



Measuring the effects of green urban space on property values using GIS metrics: A case study for the city of Rotterdam

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ABSTRACT: This research focuses on the effects of green space on property values in the city of Rotterdam. The concept of environmental injustice is examined; in which the government promotes the development of green areas mainly in high-income neighborhoods. An OLS regression analysis using 2,654 properties in Rotterdam, reveals a negative effect on property values for green space located within 100 meters from each transaction. However, after controlling for historical land usage in a TSLS regression analysis, it is revealed that green coverage within 300 meters from each transaction has a significant positive effect on property values. Furthermore, it is estimated that the effect of green coverage depends mainly on the property's distance to the Central Business District.

Contents

Chapter 1 - Introduction.....	2
Chapter 2 - Literature Review	4
2.1 House Price Determinants.....	4
2.2 Neighborhood and Location Determinants.....	5
2.3 Environmental Amenities	6
2.4 Environmental Injustice.....	11
2.5 Hypotheses.....	11
Chapter 3 - Data & Methodology	13
3.1 Data	14
3.2 Methodology	17
3.2.1 TSLS – Instrumental variable	19
Chapter 4 - Results & Discussion	21
4.1 OLS Results	21
4.2 TSLS Results	26
Chapter 5 – Synthesis	30
Chapter 6 – Conclusion.....	32
References.....	33
Appendix.....	38

Chapter 1 - Introduction

The increasing trends of urbanization and environmental awareness in the last decades have created an interesting consequence in the residential market: An increasing demand of residents towards location and neighborhood preferences regarding environmental amenities, such as accessibility and proximity to green urban areas, lakes, rivers, and other physical attractions. Several EU policies promote urban sustainability by supporting and protecting urban green areas, with a mostly related example of the *Soignes Forest* within the city boundaries of Brussels (European Commission, 2010) and North Madrid, where the city council promoted policies aiming to increase environmental amenities by creating large green urban areas within the city (Riggins, 2011).

Relevant research on the effects of environmental amenities on property values has been conducted through the years in an intercontinental context, including countries such as China, Finland and the Netherlands. More specifically, research in the Netherlands has proven a positive effect of green urban areas on property values of up to 28%, while a large-scale study in the city of Jinan (China) using GIS metrics, reveals that distance to green urban spaces as well as the physical coverage of such amenities has a significant positive effect on property values (Luttik, 2000; Fanhua, Haiwei, & Nobukazu, 2007). In addition, the same conditions seem to hold in North Carelia (Finland), where a similar research using the hedonic pricing model also reveals a positive effect on property values with decreasing distance from green recreation areas and water bodies within urban districts (Tyrväinen, 1997).

Despite these documented positive effects of environmental amenities on residential prices, literature focusing on the reverse causality effect of house prices on regional environmental amenities is very limited. More specifically, current urban planning policies are potentially designed to attract high-income residents by supplying environmental amenities to certain high property price areas. Recent literature discusses the 'environmental injustice' concept, observing the fact that environmental amenities are unfairly distributed to high-income residential districts (Gould & Lewis, 2012). Furthermore, another research examines that the use of trees and green areas in the city of Tampa (Florida, USA) is unequally distributed, with a lower share of amenities in low-income and rental neighborhoods (Landry & Chakraborty, Street trees and equity: evaluating the spatial distribution of an urban amenity., 2009). Therefore, it seems that there exists a biased estimation of the effect of environmental amenities on house prices, since current policies promote the development of such attractions mostly in high-income regions.

This study aims to examine the effect of green urban areas on house prices and vice versa; considering the 'environmental injustice' concept to examine the effect of property prices on regional green areas. Therefore, by conducting both a literature review and a statistical analysis this research aims to answer the following research question:

- ***To what degree do environmental amenities increase house prices and to what degree are amenities sorting in expensive neighborhoods?***

Within the theoretical framework of property valuation studies, a most frequent methodology used refers to the *hedonic pricing model*, which explains that the overall valuation of a product depends on the existence of special characteristics which determine a set of implicit values, or “hedonic” prices (Rosen, 1974; Sheppard, 1999). In the case of residential prices, the set of implicit values includes house-specific features (i.e. number of rooms), while more broad factors such as neighborhood and location characteristics also play a key role. The basic function of property valuation is therefore presented as follows: $P = f(x_1, x_2, \dots, x_n)$, where P is the house price, and (x_1, x_2, \dots, x_n) the set of features it embodies.

Existing literature supports that the integration of economics and landscape ecology provides the benefits of a systematic analysis that includes spatial scale, rather than using only aggregated statistical data (Vermaat, Eppink, van den Bergh, Baredregt, & van Belle, 2005). In addition, research supports that environmental variables such as green space, are easily captured by using the spatial analysis module of GIS metrics (Fanhua, Haiwei, & Nobukazu, 2007).

A significant indicator in estimating the effects of green space on property values is regional green coverage; more simply, the ratio of green space to the total area of a buffer zone surrounding each transaction. Relevant research for the city of Castellon (Spain), has concluded that larger green areas have correspondingly larger positive effects on property values, and therefore suggests the substitution and merging of small gardened areas into large recreational parks (Morancho, 2003). However, other measurements such as the distance to the closest green area, and the different effects of green space at distinct locations within the city region could also indicate variations in the effect.

Therefore, the following sub-questions can be formed as complementary to the research question:

- *To what extent does proximity to green areas influence property values?*
- *How does the effect of green coverage change with varying distance to the central business district?*

Firstly, this study conducts a qualitative analysis through a literature review, in which it examines how environmental indicators are used in relevant researches to estimate the effects of natural amenities on property values. Secondly, the study specifies a methodology and presents the sources of data for the case study conducted, regarding the central districts for the city of Rotterdam. In this case study, a statistical analysis specifies the effects of proximity to urban green space and its spatial coverage on the city’s property values. In the third phase, the literature review is compared to the results of the case study presented, to examine similarities and differences in the effects of environmental amenities on property values between the case of Rotterdam and other cities in which similar studies have been conducted. Lastly, the study concludes by potentially answering the research question and sub-questions; while presenting possible policy recommendations and mentioning any limitations that are likely to exist in the context of the empirical analysis.

Chapter 2 - Literature Review

House Price Determinants

A broad analysis of housing price determinants is essential to further estimate the possible effects of environmental-specific determinants. To start with, a market of 'hedonic prices' reaches equilibrium when price variations reflect exactly the consumers' preference variations, and the price is presented as a function of the property's characteristics $P = f(x_1, x_2, \dots, x_n)$, which identifies the structure of demand (Rosen, 1974). Such characteristics can be related to housing specific features such as the total living area and the number of rooms, as well as to neighborhood characteristics such as distance and accessibility to basic amenities. Therefore, it can be observed that the variance of a property price from the mean is related to the availability of such attributes as described in the equation $\Sigma = \beta_i / \mu - x_i$; a measure of 'atypicality' in property prices widely used in urban economics (Han & Strange, 2015). Hence, it can be stated that the market value of all amenities related to the dwelling's location is capitalized by the location's implicit land value (Davis & Heathcote, 2007).

It is important to consider that the frequency of transactions in the housing market strictly depends on the consumer's willingness on voluntary mobility, which can be separated in 2 sub-categories: *Adjustment mobility*, which reflects mobility due to changes in house-specific, neighborhood and location preferences, and *induced mobility*, which reflects mobility due to income variations and changes in preferences during to the consumer's life-cycle (Clark & Onaka, 1983).

One of the largest and most inclusive literature reviews on house price determinants, refers to 125 empirical studies and examines the indicators used to determine a property's valuation, separating such attributes in 5 distinct categories: **Structure & Construction** (year of construction, total area, rooms, etc.), **Internal characteristics** (central heating, terrace, bathrooms), **External characteristics** (garden, balcony, garage), **Natural amenities** (mountain/sea view, parks, waterbodies) and **Location & Neighborhood** (crime rates, distance to central locations, transport facilities) (Sirmans, Macpherson, & Zietz, 2005, p. 11). The weight of implicit prices attributed to natural amenities is expected to increase in a strictly urban environment, where in theory, such amenities become scarce and thus more appreciated from the consumer.

A case study conducted in a strictly urban environment includes the existence of green belts as an environmental attribute which influences property valuation; more specifically, the research includes 93 urban districts in the inner city of London, revealing that accessibility to greenbelts (protected areas dedicated to green space) has strong positive effects on housing prices (Wabe, 1971). However, the use of greenbelts as an explanatory variable does not specify the implicit effects of the property's distance to such areas, as well as the effect of their total coverage. Additionally, Wabe's research estimates that the construction date has also a positive effect, while commuting distance and price to central locations (CBD) and the area's population density affect a property's valuation negatively.

A more recent case study conducted in 2008 for the state of Utah (US), an OLS regression analysis of 1,366 properties reveals unexpected results for the variable indicating the existence of mountain view, as it shows a significant negative effect on property values (Zietz, Zietz, & Sirmans, 2008). This study also reveals that other house-specific indicators such as the number of rooms and bathrooms, construction quality and the total property area have a significant positive effect.

While the abovementioned case studies create databases of house-specific variables, other studies focus on average regional property values and thus use location-specific data collection methodologies. Conducted in 1968, a case study for the city of Saint Louis in the state of Missouri (US), including data on location-specific characteristics for 167 urban districts, concludes that at a district level, variables which have a positive effect on the average property values include the median number of rooms, proximity to central locations, percentage of recently-constructed houses and accessibility to main avenues. On the other hand, variables measuring air pollution, residents per dwelling and below-average school quality have a significant negative effect on average property values (Ridker & Henning, 1968).

Overall, the examined literature studies house price determinants in general and reveals that neighborhood characteristics and the availability of consumer amenities have an important effect on house prices. Within this study, the research is focused on the potential driving effect of local amenities which reflect neighborhood attractiveness.

Neighborhood and Location Determinants

Since the beginning of the industrial revolution, economists examined the effects of urban sprawl and related variations in land values to the accessibility and distance to central market places (Von Thunen, 1875). Land rent was later developed as a function of its distance and accessibility to the Central Business District (CBD), setting cities as the central places of consumption (Alonso, 1964; Muth, 1969). Developing such theories, economists nowadays developed the idea of consumer cities, in which basic amenities are classified into four broad categories: **Accessibility, public services, variety of goods and services** and **aesthetics/physical setting** (Glaeser, Kolko, & Saiz, 2001). These attributes contribute to the consumer's willingness of voluntary mobility by contributing to both concepts of adjustment and induced mobility (Clark & Onaka, 1983).

The first category of basic amenities refers to accessibility and the ease of mobility of consumers to the central business district (CBD) and to central market places in general. Several studies have proved the effects of accessibility and mobility by identifying how such location-specific characteristics are capitalized into land prices (Cheshire & Sheppard, 1995); while others have focused on the positive effect of fast transport and infrastructure (Debrezion, Pels, & Rietveld, 2007; Fejarang, 1993). However, contemporary trends in urban planning developed several CBDs within an urban region, questioning the significance of accessibility as an effect of urban property prices (Dubin, 1992).

The effective provision for public goods and services such as good education institutes and the sense of security within a neighborhood are also proven to have a significant effect on

residential prices. The quality and availability of public schools has an important effect in the choice of community of residence (Oates, 1969; Jud & Watts, 1981; Kain & Quigley, 1970); while the quality of primary schools has a higher intra-metropolitan effect due to smaller catchment areas in the neighborhood geographical level (Haurin & Brasington, 1996). More public provisions have been identified to have an effect in the choice of residence, such as public beaches, parks, police protection, good infrastructure and parking facilities (Tiebout, 1956). Further research has focused on the negative effects of crime rates on property values within a neighborhood, by estimating the consumer's willingness to pay for crime control (Thaler, 1978; Naroff & Hellman, 1979).

According to the concept of place branding, a customer-based view of urban areas acknowledges that residents desire an attractive living environment that *"fits well to the needs and wants of its members in the household"* (Braun, 2008, p. 67). Therefore, a rich variety of goods and services within a close geographical proximity to the place of residence has an important effect on house prices, as it satisfies a higher percentage of the demand of local residents. A recent study on the effect of *Walmart* stores on local residential prices which includes data from over 1 million house transactions, shows that a new *Walmart* store increases house prices up to 3% for properties located within a 0.5 miles' radius from the store location (Pope & Pope, 2015). In addition, the quality of local retail services such as bars and restaurants and whether information about the quality is widely available to the public, affects the capitalization of nearby property values (Kuang, 2015).

Finally, an important location-specific characteristic considers the physical setting and aesthetics, which contribute to the improvement of the living environment and provide open space used by residents for recreational activities. A recent study examining the effect of proximity to large open spaces within a metropolitan area shows that open spaces can be substantially overestimated in areas which they are scarcer and in densely populated neighborhoods (Anderson & West, 2006). Aesthetics or visual quality, such as the existence of historical monuments and attractive architecture, constitutes another important determinant of property values (Li & Brown, 1980; Baranzini & Schaerer, 2011).

By examining previous studies focusing on the determinants of property values in an urban environment, it can be observed that the presence of environmental amenities as one of the determinants does not go unnoticed; many of the case studies have identified a significant effect on property values with respect to the accessibility and proximity to waterbodies and green areas, good air quality and natural view. A closer observation on studies specifically focused on the effect of environmental amenities will help to draw clear conclusions on which variables are most frequently estimated in these studies.

Environmental Amenities

From a general overview of most empirical studies focusing on the effect of environmental amenities on house prices, it can be distinguished that the aforementioned could be separated in 3 categories: **Air quality**, **wet lands** and **green areas**. Therefore, the following empirical studies are discussed separately for each subcategory. It is worth to mention that while accessibility and coverage of wet lands and green areas can be measured on per

property level basis, air quality can only be measured on a location level basis, since it is almost impossible to measure air quality for every individual property.

