an inventory of landscape characteristics that can be modulated depending on the objectives. For any point in the study, its breadth of outlook can be calculated; we can detail the way landscape is arranged in the viewshed, in open views extending to the distant horizon or dominated by nearby masks, etc. Landscape is divided up into six grounds whose content and transparency vary with distance (Skov-Petersen 2007). The analysis is broken down ground by ground with special attention to their content (agriculture, forests, buildings, roads, lakes, etc.).

Modelling and the formal ordering that it underpins allow us to transcribe these different terms of landscape categorisation into numerical form. In this way, we can chose to find them a visual expression in the form of a map or graph; or they can equally be stored in numerical form, because that is how they are transferred as explanatory variable for econometric modelling.

[Insert Figure 1 here]

3.3. Angular area related to vertical masks

The number of cells seen by type and their distribution in the different grounds provides an approximation of the landscape that is to be discussed. For example, agriculture seen from the distance may take up much of the viewshed when measured in square kilometres, but it is

---

speak of ‘ground’, by analogy with painting, for the **seen area** within each buffer.

perceived at a very low incident angle in the visual volume of the landscape. By contrast, a nearby house or tree may entirely fill the view, despite the small area they occupy. To allow for such effects, we calculate angular areas that are obtained by finding the product of the vertical and horizontal angular components of an object (it is possible to differentiate between what is due to the height of objects and to relief).

[Insert Figure 2 here]

We construct a cone whose summit ô corresponds to the observer's eye and base to the visible section of a cell, a square with sides ca and cb. The angular product aôb * aôc corresponds to its angular surface area. The angular area of a type of landscape object seen from an observation point is the sum of the angular areas of all the cells of this type composing its visual field.

The two foregoing approaches—grounds and angular area—may be combined: for identical angular areas, one type of object may not have the same effect for an observer depending on how close it is. It is therefore important to calculate the angular area of each type of object for the groundto which it belongs (the calculation is made for grounds 1, 2 and 3).

3.4. Distance from objects seen

By measuring the distance between an observation point and each cell of a given type, we can calculate a 'weighed aggregate' distance of this type, by dividing each cell by this distance and summing the ratios. For reasons of computation time, and in view of earlier econometric results (Cavailhès and Joly, 2007), the weighed aggregate distance was calculated for cells in view less than 280 m from an observation point.

Likewise for angular areas, the weighted aggregate distance from a type of object can be decomposed by grounds. This is tantamount to specifying the ground: the cells in view are defined not only by their inclusion in a particular ground but also, within this ground, by the distance at which they are located.

4. COMPARISON OF THE HEDONIC PRICES OBTAINED

4.1. The econometric model

We use the usual hedonic price equation: $\ln P_i = X_i b + \varepsilon_i$, where P_i is the price of real-estate i, X_i the matrix of explanatory variables (including an intercept), b the vector of parameters to be evaluated, and ε_i an error term. Application of this method to property values raises econometric problems that we discuss briefly. Besides the usual issues of heteroscedasticity of residuals and multicolinearity between covariates, the method involves processing spatial correlations between residuals (houses being spatialised goods) and the endogeneity of certain regressors (mainly due to the simultaneous choice of house price and some of its attributes).

Endogeneity 'may be addressed by means of spatial fixed effects. This rests on the assumption that the spatial range of the unobserved heterogeneity / dependence is specific to each spatially delineated unit' (Anselin and Lozano-Garcia, 2007). Following this method, we introduce into the equation a variable m_j characterizing the commune j: $\ln P_{ij} = X_{ij}b + b_j m_j + \varepsilon_{ij}$ that captures the effects of attributes whose values are shared by observations located in this commune, including badly measured or omitted variables. This makes it possible to not have spatial autocorrelations between the residuals of observations situated in different communes (a nullity test of Moran's index confirms this is so). We also calculate Moran's index for observations of a single commune, with a contiguity matrix where all transactions less than 200 m away are considered to be neighbouring. The significance test of this index makes it possible to determine whether or not there are spatial autocorrelations and if so to make allowance for them.

Endogeneity of some covariates is allowed for by the 'instrumental method' which allows us to check, using the Hausman's test, whether a covariate is endogenous. The estimation is then made in two steps: projection of this endogenous variable on exogenous instruments (characteristics of buyers and sellers), and then use of this projection in the main equation, estimated by the 2SLS. Sargan's test indicates whether the instruments are exogenous or not.

