Mixed Land Use in the Urban Environment

Exploring the impact of physical diversity on residential property prices in Rotterdam

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Preface

It has been a long journey with a few intermezzos in which I put this thesis aside. Notwithstanding the times that I could not bring up to take action and go forward, still the excited feeling of setting up an own research process had the upper hand. A process that ended with this work now in front of you. What I liked most were the days I spent with the program of Quantum GIS, searching for the right tools and determining the required steps in order to explore and edit the huge dataset on land-use information of the municipality Rotterdam. My intention is now to learn more about this rich program with its broad possibilities and applications.

I would like to thank some persons. First of all my parents who were very patient and kept encouraging me and made it possible to follow this study at the first place. Also thanks to my brothers Jordy and Ingmar together with Wendy and Monique who also were involved and showed their interest. In particular Ingmar who offered me to read all the jumble of ideas that I had during my orientation phase so that I could actually start with some grip to hold on and, later during the process, really understood the difficulties and the situations I sometimes got into.

Thank you Jeroen van Haaren for your supporting role as supervisor. The meetings we had and the exchange of ideas, though this may sound contrary considering the long time it sometimes took for me to send my work, kept me enthusiastic and offered me new insights in how to approach the research.

Then my friends Herman and Jelle for the good times we had and still have; I can call myself lucky with such roommates. Thanks for the support and for letting me work on your computer and laptop on "occasion".

Also thanks to the department of Rotterdam for providing me the needed data. I hope this work returns the favor (a Dutch version of the summary shall be sent shortly).

And finally, I find myself, honestly speaking, in a state of both relief and satisfaction.

Hope you enjoy reading this paper!

June, 2015

Summary

This cross-sectional study explores what impact mixed land-use and individual land-use types have on residential property prices per square meter (N=2488, year: 2012) in a subarea within Rotterdam, the Netherlands. Mixed land-use here is defined as "*the combination of land-uses on spatial basis through the allocation of different types of uses to contiguous land-plots*". In particular the physical dimension of these uses is considered: the way they are locally experienced by residents in the urban environment. The method applied is a hedonic regression (run by STATA) with municipality fixed effects and heteroskedasticity-robust standard errors clustered at the neighborhood level in order to partly resolve the problem of positive spatial autocorrelation among residuals. The models control for average house characteristics, socio-economic features and accessibility variables on the block level. Land-use information obtained from the municipality is edited and operationalized with Quantum Geographic Information Systems (QGIS). The observations are the centers of blocks and land-use information is aggregated within buffer areas with radii of 100 meters around the centers to represent the direct living environment which residents perceive on a daily base. Physical mix is characterized by calculating indices of entropy (measure of dispersion and dominance) and fragmentation (edge-to-interior ratio) that include the elements green, water, open space, infrastructure, parking space and build-up area.

Results indicate that physical mix and pattern of mix are in general not considered as relevant factors in explaining residential property price per square meter within the research area (with the two sub-municipalities "Kralingen-Crooswijk" and "Charlois" forming the exceptions). Some individual physical elements of the mix actually have a significant effect. Water bodies have consistently a positive effect and also the presence of an urban park within 500 meters of a block is positively valued. Little green parcels of land, on the contrary, are not relevant natural elements through the eyes of residents. Parking space negatively affects residential property price per square meter. When a concentric ring of another 100 meters is included in the analysis, infrastructure land-use becomes a negative factor in the first 100 meters. An increase in amount of public open space increases price per square meter.

These findings can be useful for urban planners and developers in Rotterdam (or other comparable cities) as scarce space can be used more efficiently in terms of extracting higher rents per square meter dwelling. Moreover, supply of living environments will be more in accordance with (potential) residents' demand.

Chapter 1 - Introduction

Cities always have been, or are by definition, diverse with their broad supply of facilities, jobs and amenities. However, with her famous books ‘The Economy of Cities’ and ‘The death and life of great American cities’ Jane Jacobs was one of the first to introduce the idea of diverse locations in terms of primary functions of living and working at the smaller scale (Koster & Rouwendal, 2012). She opted for mixed neighborhoods in order to be socially and economically vital and sustainable for both the local communities within these neighborhoods and the city as a whole (see TNO, 2009).

Throughout the urban economics and regional science study field this idea of spatially mixing functions is broadly referred as the concept of **mixed land-use**. This paper focuses on another dimension than functional mix and which is often overlooked but inextricably bound up with mixed land-use: diversification in physical appearance, i.e. how the environment looks like through the eyes of residents. Especially from a resident’s point of view this is a relevant aspect because of the daily perception they have of their living environment. So, there are several ways to interpret the term “mixed land-use” (see chapter 2) but, in short, this paper deals with mixed land-use at the physical dimension thereby distinguishing between physical elements like water, green and infrastructure.

In the Netherlands “… where land is seen as scarce and the need is felt to improve spatial quality[1], ‘mixed land-use’ has become a highly popular concept in discourses on spatial planning” (Lagendijk, 2001, p. 145). Governmental bodies have direct influence on the allocation of land plots and distribution of different land-use functions through zoning regulations and pro-active land policy[2]. It is therefore a powerful tool for these organizations in achieving a multitude of

[1] The term spatial quality is generally related to the valuation of land, which can be measured by various aspects related to various disciplines (like environmental or economics). Deducted from the discussion of Lagendijk (2001) spatial quality means in the context of this research the extent to which functions embedded in land plots are in such a way characterized that interactions between and combinations of activities and people are fostered so that space is used efficiently and effectively and thereby more valued.

[2] In the Netherlands cities extensively apply the public land development strategy. Some government organization, like a municipality, first buys and owns developable land and decides what purpose it should fulfill before it is sold again (with profit) to an appropriate party (mostly private sector) that eventually carries out the actual development (van der Krabben & Jacobs, 2013).

policy goals (van der Krabben & Jacobs, 2013) and, in particular, they can determine the degree and composition of “the mix” on a local basis. Gaining knowledge about how people experience and value mixed environments is therefore very useful for these organizations.
Investigating the topic of mixed land-use is worthwhile for municipalities and cities that encounter problems related to congestion, stagnation of the real estate market and deprived neighborhoods. For instance, the city of Rotterdam states that it is striving to become more attractive as a place to live, work and visit. This part of the strategy is connected with a presumed insufficient match of supply and demand (especially higher-educated people) in the housing market (particularly with regard to the urban habitat) (Stadsvisie Rotterdam, 2007). This paper provides insight in residents' choices relating to the physical living environment in which their place of residence is located. Such insight would support urban spatial planning aiming for attracting and retaining (potential) residents. At the moment there is actually a situation in which this insight can be put into practice. Because of a spatial shift of port activities to Maasvlakte 2 in recent years, some land plots are ready for (re)development (Stadsvisie Rotterdam, 2007). If the municipality has the intention to convert these plots to (predominantly) residential areas then there exist a potential of extracting higher rents at these locations by meeting people's demands regarding their preferred living environment.