Air quality literature

A qualitative research focused on the impact of air quality variables on property valuation refers to 12 relevant case studies carried from 1968 to 2000, and examines the main indicators of air quality measurements to reveal that NO₂ and SO₂ concentration are the most frequently included variables. Nevertheless, the study concludes that since air quality variables are typically unknown to the actors involved in housing transactions, such variables often have an insignificant effect on house prices (Boyle & Kiel, 2001).

While most case studies regarding air quality use a large pool of variables indicating the large variety of air pollutants, a specific empirical research conducted for the metropolitan area of Boston (US), only focuses on the effects of NO₂. The study reveals a significant negative effect on median property values, approximating an average decrease of \$304.12 per property value (Harrison & Rubinfeld, 1978).

Another case study for the metropolitan area of Seattle (US), reveals the significant negative effects of NO₂, TSP, Ozone and SO₂ particle concentration on average property values at district-level; however, only 25 out of the 70 air pollutant indicators showed a significant effect (Palmquist, 1982). A comparable case study on 4 cities in the US estimates the consumers' willingness to pay for properties with variability in air quality, indicating a significant negative effect on 23 out of 80 used variables corresponding to various air pollutants (Zabel & Kiel, 2000).

Lastly, a micro-environment case study focused in only two urban districts in the state of Selangor (Malaysia), uses the Air Quality Index as an explanatory variable to reveal that there is a positive correlation between improving air quality and house prices. However, this study omits other house-specific, neighborhood and location variables, and thus reduces the explanatory power of its statistical analysis (Azmi, Azhar, & Nawawi, 2012).

Wetland literature

While some decades ago water used to be one of the main means of transportation, in recent years, urban planners are engaged in a long debate on whether small waterbodies within urban areas should be preserved, or replaced by land for further development. Consequently, an opportunity cost exists between obtaining the positive externalities of wetlands, or instead, create more land to tackle problems such as the shortage of housing and overpopulation. A relevant study for the city of Hangzhou (China), reflects the abovementioned debate by mentioning the positive externalities of preserving urban wetlands, such as the cold-island effect: Waterbodies help avoid abnormally elevated temperatures in the city's environment. On the other hand, the authors discuss that such amenities are threatened by the expansion of urban settlements (Zhang, Jiang, & Zhu, 2015).

Furthermore, by examining relevant literature, it can be observed that urban wetlands, by providing positive benefits such as improving the living environment, leisure activities, aesthetics and means of transportation, they consequently bring a positive effect on

property values. An OLS regression analysis including 14,485 property transactions in the city of Portland (US), concludes that: increasing one acre in the total coverage of the nearest wetland, has a positive effect on nearby properties by \$24.39. Furthermore, an increasing distance to the nearest wetland decreases property values by \$436.17 per mile (Mahan, Polansky, & Adams, 2000).

Another case study for the area of New Hampshire (US) examines the effects of proximity to lakes for lakefront properties located in 59 towns and settlements, revealing a decrease in house prices by \$107.29 per foot of increasing distance from the lake. The study also shows a positive effect of water quality and the total coverage of the lake on prices of the observed properties (Gibbs, Halstead, Boyle, & Ju-Chin, 2002). Nevertheless, this study focuses only on lakefront properties, and thus lacks comparison between properties which have access to waterbodies and properties which do not.

From a different point of view, some case studies replicate the negative effects of proximity to waterbodies by referring to higher flood risks, in which case the residents are often required to pay higher taxes for property insurance. A statistical analysis of 29,887 property transactions in Florida (US), examine the effect of flood zone areas on property values: The authors estimated a decrease of \$1034.38 in the values of properties located within flood zone areas (Harrison, Smersh, & Schwartz, 2001). Consequently, a question arises whether the positive externalities of accessibility and proximity to wetlands overcome the negative externalities attributed to higher flood risks.

Overall, by comparing existing literature, it can be observed that there is stronger evidence on the effects of wetlands than the effects of air quality on property values. However, while air quality effects are often insignificant, effects of urban wetlands can sometimes provide contradicting results.

Green area literature

The main mechanisms through which green urban areas offer a premium on property values, as observed in previous literature, are mainly driven by residents' preferences towards recreational areas and aesthetics, while green areas can also act as the main driver of an improved air quality. Furthermore, important variables for measuring the effects of green urban space include its proximity and accessibility to residential properties, as well as the total geographical area of such amenities which is accessible to local residents.

An empirical study carried in Joensuu (Finland), estimates the variation in sales data from 1006 local property transactions by observing the distance of each property to the nearest green recreational areas and forests, while accounting for the relative area of green space accessible to each property. The main results of the statistical analysis show a negative effect on property values by 41.78 FIM per 100 meters of increasing distance to the nearest green recreational area, while the coverage of such areas has a positive effect on nearby properties by 7.36 FIM per m² of green space. On the other hand, the analysis shows that properties located further away from coniferous forests were sold for higher prices; more specifically, there was a positive effect of 471.46 FIM per 100 meters of increasing distance to the nearest forested area. Consequently, the author concludes that "... *the notion of*

dense, mature coniferous forests may not be appreciated close to a house in these latitudes" (Tyrväinen, 1997, p. 220).

In the Netherlands, a case study collecting NVM data for more than 3000 property transactions in the areas of Emmen, Appeldoorn and Leiden, explores the effects of attractive landscape views such as green and water. The author estimates a premium/implicit price effect with an average of 9% for houses facing water, while the analysis reveals a premium varying from 6% to 12% for properties facing green open spaces (Luttik, 2000). In general, the study concludes that properties favored by an attractive environmental landscape view, entail higher values than properties facing less attractive landscapes. However, the study does not mention a measurement of "attractiveness", which could defer in the perspective of each consumer. Another limitation of this study, as explained by the author, lies in the robustness of the data collected, since the presence of green space was eminent for most of the properties; thus the values of properties without access to such amenities could not be sufficiently compared.

Previous literature reveals further evidence for the positive effects of green urban space for the city of Castellon (Spain), where approximately 1000 properties were compared with respect to their proximity to the nearest green urban area, as well as the size of the corresponding areas. The study uses an OLS regression analysis to reveal that there is a significant negative effect on property values by €1,800 per 100 meters of increasing distance to the nearest green area; the analysis controls for house-specific variables such as the number of rooms and lot size, as well as location-specific characteristics (Morancho, 2003). Apart from the OLS regression, this study replicates reciprocal and double-logarithmic regressions, to show that the results were similar in most cases.

Finally, a large-scale empirical study including 124 housing clusters in Jinan City (China), uses GIS metrics to measure several indicators shaping the quality of green urban areas such as the distance of each property to the nearest park, plaza and scenery forest, while accounting for the travel time of residents to such amenities. The research also includes variables accumulating the size of corresponding green areas as well as the green patch density and richness at a buffer zone of 500 meters from each property. The statistical analysis reveals a premium of 2.1% per m² in the property's value for an additional 1% of green space within a 300 radius, while a 1% shorter travelling time to green recreational areas increases a property's value by 1.8% per m² (Fanhua, Haiwei, & Nobukazu, 2007). However, the authors conclude that increasing the density of individual green spaces within a proximity of 500 meters to a property will have a negative effect on its value, since it entails negative externalities such as noise and lights during the night.

A general overview of literature focused on the effect of green urban areas, shows the consumers' appreciation towards such amenities, as reflected through implicit prices on property values.

Table 1 summarizes the literature reviewed concerning the effect of environmental amenities, including the location of each case as well as the methodology used and the main findings:

Table 1: Summary of the literature reviewed concerning environmental amenities

Authors	Year	Area	Dependent variable	Independent variables	Value of coefficient	Methodology
(Harrison & Rubinfeld)	1978	Boston (US)	Median house value	NO2 concentration	\$-304.12	OLS regression, Semi-log model
(Palmquist)	1982	Seattle (US)	Property sales value	NO2, SO2, TSP, O3 and Ozone metrics	\$-479.69 (for O3 variables)	OLS & GLS regression models
(Zabel & Kiel)	2000	US	Property sales value	NO2, SO2 and TSP	not reported	Log - Linear & Log - Log regression models
(Mahan, Polansky, & Adams)	2000	Oregon (US)	Property sales value	Wetland size, type and proximity	\$24.39/acre (size) \$436.17/mile (proximity)	OLS regression
(Gibbs, Halstead, Boyle, & Ju-Chin)	2002	New Hampshire (US)	Property sales value	Lake proximity, water quality, lake area	\$107.29/ft. (proximity) minimum of \$213.58/m2 for water quality	OLS regression
(Harrison, Smersh, & Schwartz)	2001	Florida (US)	Property sales value	flood zone areas	\$-1034.38 if property is located in flood zone area	OLS regression
(Tyrväinen)	1997	Joensuu (North Carelia, Finland)	Property sales value	distance to parks, forests & greenland coverage	(-)41.78FIM/100m distance to park 471.46/100m distance to 7.36/m2 forest coverage	OLS regression
(Luttik)	2000	Netherlands	Property sales value	green view, water view, presence of green & water within each area	6-12 % premium for green view, 8-10% premium for water view	OLS regression
(Visser, van Dam, & Hooimeijer)	2008	Netherlands	Mean house value (single/family dwellings per sq. m.)	Green & wet land coverage, proximity, and number of high-rise buildings	not reported	OLS regression
(Morancho)	2003	Castellón (Spain)	Property sales value	green view, distance and size	€-1800/100m distance to green areas	OLS regression, double - logarithmic, Reciprocal model
(Fanhua, Haiwei, & Nobukazu)	2007	Jinan (China)	Property sales value	distance and size of green areas, type (plaza, park, scenery forest), green view, and percentage coverage	¥141.094 & ¥188.58 for size-distance index to forest and plaza, ¥417.78 for green coverage	OLS regression & Semi-log model

Considering that this research is based on the effects on environmental amenities in the Netherlands, very few studies have situated in the same geographical space; identifying house price variations due to differences in the residential environment (Luttik, 2000; Visser,

van Dam, & Hooimeijer, 2008). Since the majority of the studies concern specific countries/regions with large differences in the physical environment and geographical space, the **external validity of the results can be controversial**. In addition, very few studies have considered the concept of *environmental injustice*, identifying an unequal distribution of environmental amenities with the majority distributed in high-income neighborhoods. In this case, the implicit value of environmental amenities on house prices can be biased due to unequal distribution.

Environmental Injustice

The *environmental injustice* concept was introduced very recently in the research of Gould and Lewis (2012) in the case of Brooklyn's Prospect Park, which identifies that the working class and minority residents are progressively priced back from environmental amenities within urban areas. The authors provide evidence that urban greening policies tend to increase environmental inequality and reduce the access of poorer communities to environmental amenities (Gould & Lewis, 2012).

Furthermore, relevant research on the effect of high-income neighborhoods on green urban space for the Milwaukee area (Wisconsin, USA) concludes that there exists an unequal distribution of environmental amenities, as the newly planned urban forest does not extend within residential areas with low-income residents and ethnic minorities (Heynen, Perkins, & Roy, 2006). In addition, another study in the case of Florida (USA) supports the hypothesis of unequal distribution by estimating a significantly lower proportion of tree coverage in neighborhoods containing a higher proportion of ethnic minorities, low income residents and renters, questioning the effectiveness of local investment policies in urban planning (Landry & Chakraborty, Street trees and equity: evaluating the spatial distribution of an urban amenity, 2009). The concept is also evident in other regions, considering a case study in Rio de Janeiro (Brazil), which concludes that "*Socioeconomic and education levels of the population seem to play a more causal on tree quantity and species diversity.*" (Pedlowski, Da Silva, Adell, & Heynen, 2002, p. 1). Finally, environmental inequality is also evident in the case of Montreal (Canada), in a case study which identifies that "*disparities in the distribution of vegetation in Montreal which disfavour low-income people and, to a lesser extent, visible minorities.*" (Apparicio, Séguin, Landry, & Gagnon, 2012, p. 1).

Since urban planning policies are evident to promote investments concerning the development of environmental amenities in favour of high-income neighbourhoods, it can be assumed that high property values within a neighbourhood significantly affect the availability, quality and proximity to such amenities. Therefore, it is crucial to estimate the effects of property values on nearby environmental amenities to identify the biased estimates of the amenities' implicit value on property values; in the case of reverse causality.

Hypotheses

According to the above literature, it can be derived that environmental amenities play a key role in location-specific characteristics by creating an implicit value on residential prices. Furthermore, it is categorized as one of the basic amenities in the concept of city marketing, by approaching the subject from a consumer-based view concerning the physical setting and aesthetics (Braun, 2008). In most of the cases, environmental amenities such as the

availability and proximity to green areas and waterfront, produce a positive value on the capitalization of property values. However, since the above cases are location-specific, the external invalidity of the findings prevents the results from being representative of distinct locations and settings.