4.2. Study region and data

The study region is in Burgundy (France) around the city of Dijon. The outer limit of the area is bounded by an access time to Dijon of less than 33 minutes or a distance by road of less than 42 kilometres. The inner bound is that of the built-up area of Dijon (excluded from the study area because our landscape analysis models do not apply well to spaces where building heights are very variable). The area covers 3408 km² and numbers 140 703 inhabitants.

The property data are from real-estate lawyers (*notaires*) and pertain to 2665 sales between 1995 and 2002. They have been precisely located by ascribing geographical coordinates to them, so each house could be matched with the landscape on view from it.

4.3. Results

The results for housing attributes and other location variables are analogous to those obtained elsewhere (Cavailhès et al., 2009). The purpose of this paper being to test the results obtained using different landscape metrics, we present only the results relating to these variables.

Quantities of landscape seen according to the metrics

The three types of landscape metrics lead to measurements of seen objects that differ markedly in magnitude. The correlation between the number of tree-covered cells seen at less than 70 m and their angular area is quite low ($R^2 = 0.47$). The correlation is better between this number of cells and their weighted aggregate distance ($R^2 = 0.76$). These results are fairly logical since, for a tall object, the angular area varies greatly with its distance from the observer. By examining the connection with farmland seen at less than 280 m away, better statistical relations are obtained because, on the one hand, farmland is a flat object and because, for the other hand, we are interested in a more extended horizon. The R^2 value is 0.62 (angular area) or 0.94 (weighted aggregate distance).

Overall econometric results

Three types of model were estimated: a fixed-effects model estimated by the OLS and with the instrumental method by the 2SLS, and lastly a random-effects model. The instrumental method shows that the floor space is endogenous and Sargan's test indicates that the other covariates are exogenous; the landscape variables are all exogenous, contrary to results reported for the United States (Irwin, 2002; Irwin and Bockstael, 2001). In all three cases the model is homoscedastic and the Moran's index test on neighbouring residuals (within and between communes) shows that these are not spatially autocorrelated. For all three estimations, the orders of magnitude of the coefficients, the signs and the standard variations are quite close to one another.

Since one variable is endogenous and the random-effects model is statistically less sure than the fixed-effects model estimated by the instrumental method (cf. Cavailhès et al., 2009), we present only the main results of the latter model in Table 1. Moreover, the estimates are made for angular area from zero to infinity and for distances from cells from 0 to 280 m, then by decomposing these variables by the ground to which they belong (cf. supra).

[Insert Table 1 here]

The results in Table 1 concern only landscape variables with significant parameters. Full results using distance buffers are reported in Cavailhès et al. (2009). They are similar to those in Table 1 column (1), showing that the omission of non-significant landscape variables did not affect too much the parameters. To save space, the non-landscape variables (characteristics of the property and its location) have not been reported (see full results in Cavailhès et al., 2009).

Let us note, lastly, when reading this table that only the Student's t values are of interest: the parameters, measured in different units (number of cells, square degrees, number of cells weighted by distance) cannot be compared from one column to the next.

The adjusted R^2 values of the five regressions shown in Table 1 are quite similar and very close to 0.66. However, insofar as house prices depend mainly on the house's characteristics (size, comfort, etc.) and its location rather than with the landscape seen, it is preferable to examine the adjusted partial R^2 value of landscape composition variables to compare the effect of the metrics. This varies from 0.02 to 0.03, showing that these variables 'explain' nearly 2-3% of the variance of the model.

The partial adjusted R^2 values of the landscape variables are slightly better for the ground metric (0.03), because objects that are present in the grounds but out of sight (tree-covered cells, farmland) are added to the objects seen. If we confine ourselves to seen objects alone, which make up the landscape seen in the strict sense, the ground metric leads to worse partial R^2 and partial (0.019) adjusted R^2 values (0.017). It is better to measure seen landscapes by angular areas (for all objects in view from 0 to infinity: partial adjusted R^2 =0.024) or by weighted aggregate distances (from 0 to 280 m: partial adjusted R^2 =0.024). Lastly, it is by combining inclusion within grounds and angular areas and above all weighted aggregate distances that the best partial adjusted R^2 values are obtained. This is not surprising because the latter two metrics combine the advantages of grounds and the position of objects within them. It is therefore a more precise measure. We obtain adjusted partial R^2 values that rise to 0.024 and 0.026.

