Real Estate Values, Tree Cover, and Per-Capita Income: An Evaluation of the Interdependencies in Buffalo City (NY)

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Abstract. The variables that influence the price formation mechanisms of urban real estate units concern both the socio-economic both the infrastructural and environmental system of the city. In literature, the links between real estate and territory are not widely investigated. This is especially with reference to the correlation levels between Real Estate Prices and the provision of urban greening. In this perspective, aim of the research is to examine functional relations between property prices, environmental factors, and socio-economic parameters.

The applied methodology is based on statistical correlation analysis. This supports the construction of an innovative model for the estimation of the function that explains the dependence of property values on social and environmental factors that characterize the city. The elaborations concern data derived with the Tool *i-Tree Landescape*. Through Geographic Information Systems (GIS), these data are useful to obtain thematic maps illustrating the spatial distribution of Real Estate Prices, Tree Cover, and Per-Capita Income. The surveyed geographical units are the Census Blocks of Buffalo City in New York State (USA).

Keywords: Urban real estate · Tree cover · Per-Capita Income · Geographic Information Systems (GIS) · Correlation analysis · Optimization algorithm

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1 Introduction

The planning of city's development cannot be separated from the analysis of its socio-economic, productive and environmental system. It is essential, in fact, to define the territory, its boundaries and functional character in the perspective of «… economic development, social inclusion and environmental protection» [1].

Since 2007, the European Commission has been promoting design initiatives based on «eco-logically sound urban design practices» , i.e. interventions that provide for the creation of new green areas with which to raise the environmental level, social, and cultural quality, as well as the income capacity of the city [2–5].

The multiple effects generated by renewal urban projects nature-based are generally expressed in terms of eco-system services, in other words «… direct and indirect contributions of ecosystems to human well-being» [6]. From literature, the main urban ecosystem services are: pollutant removal, carbon storage and sequestration, micro-climate adaption, landscape improvement, biodiversity, and soil protection, water resource regulation [7, 8]. It is proven that natural resources provide life-support, cultural and aesthetic benefits [9], as well as increase in the market value of urban property [10].

Millennium Ecosystem Assessment (2005) classifies ecosystem services in four categories: provisioning, regulating, cultural, and supporting services [11]. Each category pursues a specific objective, and is a function of reference territory size, which may coincide with the individual building, the block in which the building itself is located, but also with city portions [12].

According to the geographical and urban features of study area and MEA category, the ecosystem services «… can systematically influence, according to a medium-long term logic, the orientation of a specific urban environment in terms of development strategies» [13]. In this regard, Glaeser (2008) reports that the presence of natural elements and/or green areas in built-up areas can significantly affect the growth of the local economic-productive system, as well as the urban real estate market [14, 15].

It is well known that the main extrinsic variables that can affect the market value of urban buildings include the urban quality (quality of roads, buildings, squares), the green plots (public parks, and gardens), the social and demographic context, the public transport, the proximity to the Central Business District (CBD), the landscape views, the historical significance of the area, the air pollution level [16–18]. In addition to these also «… factors on the urban heat island, distribution of greenery, building density and geometry, and air quality» [19].

The literature explores the relationship between Real Estate Prices (REP) and socio-economic parameters of the territory. In many cases the correlation between REP, per capita income of the inhabitants, and population density is highlighted [20, 21]. Some studies estimate the dependence between REP and distance of the property on both urban parks and water bodies (lakes, rivers) [22–25], both from mobility services [26–28]. There are still few scientific investigations concerning the correlation of REPs with both the distribution of greenery and air quality in cities [29].

To establish the logical-functional dependence between variables, analyses developed with different techniques can be conducted. It should mention: regression models,

neural networks, time series, and hedonic pricing method. This last one evaluates quantitative values for environmental or ecosystem services that directly affect market prices for residential building, isolating with multivariate regression techniques the contribution by interest attributes on observed prices [30, 31].

2 Work Aim

Objective is to investigate the correlation levels between Real Estate Prices and the socio-economic and environmental city parameters. The considered attributes that influence property value are Tree Cover and Per-Capita Income.