Therefore, the following hypothesis is formulated to examine the effects of environmental amenities on property values in the country of interest; the Netherlands:

- **Hypothesis 1: Residential prices are positively affected by the presence of environmental amenities.**

On the other hand, several studies have shown that investment in such amenities is unequally distributed within urban regions, mostly in favor of high-income neighborhoods (Gould & Lewis, 2012; Apparicio, Séguin, Landry, & Gagnon, 2012; Pedlowski, Da Silva, Adell, & Heynen, 2002; Landry & Chakraborty, Street trees and equity: evaluating the spatial distribution of an urban amenity, 2009). In this case, the estimates of implicit values are biased in the case on reverse causality; in the sense that property values also influence the distribution of environmental amenities in the intra-metropolitan level. This results in a social exclusion problem, since specific population groups such as low-income and ethnic minorities enjoy less proportion of such amenities. The purpose of this research is not only to promote the development of green areas within the city, but also to promote an equal spatial and social distribution in the development of physical amenities. Therefore, a second hypothesis is formulated to examine the existence of environmental inequality within the urban region:

- **Hypothesis 2: Estimates of implicit prices of environmental amenities are biased in the case of reverse causality.**

The above hypothesis examines causality by measuring the effect of high residential prices on the development of green areas, in a sense that high income residents express a higher demand for environmental amenities. Therefore, it corresponds to the second part of the main question of this research, exploring to what degree are environmental amenities sorted in certain high-income neighborhoods.

In the following chapters, the main findings of this extensive literature review will be compared to the results of the following statistical analysis for the city of Rotterdam (Netherlands), to assist in drawing clear conclusions on the influence of the environmental amenities on property valuation.

Chapter 3 - Data & Methodology

According to previous literature, it can be observed that the most frequently used methodology of estimating the effects of environmental amenities on property values is the OLS regression, where the transaction price is set as the dependent variable and the selected house specific features and neighborhood characteristics set as the explanatory variables. Accordingly, OLS regression is used in 2 types of methodologies, in which the dependent variable is set on individual level (house-specific transaction price) or on aggregate level (average or median transaction price per region). This research focuses on measuring effects on individual level, as in accord with the ecological fallacy theorem, which highlights that the results of an aggregate analysis might not be representative on individual level (Robinson, 2009).

The regression analysis corresponds to the hedonic pricing model $P = f(x_1, x_2, \dots, x_n)$, where P represents the house price and x_1, x_2, \dots, x_n the set of house-specific, neighborhood and location characteristics (Rosen, 1974), can form the following linear equation:

$P_i = \theta_0 + \sum \beta_k x_{ik} + \varepsilon_i$, where P represents the house price in location i , θ_0 is a positive constant, $\sum \beta_k x_{ik}$ represents the sum of explanatory variables and ε_i is the error term.

The biggest threat for the normal distribution of data through a level to level OLS regression, as reflected through the previous studies, is heteroskedasticity. To avoid such a threat, some of the studies have used GLS and logarithmic models (Harrison, Smersh, & Schwartz, 2001; Zabel & Kiel, 2000; Palmquist, 1982; Fanhua, Haiwei, & Nobukazu, 2007); while others have used the reciprocal model (Morancho, 2003). Therefore, a log-level OLS regression in the form $\ln(y_i) = \theta_0 + \sum \beta_k x_{ik} + \varepsilon_i$, where $\ln(y_i)$ represents the natural logarithm of the house price in location i , can be used to eliminate heteroskedasticity resulting from a wide variance in the observations (Cho, Bowker, & Park, 2006). However, the use of robust or White-Huber standard errors through a simple procedure can eliminate the effect of heteroskedasticity in the dataset.

Although the effect of green space on residential prices can be effectively measured through a regression model, the specific causality of the explanatory variable should be tested to additionally examine the effect of reverse causality, in a case which implies that high transaction prices determine the development of green areas in a specific region. Therefore, this research employs the instrumental variable approach, through which the true causality of the variables can be identified. It is important that the instrumental variable chosen has no correlation to the dependent variable (transaction prices), but is correlated to the explanatory variable of interest (green space). More specifically, old maps from 1911 illustrating the area of interest are used to examine whether a green area was pre-designed as part of the urban planning, and thus implied an effect on nearby house prices, or whether it was later developed because of increasing house prices.

Other studies have used socioeconomic data (Gould & Lewis, 2012; Heynen, Perkins, & Roy, 2006); however, variables such as income and social status are found to be correlated to

property values. Therefore, the use of historical urban planning is a more effective tool since it can be uncorrelated to property values but predetermine the use of certain areas for natural attractions.

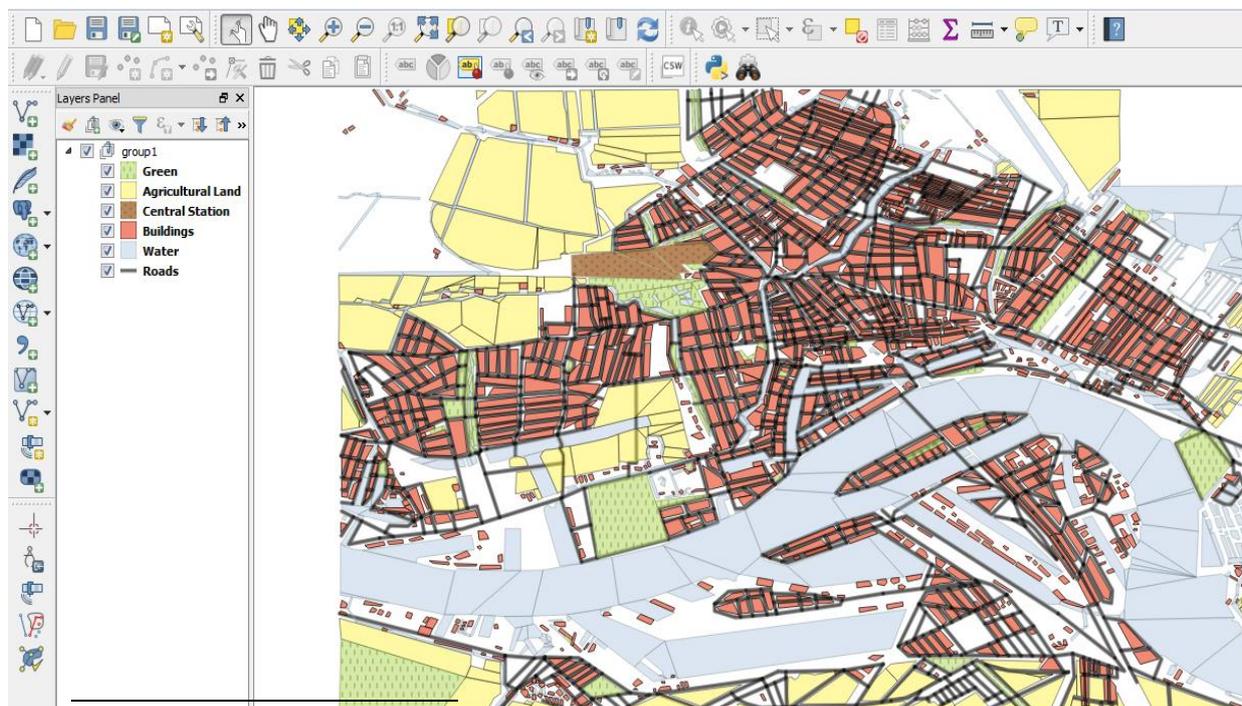
Consequently, an OLS regression analysis is used to examine the 1st hypothesis, testing the effect of green areas on residential prices, while a 2-staged least squares approach is used to examine the 2nd hypothesis in which old maps are used as an instrumental variable. In the next sections, the database used for the present case study is explained in detail.

Data

The geographical area examined in this research consists of a large region in the center of Rotterdam covering approximately 250 km², bounded by the A20 and A16 motorways on the North and East accordingly, and stretching up to Blijdorp on the West and the Northern part of Feyenoord on the South. The specific area was chosen as it surrounds the Central Business District of Rotterdam, and it corresponds to the scope of this research on examining the effect of environmental amenities in a strictly urban environment where natural resources are theoretically scarce.

The maps used in QGIS software were gathered in high quality georeferenced images (GeoTIFF)¹ as provided by the Dutch government on the land registry website (Publieke Dienstverlening op de Kaart, 2017). Old maps (1911) for the city of Rotterdam are used as an instrumental variable and can be found online (Klokan Technologies GmbH, 2017) in an archive of more than 400,000 worldwide maps; they are used to examine the price behavior in areas for which green space is predetermined by historical urban planning. The following figure illustrates the digitized version of the 1911 map (Figure 8), after being processed in QGIS:

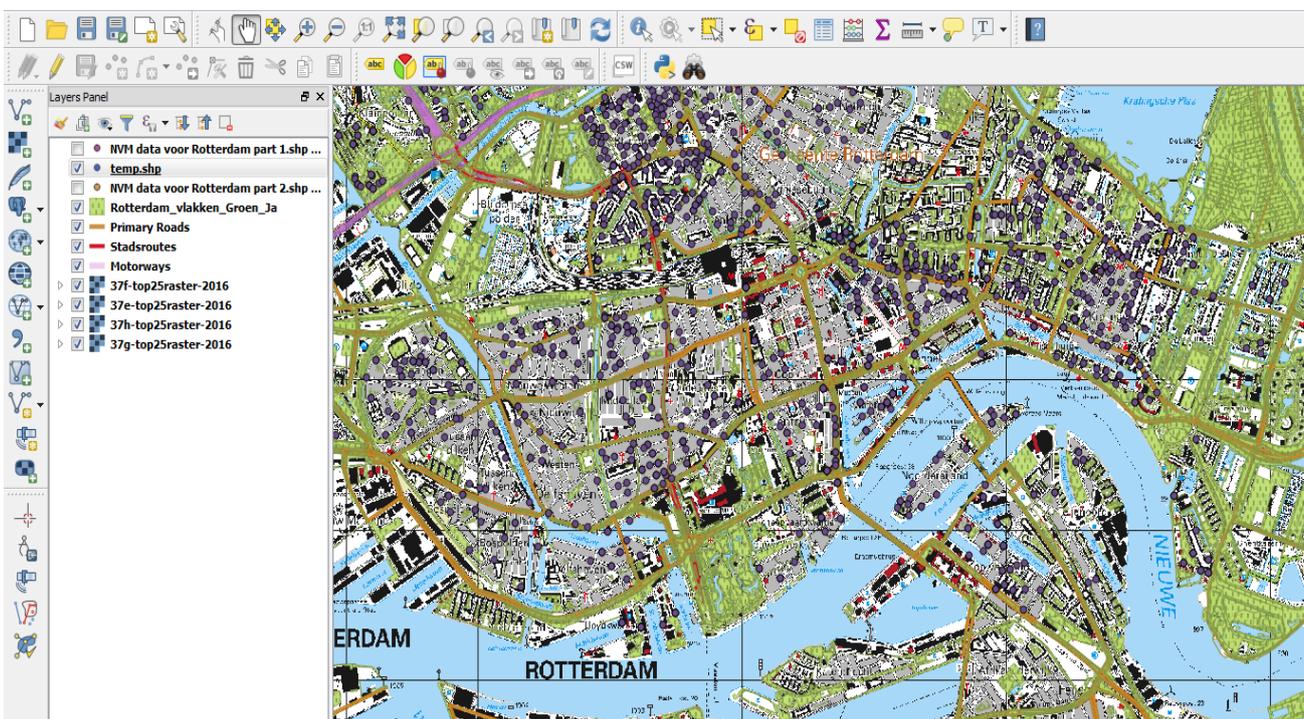
Figure 1: Digitized 1911 map of Rotterdam in QGIS



¹ Geostationary Earth Orbit Tagged Image File Format

Furthermore, the database provided by the largest Dutch Association of Realtors and Appraisers (NVM)² consists of 2,654 house transactions occurred in 2012 within the city of Rotterdam and includes information on individual transaction prices, transaction details such as the date of sale and the duration of each transaction, total living area in square meters and several house characteristics such as the floor number, number of bedrooms, kitchens, bathrooms, balconies etc.³ (NVM, 2017). The obtained transactions are geocoded according to the zip code of each transaction in QGIS using a set of Python plugins, to analyze the neighborhood characteristics of each location (MMQGIS, 2017). The following figure illustrates the digitized version of the 2012 map including the geocoded locations of housing transactions, after being processed in QGIS:

Figure 2: Digitized 2012 map of Rotterdam in QGIS



As the target of this research is to identify the effect of green urban areas on property values, the dependent variable used for the regression analysis is the transaction price of each property sold within 2012 in Rotterdam. The explanatory variables of interest represent the presence of green space in proximity to the coordinates of each transaction. Therefore, the measure consists of the percentage of green areas to the total area of a buffer zone with radii of 100 and 300 meters around the coordinate of each property transaction. Two buffer zones were selected, to reflect the possible effect of distance to the nearest green area. The following equation is used to calculate the percentage of green areas in the buffer area of each property sold:

² Nederlandse Vereniging van Makelaars en Taxateurs

³ The database consists of 71 variables; specific house types appear to have 2,112 out of 3,106 missing observations and are therefore not used in the statistical analysis. Other variables such as the presence of an elevator, attic, elderly houses, permanent/leasehold types of transactions, are far from the scope of this research.