[Insert Table 2 here]

Landscape objects influencing price

By examining the number of objects seen for the grounds in which they are included (Table 1, column 1), we observe, as in Cavailhès et al. (2009), significant parameters for trees located less than 70 m away, for farmland between 70 and 180 m (positive effects) and for the view of roads and railway lines up to 280 m away (negative effect); this effect is not significant when these infrastructures are present but unseen. The absence of any effect beyond a few tens of metres may be explained by the study area having a 'non-descript' farmland and forest landscape with no particularly remarkable features such as a view of the sea or of snow-capped mountains, etc.

With the other metrics, these results remain stable overall: the significance of the parameters, are very similar in the different equations. The main difference is related to the adoption of a quadratic from for trees. When a wooded landscape is measured by its angular area, a saturation effect occurs, making the quadratic term significant: it is known that an abundance of nearby trees brings in the horizon and it is understandable that this is reflected by depreciation of the property.

We notice also that the use of finer variables, combining inclusion within a ground and a measure of location in the ground (aggregate distance or angular area) leads to a refinement of certain results: it is no longer farmland within 71 and 280 m that contributes significantly to price but only farmland between 71 and 140 m when location within grounds is measured. A few variations are also observed for road networks, but not for tree-covered areas: it is always the first 70 m that count.

Comparison of results for the metrics

Since the estimated parameters are not directly comparable because of the different measurement units, we present in Table 3 the effect on property prices of an increase of one standard variation of landscape variables.

For communication networks the results are pretty much identical, whichever landscape measure is used.

[Insert Table 3 here]

For tree-covered areas, the highest result is obtained with the angular surface metric when the location in the ground 0-70 m is taken in consideration: the adjusted partial R^2 is equal to 0.053. The adjusted partial R^2 is equal to 0.042 with the total angular surface. The results with the weighted aggregate distance are lower, the hierarchy being the same: 0.042 when the location in the ground 0-70 m is taken in consideration, 0.024 otherwise. The adjusted partial R^2 is only 0.02 with the ground metric (ground 0-70 m). This seems to indicate that for a tall object like a tree, a wood or a copse, which may mask the view and occupy a large proportion of the very near landscape, the distance should be measured quite precisely: inclusion within the first 70 m buffer is too coarse a variable. The somewhat mediocre correlation observed between this latter variable and those that take account of position within the buffer ($R^2 = 0.47$ or 0.76) is reflected by the marked spread of the results, since they may be more than doubled depending on the metric.

For farmland, the total angular areas or weighted aggregate distance up to 280 m away affect price by 2 to 3%, which is the same value obtained with the metrics for the 71–140 m ground, which in turn is less than the number of cells in the 71–280 m ring (+4.6% for one standard deviation). These differences are less important than for trees, which may be explained by a different perspective effect for a flat object that is incapable of masking the view.

4.4. The hedonic price of a reduction of view

The price of a marginal loss of landscape, due, say, to a new building closing out 10% of the view, is calculated for each house of the database from values predicted by the models: the price of this loss of landscape is equal to the sum of quantities of each object weight by its price.

We only use here the three variables for which we use different metrics: tree cover, farmland and networks that are actually in view, excluding objects that are present but unseen.

Figure 3 shows as XY graphs the results for the 2665 observations on which the estimates were made. These graphs also show the R^2 values for the hedonic prices of the three landscape variables analyses, estimated point by point, and which are 0.48, 0.58 and 0.78. The first two values are quite low.

[Insert Figure 3 here]

Despite this rather weak link for individual hedonic results, the aggregate results are quite similar, as shown in Tables 2 and 3: around 4% per additional standard variation of tree-covered areas, 2–4% for the same variation of farmland in sight, and -1% for one standard deviation of additional transport network. It might be thought that the geographical method of measuring landscapes has substantial effects on price estimations of a particular landscape seen from a particular house but that such individual differences fade when we reason in terms of aggregates: the individual deviations due to the metric used are absorbed by the residual of regression and the statistical estimation of the 'mean' effect depends little on the way landscape is measured.

5. CONCLUSION

In the economic evaluation of landscapes, it is difficult to express the view of landscape into quantitative variables so as to introduce it into econometric models. Geographers use a battery of approaches ranging from analysis of photographs to quantitative geography models using satellite images and digital elevation models. The explanatory variables of landscape value range from psychology (mystery, order, harmony, etc.) to landscape ecology. However, little economic valuation works have yet been done.