A substantial amount of research is devoted to factors affecting the price of property, including accessibility to centers of activity and infrastructure networks, as well as socio-economic characteristics within and across spatial units of analysis like neighborhoods. On the other hand, the impact of “mixed environments” on more abstract defined variables like crime and disorder (Sampson & Raudenbush, 1999; Cahill, 2004), social cohesion (Talen, 1999) and local “buzz” or liveliness (Mehta, 2007) has been researched. Research on the relationship between mixed environments and the price of local housing units is scarcer. While diversity in employment sectors (functional mix) within the neighborhood area has effect on property values (Van Cao & Cory, 1982; Song & Knaap, 2004; Koster & Rouwendal, 2012), less is known about the analogous impact of mixed living environments in terms of physical appearance of the different elements (land-uses) that comprise the area under consideration. The basic thought is that in search of a home in the urban area people consider the representation of the living environment as one of the location factors.

This paper will seek to answer the following question:

What effect does mixed land-use have on residential property prices?

Several steps and pieces of information are needed to give a proper answer to the main research question. First of all, the relevance of the concept of mixed land-use (MLU) from an urban economics perspective should be made clear. What theoretical insights are provided by the literature that would promote mix? Another related but more specific issue is how the (possible) relationship between diversity in the physical urban environment and prices of residences can be explained. Why would a more diverse living area create a premium (or discount) on house prices? This study builds on previous research on the relationship just outlined and compares results (in a different way and/or context) so that statements about generality of the findings can be made.

The following sub-questions are formulated:

Sub-question 1: Why would mix affect urban attractiveness?

Sub-question 2: Why would mix affect price levels of dwellings?

Sub-question 3: What are the effects of different land-use patterns and land-use mix on residential property prices in Rotterdam?

There are only a couple of studies that investigate the effects of variations in urban physical habitats on residential property price. The study performed by Geoghegan et al. (1997) revealed that local diversity and fragmentation (the extent to which the landscape is divided into many land-plots) influence property values. The work of Baranzini & Schaerer (2011) shows that diversity in land-uses has an effect on rents but that the effect depends on the way diversity is constructed: diversity in the built environment has a negative effect and diversity in the natural environment does not have an effect (only total surface and total view of natural elements combined positively affect rents).

This paper aims to add to these scarce contributions in three ways. First of all, previous mentioned studies were taken in the region around Washington DC and Geneva, Switzerland respectively: two entirely different areas. The focus on another type of city like Rotterdam as a case study is worthwhile because it provides new empirical evidence to the subject of matter.

The second way in contributing to the literature has to do with the method of how to approach the relationship. Although straight line distance variables regarding land-use types have been used on regular base, the *aggregation level* on which spatial specific variables, such as land-use surface and diversity, are measured is a crucial and relatively new part of the debate (Acharya & Bennet, 2001). One-dimensional type of measuring (distance) is applicable for place-specific kind of features (amenities and stations for example) which can be approached as points in space. But when it comes to measuring effects of land-uses forming polygons in the urban environment, two-dimensional measurement within a predefined area of focus is more proper (Geoghegan et al., 1997). Besides the consideration of whether to use administrative boundaries or fixed radii around observations as spatial units of analysis, there is the choice of corresponding size. Especially in dense urban areas where personal space is small, the environment that would matter for residents likely encompasses the area which they can see from their place of residence and experience and use on a daily basis. In this same line of thought, Acharya & Bennet (2001) used a quarter of a mile to proxy for that area that is within residents' sight and one mile to capture the area that is within average walking distance from someone's home. Geoghegan et al. (1997) choose in a similar way their areas of focus by aggregating at 100 meters and, "to capture the scale issue", a larger radius of 1 kilometer. Koster & Rouwendal (2012) use a radius of 500 meters in their main analysis, because they expect that the effects of mixed land-use are very local[3]. But up to what distance from the house is the area considered as 'local'? Here, the general analysis is taken place at a distance of 100 meters and subsequently extends with the use of a concentric ring of 100 meters around the first buffer to see if there is a shift in valuation of different land-uses and mixed land-use.[4]

[3] They did however checked for robustness of the results by employing buffer sizes of 300 and 700 meters; no significant different effects of diversity and most of the considered land-use categories were detected.

[4] This paper has also looked at buffer sizes of 50 and 200 meters. Results are presented in the appendix.

Lastly, specific land-use types will be part of the mix which often are neglected as elements in urban areas possibly affecting residential property prices: land occupied by infrastructure and parking space. These are quite important land-uses because they stand for internal/external accessibility and mobility and make on average great part of the urban fabric. At the same time such necessary land-uses spill over negative side effects, such as noise and pollution, which make these uses interesting components in urban planning schemes.

This paper is arranged as follows. To make clear what is meant by the term “mixed land-use”, the next chapter will first discuss several concepts involving mix and subsequently provides the working definition used in the context of this research. The purpose of chapter three is twofold. Firstly, theoretical arguments are given for mixing land-uses in the urban area. Second, connections of MLU and elements of the mix with residential property price are clarified; what explanations are there for residents’ appreciation towards the physical appearance of living environments. Chapter four deals with the methodology as applied, construction of the models and variables used. Then chapter five will present the generated results together with interpretations of the findings. Chapter six concludes, discusses the shortcomings of this paper and gives recommendations for future research.

Chapter 2 – Mixed land-use concepts

Mixed land-use concepts come in several forms and therefore are not very well understood or defined (Hoppenbrouwer & Louw, 2005; Yang, 2008). Some scholars even suggest these are ambiguous because they supposedly offer benefits in various ways but on grounds of several mechanisms (Rowley, 1996; Lagendijk, 2001). This chapter first gives a quick review of related concepts involving some type of mixing within urban environments. Then it sets out the working definition that is suitable and on which assumptions this definition is restricted in light of the current research.

The name of the concept indicates that it consists of two components. **Land-use** is *the way in which land functions or appears*, e.g. in public areas. Generally, public organizations and governmental bodies allocate parts of land (land plots) and assign functions to these or arrange them, which together create the "landscape" of blocks, neighborhoods, municipalities, cities and regions. The term **mix** in general points to *a unity that consists of multiple and different elements combined*. Combining these two components implies **mixed land-use** is:

- *A setting where land-uses* (the elements) *form combinations on a spatial basis through the allocation of different types of uses to contiguous land-plots*. -

One way of approaching the concept of MLU is looking at functions and facilities that buildings contain and supply, i.e. functional mix. Therefore, it is typical for urban environments. In Song & Knaap (2003, 2004) and Koster & Rouwendal (2012) distinction is made in <u>type of sector</u> which determines what constitutes the mix accordingly. They categorize land-uses into public institutional/governmental, leisure, commercial, industrial, and of course residential. The combination and distribution of different facilities in an area defines the nature of the local mix: predominantly residential with the rest of the land devoted to recreation (typical for areas in the urban fringe) or residential land-use combined with retail and public organizations (center area character).