Equation 1: Percentage of green area for each observation

$$\text{green \%} = \frac{\text{green space coverage (m}^2\text{)}}{\pi r^2}, \text{ where } r = 100\text{m and } r = 300\text{m.}$$

A set of additional explanatory variables were chosen from the NVM database, to accurately estimate and explain any variations in the dependent variable (transaction price). These include interior house characteristics such as the construction period, number of rooms, the presence of gardens, parking place, roof terrace and the total living area, as well as neighborhood characteristics evaluating the proximity to the CBD. The following table shows detailed descriptive statistics for the variables mentioned:

Table 2: Descriptive Statistics

VARIABLE	DESCRIPTION	# OBSERVATIONS	MEAN	STD. DEV	MIN	MAX
TRANSACTIEPRIJS	Transaction price (€)	2,667	187,979.5	121,430.6	15,000	1,300,000
CBDDIS	Distance to Central Business District (Km)	2,667	4.186984	2.916889	0.2316734	25.11311
CONS_PERIOD	Construction period (1<1500, ... ,9>2001)	2,667	5.121703	2.413813	1	9
NOORD	Location of dwelling (0=South, 1=North)	2,667	0.7377543	0.4399384	0	1
_PARKEER	Property includes a parking place (0=No, 1=Yes)	2,667	0.1525998	0.3596691	0	1
ROOMS	Number of rooms	2,667	3.925019	1.556824	1	44
ROOFTERRACE	Number of roof terraces included in the property	2,667	0.0847777	0.2905244	0	2
SQUAREMETERS	Total interior area (sq. meters)	2,667	100.4763	39.00383	36	360
LNLOT	Natural logarithm of the plots of land used (0 for apartments)	2,667	1.679184	2.453269	0	8.66164
GARDEN	Property includes a garden (0 = No garden, 1 = garden)	2,667	0.3711379	0.4832003	0	1
PERCGREEN3	Green to total area in buffer zone with radius 300 meters	2,667	0.1972384	0.1175077	0.0033074	0.8098773
PERCGREEN2	Green to total area in a buffer zone between 100m-300m	2,667	0.202244	0.1210205	0.0037208	0.8492038
PERCGREEN1	Green to total area in buffer zone with radius 100 meters	2,667	0.1571936	0.1312919	0	0.7006386

As it can be observed through the descriptive statistics, the mean value of the dependent variable (transaction price) is €187,979.50; however, the significant difference between the mean and the maximum values might suggest the presence of outliers in the dataset. Furthermore, most of the transactions include apartments of medium quality within the residential zone of Rotterdam. The average presence of green space within the buffer zone of each residence is approximately 15.7% given a radius of 100 meters and 19.7% given a radius of 300 meters. The variable *percgreen2* indicates the green are coverage in a buffer zone which stretches from 100m to 300m distance from each transaction, with a mean coverage of 20.2%.

Finally, an instrumental variable is embodied in the regression analysis to examine the presence of reverse causality effect, in a case which high transaction prices attract the development of green areas. In general, a valid instrumental variable must satisfy the following 2 conditions:

1. Instrument exogeneity: IV is unrelated with the error term ($\text{Corr. (IV, } u) = 0$).
2. Instrument relevance: IV is a good predictor of the endogenous variable (green space), ($\text{Corr. (IV, \%Green)} \neq 0$).

The presence of green areas as measured in 1911 in old maps is valued as a useful and valid instrumental variable, since it is unlikely to be correlated to the error term (does not cause endogenous variation on the dependent variable) and can act as a good predictor of present green space in a sense that predetermined green areas in 1911 are likely to remain as such in 2012.

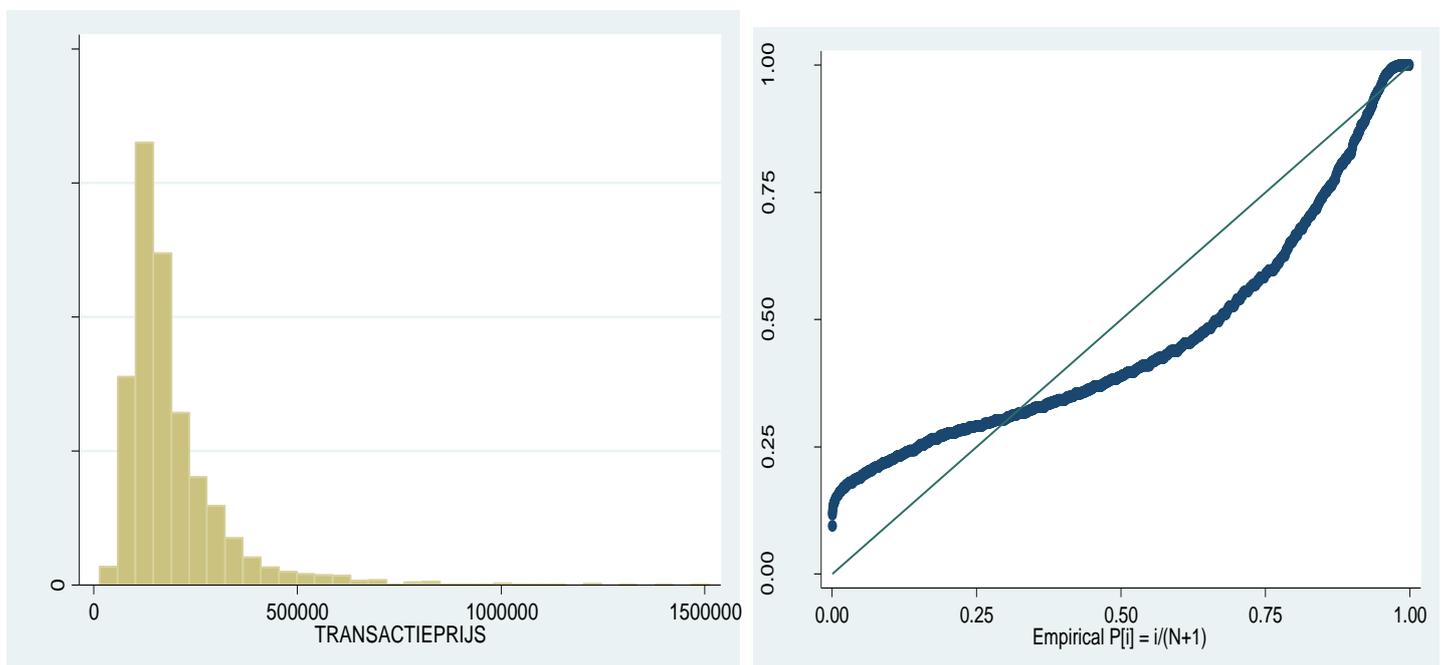
Methodology

The most appropriate method for the statistical analysis of this case study will be selected after testing the normality of distribution of the data collected, signs of heteroskedasticity (variability in residuals) and signs of collinearity between the explanatory variables.

To start with, a linear distribution demands a normality in the distribution of the dependent variables (property values): in the form $Y = (1/\sigma * (2\pi)^2) * e^{-(x - \mu)^2/2\sigma^2}$, where X is a random explanatory variable, μ represents the mean observation and σ is the standard deviation (Stat-Trek, 2016).

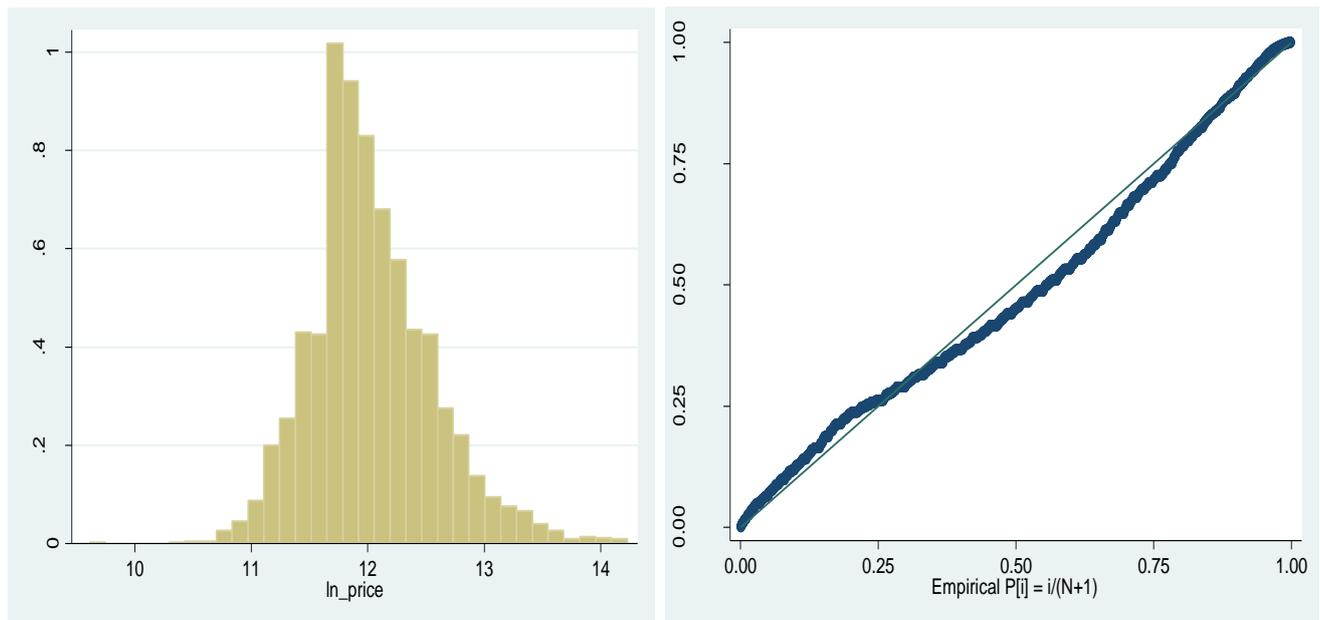
Producing a histogram and a P-P plot for the distribution of the dependent variable (house prices) in STATA, assists in assessing the normality of the distribution:

Figure 3: Histogram & P-P plot of Regression on data distribution of dependent variable (Transaction price)



The above figures illustrate a positive skewness in the observations of the dependent variable and a significant deviation from the least squares regression line, implying that the dependent variable might differ significantly from a normal distribution. Therefore, a log transformation of the dependent variable is expected to improve the normality of the distribution and thus improve the validity of the statistical analysis, as supported by relevant research (Zabel & Kiel, 2000; Morancho, 2003). The following histogram and P-P plot of the log-transformed variable illustrate an improvement in the normality of distribution:

Figure 4: Histogram & P-P plot of Regression on data distribution after the log-transformation (\ln_price)



A second threat to be eliminated for the use of a linear regression analysis, as observed through the studied literature, exists through multicollinearity: i.e. when 2 or more explanatory variables are highly related (Cho, Bowker, & Park, 2006). Multicollinearity exists, and therefore acts as a violation of the linear regression assumptions if two or more explanatory variables have a correlation coefficient greater than 0.8 (Judge, Hill, Griffiths, Lütkepohl, & Lee, 1982, p. 620). Multicollinearity between the explanatory variables can be identified through correlation and covariance diagnostics test, as observed in the following table:

Table 3: Correlations and Covariances test of the explanatory variables

	square~s	rooms	roofte~e	_parkeer	wijkcode	_noord	lnplot	percgr~3	percgr~1	Cons_p~d	garden
squaremeters	1.0000										
rooms	0.6674	1.0000									
roofterrace	0.2157	0.1115	1.0000								
_parkeer	0.3060	0.0894	0.0666	1.0000							
wijkcode	0.0760	0.1348	0.0032	-0.0098	1.0000						
_noord	0.1106	0.0413	-0.0039	0.0546	-0.5651	1.0000					
lnplot	0.5374	0.5137	0.0171	0.1440	0.4024	-0.1756	1.0000				
percgreen3	0.0349	0.1128	-0.0662	-0.0130	0.3885	-0.0913	0.2978	1.0000			
percgreen1	-0.0588	-0.0082	-0.0860	-0.0113	0.2767	-0.0078	0.0396	0.7131	1.0000		
Cons_period	0.0341	-0.0426	0.0415	0.3246	0.2219	-0.0288	0.0783	0.1399	0.1799	1.0000	
garden	0.3468	0.3396	0.0092	0.0510	0.2029	-0.0303	0.5703	0.1406	-0.0337	-0.0513	1.0000

Positive collinearity exists between the area of the dwelling and the number of rooms (0.6674); as expected, larger properties include a larger number of rooms. In addition, there is a positive relation between the percentage of green space at a radius of 300 and 100 meters (0.7131), which can be explained as a large plot of green space in proximity to each transaction can lie in both buffer zones (at 300 and 100 meters radius). In this case, the variable *percgreen2* is employed which estimates the difference between the 2 abovementioned coverages. In general, none of the explanatory variables appear to have a correlation coefficient greater than 0.8, therefore it can be concluded that there is no violation of the normality distribution due to multicollinearity.

Furthermore, the threat of heteroskedasticity exists in case of an unequal variance between the actual and predicted results of the dependent variable (transaction price). A simple procedure following a Breusch-Pagan / Cook-Weisberg test in STATA, can identify the existence of heteroskedasticity, in which case robust standard errors are used to prevent it.

Consequently, whilst threats such as non-normality in the data distribution, heteroskedasticity and multicollinearity can be identified and eliminated, it can be concluded that a linear OLS regression analysis is the most appropriate methodology for our case study. Nevertheless, it is important to use a level of log-linear regression approach to prevent such threats.

TSLS – Instrumental variable

The instrumental variable is employed in a separate regression analysis in addition to the explanatory variables as mentioned above. Relevant literature examining the effect of amenities and the social structure of cities on household income has effectively used the historical land usage as an instrumental variable, estimating that high-income households locate themselves close to high-amenity neighborhoods (Kaigne, Koster, Moizeau, & Thisse, 2017). Historical land usage in the city of Rotterdam depicts several pre-designed green areas; however, since the maps used for Rotterdam in 1911 illustrate a smaller fraction of the geographical area of Rotterdam, there also exists less information on green areas in the city. Therefore, transactions are filtered down to the amount of which information is available, in this case, 1174 observations. The instrumental variable is represented through dummy variables, indicating the presence of green areas within 2 separate buffer zones within walking distance from each transaction: at 100 and 300 meters radius.