Here we examine the results of econometric estimations obtained by using three metrics relating to landscape attributes: (i) division of the viewshed into grounds according to their remoteness, (ii) visual scope measured by angular areas of vertical masks due to relief and objects, and (iii) the aggregate area of objects seen weighted by their distance from the observer. These three metrics quantify the objects seen differently, as is clearly shown by comparison of individual results. The landscape metric has important effects on price estimations of a particular landscape seen from a particular house. However, the results obtained for the three metrics are rather similar in aggregate terms. It may therefore be thought that the method is not of much use to an architect or promoter seeking to estimate the value of a particular landscape, but that it may be used by town planners interested in the mean value of the view for a town for which they are responsible.

LITERATURE CITED

Acharya, G., Bennett, L.L. (2001) Valuing open space and land-use patterns in urban watersheds. *Journal of Real Estate Finance and Economics*, 22: 221-237.

Anselin L., Lozano-Garcia N. (2007) Errors in variables and spatial effects in hedonic house price models of ambient air quality. Empirical Economics.

Bastian, C.T., McLeod, D.M., Germino, M.J., Reiners, W.A., Blasko, B.J. (2002) Environmental amenities and agricultural land values: a hedonic model using geographic information systems data. *Ecological Economics*, 40: 337-349.

Bolitzer, B., Netusil, N.R. (2000) The impact of open spaces on property values in Portland, Oregon. *Journal of Environmental Management*, 59: 185-193.

Brossard T., Cavailhès J., Hilal M., Joly D., Tourneux F.P., Tritz C., Wavresky P. (2008a) La valeur des paysages périurbains dans un marché immobilier en France. In: Des Rosiers F., Thériault M. *Information géographique et dynamiques urbaines volume 2*. Ed. Lavoisier - Hermès Science Publication, pp. 225-248

Brossard T., Cavailhès J., Hilal M., Joly D., Tourneux F.P., Tritz C., Wavresky P. (2008b) Le marché immobilier, révélateur du prix du paysage. In: Brossard T., Wieber J.C., *Paysage et information géographique*. Ed. Lavoisier - Hermès Science Publication, pp. 207-231.

Caruso G. (2002) La diversité des formes de la périurbanisation en Europe In: Perrier-Cornet, Ph. (ed.), *Repenser les campagnes*. DATAR, Editions de l'Aube, pp. 67-99.

Cavailhès J. (dir.), Joly D. (dir.), Brossard T., Hilal M., Tourneux F.P., Tritz C., Wavresky P. (2006) *Les paysages périurbains et leur prix*. Besançon, Presses Universitaires de Franche-Comté, 192 p.

Cavailhès J., Brossard T., Hilal M., Joly D., Tourneux F.P., Tritz C., Wavresky P. (2008) Pricing the homebuyer's countryside view. In: Baranzini A., Ramirez J., Schaerer C., Thalmann P. (eds) *Hedonic Methods in Housing Markets*, Spinger, pp.83-99.

Cavailhès J., Brossard T., Cavailhès J., Foltête J.C., Hilal M., Joly D., Tourneux F.P., Tritz C., Wavresky P. (2009) GIS-based hedonic pricing of landscape. *Environmental and Resource Economics*, forthcoming.

Clay G.R., Daniel T.C. (2000) Scenic landscape assessment: the effects of land management jurisdiction on public perception of scenic beauty. *Landscape and Urban Planning*, 49 (1): 1-13.

Correll, M.R., Lillydahl, J.H., Singell, L.D. (1978) The effects of greenbelts on residential property values: some findings on the political economy of open space. *Land Economics*, 54, 2: 207-217.

Davodeau, H. (2005) Les paysages, une nouvelle préoccupation dans la gestion des espaces périurbains. *Cahiers d'Economie et de Sociologie Rurales*, 77: 65-84.

Des Rosiers, F., Thériault, M., Kestens, Y., Villeneuve, P. (2002) Landscaping and house values: an empirical investigation. *Journal of Real Estate Research*, 23: 139-161.

Dumas, E., Geniaux, G., Napoleone, C. (2005) Les indices de l'écologie du paysage à l'épreuve du marché foncier. *Revue d'Economie Régionale et Urbaine*, 1 : 83-106.

Garrod, G.D., Willis, K.G. (1998) Using contingent ranking to estimate the loss of amenity value for inland waterways from public utility service structures. *Environmental and Resource Economics*, 12: 241-247.

Geoghegan, J., Wainger, L.A., Bockstael, N.E. (1997) Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS. *Ecological Economics*, 23: 251-264.

Gustafson, E. J., 1998. Quantifying landscape spatial patterns: what is the state of the art? *Ecosystem*, 1-2: 143-156.

Hamilton, S.W., Schwann, G.M. (1995) Do high voltage electric transmission lines affect property values? *Land Economics*, 71, 4: 436-444.