The relationship between Real Estate Prices, Tree Cover, and Per-Capita Income is estimated using a linear regression model between the variables. The methodological approach on the basis of model consists of the following steps: preparation of source data and geographical maps on data distribution; analysis of spatial structure data; development of regression model describing the correlations between prices and explicative variables.

The study model is implemented with reference to Buffalo City in New York State (USA).

According to literature, linear regression models can be solved both through statistical analysis tools and mathematical programming algorithms [32]. In the present manuscript, Operational Research algorithms able to solve real linear mathematical systems set as optimization problems are used. The optimization algorithms for the estimation of correlation between multiple variables are reflected in studies concerning land-use, urban planning [33–39], and urban real estate appraisal [40–44].

The mathematical programming environment used for writing the regression system is A Mathematical Programming Language (AMPL). It is a simple and intuitive tool used for structuring mathematical programming problems. Resolutions can be developed through specific software. Some examples are CPLEX, FortMP, MINOS, and KNITRO.

The paper is divided into four sections: Sect. 3, which describes the regression model and reports the algorithms written in AMPL; Sect. 4, case study, which describes the City of Buffalo (4.1), collects the data of the study variables (4.2), and estimates the correlation coefficients (4.3); Sect. 5, which discusses the results; Sect. 6, which presents conclusions and research perspectives.

3 Model Description

In order to detect the logical-functional dependencies between study variables, a multivariate statistical analysis is used. This allows both to identify the relationships between the parameters, and to establish the terms useful for spatial correlation between them.

Methods of multivariate statistics are: (i) Principal Component Method, in the case of variables measured on qualitative scale; (ii) Correspondence Method, where both

quantitative and qualitative variables are concerned; (iii) Factor-Real Analysis Method, where all variables are expressed on quantitative metric.

In the present work, a Factorial Analysis Method is used, according to which the regression function defines the dependence of Y on the x_j variables by means of the β_j coefficients (with j = 1, …, k).

In this case, which considers the two independent variables x_1 = Tree Cover (TC) and x_2 = Per-Capita Income (PCI), the multiple regression function is of the type:

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \tag{1}$$

where the variable Y = Real Estate Prices (REP) depends on x_1 and x_2 through the coefficients β_0, β_1, β_2; ε indicates the random variable, i.e. the error.

The coefficients β_0, β_1, β_2 are estimated by solving the minimisation function:

$$b := \min \sum\nolimits_i \varepsilon_i^2 := \min \sum\nolimits_i (y_i - \beta_0 - \beta_1 x_{1i} - \beta_2 x_{2i})^2 \tag{2}$$

where β_0 is the known term of the regression equation; β_1 and β_1 express the coefficients of x_1 and x_2 of the i-th analysis unit.

Equation (2) can be solved by using the programming algorithms of Operational Research, capable of solving systems of linear equations in order to maximize and/or minimize an objective function. In the case of (2), Quadratic Linear Programming algorithms are used.

The AMPL software is used to structure the model. In practice, the use of the AMPL programming environment allows to write the regression problem through the following steps:

1. Identification of the problem elements as SETs;
2. Specification of the parameters (PARAM) to be included in the system to be solved;
3. Definition of the variables' value (VAR);
4. Structuring of the objective function, of maximization (MAXIMIZE) or minimization (MINIMIZE), as a linear algebraic expression.

These steps define the structure of a model in parametric form (.mod file) to which the problem data are associated with a separately written .dat file.

With regard to the correlation of Real Estate Prices (REP) with Tree Cover (TC) and Per-Capita Income (PCI), the analysis units, i.e. the census areas into which the study territory is divided (set UNITS), are evaluated according to three parameters (param REP, TC, PCI). The objective is to estimate the coefficients β_0, β_1, β_2 by means of a function aimed at minimizing the summa of the quadratic difference among the values of the parameters.