Grant (2002) more or less follows the same approach of land-use functions but disentangles the phenomenon of mixing into three conceptual levels. The first level concerns increasing the intensity of uses. Supply of more differentiated forms of some specific land-use type is central at this level. Good examples that fit in this type of mixing are variations in forms and tenures of housing in a community.

Grant's second level is perhaps best associated with the mixed land-use concept in the context of this research: increasing the diversity of uses by encouraging a compatible mix. The degree of compatibility, i.e. the likelihood of conflict, between different land-use types adjacent to or in close proximity from one another is an important factor at this level of mixing. This issue is discussed in more detail in the next chapter. The author also points to the possibility of synergy effects arising from interactions between complementary uses. So this level also partly overlaps with the multifunctional land-use concept (see textbox).

The third level is about integrating segregated uses seemed incompatible, mostly in areas that predominantly serve the residential function. Land plots serving industrial activity are the most obvious that are subject to zoning regulations because of pollution, noise and bad scenery for surrounding residences (Hoppenbrouwer & Louw, 2005).

Another way of interpreting mixed land-use is taking the whole environment into consideration: the buildings and all space between the buildings. Although the build-up area takes a prominent role as physical element in the urban landscape, the urban experience encompasses more than that. As opposed to functional mix that focuses on urban functions and facilities, physical mix focuses on urban form and includes the various elements out of which every environment comprises. The underlying factor that characterizes this type of mix is view of those elements. Amount of view instead of presence of or proximity to particular land-uses like water and green are increasingly part of hedonic analysis (Baranzini & Schaerer, 2011).

Table 1: Three main definitions of concepts involving mixing land-uses (see box 1 for a supplementary discussion)

Sources	Definition	Scale	Type/measurement	Categories
Van Cao & Cory (1982); Song & Knaap (2003, 2004); Koster & Rouwendal (2012)	Mixed land-use	Neighborhood	Sector and employment mix, relative balance between (service) jobs and residents/households	Single and multi-family residential, commercial, public institutional, industrial, public parks and leisure
Rowley (1996); Grant (2002); Hoppenbrouwer & Louw (2005)	Mixed-use development	Various	Social mix and (in)compatible functional mix	Abovementioned + households and house-types
Vreeker et al. (2004); Louw & Bruinsma (2006); Vreeker (2008), see also Lagendijk (2001)	Multiple (or multifunctional) land-use	Primarily within buildings (also neighborhood), time	Complementary (economic) activities, synergy effects	Agglomeration and cluster economies

Box 1: Differentiation in mixed land-use concepts

Apart from the main research two other concepts that involve some form(s) of mixing land-uses shall be discussed in this textbox.

The first one is called 'mixed-use development' and works at a broad context. This concept has many definitions (Mashhoodi & Berghauser Pont, 2011) and still needs to be theoretically and empirically substantiated (Rabianski et al., 2009). But there are some facets that frequently appear at the surface. The first one aims, next to 'functional mix', for a 'social mix' as well. An important role here is assigned to differentiation within the residential land-use function. By encouraging a mix of housing types and tenures, proponents of the mixed-use development concept suggest, a desirable differentiated group of residents and renters of different household types is attracted. This would engender prosperity into the neighborhood by means of social interaction and community forming.

Rowley (1996) brings forth a conceptual model of mixed-use development that includes texture, scale or setting (from within buildings to districts and neighborhoods), location (from city center to suburban and green-field locations) and approach (from conservation to redevelopment). The internal texture refers to the quality and presentation of a land plot and grain (manner of mixing), density and permeability (possibility of mixing) are key features. Also according to Hoppenbrouwer & Louw (2005) the particular scale whereat mixed-use development is applied to is deterministic for the concept. Different scales are used and referred to in various papers dealing with mixed-use development (see for some examples Hoppenbrouwer & Louw, 2005, p. 971; Rabianski et al., 2009, p. 207) which indicates that this concept is possibly applicable at multiple spatial scales or that it is indeed lacking in definition. To make clarity in this, Hoppenbrouwer & Louw (2005) expand Rowley's (1996) model and develop a typology for mixed-use development that distinguishes between several dimensions: shared premises, vertical, horizontal and time. Then they combine the dimensions with the scales (building, block, district and city) and features of texture to make clear which relations between the two determinants are most likely to occur (p. 974).

Another more recently developed and discussed concept finds its origins in the economic field: multifunctional (or multiple) land-use. Multifunctional land-use is a "successor" of the mixed land-use concept but also not yet proper defined (Louw & Bruinsma, 2006). The concept appeared in the late 1990s in Dutch spatial planning and had the intention to overcome increasing problems related to shortcomings of supplied space through triggering synergy effects of different uses placed in close proximity (Vreeker et al., 2004; Vreeker, 2008; Rodenburg et al., 2011). The crux lies in finding those activities (engendered by land-use types) that complement each other such that their combined presence would create more output than in case those activities were separated. This focus on synergy-effects clearly makes multifunctional land-use stand apart from the other concepts (Vreeker et al., 2004). A good example of putting into practice this type of mixing is clustering different types of businesses that can share knowledge and assets.

In practice this concept is also promoted at the premises level, where several activities can be performed simultaneously or in sequence. Space in a building might be used for education during the day and meetings in the evening. This inclusion of the time dimension forms a second aspect that multifunctional land-use dissociates from the other concepts dealing with mixing land uses (Louw & Bruinsma, 2006).

Considered the purpose of identifying the effects of land-use mix and elements of the mix on residential property price, and this is related to the compatibility aspect regarding residential land-use, makes it that Grant's (2002) second level of mix is most applicable in respect of the research question.

In this paper the term mixed land-use will be referred to as mixing physical elements that different land-use types contain across land plots and not within single plots of land (shared premises). High-rise buildings contain multiple functions in the vertical dimension, but here only the horizontal dimension is considered because (1) the dataset only consists of surface data and (2) the scope lies in how land-use is presented to people, not on detailed information regarding facilities and employment within high-rise buildings. The land plot beneath a particular building facilitates in this case the space for the entire building structure which will be ascribed to a main land-use type, like build-up area or building.

Chapter 3 – Mixed land-use: theoretical foundations and evidence

This chapter first discusses the presumed benefits and possible drawbacks associated with the concept of mixed land-use (in theory) by means of a systematic literature review. Then in the next subsection a switch is made from theory to practice by reviewing studies that empirically explore whether and to what extent different land-use types and diversity within urban environments have an effect on residential property prices.