Hobden D.W., G.E. Laughton, K.E. Morgan (2004) Green space borders: a tangible benefit? Evidence from four neighbourhoods in Surrey, British Columbia, 1980–2001. *Land Use Policy*, 21: 129-138.

Irwin E.G., Bockstael N.E. (2001) The problem of identifying land use spillovers: measuring the effects of open space on residential property values. *American Journal of Agricultural Economics*, 83 (3), p. 698-704, 2001.

Irwin, E.G. (2002) The effects of open space on residential property values. *Land Economics*, 78: 465-480.

Johnston, R.J., Swallow, S.K., Bauer, D.M. (2002) Spatial factors and stated preference values for public goods: considerations for rural land use. *Land Economics*: 481-500.

Joly D., Brossard T., Cavailhès J., Hilal M., Tourneux F.P., Tritz C., Wavresky P. (2009) A quantitative Approach to the visual evaluation of landscape. *Annals of the Association of American Geographers*, forthcoming

Kaplan, R., Austin, M.E. (2004) Out in the country: sprawl and the quest for nature nearby. *Landscape and Urban Planning*, 69: 235-243.

Kaplan, R., Kaplan, S., Bown, T.(1989) Environmental preferences. A comparison of four domains of predictors. *Environment and Behavior*, 21: 509-530.

Kestens Y., M. Thériault and F. des Rosiers. (2004) The impact of surrounding land use and vegetation on single-family house prices. *Environment and Planning B*, 31: 539-567.

Le Jeannic, T. (1997) Trente ans de périurbanisation : extension et dilution des villes. *Economie et Statistique* 307, 7: 21-41.

Lee, C., Fujita, M. (1997) Efficient configuration of a greenbelt: theoretical modelling of greenbelt amenity. *Environment and Planning* A, 29: 1999-2017.

Mahan, B.L., Polasky, S., Adams, R.M. (2000) Valuing urban wetlands: a property price approach. *Land Economics*, 76: 100-113.

McGarigal K., Marks B. (1995) Fragstats: Spatial pattern analysis program for quantifying landscape structure. Technical Report PNW-GTR-351, Portland.

Mooney S., Eisgruber L.M. (2001) The influence of riparian protection measures on residential property values: the case of the Oregon plan for salmon and watersheds. *Journal of Real Estate Finance and Economics*, 22: 273-286.

Morancho A. (2003) A hedonic valuation of urban green areas. *Landscape and Urban Planning*, 66: 35-41.

Palmer, J.F. (2003) Using spatial metrics to predict scenic perception in a changing landscape: Dennis, Massachusetts. *Landscape and Urban Planning*, 69: 201-218.

Paterson, R.W., Boyle K.J. (2002) Out of sight, out of mind? Using GIS to incorporate visibility in hedonic property value models. *Land Economics*, 78: 417-425.

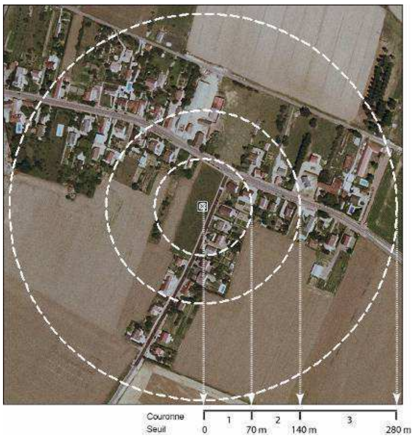
Roe, B., Irwin, E.G., Morrow-Jones, H.A. (2004) The effects of farmland, farmland preservation, and other neighborhood amenities on housing values and residential growth. *Land Economics*: 55-75.

Skov-Petersen, H. (2007). To see or not to see: Assessment of Probabilistic Visibility. In *International Conference on Geographic Information Science*, 10th AGILE, Aalborg University, Denmark.