The method used to consider the instrumental variable is a two-staged least square regression (TSLS). At first stage, a regression analysis shows the effect of pre-determined green areas (as observed through historical land usage) on the current green areas. A significant effect of historical land usage on current green space satisfies the first condition of instrumental variable validity (instrument relevance). The second condition (instrument exogeneity) cannot be statistically tested, therefore it can be assumed that if violated, the instrument is correlated to the error term, and the impact of amenities should decline since the instrument absorbs part of the bias of the endogenous variables (Arzaghi & Henderson, 2008).

At second stage, transaction prices are regressed on the predicted values of green space as regressed at the first stage, including the abovementioned explanatory variables. If the effect of green spaces as predicted through TSLS are lower than the corresponding coefficients as predicted through OLS, there is evidence of upward omitted variable bias in the OLS estimates, and therefore the case of reverse causality exists, where high-income neighborhoods attract the development of more green spaces.

Summarizing the abovementioned methodologies and dataset, it can be concluded that 3 general functions can be formed for the OLS and TSLS regression models, as in accord with the hedonic pricing model; where the dependent variable represents property values and the dependent variables represent the property's characteristics:

Equation 2: Price function for OLS regression analysis

$$\ln(\text{SalesPrice}) = f(\text{Cons. period}, \ln(\text{plot}), \text{noord}, \text{parkeer}, \text{rooms}, \text{roofterrace}, \text{squaremeters}, \text{garden}, \text{percgreen3}, \text{percgreen2}, \text{CBDDis}, \text{CBDDisgreen300}, \text{CBDDisgreen200})$$

The variables *CBDDisgreen300* and *CBDDisgreen200* estimate the interaction effect of distance to the central business district and the percentages of green areas coverage for each transaction. These variables are included to examine the effect of green space for properties located in different neighborhoods. For instance, a household further away from the center might give a higher valuation to green space than a household located in the CBD.

The first stage of the TSLS approach regresses the instrumental variable (presence of green space in 100 and 300 meters radius buffer zone) on the explanatory variables of interest (*percgreen1*, *percgreen3*). Other control variables are included in the regression to add explanatory power to the model. Therefore, the following functions are used to examine the relevance of the instrumental variable:

Equation 3: Function for first-staged results of TSLS regression analysis

$$\text{percgreen1} = f(\text{green100}), \text{percgreen3} = f(\text{green300})$$

The variables indicating the presence of green space through historical planning are expected to have a negative effect on the presence of green areas in 2012, since most of green urban areas in 1911 were reformed as part of the current residential area. Consequently, the estimates of the first stage results are included in the second stage of the TSLS. The estimates are included in a general function among other explanatory variables, as shown in the function for the second-staged TSLS regression analysis:

Equation 4: Function for the second-staged results of TSLS regression analysis

$$\ln(\text{SalesPrice}) = f(\text{Cons. period}, \ln(\text{plot}), \text{noord}, \text{parkeer}, \text{rooms}, \text{roofterrace}, \text{squaremeters}, \text{garden}, \text{percgreen1(est.)}, \text{percgreen3(est.)}, \text{CBDDis}, \text{CBDDisgreen100}, \text{CBDDisgreen300})$$

As mentioned, the coefficients for the effect of green space on transaction prices will be compared between the OLS and TSLS models to identify the possibility of omitted variable bias in the OLS model, and thus provide evidence for the effects of reverse causality.

Chapter 4 - Results & Discussion

OLS Results

The OLS regression analysis is carried out in 3 models with minor differences, as described below:

1. % of green areas within 100m radius buffer zone and % of green areas within 300m radius buffer zone are the explanatory variables of interest.
2. % difference of green areas between 300m and 100m radius is the explanatory variable of interest⁴.
3. % difference of green areas between 300m and 100m radius is the explanatory variable of interest, robust standard errors are used to eliminate heteroskedasticity.

The coefficients and significance levels are assigned next to each variable, while the standard errors are included in brackets. Overall, all 3 models show a significant positive effect of specific housing characteristics on property values, such as the construction period for recently constructed houses, the plots of land used, size in square meters, the presence of a parking place, a roof terrace and a garden, while an increasing number of rooms has an insignificant negative effect on the property value. This could be explained as households are preferred to include large open spaces instead of being separated in smaller rooms. The largest effects on prices concerning housing characteristics are indicated in the presence of a parking place (14.8% higher property values) and for newly constructed houses (24% higher values for houses constructed later than 2001; 20% higher values for houses constructed between 1991-2001).

An important distinction between households located in the North and the South can be observed since North located households entail approximately 23% higher property values. Other location characteristics can be observed by considering the distance to CBD, which has a significant negative effect of 2% for every additional kilometer distance to the city center.

The 3 models estimate some unexpected results concerning the households' preferences to green spaces. More specifically, the 1st model estimates a strong negative effect on the presence of green areas within 100 meters from a household (1% increase in the area occupied by green has a significant negative effect of 0.0026% on property values)⁵, while the presence of green areas within 300 meters from a household has also a negative but insignificant effect. Therefore, it can be concluded that for the case of Rotterdam, households value negatively the presence of green space near the property. However, preferences with respect to green area coverage might alter when considering distance to

⁴ The buffer zone starts at 100 meters and ends at 300 meters from each transaction, forming a donut-shaped buffer zone.

⁵ The expected change in Y associated with a p% increase in X can be calculated as $\beta^{\wedge} \cdot \log ([100 + p]/100)$ Invalid source specified..

the city center; therefore, the interaction effects of green coverage and distance to CBD are used to estimate this effect.

Table 4: Results for the OLS regression models 1,2 & 3

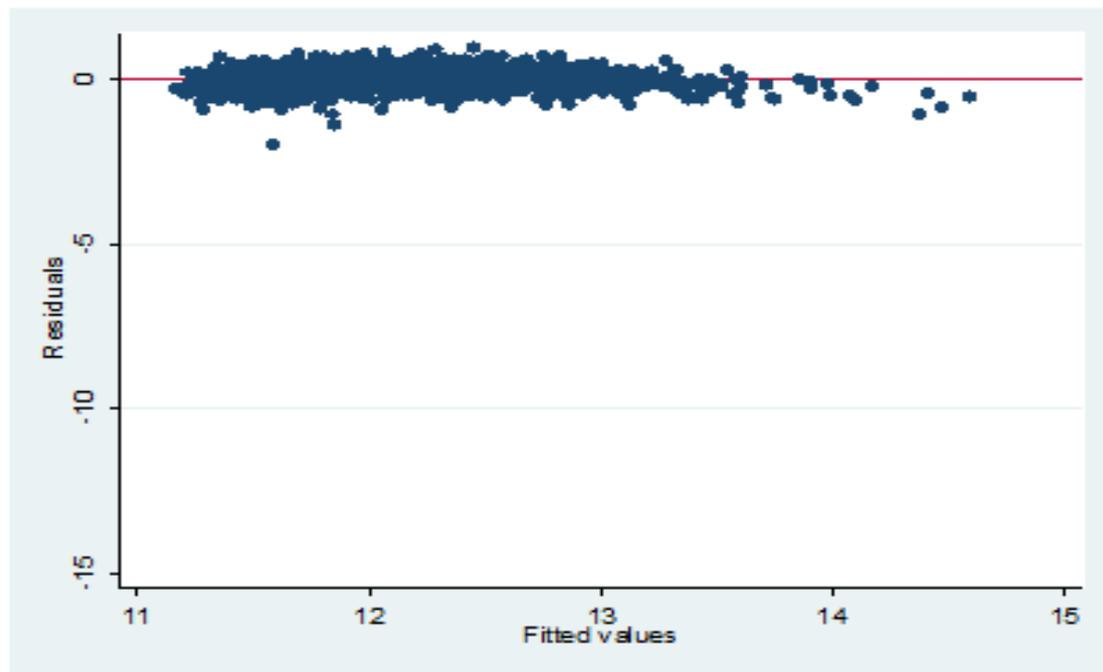
	1	2	3
	<i>Dependent variable: ln(salesprice)</i>		
	<i>OLS(1): R sq. = 0.6426</i>	<i>OLS(2): R sq. = 0.6426</i>	<i>OLS (robust)</i>
Observations:	2,667	2,667	2,667
Constant	10.91848*** (0.0459)	10.91848*** (0.0459)	10.91848*** (0.0525507)
Variable Description:			
Construction period			
_1906_1930	-0.0714712* (0.0382234)	-0.0714712* (0.0382234)	-0.0714712* (0.0452999)
_1931_1944	0.0376981 (0.0386069)	0.0376981 (0.0386069)	0.0376981 (0.0354167)
_1945_1959	0.0256078 (0.0394045)	0.0256078 (0.0394045)	0.0256078 (0.0355885)
_1960_1970	0.0328873 (0.0424062)	0.0328873 (0.0424062)	0.0328873 (0.0423041)
_1971_1980	0.0092058 (0.0430526)	0.0092058 (0.0430526)	0.0092058 (0.0372264)
_1981_1990	0.0548523 (0.0394515)	0.0548523 (0.0394515)	0.0548523 (0.034511)
_1991_2000	0.2007062*** (0.0396303)	0.2007062*** (0.0396303)	0.2007062*** (0.034007)
_2001 and later	0.2463628*** (0.0417683)	0.2463628*** (0.0417683)	0.2463628*** (0.0355897)
ln(plot)	0.0255411*** (0.0045092)	0.0255411*** (0.0045092)	0.0255411*** (0.005801)
Noord	0.2261908*** (0.0181575)	0.2261908*** (0.0181575)	0.2261908*** (0.0187239)
Parking place	0.1489966*** (0.0211369)	0.1489966*** (0.0211369)	0.1489966*** (0.0171265)
Number of rooms	-0.0078886 (0.005956)	-0.0078886 (0.005956)	-0.0078886 (0.0050899)
Roofterrace	0.044786** (0.0236054)	0.044786** (0.0236054)	0.044786** (0.0197847)
Size (square meters)	0.0089855*** (0.0002748)	0.0089855*** (0.0002748)	0.0089855*** (0.0003389)
Garden	0.0631638*** (0.0168807)	0.0631638*** (0.0168807)	0.0631638*** (0.013769)
% coverage of green areas (100m radius buffer zone)	-0.2638603** (0.1402803)	-0.2832792** (0.1280616)	-0.2832792** (0.1009644)
% coverage of green areas (300m radius buffer zone)	-0.1747701 (0.1608125)	-	-
% coverage of green areas (300m-100m buffer zone)	-	-0.1553512 (0.1429444)	-0.1553512 (0.1156987)
Distance to CBD (Km)	-0.0227548*** (0.0054123)	-0.0227548*** (0.0054123)	-0.0227548*** (0.0051469)
Interaction1 CBD Distance x % of green areas (100m)	0.0621055*** (0.023994)	0.0634378*** (0.0219686)	0.0634378*** (0.0188031)
Interaction2 CBD Distance x % of green areas (300m)	0.0119904 (0.0273094)	-	-
Interaction3 CBD Distance x % of green areas (300m - 100m)	-	0.0106581 (0.024275)	0.0106581 (0.0204708)
***= Significant at 1% significance level			
**= Significant at 5% significance level			
*= Significant at 10% significance level			

There is a significant positive effect for the interaction variables concerning distance to CBD and green area coverage within 100 meters. More specifically, for a marginal kilometer of

distance from the CBD, the negative effect of green area coverage diminishes by approximately 0.00062%. Therefore, by performing a simple calculation it can be interpreted that the negative effect of green area coverage (0.0026% decrease on property values for 1% marginal green coverage), becomes positive for households located more than 4.33 kilometers further away from the city center. Furthermore, the interaction effect of distance to CBD and green coverage within 300 meters radius is also positive but insignificant. Overall, it can be deduced that households near the city center value negatively the presence of green space within 100 meters, however this effect diminishes with increasing distance from the city center, eventually becoming positive at 4.33 kilometers. Green coverage within a radius of 300 meters from each transaction does not seem to have significant effects on property values. The interpretation of the interaction effect implies different preferences between urban and sub-urban households, or differences between the quality of green space located near the central district and the quality of green located in sub-urban areas.

A scatterplot of residuals versus predicted values for model 1 indicates whether heteroskedasticity exists, and thus the need of producing a model using robust standard errors. As it can be observed, there is a significantly constant variance in the residuals and they are estimated relatively close to 0, indicating a good predicting power of the regression:

Figure 5: Scatterplot of Residuals versus predicted values for OLS model 1



The 2nd model is performed to eliminate the effects of multicollinearity between the explanatory variables of interest. As mentioned, there is a high correlation between the presence of green space within 100 meters and 300 meters radius from each transaction point. Consequently, this model separates the 2 buffer zones by measuring green coverage up to 100 meters and green coverage starting from 100 meters and stretching up to 300 meters from each transaction. Although certain green areas might overlap in both buffer zones, the correlation between the 2 explanatory variables is expected to decrease in comparison to the 1st model. Without any significant alterations in the coefficients of other

control variables, the 2nd model estimates an even stronger negative effect for green coverage within 100 meters. More specifically, 1% increase in green coverage has a significant negative effect on property values by 0.00283% (compared to 0.0026% in the 1st model). Furthermore, there is no significant effect on green area coverage observed between a 100 and 300 meters buffer zone from each transaction. The interaction effect of distance to CBD and green coverage within 100 meters is slightly higher than in model 1; an additional kilometer distance from the city center diminishes the negative effect of green coverage by 0.00063% (compared to 0.00062% in the 1st model). Eventually, the effect of green coverage within 100 meters becomes positive at 4.49 kilometers further away from the city center.