§ 3.1 – Foundations of mixed land-use

The mixed land-use concept has an important role in contemporary urban development movements in North American and European cities (see the introductory part for a short overview). It emerged as reaction to post World War II town planning that was influenced by the international movement of Congrès Internationaux d'Architecture Moderne (CIAM). This movement laid the focus on segregation of the four common uses: housing, employment, recreation and transport (see Hoppenbrouwer & Louw, 2005; Mashhoodi & Berghauser Pont, 2011). Urban sprawl, a well-known phenomenon that is subject in the research field of urban planning and development, is ascribed to this kind of planning (see Vreeker et al., 2004). According to Lagendijk (2001) this mono-functional use of space falls short compared to mixed land-use, both in quantitative and qualitative respect; quantitative, because with mixing land-uses (scarce) space is more efficiently used[5]; qualitative, because benefits accrue from increased land valuation (this shall be dealt with in the next paragraph).

Jane Jacobs (1961) was a key proponent of mixed-use development as opposed to segregation of uses. She opted for diverse neighborhoods that should contain living, working and service functions placed in a fine-grain manner so that there are many alternatives at each point in space. The reasoning is that this would serve as catalyst for the supply of different activities and with that a vast group of people being concentrated together performing those activities. In addition, demand

[5] Although this also depends on building adaptability (see March et al., 2012).

for other (secondary) functions arises, mostly retail, catering facilities and cultural facilities. This mixing of functions that show different patterns in time of usage elicits active streets throughout the whole day what in turn creates more opportunities for people to socially interact with one another. All these localized effects should lead to an increase in vibrancy and vitality of neighborhoods (see Hoppenbrouwer & Louw, 2005; TNO, 2009). Even an increase in safety is considered to be an effect[6]. Jacobs defined four preconditions an area must hold for generating the required (balanced) diversity in order to trigger the above mentioned chain reaction[7]. Actually, three of those preconditions (more than two primary functions, short blocks and a dense concentration of people, including residents themselves) are just mentioned. The fourth precondition points to a mingling of buildings which vary in age and condition.[8]

The combined effects just outlined could be categorized as one of the two major objectives mixed land-use (and mixed-use development) aims for, namely **(economic) vitality** at the neighborhood scale. The second aims for a **change in the general modal split** in and around mixed-use areas. When multiple functions or facilities are spatially gathered, activities can be done within walking distance so to speak. Accordingly, less travel distance and less number of trips are required resulting in decreasing needs for traveling by car and increase the probability someone chooses to walk, bike or use some mode of public transportation (Hoppenbrouwer & Louw, 2005; Vreeker, 2008; see also Grant, 2002). This in turn has secondary effects like people getting more exercised and some environmental benefits like reduced air pollution (Heath et al., 2006).

All these (positive) effects with their secondary effects in general are taken for granted (Hoppenbrouwer & Louw, 2005) and make mixed land-use sound as the solution to all kinds of typical urban related problems like congestion, deprivation and crime. It is of course legitimate to question if these mentioned effects, and especially the secondary effects, are attributed to an

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[6] Jacob's Street Control Model explains the working of neighborhood monitoring through a constant flow of "eyes on the street" by residents and business owners in mixed-use settings. For a more detailed discussion on this topic, see Browning et al. (2010).

[7] For the exact formulations, see Rowley (1996, p. 88); Rabianski et al. (2009, p. 205-206) or, for a comprehensive discussion in Dutch, TNO (2009).

[8] This is a good example of Grant's (2002) first level of mixing that more emphasizes with the concept of mixed-use development.

environment that is mixed to a certain degree. For example, Jackson (2003) points to the lack of substantiated evidence for mixed land-use being the cause of increased physical activity and the question whether this goes hand in hand with reduced car trips.

Besides taking into question the assumed benefits there are some arguments actually against mixed land-use. Certain uses bring forth, besides the fulfillment of their main function, additional “products” through the activities that they engender. These are called externalities (Geoghegan et al., 1997; Taleai et al., 2007) and can be transferred to adjacent land as well. They can be (experienced) positive, like sense of urban living emanating from terraces. On the other hand, externalities can be negative as well. Some examples include noise, bad aesthetics, pollution and congestion. In addition, Lynch (2000, p.92) brings the discussion to the personnel level by stating that too much diversity leads to an abundance of supply which results in urban stress (in Hoppenbrouwer & Louw, 2005, p. 969). So although mixed land-use has several (presumed) benefits, negative effects might dominate behind a certain level of building intensity or density (Vreeker, 2008) assuming positive effects have diminishing marginal utility and negative effects are proportional to quantities of the land-use that produces the externalities.

Taking notice of the discussed effects of mixed land-use and the fact that the concept involves allocating different types of land-uses at the smaller scale (with the accompanied characteristics and effects on their surroundings), the degree of compatibility between the functions of land plots, i.e. what constitutes the mix, thus contributes greatly to the concept’s effectiveness. Moreover, compatibility is necessary especially for the second major objective of MLU. Efficient streams of people performing their daily activities while using other modes of transport than the car is likely to be achieved if adjacent (or proximate) land-uses are complementary in such a way that they fit in people’s daily schemas.

Mixed land-use is thus in theory beneficial for neighborhoods by functioning as a catalyst that fosters local (economic) activities at close range (and discourages the use of a car), thereby generating lively streets during all parts of the day (with assuming secondary effects like safety and more healthy people). In addition scarce urban land would be used more efficiently opposed to segregation of different land-uses. However, negative spillover effects might dominate behind some threshold level of intensity and this effect should be taken into account.

§ 3.2 – Valuation of mixed environments and elements of the mix

Now that we have discussed the reasoning behind the concept of mixed land-use from a pure urban planning point of view, we can carry on by exploring what is known about residents' preferences for mix. While the benefits in the subsection above are to a large extent based on theories, identification of tangible and measurable effects would justify the consideration of mixed land-use concepts in urban planning schemes. As Lagendijk (2001) pointed, MLU is also beneficial in qualitative respect through increases in land-use valuation by residents. Besides standard factors like physical characteristics of a property and location, people also take into account the (direct) living environment surrounding the property (Geoghegan et al., 1997). These considerations show that with transactions in the housing market people actually are buying a piece of living environment in addition to the house itself (Acharya & Bennet, 2001; Andersen & West, 2006; Hui et al., 2007). And the more the living environment is in accordance with the desired demand the higher the associated quality of the area and the more people are willing to pay for it. So the benefits of mixed land-use discussed here are counted via positive impacts on residential property prices.

Putting aside the question whether MLU has an effect on residential property prices or not, in order to understand the meaning of this effect it must be clear what impact individual types of land-uses, which are part of the mix, have and the reasons why these are of influence. If it is the case that people value a mixed (living) environment that supplies at least some specific facilities to certain degrees then this would have total different implications for designing and adapting the urban landscape than when people just value a heterogeneous (living) environment per se. Thus, an overview of residents' preferences regarding different types of land-uses shall be presented first.