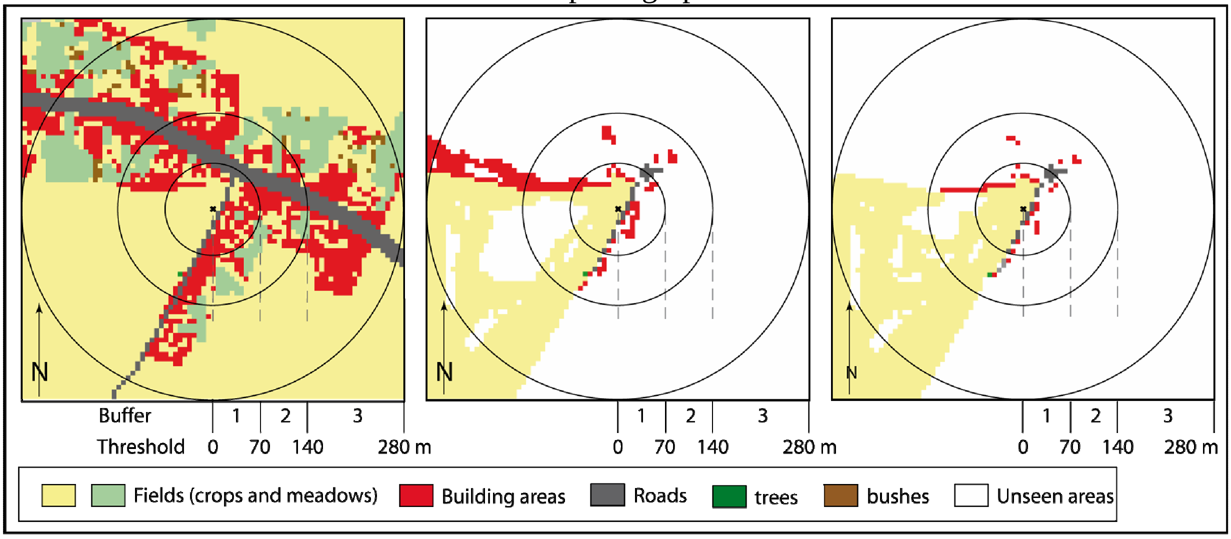
Smith, V.K., Poulos, C., Kim, H. (2002) Treating open space as an urban amenity. *Resource and Energy Economics*, 24:107-129.

Thorsnes, P. (2002) The value of a suburban forest preserve: Estimates from sales of vacant residential building lots. *Land Economics*, 78: 626-441.

Tyrväinen L.A. and A. Miettinen. (2000) Property prices and urban forest amenities. *Journal of Environmental Economics and Management* 39: 205-223.



orthophotograph



(a) Land cover. (b) Landscape seen. (c) Exposure to view.

Figure 1. Landscape models around a transaction up to 280 m away (Buffers 1, 2 and 3).

Each point is surrounded by landscape features described in terms of land use. Diversity and abundance can be specified by counting these features. In (a) the landscape, seen from overhead, is completely accessible to view and exhibits the structure of the orthophotograph despite the coarser resolution. In (b), the plan shows the segment of landscape that can be seen in three dimensions by an observer located at the centre of the circles; notice that most of the surrounding landscape is masked. In (c), all the pixels from where an observer can see the central point are shown. Figures figures (b) and (c) cannot be superposed: so seeing and being seen are complementary and non-symmetrical terms.