The 3rd model further improves the precision of the OLS regression by performing an OLS with robust standard errors. By observing the results, there is no significant alteration in the standard errors compared to model 2. In general, several explanatory variables appear to have slightly lower standard errors, including the construction period dummy variables, the presence of garden roof terrace and the number of rooms, showing signs of upward bias in the standard errors of the 2nd model, while other variables have slightly higher standard errors showing signs of downward bias. However, the differences are minor, therefore no important effects are expected on the precision of the coefficients.

Finally, the explanatory power of all OLS models performed is significantly strong since the R^2 figures are close to 0.6426, indicating that a high proportion in the variations of the dependent variable can be explained through the model.

By considering all OLS models estimated, the results suggest the following equation as a predictor of property values in Rotterdam, including a set of house-specific, location and environmental characteristics as explanatory variables:

Equation 5: Predictor of ln (Sales Price) as per OLS model 2

ln(Sales Price)

$$\begin{aligned}
 &= 10.91848 - 0.0714712 x_1 + 0.0376981 x_2 + 0.0256078 x_3 \\
 &+ 0.0328873 x_4 + 0.0092058 x_5 + 0.0548523 x_6 + 0.2007062 x_7 \\
 &+ 0.2463628 x_8 + 0.0255411 x_9 - 0.2261908 x_{10} + 0.1489966 x_{11} \\
 &- 0.0078886 x_{12} + 0.044786 x_{13} + 0.0089855 x_{14} \\
 &+ 0.0631638 x_{15} - 0.2832792 x_{16} - 0.1553512 x_{17} \\
 &- 0.0227548 x_{18} + 0.0634378 x_{19} + 0.0106581 x_{20} + \varepsilon_i
 \end{aligned}$$

Where $x_1 - x_8$ = dummy variables for construction period (1906 – 1930, 1931 - 1944, 1945 – 1959, 1960 – 1970, 1971 – 1980, 1981 – 1990, 1991 – 2000, 2001 and later), x_9 = natural logarithm of plots of land used, x_{10} = Dummy variable for North, x_{11} = presence of parking place, x_{12} = number of rooms, x_{13} = presence of roof terrace, x_{14} = size in square meters, x_{15} = presence of garden, x_{16} = % coverage of green areas (100m radius buffer zone), x_{17} = % coverage of green areas (300m-100m buffer zone), x_{18} = Distance to CBD (km), x_{19} = Interaction1 CBD Distance x % of green areas (100m), x_{20} = Interaction3 CBD Distance x % of green areas (300m - 100m) and ε_i = error term.

Referring to the 1st hypothesis of this research, the OLS regression analysis suggests that the effect of green coverage within 100 meters on the property value mainly depends on the property's distance to the CBD, while there is not enough evidence that green coverage located further than 100 meters from each dwelling has a significant effect on its value. More specifically, green coverage within 100m buffer zone has a significant negative effect on property values, which eventually becomes positive if the dwelling is located at a distance of at least 4.49 kilometers from the CBD. The negative effect could imply that urban households prefer green space at some walking distance but not too close to their properties. Despite the advantages green urban spaces can offer to households such as leisure activities, aesthetics and a healthier environment, if located too close to residential areas can create an important opportunity cost of forgoing further residential expansion, education centers and shopping districts.

It is important to be critical on the fact that the coefficients and thus the effects corresponding to the presence of green spaces are weaker than other explanatory variables such as house-specific and location characteristics. There are two possible outcomes considering the abovementioned observation:

1. The possibility that according to the hedonic pricing theory, the implicit valuation of the price corresponding to environmental factors is less important for households than other characteristics as mentioned above.
2. The possibility that there exists a bias in the coefficients concerning environmental factors due to omitted variable bias.

Considering the possibility of omitted variable bias, causes of biasness such as the non-normality of the distribution, multicollinearity and heteroskedasticity have been eliminated by performing a log-linear regression analysis using robust standard errors. In addition, by comparing OLS models 1&2 to model 3, it can be observed that the robustness of standard errors has not caused large alterations in the coefficients and therefore is not a cause of omitted variable bias. Another possibility of omitted variable bias is the case of reverse causality; as mentioned in the 2nd hypothesis of this research. Consequently, the 2nd regression analysis (TSLS) is performed using the instrumental variable of historical land usage.

The following procedure also examines whether the negative effect of green coverage, as in accord with the OLS regression models, is an effect of the existence of reverse causality. Although the first assumption in the case of reverse causality is that government promotes the development of green spaces close to high value properties, in this case the opposite effect can also hold; where low value properties attract the development of higher green coverage within 100 meters radius. This effect can be explained by observing the trends in Dutch housing market, where large residential complexes are usually divided into many small apartments with low average value, located around common gardens. In this way, the development of such low value residential complexes causes the development of common gardens and thus property values correlate negatively to the presence of green coverage. In this case, a change in the sign of green coverage coefficients is expected in the 2nd stage of TSLS results.

The following figure illustrates an example of low value properties located in Rotterdam, where the common gardens between residential complexes constitute the main part of green area coverage in proximity to the properties (Erasmus Magazine, 2016):

Figure 6: Example of low-value residential complexes with common green space in Rotterdam



TSLS Results

The first stage of the TSLS regression analysis sets the green coverage within 100 and 300 meters from each transaction as the dependent variables of interest (in 2 separate models), while the explanatory variables of interest include the presence of green space within the abovementioned buffer zones in historical land usage; more specifically, by observing historical maps of Rotterdam from 1911. The first stage regression also includes a set of control variables which are expected to influence green coverage, such as the property's construction period, plots of land used, whether the property is in North Rotterdam, the number of rooms, size in m^2 , the presence of private garden and the distance to CBD.

Control variables corresponding to the property's construction period appear to have a considerable influence on nearby green coverage. In general, properties constructed between 1981 – 2012 have significantly higher percentages of green coverage than properties constructed between 1500 – 1905. Other house-specific characteristics do not seem to have a considerable influence on green area coverage within 100 and 300 meters.

Location characteristics such as the property's distance to CBD and whether the property is in the North have a significant effect on green coverage. More specifically, dwellings located North have significantly higher percentages of green coverage by 6.3% within a 100 meters buffer zone, and 9.7% within a 300 meters buffer zone. In addition, a marginal kilometer of distance from the CBD has a significant positive effect of 2.4% and 3.4% on green coverage within 100 and 300 meters respectively.

Finally, the instrumental variables which indicate whether there is a predetermined green space through historical land usage in 1911 within the two buffer zones from each transaction, appear to have a negative effect on current green coverage. More specifically, the existence of green space within a 100 and 300 meters radius in 1911 decreases current green coverage by 1.6% and 2.5% respectively; both coefficients are significant at 1%).

Table 5: Results for 1st and 2nd stage TSLS regression model

	4	5	6
	<i>Dependent variable: % of green areas (100m radius buffer zone)</i>	<i>Dependent variable: % of green areas (300m radius buffer zone)</i>	<i>Dependent variable: ln(salesprice)</i>
	TSLS(1): 1 st Stage	TSLS(2): 1 st Stage	TSLS(3): 2 nd Stage: R ² =0.7677
Observations:	1,160	1,160	1,174
Constant	-0.0212187 (0.01897)	-0.0327953 (0.0138312)	10.82729*** (0.0921451)
Variable Description:			
Construction period			
_1906_1930	-0.0317295*** (0.0095563)	0.0019281 (0.0068231)	-0.1210677** (0.0523511)
_1931_1944	0.0409405*** (0.0106498)	0.0475471*** (0.0079176)	-0.0993694 (0.0677917)
_1945_1959	0.0216095* (0.0111211)	0.0142788* (0.0075076)	0.0573299 (0.0421533)
_1960_1970	0.0252769 (0.0229484)	0.0108258 (0.0251115)	-0.0443802 (0.0621794)
_1971_1980	0.0486613** (0.0248261)	0.019869 (0.0157407)	-0.0410901 (0.0692051)
_1981_1990	0.0440428*** (0.0111074)	0.0341358*** (0.0079896)	-0.0463537 (0.056884)
_1991_2000	0.0261732** (0.0113057)	0.0162517** (0.0075136)	0.176843*** (0.0456244)
_2001 and later	-0.0030065 (0.0130027)	-0.0038933 (0.0081999)	0.2699783*** (0.0412039)
ln(plot)	-0.0014923 (0.0022978)	-0.0015322 (0.0015)	0.0056886 (0.008946)
Noord	0.0632391*** (0.0104325)	0.097371*** (0.0086029)	0.103108 (0.07559)
Parking place	-	-	0.1267134*** (0.0275026)
Number of rooms	-0.0020338 (0.0034865)	0.0045015* (0.0023095)	-0.0215843* (0.0119083)
Roofterrace	-	-	0.08631*** (0.0310834)
Size (square meters)	0.0001977 (0.0001299)	-0.0000868 (0.0000909)	0.009353 *** (0.0005496)
Garden	0.0014201 (0.0068702)	-0.0033871 (0.0045812)	0.1190434*** (0.0196887)
% coverage of green areas (100m radius buffer zone, as estimated in 1st stage)	-	-	-0.560323 (1.163235)
% coverage of green areas (300m radius buffer zone, as estimated in 1st stage)	-	-	2.885946*** (0.9340022)
Distance to CBD (Km)	0.0246068*** (0.0039137)	0.0344127*** (0.003097)	-0.0260509 (0.0416407)
Interaction1 CBD Distance x % of estimated green areas (100m)	-	-	0.3643037 (0.3100522)
Interaction2 CBD Distance x % of estimated green areas (300m)	-	-	-0.5216754* (0.2932858)
(IV1) Presence of green space (100m radius buffer zone),1911	-0.0161853*** (0.0062275)	-	-
(IV2) Presence of green space (300m radius buffer zone),1911	-	-0.0254579*** (0.0051574)	-
***= Significant at 1% significance level **= Significant at 5% significance level *= Significant at 10% significance level Models 4,5 and 6 estimated with robust standard errors			

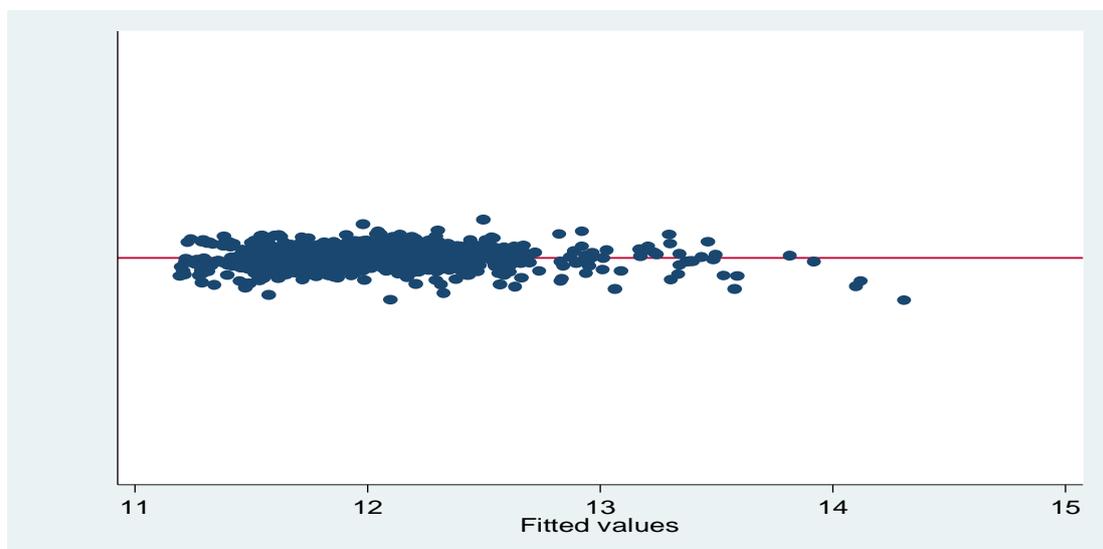
The 2nd stage of the TSLS regression analysis (model 6) estimates the effects of the predicted values of the 1st stage (green coverage) on the property sales price as the dependent variable. The control variables used in the OLS regression are also included in the 2nd stage of TSLS to add explanatory power to the model. The scope of performing a TSLS is to analyze and compare in detail the results to the OLS model after controlling for historical land usage, to identify the possible effects of reverse causality.

An important notice is that after controlling for historical land usage, variables such as location characteristics (North, distance to CBD) do not have a significant effect on property values. In addition, the number of rooms has a significant negative effect of 2.15% on property values under TSLS (significant at 10% significance level), while the effect under OLS is insignificant. The presence of garden in a property has also a larger effect after controlling for historical land usage, with a significant positive effect of 11.9%, compared to 6.3% as estimated in the OLS model.

Concerning the variables of interest, green coverage within 100 meters and its interaction effect with distance to CBD after controlling for historical land usage have no significant effect on property values, while the most important contradiction is that TSLS estimates green coverage within 300 meters to have a significant positive effect on property values: 1% increase in green coverage within 300 meters from each property implies a 0.029% increase in its value (significant at 1% significance level)⁶. Furthermore, the interaction between distance to CBD and green coverage within 300 meters has a significant negative effect on the dependent variable, as an additional kilometer from the center causes the positive effect of green coverage to diminish by 0.00522% (significant at 10% significance level). Eventually, the model suggests that at 5.53 kilometers from the CBD, households value negatively the coverage of green space within 300 meters.