The regression model written in the AMPL programming environment is in Table 1. In compliance with AMPL syntactic rules, the β_0, β_1, β_2 coefficients, i.e. the unknowns of the problem, are indicated with the letters y, x_1, x_2 respectively.

Table 1. The regression model written in A Mathematical Programming Language (AMPL) software (.mod file).

Multiple linear regression analysis model
SETS
set UNITS;
PARAMETERS
param REP {i in UNITS};
param TC {i in UNITS};
param PCI {i in UNITS };
VARIABLES
var y ≥ 0;
var x1 ≥ 0;
var x2 ≥ 0;
OBJECTIVE FUNCTION
minimize *objective*: sum {i in UNITS} (REP[i] – x1·TC[i] – x2·PCI[i] – y)^2;

The analysis units (set UNITS) are described according to three factors (set PARAMETERS): Real Estate Price, Tree Cover, and Per-Capita Income.

The unknowns (y, x_1, x_2) are continuous. The objective function is:

$$\text{minimize objective: sum } \{\text{i in UNITS}\}\,(\text{REP}[\text{i}] - x1 \cdot \text{TC}[\text{i}] - x2 \cdot \text{PCI}[\text{i}] - \text{y})^2$$

The MINOS optimization software was used as a solver implementing Quadratic algorithm for the problem of linear regression considered.

4 Application of the Model to Buffalo City (NY)

4.1 Study Area

Buffalo is the second largest city in the U.S. State of New York. The city is the county seat of Erie County, and a major gateway for commerce and travel across the Canada–United States border, forming part of the bi-national Buffalo Niagara Region.

It is located on the eastern shore of Lake Erie, at the head of the Niagara River, 16 miles (26 km) south of Niagara Falls. According to the United States Census Bureau, the city has an area of 52.5 square miles (136 km^2), of which 40.6 square miles (105 km^2) is land and the rest water. The total area is 22.66% water. The city consists of 286 Census Blocks with an average extension of 0.39 km^2.

Buffalo's economy has begun to see significant improvements since the early 2010s. In 2016, the U.S. Bureau of Economic Analysis valued the Buffalo area's economy at $54.9 billion. In the same year, the city's median household income is $24,536.00 and the median family income is $30,614.00.

As regards the environmental-forestry component, the Buffalo parks system has over 20 parks with several green areas accessible from any part of the city. The Olmsted Park and Parkway System is the hallmark of Buffalo's many green spaces [45].

4.2 Data Collection and Statistical Analysis

In order to investigate the correlations between socio-economic factors and ecosystem services, the data set is constructed with the values of the variables considered, Real Estate Prices, Tree Cover, Per-capita Income. The data refer to the Census Blocks Tracks of city studied considered. The values of the variables are collected using *i-Tree Landscape* Tool that gives information on tree cover, land use, and basic demographic characteristics of the census areas in United States of America. Canopy Cover data are taken directly from 2011 National Land Cover Data (NLCD), while U.S. Per capita Income and Real Estate Prices from 2011 U.S. Census Bureau data.

The statistic description of variables referring to Buffalo City is in Table 2.

Table 2. List of variables and its statistic description.

Variables	Descriptive statistics			
	Mean	Standard deviation	Minimum	Maximum
Real Estate Prices [$]	75,140.85	61,357.07	225.0	368,900.00
Tree Cover [%]	4.82	5.77	0.03	59.20
Per-Capita Income [$]	19,190.63	10,696.74	2,434.00	76,395.00

A thematic map representative of corresponding numerical values is constructed for each variable (Fig. 1). This is done through Geographical Information Systems (GIS). The realization of the thematic maps allows a first comparison among values, useful to highlight the correlation levels.

From the comparison between maps in Fig. 1, it is evident the correlation between the variables. In particular, there is a strong correlation among those at North of Buffalo. The Census Blocks falling in this portion of territory are characterized by high values of Real Estate Prices, Tree Cover and Per-Capita Income. Here there is the presence of the Delaware Park and the Urban Zoo.