Valuation of land-uses

Residents within or close to the city center likely considered the advantages (e.g. broad supply of goods and services) against the disadvantages (e.g. density and congestion). However, people's preferences about the direct living environment gradually changes through the life cycle (McCarthy, 1976). The point is, in almost every case of location decision, choices are to be made which leads to giving up or accepting less of some attribute(s) in the eventual living environment. People actually pay for desirable living areas, especially if these become scarce (Geoghegan et al., 1997). If some less common positively valued element is added, it would lead to a higher upgrade in valuation of the area in question than if some element already present in abundance is intensified. Therefore, elements expected to boost residents' appreciation towards their living environment are those that are generally scarce in urban neighborhoods but valued at the same time. Typical (natural) land-uses that are valued because they are less present or absent in dense areas are open space (Fausold & Lilieholm, 1999), green spaces (Cho et al., 2008) and water surfaces which indeed are not the typical landscape elements found in urban environments. In fact, these type of land-uses are relevant urban environmental elements to incorporate (or not) in land-use policy because they have to be considered against the choice for housing development in the context of increasing populations and urban expansion (Luttik, 2000; Anderson & West, 2006).

What is actually known concerning presence and amounts of different land-use types and their effects on residential property price? Several main types shall now be discussed in this context.
In this paper a distinction is made between green spaces and open spaces[9], although in multiple these two are together classified as open space (among them Fausold & Lilieholm, 1999; Anderson & West, 2006; Cho et al., 2008; Bartholomew & Ewing, 2011; Brander & Koetse, 2011). Results of these studies regarding the impact on residential property price are somewhat mixed. This is likely due to methodological issues like the various settings in which these studies took place and the way green open space is specified (Bartholomew & Ewing, 2011; Brander & Koetse, 2011). Anderson & West (2006), for example, find heterogeneity in value for proximity to open space (two specific types of parks, golf courses and cemeteries) when controlling for size, population density, income and multiple other neighborhood characteristics.

[9] The reason for this is that green pieces of land are more natural (looking) and provides more opportunities for recreation than open spaces like pathways and squares, which in turn look more unnatural and more having the purpose of walking space.

Ordinary green spaces (e.g. strips) have either no significant (Hui et al., 2007) or in some cases a positive impact (Luttik, 2000). Urban parks form a special type of green (open) space because besides their appearance of a green area for properties nearby they are associated with recreational opportunities for a wide public producing noise. For the same reason Baranzini & Schaerer (2011) find a positive impact on rents in Geneva, Switzerland of total surface of urban parks but a negative impact of the amount of view on an urban park within one kilometer. Luttik (2000) however, is less conclusive in determining whether parks in vicinity influence property price at all. Wrapping up these findings may suggest that people prefer an area with many small parcels of green to one that has few large plots of green (see Cho et al., 2008).

Water is a less common land-use type in cities and "… is [therefore] a highly prized element in the [urban] landscape" (Kaplan and Kaplan, 1989, in: Luttik, 2000, p. 166). Just like other typical natural environmental land-use types, water gives residents a pleasant feeling and relieves them from urban stress (Baranzini & Schaerer, 2011). Accordingly, this type of land-use increases home values or rents if situated nearby (Luttik, 2000; Baranzini & Schaerer, 2011).

Infrastructure is an interesting land-use. This is because the supplied facility (transportation) by far does not correspond to the land it covers (rail lines, roads). In other words, it is not possible to start making use of the facility at every point in space where transportation functions but only at certain locations: the stations or highway ramps. These locational access points are linked with accessibility and proximity to other places of economic activity, like the city center.

While effects of access points have been studied broadly over the years (more on this in the subsection "controlling for accessibility" in the methodology section), very little research is conducted on the impact of a view at and presence of infrastructure on the value of close-by residences. Strand & Vågnes (2001) find a ten percent increase in property price in Oslo when distance to a railroad line doubles within a 100 meter boundary. The study conducted by Kilpatrick et al. (2007) concludes that in case the benefits of location nearby access points of transit corridors are absent (very hard or impossible to reach) proximity to railroad tracks has a negative impact on housing values.

Similarly, the levels of negative externalities produced by the users of infrastructure are good proxies for determining the impact of the presence of infrastructure land-use[10]. Andersson et al. (2010) confirm the expected negative impact on property prices of both road and railway noise in a municipality in western Sweden. Brandt & Maennig (2011) find the same for the effect of road noise on the prices of condominiums in Hamburg and in addition detected a disproportional increase in discount by rising noise levels (i.e. as distance to a road decreases).

Some studies distinguish between the presence of some environmental attribute in the neighborhood and the actual view of that particular attribute (Luttik, 2000; Baranzini & Schaerer, 2011). Indeed, lacking incorporation of variables that indicate visibility of specific environmental attributes causes to under- or overestimate the impact of different land-use covers on housing prices (Paterson & Boyle, 2002; Cavailhès et al., 2009). "Interestingly, Cavailhès et al. (2008) do not only consider the landscape seen from the house, but also the view that others have of this house. They find that individuals are willing to pay a premium for a house with a view, but that being exposed to the view from other houses lowers its price. Moreover, they conclude that view has a greater influence on real-estate value than mere land-use around the property." (Baranzini & Schaerer, 2011, p. 193).

Since this research is at a very local scale, most part of the living environment under consideration is assumed to be within sight from the place of residence. But the distinction in mere presence and actual sight of particular types of land-uses may be accounted for when interpreting the upcoming findings.

What general conclusions can be made from the literature review regarding effects of various land-uses on residential property price? Natural elements in the urban landscape are rare and positively valued and so translated in higher residential property price. Among them are green (open) spaces in some cases and water bodies. Distinction between presence and actual view of a land-use type might be of relevance though. Housing prices can drop if located within sight of other residences.

[10] Maybe it is the best way to capture the effects of infrastructure because noise pollution might be more of relevance for residents than just the presence of it. Compare a situation where infrastructure is close but not in sight to a situation in which infrastructure is located at some distance and still in sight but noise is negligible.

Infrastructure is valued positively only if the access points are in proximity, otherwise the negative externalities dominate and causes housing prices to decrease.

Valuation of mixed land-use

Empirical research about the connections of residents' preferences and mixed environments in general is scarce. There are some examples of studies that focus on functional mix mainly applied to the built environment. Van Cao & Cory (1982) find for neighborhoods in the city of Tucson, Arizona increasing residential property values when there is, over low ranges, an increase of non-residential land-use (i.e. industrial, commercial and public land-use) and multi-family land-use. Similar results come from a study conducted in neighborhoods of Washington County, Oregon. Provided that single-family residential land-use makes out the majority, an even distribution of above mentioned land-use categories leads to increasing housing prices (Song & Knaap, 2003, 2004). Lastly, constructing degree of mix on the base of employment data instead of land-use characteristics, Koster & Rouwendal (2012) conclude that households in general value diverse neighborhoods positively in a radius of 500 meters.