A scatterplot of residuals versus fitted values is also created for the 2nd stage of the TSLS model, in which it can be observed that the model has a good predicting power (residuals are close to 0) and that the residuals have a constant variance:

Figure 7: Scatterplot of residuals vs fitted values for the 2nd stage TSLS model

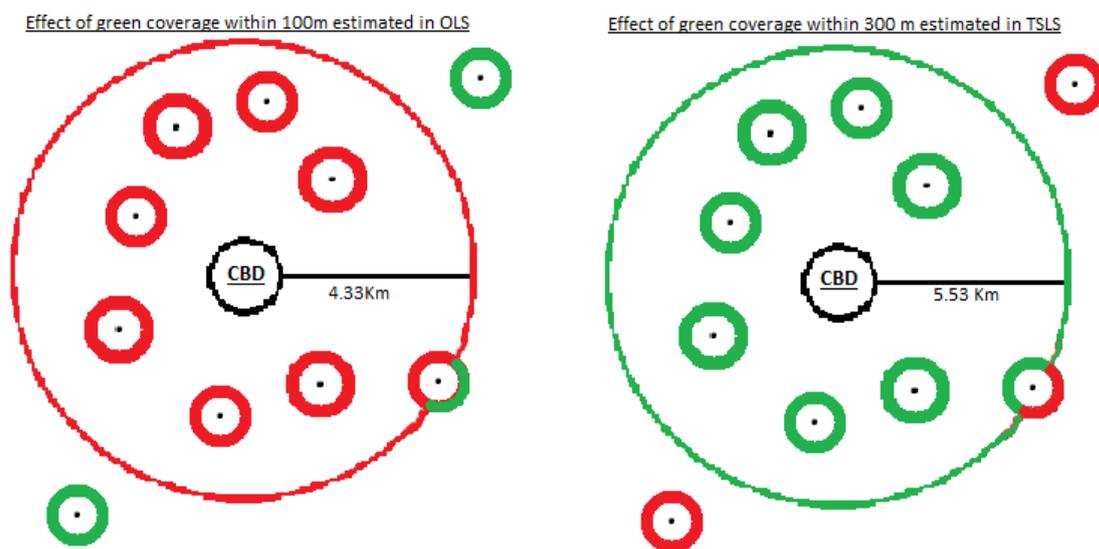


⁶ The expected change in Y associated with a p% increase in X can be calculated as $\beta^{\wedge} \cdot \log ([100 + p]/100)$ Invalid source specified..

Finally, the model fitness of the TSLS model is considerably higher than the OLS model, as by comparing the R-squared values it can be observed that the model has an R-squared equal to 0.7677, compared to 0.6426 in the OLS model. Thus, the model fitness implies a higher explanatory power after controlling for historical land usage.

The following diagram summarizes and compares the results concerning the effects of green coverage as estimated in OLS (left diagram) and as estimated in TSLS (right diagram). Negative effects on property values are marked with red color while positive effects are marked with green. The distance from the central business district at which the effect turns from positive to negative and vice versa is set as the radius of each diagram. It is important to note that the effect under OLS is for buffer zones up to 100 meters radius, while the effect under TSLS concerns buffer zones up to 300 meters:

Figure 7: Comparison of the effects of green coverage between OLS and TSLS



By examining the contradicting results of the 2 models and comparing their explanatory power, it can be assumed that TSLS manages to capture a reverse causality effect which causes a downward bias in the OLS estimates. Although the 1st stage of the TSLS regression does not achieve a high explanatory power on the dependent variables of green coverage, controlling for historical land usage creates significant changes in the effects of green coverage on property values. A logical explanation for the contradiction in the results, as abovementioned, is the typical Dutch design of dwellings, in which low value properties located in large residential complexes typically include a common green area with direct access to all ground-floor dwellings. This trend increases the percentage of green coverage within 100 meters, however mainly for low value properties. Thus, reverse causality exists between property values and green coverage, estimating a negative coefficient under OLS. On the other hand, controlling for historical land usage in TSLS causes green coverage within 100 meters to be insignificant, while green coverage within 300 meters has a significant positive effect.

Finally, it is important to note that the effect of green coverage mainly depends on the property's distance to the central business district; the effect turns from negative to positive

at 4.33 kilometers under the OLS regression, while it turns from positive to negative at 5.53 kilometers under TSLS.

Chapter 5 – Synthesis

The estimated effects attributed to environmental amenities on property values, as presented in the case study for the city of Rotterdam, should be compared to the main findings of previous literature to draw clear conclusions. Since this study is focused on environmental variables, other characteristics such as house-specific attributes are not mentioned in the present chapter. As observed in the Results & Discussion section, the TSLS regression analysis is considered to improve the precision of the coefficients provided under OLS and reduces any omitted variable bias by identifying the reverse causality effects. Therefore, the TSLS results are compared to previous empirical studies to identify any similarities or differences. At this point, it is important to note that since the majority of the studies concern specific countries/regions with large differences in the physical environment and geographical space, the external validity of the results can be controversial. Consequently, large differences in the coefficients corresponding to environmental amenities can be expected between different studies.

Firstly, many similarities can be observed between the methodology of this case study and methodologies used in previous literature: After eliminating normality threats such as multicollinearity and heteroskedasticity, a log-linear level of OLS regression is one of the most frequent methodologies used in related studies (Morancho, 2003; Zabel & Kiel, 2000; Fanhua, Haiwei, & Nobukazu, 2007). Nonetheless, some concerns may rise on the external validity of such studies, due to the differences in consumer preferences in distinct locations through which each study has been conducted. A possible solution to validate such studies externally is to limit the amount of variables used so that they are applicable internationally; thus the estimates of the effects of such variables can be used in models aimed for forecasting, to explain variations in property values regarding the corresponding environmental attributes.

The TSLS regression analysis suggests a significant positive effect of green coverage on property values; an increase of 1% in green coverage within 300 meters from each housing transaction increases the property value by 0.029%. To convert this percentage into a price premium, we consider as an example the mean property value out of 2,664 observations in the city of Rotterdam: €187,979.50. Therefore, the statistical analysis suggests an average increase of €54.50 in the property value for an increase by 1% in green coverage within 300 meters. To evaluate the effect of environmental amenities on a property's sales value, previous studies have regressed variables mainly focusing on the property's distance to the nearest green space (Morancho, 2003; Tyrväinen, 1997). The study focused in North Carelia (Finland), estimates an increase of 7.36FIM (€1.24) per square meter for a marginal 1% increase in the percentage of green within the neighborhood (Tyrväinen, 1997), while others support that *"...proximity to the green area is more relevant than its size"* (Morancho, 2003, p. 40).

Only one of the previous studies examined uses green coverage through GIS metrics as an explanatory variable on property values, revealing an increase of ¥417.78 (€54.02) for an

increase by 1% in green coverage within 300 meters radius. Despite the different geographical location (Jinan City, China), this is a considerably close measurement to the estimated premium of this research. The authors claim that *“Including both the distance to and the size of the nearest green space as independent variables in the hedonic model would result in a biased estimation”* (Fanhua, Haiwei, & Nobukazu, 2007, p. 245). In addition, this study reveals that increasing the intensity of plantations within the existing green areas depresses property values. The current research estimates a negative coefficient in the interaction between distance to CBD and green coverage; therefore, by combining these results it could be assumed that green spaces further away from the CBD have a higher intensity of plantation, and thus there is a negative effect on property values located in the suburbs.

A limited number of studies focuses in the geographical location of the Netherlands. Regressing green coverage on property values reveals positive but insignificant effects for the presence of green space within 50 meters and the percentage coverage of wooded areas and parks in the neighborhood (Visser, van Dam, & Hooimeijer, 2008). While this study does not report a price premium on property values resulting from the effect of green space, other studies focused in the Netherlands regress variables such as green and water view, revealing a premium on house prices between 6 – 12% (Luttik, 2000).

Concerning the reverse causality effect, previous literature focused in the USA, suggests higher investment in green areas for high-income neighborhoods (Landry & Chakraborty, 2009; Gould & Lewis, 2012; Apparicio, Séguin, Landry, & Gagnon, 2012; Heynen, Perkins, & Roy, 2006). Furthermore, literature using data for Dutch cities supports that *“richer households sort themselves into high amenity locations”* (Kaigne, Koster, Moizeau, & Thisse, 2017, p. 1). However, government and urban planning policies differ between countries. In the case of Rotterdam, the typical design of residential complexes appears to imply a high correlation between low-value properties and green coverage within 100 meters, as illustrated in *Figure 6*. Hence, the case of environmental injustice does not seem to have a considerable influence in Rotterdam; however, controlling for the quality of green space (diversity, size, intensity) could have provided different results. Although both low and high-income households have accessibility to green space, its quality can significantly vary between the two income groups.

Chapter 6 – Conclusion

This research attempts to apply the hedonic pricing model to evaluate the effect of green urban space on property values in the city of Rotterdam, by embodying spatial characteristics through GIS metrics in a combination of economics and spatial ecology. Through an extensive literature review and an OLS regression analysis, this study aimed to answer its proposed research question:

- ***To what degree do environmental amenities increase house prices and to what degree are amenities sorting in expensive neighborhoods?***

According to relevant studies examined in the literature review, it can be concluded that some of the most important attributes regarding environmental amenities which influence property values include the property's distance to the nearest green urban area, as well as the total coverage of the corresponding areas. Case studies which exclusively focused in the effects of such attributes revealed a negative relationship between increasing distance to green areas and property values (Morancho, 2003; Tyrväinen, 1997; Luttik, 2000); while establishing a positive relationship between green coverage and property values (Fanhua, Haiwei, & Nobukazu, 2007). The concept of environmental injustice has been cited in several studies, supporting that environmental amenity developments mainly occur in high-income neighborhoods (Apparicio, Séguin, Landry, & Gagnon, 2012; Gould & Lewis, 2012; Heynen, Perkins, & Roy, 2006).

The use of GIS metrics in the case study for Rotterdam, aims to set a spatial overview of the allocation of green spaces in a strictly urban environment, and identify their influence on nearby property values. Consequently, the statistical analysis of this research explores the effect of green area coverage within 100 and 300 meters on individual property values. The OLS regression results reveal a negative effect of green coverage within 100 meters on property values, while the effect of coverage within 300 meters remains insignificant (*Table 4*). However, after controlling for historical land usage through a TSLS regression model, the results reveal a positive effect for green coverage within 300 meters, while the effect is insignificant at 100 meters radius (*Table 5*). The contradicting results reveal a reverse causality effect of property values on green coverage, due to the typical design of Dutch residential complexes: Low value properties are designed to have access to low-quality common green space (*Figure 6*: Example of low-value residential complexes with common green space in Rotterdam).

The statistical analysis models used in this study capture several characteristics which have explanatory power on the variability of property values (house-specific features, location and neighborhood characteristics). The inclusion of an interaction effect which combines distance to the central business district and green coverage has rarely been observed in previous studies, and thus differentiates this research from previous literature. Other variables such as accessibility to public transport, education institutions and shopping centers are also expected to influence property values, therefore the omission of such variables is therefore expected to act as a limitation. Additionally, even though the buffer

zones selected for measuring green coverage are in accord to previous empirical studies, a higher variability of buffer zones (within walking distance) could improve the results and add explanatory power to the model.

Research on the economic and ecological valuation of urban green space in comparatively limited in the Netherlands. The use of GIS metrics in evaluating the effect of urban green space can be implemented to target specific locations in the city of Rotterdam, and thus improve the positive social benefits of relevant investments. Most of the current green space developments in Rotterdam are focused on the Northern part of the city, as it can be observed in the spatial allocation of Rotterdam's *Community Gardens* (EuroCities, 2013). Therefore, future policies for Rotterdam promote the development of green space in the South, to transform the area into a more attractive residential destination for future households (Rotterdam Climate Initiative, 2013). According to the statistical analysis, it can be observed that the Northern part of Rotterdam is an attractive destination for high-income households, since North located households entail approximately 23% higher property values. Consequently, further investment in development of urban green space in the Southern part can benefit both low and high-income residents through the creation of jobs and the attraction of high-income households in the South.

For further research, variables indicating the quality of urban green space can be included in a statistical analysis to further distinguish the differences in allocation between low and high-income neighborhoods. The positive impact of green coverage on property values implies that an equilibrium of urban green space should be available at any location.