Differently for the central and southern areas of the study city. These zones are characterized by the Museum of Science, Medical Center, and Cimitery. These are areas crossed by the Buffalo River, as well as road infrastructures connecting Buffalo with nearby urban conglomerates such as Rochester. The presence of both anthropic and natural elements in Buffalo causes the formation of surfaces with Real Estate Prices, Tree Cover, and Per-Capita Income values that are not homogeneously distributed. This results in lower levels of correlation between variables.

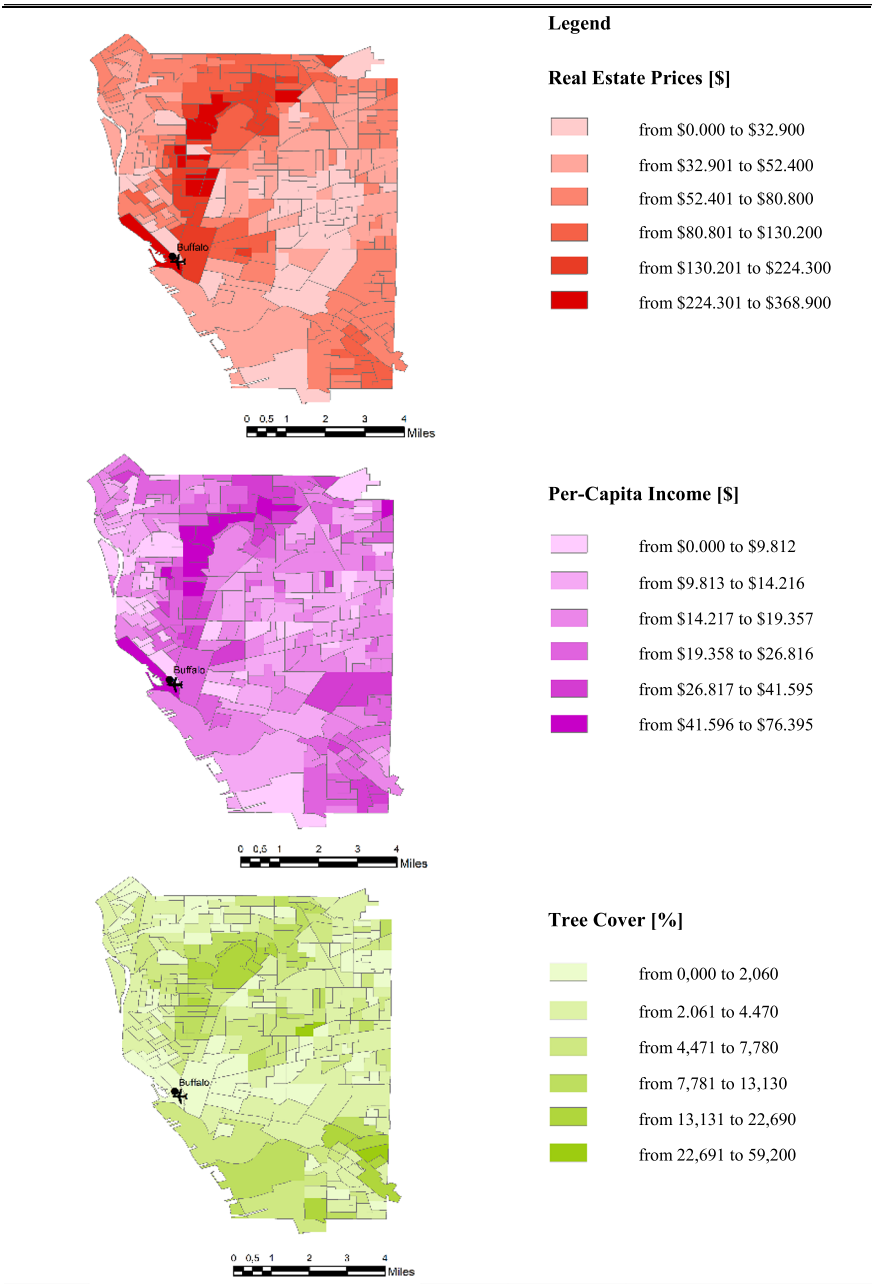

Fig. 1. Spatial distribution of Real Estate Prices, Pre-Capita Income, and Tree Cover in Buffalo (NY).