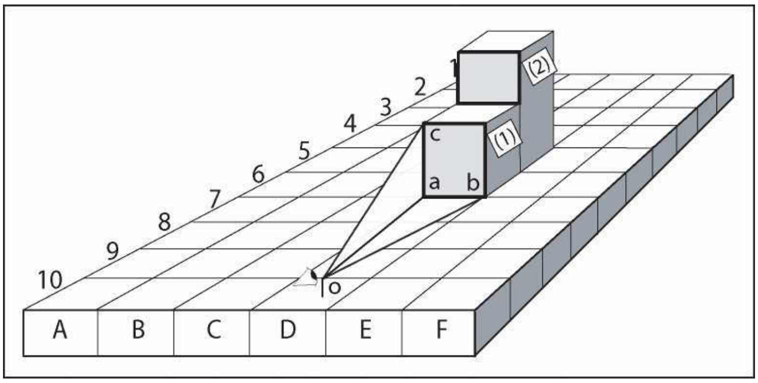
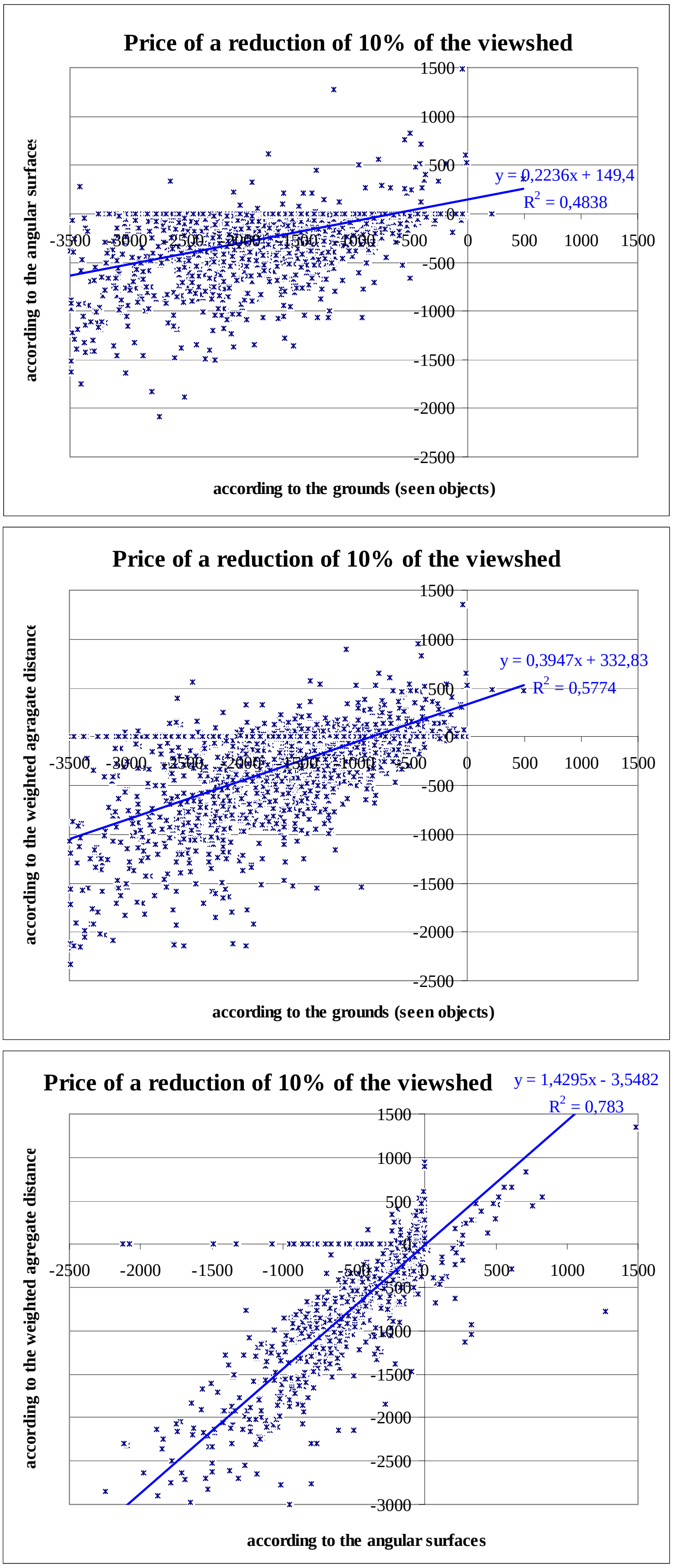


Figure 2. Angular area of vertical masks



Figures 3. Hedonic price of loss of 10% of landscape seen by the three metrics.

Table 1. Econometric Results

		(1) buffers		(2) angular surface (total)		(3) weighted agregate distance (total)		(4) angular surface distributed by grounds		(5) weighted agregate distance distributed by grounds	
adjusted R^2		0,66262		0,65915		0,65737		0,65962		0,66085	
		estimate	Student' t	estimate	Student' t	estimate	Student' t	estimate	Student' t	estimate	Student' t
TREES SEEN	< 70m	0,004075	2,0			0,091744	2,2	0,016021	2,9	0,188559	3,6
(TREES SEEN)²	< 70m							-0,00069	-2,0		
TREES SEEN* LOT/LSPACE	< 70m	-0,00014	-1,3			-0,00659	-3,3	-4,43E-07	-3,7	-0,00937	-4,1
TREES UNSEEN	< 70m	0,001784	3,6								
TREES UNSEEN* LOT/LSPACE	< 70m	-0,00007	-4,2								
TREES SEEN	0-40km			0,014791	2,2						
(TREES SEEN)²	0-40km			-0,00086	-1,7						
TREES SEEN* LOT/LSPACE	0-40km			-0,00041	-2,9						
AGRI SEEN	71-280m	0,000139	4,3								
AGRI SEEN * LOT/LSPACE	71-280m	-0,00643	-5,8								
AGRI SEEN * POSUD	71-280m	-0,00005	-1,7								
AGRI SEEN	71-140m							0,013381	2,4	0,024959	3,1
AGRI SEEN * LOT/LSPACE	71-140m							-0,00156	-4,3	-0,00144	-5,2
AGRI SEEN * POSUD	71-140m							-0,00773	-1,6	-0,01317	-1,5
AGRI UNSEEN	71-280m	0,000037	2,9								
AGRI UNSEEN * LOT/LSPACE	71-280m	-0,00214	-2,5								
AGRI SEEN	0-40km			0,072276	2,4	0,005784	2,6				
AGRI SEEN * LOT/LSPACE	0-40km			-0,008	-4,0	-0,0004	-4,5				
NETWORKS SEEN	0-280m	-0,00025	-1,9								
NETWORKS UNSEEN	0-280m	0,00007	1,3								
NETWORKS SEEN	71-140m							-0,06713	-2,4		
NETWORKS SEEN	0-70mm									-0,01875	-2,2
NETWORKS SEEN	0-40km					-0,01414	-2,1				