Less research is done on diversity measured within the physical environment dimension. Geoghegan et al. (1997) construct two types of landscape indices, called "diversity" and "edge to interior ratio" (fragmentation, more on this in the methodology), which they measure at radii of 0.1 and 1.0 kilometer around houses located within 30 miles from Washington DC. At both distances they found no significant effects on housing prices for the two types individually, though the impact was jointly significant at the 10-percent level (the smaller buffer) and the 0.005-percent level (the larger buffer). Baranzini & Schaerer (2011) distinguish between two dimensions in which diversity can take place and measure these indices based upon view and surface levels (radius of 1 kilometer) of land-use. For both types of measurement the researchers find negative effects of built environment diversity on rents but insignificant results for natural land-use diversity.

It seems that people in general do not appreciate a heterogeneous local living environment (Geoghegan et al., 1997). Regarding mix among housing types Yang (2008) suggests that residents need some level of homogeneity at smaller scales will they appreciate diversity of housing supply at a greater distance. The same mechanism might be at work for diversity within the physical environment so that an ordered and recognizable environment is favored over a chaotic scene.

To summarize this part, functional mix seems to have a positive overall impact on residential property price. Residents of dense urban areas give up personal space with the expectation of being close to various facilities (employment sectors). The same positive associations towards physical mix do not necessarily hold. Landscape fragmentation and nature of the mix (what types of elements are considered as parts of the mix) are relevant factors in this relationship.

§ 3.3 - Conclusions

Mixed land-use is a multi-faceted concept (see chapter two) but is basically a situation where contiguous land-plots differing in usage or form are combined on a spatial basis. The concept can be applied to several interrelated dimensions which makes it flexible to apply but less of use regarding measuring tangible effects like changes in residential property prices. Although mixed land-use is mostly being connected with functional mix, it does bring physical mix as well. This is because different functions embedded in land-uses also differ in their appearance.

When it comes to the mixing of functions and facilities supplied in and around residential areas, theory complements empirical findings about what people value in their neighborhood. Functional mix at the local scale contributes to convenience in performing daily activities and socializing within perceived neighborhoods.

There is tendency to state that people do not consider the degree of physical mix at particular scales but the way it is mixed (fragmented or not) might be a factor. Also the different elements that constitute the mix matter. Residents like to reside close to water bodies and, to a lesser extent, green and open spaces and are willing to pay for those natural elements in their direct living area. The factor of view is in some cases deterministic for the nature of the effect of different land-use elements.

Chapter 4 – Methodology

While the former two chapters provided the theoretical framework and supportive background research, this chapter moves on to the methodology behind the analysis and operationalizes the data before the empirical analysis can start. More specifically, in this section a description of the method used is presented together with the construction of the models and the variables included. Then a discussion about how to measure "mix" is held. Also some specific methodological issues which this analysis encounters are mentioned. Finally a description of the data used and the specific research area are given.

§ 4.1 - The Hedonic Pricing Model

In urban economics a substantial amount of research is devoted to the valuation of all sorts of elements and phenomena throughout the urban fabric by urban actors, like residents. The best known method in determining the influence, or better magnitude, of these *location factors* on location decisions of residents is through analyzing revealed preferences with property transaction prices as dependent variable in a hedonic pricing model. An application of Rosen's hedonic model (1974) treats a house as a bundle of features, each feature contributing to (or regressing) the house value (see for example Baranzini & Schaerer, 2011). The basic model has the following form:

$$Y = a + b*x + e$$

In which Y is the dependent variable, "a" is a constant term, "x" is the independent variable for which "b" is the coefficient and "e" is an error term. This basic hedonic model can be adjusted to the various variables that are part of the analysis. These shall be discussed first before the above model is converted in the proper form for this research.

Controlling for house characteristics

House characteristics form without a doubt the primary set of factors people care about and evaluate accordingly in their search for a new home and these specific factors have therefore been investigated and controlled for in a substantial amount of studies (see for the most used characteristics Sirmans et al., 2005; Sirmans et al., 2006). The meta regression analysis conducted by Sirmans et al. (2006) confirmed that square footage/lot size, age and number of (bath)rooms are among the house characteristics which effects on house price have not changed over time. These shall be included in the analysis.

Controlling for socio-economic features

In their concluding remarks Miles & Song (2009) recommend to control for social dimensions, such as income or crime rates, when analyzing the effects of "physically good" neighborhoods on quality of life as experienced by residents. This is because these so-called good neighborhoods in terms of connectivity, accessibility, density and mix vary in social respect. According to the authors effects of the built environment on housing values would be over- or underestimated if variations in the social dimension are not accounted for.

Rohe & Stewart (1996) and, albeit somewhat reserved in their concluding remarks, Ding & Knaap (2002) observe that homeownership rate is positively correlated with residential property values. Assuming residents care about their living environment and the proportion of rental housing in a neighborhood is positively correlated with deterioration of the neighborhood living environment (Wang et al., 1991), it is intuitive to say that the amount of rental housing units relative to owner-occupied housing units has a negative impact on property prices of the owner-occupied houses. Additionally, rental units are in general less well-maintained. An explanation could be that the flow-through is more volatile within the rental-housing market than within the occupied-housing market. Renters have less incentive to take care of their rental units because they stay a shorter amount of time and get less attached to their living environment (see Wang et al., 1991). Visser et al. (2008) did research to residential environment determinants (physical environment, locational and socio-economic) of house prices in the Netherlands. They noticed that when social status and ethnicity composition of the neighborhood were included, the effect of proportion of rental housing in that same neighborhood almost disappeared. Following the discussion by Rohe & Stewart (1996) it is much likely the case that socio-economic characteristics of people and households (e.g. social status, income, composition, ethnicity) to some degree cohere with tenure status and housing form (e.g. attached, rent, owned). This said and given that this research does not have access to data regarding most of these relevant socio-economic characteristics of residents on a local level, information on the percentage of rental housing together with proportions of several dwelling types like multifamily housing (data which is available on the block level) are good proxies in representing the socio-economic dimension. Accordingly most part of the presumed effects of socio-economic characteristics on residential property prices is still accounted for.

Controlling for accessibility and proximity

Theory about the valuation of location reflected in land values go back to the sixties at the hand of Alonso, among others, with his *bid rent model*. It states that the land price gradient with the city center as reference point (i.e. monocentric city) is negative, which means that locations tend to decrease in value when distance increases to the central point of economic activity (see for example Debrezion et al, 2007; Hess & Almeida, 2007). However, the relationship has gotten more complicated in contemporary cities because they have become polycentric (see Hui et al., 2007), i.e. multiple locations of economic activity exist across the entire urban area (from the formal center to the outer urban fringe). Frew & Wilson (2002) found decreasing house values in Portland, Oregon as distance increases from the city center as expected. But housing values increase again (albeit to lesser heights) at locations closer to beltways where suburban centers are formed. So overall, the slope of the line which presents the effect of distance to the city center on property price is downwards but at intermediate points (the sub centers) the line shows sub optima.