4.3 Estimation of Correlation Coefficients Between Variables

For the application of the proposed regression model, 287 census areas in the City of Buffalo (NY) are examined. The estimation of the correlation levels is performed by analysing census areas with the same level of infrastructural endowment and biome. For each census area of analysis is detected the:

a. Geographical extent expressed in square kilometres;
b. Median Real Estate Price in $;
c. Tree Cover in %;
d. Per-capita Income in $.

Table 3 show data-set excerpt with the values of the three parameters. On the data of Table 3 is implemented the regression model in Table 2. Thus, the regression model written in AMPL (.mod file) is in Table 4.

The .mod file in Table 4 is associated with the .dat file in Table 5.

The .mod and .dat files are called in the AMPL command line, specifying the solver that implements the algorithm:

```
ampl: reset;
ampl: model FILE.mod;
ampl: data FILE.dat;
ampl: option solver Minos;
ampl: solve.
```

The values of $y = \beta_0$, $x_1 = \beta_1$, $x_2 = \beta_2$ obtained by implementing the regression model with MINOS software are:

$$\beta_0 := 24451.548780$$
$$\beta_1 := 0.668540$$
$$\beta_2 := 0.862783$$

Table 3. Data matrix.

Census blocks	*a.* Area [Km^2]	*b.* Median real estate price [$]	*c.* Tree cover [%]	*d.* Per-capita income [$]
0	0.15	32,200.00	4.01	9,205.00
1	0.48	35,417.00	3.21	12,708.00
2	0.44	69,924.00	9.22	52,698.00
3	0.22	38,060.00	4.17	15,767.00
4	0.13	44,489.00	0.00	23,225.00
5	0.14	34,949.00	2.76	12,166.00

(*continued*)

Table 3. (*continued*)

Census blocks	*a.* Area [Km^2]	*b.* Median real estate price [$]	*c.* Tree cover [%]	*d.* Per-capita income [$]
6	0.41	36,938.00	2.04	14,471.00
7	0.24	35,768.00	6.97	13,111.00
8	0.22	42,110.00	2.20	20,466.00
9	0.19	37,040.00	4.60	14,588.00
10	0.29	45,989.00	1.04	24,963.00
11	0.18	34,461.00	3.91	11,599.00
12	0.32	34,977.00	9.23	12,193.00
13	0.12	33,988.00	1.30	11,053.00
14	0.18	41,478.00	9.58	19,727.00
15	0.20	47,589.00	2.69	26,816.00
16	0.23	33,651.00	3.42	10,660.00
…	…	…	…	…
143	0.29	35,834.00	2.80	13,191.00
144	0.32	37,155.00	3.71	14,721.00
…	…	…	…	…
270	0.32	37,924.00	1.51	15,614.00
271	0.23	34,208.00	1.88	11,307.00
272	0.10	33,553.00	2.69	10,547.00
273	0.18	32,430.00	1.83	9,246.00
274	0.23	52,024.00	13.87	31,947.00
275	0.15	66,425.00	10.96	48,641.00
276	0.25	42,982.00	5.25	21,474.00
277	0.17	39,274.00	2.21	17,179.00
278	0.10	37,795.00	3.56	15,463.00
279	0.47	35,405.00	1.56	12,695.00
280	0.24	39,264.00	6.50	17,164.00
281	0.94	37,285.00	3.06	14,873.00
282	0.42	38,803.00	6.98	16,629.00
283	0.17	37,018.00	0.98	14,565.00
284	1.06	38,363.00	2.15	16,123.00
285	0.26	34,953.00	4.55	12,169.00
286	3.03	24,456.00	7.43	0.00