		partial R^2		adjusted partial R^2	
		objects seen	objects seen and unseen	objects seen	objects seen and unseen
grounds		0.01895	0.02976	0.01674	0.2611
angular surface	total	0.02599		0.02379	
	distribued by grounds	0.02631		0.02375	
weighted aggregate distance	total	0.02213		0.02029	
	distribued by grounds	0.02631		0.02375	

Table 2. Partial R^2 and adjusted partial R^2 of the landscape variables

	metric:	**effect of 1std change**
TREES SEEN (0-70m)	grounds	2,0%
TREES UNSEEN (0-70m)	grounds	4,6%
TREES SEEN (< 70 m)	angular surface	5,3%
TREES SEEN (< 70 m)	weighted agregate distance	4,2%
TREES SEEN (0- 40 km)	angular surface	4,2%
TREES SEEN (< 280 m)	weighted agregate distance	2,4%
AGRI SEEN (71-280m)	grounds	4,6%
AGRI UNSEEN (71-280m)	grounds	2,9%
AGRI SEEN (71-140m)	angular surface	3,1%
AGRI SEEN (71-140m)	weighted agregate distance	3,1%
AGRI SEEN (0- 40 km)	angular surface	2,1%
AGRI SEEN (< 0-280m)	weighted agregate distance	2,3%
NETWORKS SEEN (0-280 m)	grounds	-1,1%
NETWORKS UNSEEN (0-280 m)	grounds	1,2%
NETWORKS SEEN (71-140 m)	angular surface	-1,3%
NETWORKS SEEN (0-70 m)	weighted agregate distance	-1,3%
NETWORKS SEEN (0-280 m)	weighted agregate distance	-1,2%

Table 3. Effect on the house price of an increase of one standard deviation of landscape variables depending on the metric used.

APPENDIX : LANDSCAPE VARIABLES USED

Landscape variables:	**according to rings: < 70 m, 70-140 m, 140-280 m, 280-1200 m, 280-1200 m,1.2-6 km, 6-40 km. Cells SEEN and UNSEEN are distinguished. Rings may be merged**
ABBREVIATION	**DEFINITION**
TREE	number of cells of tree-covered area (R_TREE: rate of these cells)
TREE * LOT/LSPACE	number of cells of tree-covered area * LOT/LSPACE
AGRI	number of cells of agriculture (R_AGRI: rate of these cells)
AGRI * LOT/LSPACE	number of cells of agriculture * LOT/LSPACE
AGRI * POSUD	number of cells of agriculture * class UD of the zoning scheme
NETWORK TRANSPORT	number of cells of road/railroad (R_NETWORKS: rate of these cells)
BUILT	number of built cells (R_BUILT: rate of these cells)
BUSH	number of cells of bush (R_BUSH: rate of these cells)
WATER	number of cells of water
DECID_PACHES	number of patches of deciduous trees within a 70 m radius
DECID_EDGE	length of deciduous wood edges within a 70 m radius (m)
AGRI_PACHES	number of patches of crops betwen 70 - 140 m
COMPACT	compactess index (0=compact forms; 1=elongate forms), < 70 m
BUILT ANGULAR SURFACE	angular surface made by built cells (square degrees)
AGRI ANGULAR SURFACE	angular surface made by cells of agriculture (square degrees)
TREE ANGULAR SURFACE	angular surface made by tree-covered cells (square degrees)
BUSH ANGULAR SURFACE	angular surface made by cells of bushes (square degrees)
NETWORK ANGULAR SURFACE	angular surface made by cells of roads and railroads (square degrees)
WATER ANGULAR SURFACE	angular surface made by cells of water (square degrees)