Other locations that are intertwined with accessibility and proximity to economic activity are (railway) stations. Research on this topic is too substantial to deal with in order to justify railway stations to control for accessibility or proximity factors. Fortunately, Hess & Almeida (2007) did an extensive literature review of studies examining the relationship between rail station access and residential property value[11]. The majority of the results indicate positive effects and this is especially the case with houses located nearby, although the nature of this effect in some cases is reversed when the station is too close. This effect is explained by negative externalities, like noise, congestion (of people or cars) and bad view aesthetics, which are at work at very close rate. In addition, also crime related activity has effect on the impact (Bowes & Ihlanfeldt, 2001). The same

[11] I also would like to refer to the meta-analysis done by Debrezion et al. (2007).

pattern of effects at various distances is noticeable if locations of highway ramps relative to houses are considered (see Frew & Wilson, 2002).

Table 2: Selection of variables controlling for residential property price

Source	**Factor**	**Presumed effect**[a]
Sirmans et al. (2006)	*House characteristics*	
	Size	Positive
	Age	Negative
	Number of rooms	Positive
	Locational accessibility	
Frew & Wilson (2002)	Distance to city center	Overall negative
Frew & Wilson (2002)	Distance to highway ramp	Positive for small distances, negative for greater distances
Hess & Almeida (2007)	Distance to light and heavy rail transit stations	Negative (positive at very close rate)
Luttik (2000); Baranzini & Schaerer (2011)	Distance to park or some other form of recreational opportunity	Uncertain
	Socioeconomic	
Waddell et al. (1993)	Distance to health related services	Negative
Wang et al. (1991)	Percentage of rental housing	Negative

a: A negative effect of a "distance-to variable" implies that when distance increases (decreases) property value would decrease (increase).

So taking the above discussions into account, residential property prices are likely reflecting the preferred choices made by residents with regard to properties of their house, socio-economic environment and location of their house relative to other locations (table x shows an overview of selected control variables). In addition, with the same line of reasoning, attributes related to the direct physical living environment, like degree of mix, might also be part of this bundle of choices and hence deterministic in explaining variations in residential property prices across space. In order to include variables representing diversity into the model, conceptualization of these types of variables is required first.

§ 4.2 - Construction of a 'mix-variable'

In order to investigate whether there is an effect of physical mix on residential property price, a numerical value that indicates the "degree of diversification" of housing units' surrounding areas is needed. There is, not surprisingly, no universal way for measuring diversification in general, because of the specific adaptation in various contexts and relevance in various disciplines (see Geogeghan et al., 1997; Song et al., 2013), and urban landscapes in particular. As will be made clear, different measures lay focus on different aspects, like pattern, spread and dominance, that all can say something about the appearance and nature of an area. Several measures are outlined first before the proper way(s) of measuring physical mix is chosen.

Song et al. (2013) compare and classify fourteen ways of measuring urban land-use mix and explain their strengths and limitations as to give guidance to future research in choosing the appropriate type of measure when dealing with spatial data. Through an analysis of 1000 simulations and a real life case (City of Hillsboro in Metropolitan Portland) they test the statistical relationships between the measures. Two critical context related pieces of information are required in order to choose the right type of measure. First, distinction is made between balance of land-use types within an area as a whole (integral measure) and evenness in land-use distributions among subdivisions (divisional measure). So it is necessary to determine at what scale mix should be measured and if the value is to be compared to some reference area. Secondly, the number of different land-uses considered in the mix is of relevance. In case one or two distinct land-uses are examined, a single-dimensional measure is appropriate (with two land-uses that exclude each other out, information of only one land-use is required to deduct the missing information of the other land-use). In case more than two land-uses are part of the analysis, a multi-dimensional measure is required.

In this paper six types of land-use will be part of the measured mix. This is more than the threshold level of two which indicates the use of a multidimensional measure. Although comparison is made between living environments to the extent they are mixed and what effect this brings about on residential property price, it is of no interest to compare them to the total research area. All the measured mix-values extracted from the buffer areas around housing units are to be linked to accompanying property prices.

Taking note of the assumptions and the specific context related information of this research Song et al. (2013) recommend using the Entropy Index. Entropy is a measure of variation, dispersion or diversity (see Song & Knaap, 2004). This index finds its origins in the biology field and is also known as the Shannon diversity index. It was developed to measure degree of dominance of species but has started in being used in ecological economics as well (see Geoghegan et al., 1997). It is calculated by the following formula:

$$\mathrm{ENT} = -\left[\sum_{j=1}^{k} P^{j} \ln(P^{j})\right] \Big/ \ln(k)$$

Entropy Index (Geoghegan et al., 1997; Baranzini & Schaerer, 2011; Song et al., 2013)

where k is the number of different land uses included and P is proportion of land-use j compared to the total area covered by the buffer. The index takes on a value between 0 and 1.

Another measure that is possible to use considering the abovementioned discussion is the Herfindahl-Hirschman Index. It is a commonly accepted way of measuring market concentration (see Song et al., 2013) at the hand of the following formula:

$$\mathrm{HHI} = \sum_{j=1}^{k} (100 * P^{j})^{2}$$

Herfindahl-Hirschman Index (Song et al., 2013)

Also here is k the number of different land uses included and P the proportion of land-use j compared to the total area covered by the buffer. Because proportions are multiplied by 100 and then squared, the value ranges from 0 to 10,000 but rescaling is possible such that the minimum would be 1/k (which is reached in case there is an equal distribution of all land-use types) and the maximum would be 1 just like the Entropy Index.

According to Song et al. (2013) this measure is interchangeable with the ENT-index[12]. Moreover, all the integral measures show very similar values. The two indices look especially at *dominance* and are therefore sensitive to the size of the particular land-use most present (Geogeghan et al., 1997; Song et al., 2013).

Both the Entropy Index and the Herfindahl-Hirschman Index only take proportions of land-uses into account. So no information about how an area is spatially arranged is given accordingly. The edge-to-interior ratio (also fragmentation index) actually does possess this possibly relevant aspect of **pattern** in analyzing landscape diversity. It is calculated as follows:

$$R = \sum \frac{P_i}{A_i}$$

Edge-to-interior ratio (Geoghegan et al., 1997)

Where P = perimeter length, A = area of interior, i = land cover type. It measures the degree to how land-use coverage is spatially distributed in an area. Holding the total amount of a particular type of land-use constant, an increase in total parameter length of that same land-use type means that this type is divided into more individual parcels of land scattered across space: the landscape under consideration is thereby more fragmented as other land-use types more intervene. The ratio uses other parameters than the ENT-index and is therefore complementary and not subject to multicollinearity. In order to account for a more complete representation of the physical environment the models include both an index measuring diversity (based on entropy) and one that measures fragmentation of the landscape.