Table 4. Regression model in AMPL (file .mod).

```
## Census Blocks definition ##
set BLOCKS;

## parameters of the regression problem ##
param MREP {i in BLOCKS};
param TC   {i in BLOCKS};
param PCI  {i in BLOCKS};

## explanation of variables ##
var y  {i in BLOCKS} ≥ 0;
var X1 {i in BLOCKS} ≥ 0;
var X2 {i in BLOCKS} ≥ 0;

### objective function ###
minimize objective: sum{i in BLOCKS}(MREP[i] - TC*x1[i] -PCI*x2[i]- y)^2
```

Table 5. File.dat.

```
set BLOCKS := 0 1 … 144 … 286;

param MREP :=
   0      32396
   1      35419
   2      69924
   3      38060
   4      44489
   5      34949
   6      36938
   7      32396
   8      35419
   …        …
 286      24456


param TC :=
   0       4.01
   1       3.21
   2       9.22
   3       4.17
   4       0.00
   5       2.76
   6       2.04
   7       4.01
   8       3.21
   …         …
 286       7,43


param PCI :=
   0       9205
   1       1270
   2       5269
   3      15767
   4      23225
   5      12166
   6      14471
   7        920
   8      12708
   …         …
 286       0,00
```

5 Discussions

The correlation function is derived from the processing carried out:

$$\text{REP} = 24,451.55 + 0.668540 \cdot \text{TC} + 0.862783 \cdot \text{PCI} \quad (3)$$

Equation (3) highlights the functional link of Real Estate Prices (REP) with the environmental variable Tree Cover (TC) and the socio-economic variable Per-Capita Income (PCI). The tests conducted show weak multicollinearity between the TC and PCI variables, as demonstrated by the 0.21 value of the Pearson index.

Obviously, (3) refers to a typical real estate unit, whose market value depends exclusively on TC and PCI.

From the obtained results derives a significant correlation between REP, TC, and PCI. The Census Blocks with higher Per-Capita Income and Tree Cover values are characterized by high Real Estate Prices. On the other hand, the less wealthy parts of cities have less green areas and lower Real Estate Prices. These results are in line with other U.S. cities, where the richest urban neighbourhoods, i.e., with higher PCI and REP, have a high percentage of Tree Cover [46, 47].

6 Conclusions

Socio-economic and environmental parameters of the city influence the urban real estate market. In special way, the natural elements, such as single trees and urban forests, provide multiple effects. Among these, the increase of residential building stock values in the city.

Despite in the reference literature it is recognized the relation among ecological factors and market parameters, there are few examples that examine their functional bond. In fact, the knowledge of the interdependencies including multiple variables is useful for the planning of urban sustainable actions in the respect of the reference context features.

In order to investigate the link including multiple variables, indicators representative the socio-economic and environmental urban system were identified. From the study on the urban forest benefits of Nowak D. and John F. Dwyer (2007), Tree Cover and Per-Capita Income parameters were considered as variables to be correlated to Real Estate Prices.

The novelty of the present work is characterized by the methodology implemented for the variables correlation analysis. The estimation of the relationship between Real Estate Prices, Tree Cover, and Per-Capita Income is conducted both through the construction of thematic maps with Geographic Information Systems (GIS) and by implementing statistical methodologies and mathematical programming tools. Thematic maps give the graphic representation of the values distribution. The correlation analysis then returns the function that quantitatively expresses the dependence of Real Estate Prices from Tree Cover and Per-Capita Income. For the construction of the function is defined an innovative model that implements optimization algorithms.

A case study is developed with reference to datasets taken from official sources for the City of Buffalo, in the New York State (USA). The elaborations on 287 Census Blocks demonstrate that the Real Estate Prices depend on the Tree Cover and Per-Capita Income levels. In particular, the model provides the β_1 and β_2 coefficients of the function: $\beta_1 = 0.668540$ (TC); $\beta_2 = 0.862783$ (PCI).

Research perspectives concern, on the one hand, the application of the investigation protocol to other urban realities, and, on the other one, the characterization of a function able to explain the mechanisms of formation of urban real estate values in the light not only of the socio-economic and environmental variables of the study area, but also in relation to the positional and intrinsic property characteristics.

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