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Appendix

Figure 8: Rotterdam maps 1911 (Klokan Technologies GmbH, 2017)

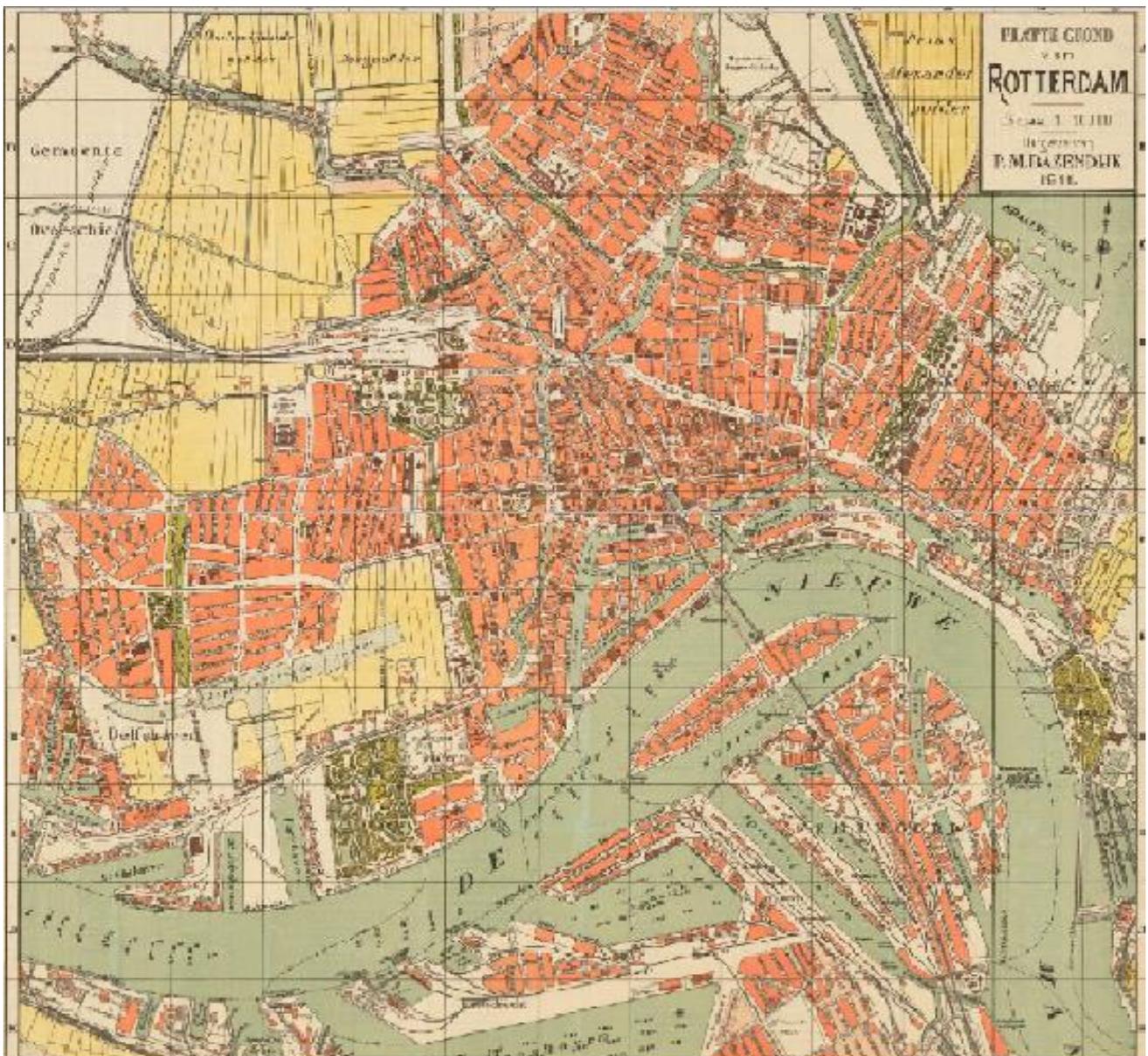


Figure 9: OLS regression (model 1) STATA output

Source	SS	df	MS	Number of obs = 2,634		
Model	527.127718	20	26.3563859	F(20, 2613)	=	234.94
Residual	293.133125	2,613	.112182597	Prob > F	=	0.0000
				R-squared	=	0.6426
				Adj R-squared	=	0.6399
Total	820.260843	2,633	.311530894	Root MSE	=	.33494

lnsalesprice	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	-.0714712	.0382234	-1.87	0.062	-.1464224	.00348
_1931_1944	.0376981	.0386069	0.98	0.329	-.0380051	.1134014
_1945_1959	.0256078	.0394045	0.65	0.516	-.0516594	.1028749
_1960_1970	.0328873	.0424062	0.78	0.438	-.0502657	.1160404
_1971_1980	.0092058	.0430526	0.21	0.831	-.0752149	.0936265
_1981_1990	.0548523	.0394515	1.39	0.165	-.0225072	.1322117
_1991_2000	.2007062	.0396303	5.06	0.000	.1229963	.2784161
_2001enlater	.2463628	.0417683	5.90	0.000	.1644605	.3282651
lnplot	.0255411	.0045092	5.66	0.000	.0166992	.034383
_noord	.2261908	.0181575	12.46	0.000	.1905862	.2617953
_parkeer	.1489966	.0211369	7.05	0.000	.1075498	.1904434
rooms	-.0078886	.005956	-1.32	0.185	-.0195675	.0037904
roofterrace	.044786	.0236054	1.90	0.058	-.0015011	.0910731
squaremeters	.0089855	.0002748	32.70	0.000	.0084466	.0095243
garden	.0631638	.0168807	3.74	0.000	.0300629	.0962647
percgreen1	-.2638603	.1402803	-1.88	0.060	-.538932	.0112114
percgreen3	-.1747701	.1608125	-1.09	0.277	-.4901028	.1405627
CBDDis	-.0227548	.0054123	-4.20	0.000	-.0333675	-.012142
CBDDisgreen100	.0621055	.023994	2.59	0.010	.0150564	.1091546
CBDDisgreen300	.0119904	.0273094	0.44	0.661	-.0415598	.0655407
_cons	10.91848	.0459	237.88	0.000	10.82848	11.00849

Figure 10: OLS regression (model 2) STATA output

Source	SS	df	MS	Number of obs = 2,634		
Model	524.570625	17	30.8570956	F(17, 2616)	=	273.00
Residual	295.690218	2,616	.113031429	Prob > F	=	0.0000
				R-squared	=	0.6395
				Adj R-squared	=	0.6372
Total	820.260843	2,633	.311530894	Root MSE	=	.3362

lnsalesprice	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	-.078914	.0381125	-2.07	0.038	-.1536476	-.0041804
_1931_1944	.0254893	.0386158	0.66	0.509	-.0502313	.1012098
_1945_1959	.0081283	.0393611	0.21	0.836	-.0690538	.0853104
_1960_1970	.0116122	.0421716	0.28	0.783	-.0710809	.0943053
_1971_1980	-.0209361	.0426574	-0.49	0.624	-.1045818	.0627097
_1981_1990	.0350739	.0393235	0.89	0.373	-.0420345	.1121823
_1991_2000	.1798653	.0394339	4.56	0.000	.1025405	.2571902
_2001enlater	.2167447	.0412717	5.25	0.000	.1358162	.2976732
lnplot	.019128	.0042378	4.51	0.000	.0108182	.0274378
_noord	.2424092	.0178695	13.57	0.000	.2073694	.2774491
_parkeer	.1527791	.0211971	7.21	0.000	.1112143	.1943439
rooms	-.0078304	.0059738	-1.31	0.190	-.0195442	.0038835
roofterrace	.0424184	.0236163	1.80	0.073	-.0038902	.088727
squaremeters	.0090154	.0002753	32.75	0.000	.0084756	.0095552
garden	.0632251	.0169261	3.74	0.000	.0300351	.096415
percgreen2	-.1469218	.0944614	-1.56	0.120	-.3321485	.0383048
CBDDisgreen200	.0001079	.012264	0.01	0.993	-.0239403	.024156
_cons	10.84985	.0433346	250.37	0.000	10.76488	10.93482

Figure 11: OLS regression using robust standard errors (model 3) STATA output

Linear regression	Number of obs	=	2,634
	F(17, 2616)	=	333.66
	Prob > F	=	0.0000
	R-squared	=	0.6395
	Root MSE	=	.3362

lnsalesprice	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	-.078914	.0440576	-1.79	0.073	-.1653053	.0074773
_1931_1944	.0254893	.035264	0.72	0.470	-.0436589	.0946375
_1945_1959	.0081283	.0356019	0.23	0.819	-.0616824	.0779391
_1960_1970	.0116122	.0435974	0.27	0.790	-.0738766	.097101
_1971_1980	-.0209361	.0375887	-0.56	0.578	-.0946427	.0527705
_1981_1990	.0350739	.0347157	1.01	0.312	-.0329991	.1031469
_1991_2000	.1798653	.034098	5.27	0.000	.1130035	.2467271
_2001enlater	.2167447	.0355035	6.10	0.000	.1471269	.2863625
lnplot	.019128	.005597	3.42	0.001	.0081531	.030103
_noord	.2424092	.0190507	12.72	0.000	.2050533	.2797652
_parkeer	.1527791	.0171245	8.92	0.000	.1192001	.1863581
rooms	-.0078304	.0051455	-1.52	0.128	-.01792	.0022593
roofterrace	.0424184	.0196891	2.15	0.031	.0038106	.0810262
squaremeters	.0090154	.0003363	26.81	0.000	.008356	.0096748
garden	.0632251	.0138625	4.56	0.000	.0360426	.0904076
percgreen2	-.1469218	.1108311	-1.33	0.185	-.3642473	.0704037
CBDDisgreen200	.0001079	.0125112	0.01	0.993	-.0244249	.0246407
_cons	10.84985	.048641	223.06	0.000	10.75447	10.94523

Figure 12: First stage TSLS regression, dependent variable % of green within 100m (model 4) STATA output

Linear regression	Number of obs	=	1,160
	F(15, 1144)	=	11.51
	Prob > F	=	0.0000
	R-squared	=	0.1331
	Root MSE	=	.08615

percgreen1	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	-.031589	.009585	-3.30	0.001	-.0503951	-.0127829
_1931_1944	.0408594	.0106685	3.83	0.000	.0199273	.0617915
_1945_1959	.0214832	.0111649	1.92	0.055	-.0004228	.0433893
_1960_1970	.0246096	.0225967	1.09	0.276	-.0197261	.0689452
_1971_1980	.0486201	.0247462	1.96	0.050	.000067	.0971732
_1981_1990	.0440435	.011148	3.95	0.000	.0221708	.0659163
_1991_2000	.0257801	.0113559	2.27	0.023	.0034994	.0480609
_2001enlater	-.0042645	.0126169	-0.34	0.735	-.0290194	.0204905
lnplot	-.0013854	.002304	-0.60	0.548	-.0059058	.0031351
_noord	.0637956	.0104882	6.08	0.000	.0432174	.0843738
rooms	-.0018355	.0034641	-0.53	0.596	-.0086321	.0049611
squaremeters	.0001738	.0001234	1.41	0.159	-.0000683	.0004158
garden	.0017307	.0068439	0.25	0.800	-.0116973	.0151587
CBDDis	.0246488	.003916	6.29	0.000	.0169654	.0323322
Green100	-.0162981	.006219	-2.62	0.009	-.0285001	-.0040961
_cons	-.0209603	.0190092	-1.10	0.270	-.058257	.0163365

Figure 13: First stage TSLS regression, dependent variable % of green within 300m (model 5) STATA output

Linear regression		Number of obs	=	1,160		
		F(15, 1144)	=	17.78		
		Prob > F	=	0.0000		
		R-squared	=	0.2495		
		Root MSE	=	.06351		
percgreen3	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	.0017766	.0068093	0.26	0.794	-.0115836	.0151368
_1931_1944	.047711	.0079126	6.03	0.000	.0321862	.0632359
_1945_1959	.014436	.0075015	1.92	0.055	-.0002823	.0291542
_1960_1970	.0116445	.0255839	0.46	0.649	-.0385521	.061841
_1971_1980	.0199393	.015739	1.27	0.205	-.0109413	.0508199
_1981_1990	.0341257	.0079583	4.29	0.000	.0185113	.0497401
_1991_2000	.0166982	.0074966	2.23	0.026	.0019895	.0314068
_2001enlater	-.0025006	.0076257	-0.33	0.743	-.0174624	.0124613
lnplot	-.0016555	.0015013	-1.10	0.270	-.0046011	.0012902
_noord	.096692	.0086247	11.21	0.000	.07977	.113614
rooms	.0042871	.0022806	1.88	0.060	-.0001875	.0087617
squaremeters	-.0000611	.0000865	-0.71	0.480	-.0002309	.0001086
garden	-.0036978	.0045731	-0.81	0.419	-.0126704	.0052749
CBDDis	.034367	.0030957	11.10	0.000	.0282932	.0404409
green300	-.0252377	.0051339	-4.92	0.000	-.0353106	-.0151647
_cons	-.0331314	.0137775	-2.40	0.016	-.0601635	-.0060993

Figure 14: Second stage TSLS, dependent variable ln (sales price) (model 6) STATA output

Linear regression		Number of obs	=	1,160		
		F(20, 1139)	=	107.00		
		Prob > F	=	0.0000		
		R-squared	=	0.7677		
		Root MSE	=	.22828		
lnsalesprice	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]	
_1906_1930	-.1210677	.0523511	-2.31	0.021	-.2237831	-.0183523
_1931_1944	-.0993694	.0677917	-1.47	0.143	-.2323801	.0336413
_1945_1959	.0573299	.0421533	1.36	0.174	-.0253769	.1400368
_1960_1970	-.0443802	.0621794	-0.71	0.476	-.1663792	.0776188
_1971_1980	-.0410901	.0692051	-0.59	0.553	-.176874	.0946937
_1981_1990	-.0463537	.056884	-0.81	0.415	-.1579628	.0652555
_1991_2000	.176843	.0456244	3.88	0.000	.0873257	.2663603
_2001enlater	.2699783	.0412039	6.55	0.000	.1891342	.3508225
lnplot	.0056886	.008946	0.64	0.525	-.0118639	.0232411
_noord	.103108	.07559	1.36	0.173	-.0452033	.2514193
_parkeer	.1267134	.0275026	4.61	0.000	.0727521	.1806748
rooms	-.0215843	.0119083	-1.81	0.070	-.044949	.0017803
roofterrace	.08631	.0310834	2.78	0.006	.0253229	.1472971
squaremeters	.009353	.0005496	17.02	0.000	.0082746	.0104314
garden	.1190434	.0196887	6.05	0.000	.0804132	.1576736
est_percgreen1	-.560323	1.163235	-0.48	0.630	-2.842646	1.722
est_percgreen3	2.885946	.9340022	3.09	0.002	1.053388	4.718504
CBDDis	-.0260509	.0416407	-0.63	0.532	-.107752	.0556503
CBDDisest_percgreen1	.3643037	.3100522	1.17	0.240	-.2440339	.9726413
CBDDisest_percgreen3	-.5216754	.2932858	-1.78	0.076	-1.097116	.0537656
_cons	10.82729	.0921451	117.50	0.000	10.6465	11.00809