With the help of Quantum Geographic Information Systems (QGIS), an open source program for handling (spatial) data, information on land-use is edited and aggregated at fixed buffered areas around locations of observations (see the appendix for the different steps during the working process with the program). In this paper degree of mix is calculated based upon buffers with radii of 100 meters (a relatively small geographical area if we were to follow Song and co-writers) so

[12] An alternative regression model with HHI is run and revealed a similar effect

problems around averaging out of land-use patterns and the sensitivity of larger areas apparently looking more mixed (Song et al., 2013) are not likely to be that much present.

§ 4.3 – Data, model constructions and research context

Description of the dataset

In this research the tax-value (in Dutch: WOZ-waarde, *Waardering Onroerende Zaken*) as determined by the Rotterdam municipality is used as proxy for residential property price. The natural logarithm of average tax value per square meter of houses within a certain block (lntaxvaluem2) is chosen as dependent variable instead of the total absolute tax value or absolute value per square meter. The choice for measuring the dependent variable as proportion to square meters is because then there is no need to deal with a possible heterogeneous distribution of magnitudes across blocks with varying average house size. The advantage of transforming the variable of interest with a natural logarithm is at least twofold. Extreme values of the dependent variable are tempered and a more flexible interpretation of the results is possible as effects are measured in percentages change.

The dataset available provides information about the *averages* of age and number of rooms for a group of houses aggregated on the *block level*.

Also on block level there is information on the proportions of rental housing units and several dwelling types available.

Because the research area (see below) does not contain main sub-centers and is located within highway intersections only two locations that function as centers are accounted for: one at the north side and one at the south side of the river Maas. In the northern part of the city the centroid of the sub-municipality "Centrum" is directed as center area whilst in the southern part this is applied to the biggest retail center area of that region called "Zuidplein".

Subway, bus and tram stations are so much spread, a great proportion of blocks are within walking distance to such internal points of access (within the research area). Train stations and ramps are less in number and do actually stand for external access points (out of the city) and these will be used as accessibility/proximity variables.

The original dataset about-land uses is subdivided into many types and very detailed. This substantial amount of information is used to not only quantify the effect of single types of main land-uses on residential property price but also to investigate whether a combination of these have an effect. In this paper the variables that constitute the mix are constructed by combining similar types of land-uses. For example, the variable “green” contains types such as hedges, grass and trees whereas the variable “waters” also contains tidewater and water courses. Other distinguished types are open spaces, build-up areas, infrastructure and parking spaces[13]. In figure 1 is an example of one observation (which is located at the center of a block) surrounded by land-use types and those parts that are within the 100 meter radius. The land-use variables measure proportions of surfaces (two-dimensional) and so this paper focuses on presence of land-use types and not the view on them.

Table x gives an overview of variables used in the models and the corresponding definitions.

Table 3: Variables and their definitions

Variable name	**Variable definition**
lntaxvaluem2	Natural logarithm of tax value per square meter
age	Age
avgrooms	Age squared
avgrent	Percentage rental dwellings
percsinglefam	Percentage of single family dwellings
percmultil	Percentage of multifamily dwellings with elevator
percmultin	Percentage of multifamily dwellings without elevator
percothermulti	Percentage of other multifamily dwellings
percunknown	Percentage of unknown dwelling type
lncenter	Natural logarithm of distance (meters) to the nearest center area
lnhospital	Natural logarithm of distance (meters) to the nearest hospital
lnpractitioner	Natural logarithm of distance (meters) to the nearest general practitioner
lnramp	Natural logarithm of distance (meters) to the nearest ramp
lntrain	Natural logarithm of distance (meters) to the nearest train station

[13] For a detailed description of the original land-use dataset and the rearrangement of all the types across the six main land-use variables, see the appendix.

	Table 3 continued
Park500*	Dummy for park within 500 meters (1) or not (0)
Centrum	Sub-municipality Centrum dummy (1) or other (0)
Charlois	Sub-municipality Charlois dummy (1) or other (0)
Delfshaven	Sub-municipality Delfshaven dummy (1) or other (0)
Feijenoord	Sub-municipality Feijenoord dummy (1) or other (0)
IJsselmonde	Sub-municipality IJsselmonde dummy (1) or other (0)
KraCro	Sub-municipality Kralingen-Crooswijk dummy (1) or other (0)
Noord	Sub-municipality Noord dummy (1) or other (0)
%Build-up100	Percentage build-up area within 100 meters
%Green100	Percentage green space within 100 meters
%Parking100	Percentage parking area within 100 meters
%Infra100	Percentage infrastructure within 100 meters
%OS100	Percentage open space within 100 meters
%Waters100	Percentage water bodies within 100 meters
ENT100	Entropy index 100 meters
Frag100	Fragmentation index 100 meters

* The five biggest parks in the research area are chosen, which are: "Kralingse Bos", "Vroesenpark", "Het Park", "Zuiderpark" and "De Twee Heuvels". Including all small parks would lead to multicollinearity regarding the variable measuring green space.

Before the analysis can start, the raw dataset should be examined first for possible outliers and ordinary observations which can individually influence the regression coefficients to be estimated.

- Some blocks have missing data on one or more control variables, like number of rooms and percentage of rental dwellings. On top of that, there are some blocks that have an average building year in the future. A total of 34 out of 2526 blocks located in the research area were deleted before the analysis started.
- Next step was to identify those observations which have extreme tax value (per square meter) and look them up on the map by using the accompanying coordinates. Among them are three locations which are clearly not representative as blocks with residential properties. One observation includes the stadium of football club Feyenoord ("de Kuip"). Another one

is located within “Kralingse Bos”, a big recreational area where no residential housing is present. The third block includes a museum, a sail and row club and some restaurants. These three observations were dropped from the dataset as well.

- After some visual inspection and diagnostics (see appendix) the remaining group of observations is skewed distributed (mainly to the right) and peaked. One method to prevent dropping more observations is to deal with them as they were having lower values. The upper 5% is ‘winsorized’ accordingly to the 95th percentile (Campbell et al, 2011), i.e. the highest 5% takes on the same value as the observation positioned at exactly the 95% spot. The resulting tests and visual plots of the same kind are presented in the appendix as well. The remaining set of observations is more acceptable regarding the normality assumption of the dependent variable in multiple regression analysis.
- One final observation is dropped from the dataset because it had an extreme and influential value in the variable “age” (in the appendix the method behind this detection is explained and executed).

The remaining 2488 observations will be subjected to a multiple hedonic regression analysis. An average block contains houses worth €1,838 per square meter (natural logarithm of 7.516337), have nearly 4 rooms (3.7) and are 60 years old. The physical environment stretches out with a radius of 100 meters from the center of a block and therefore occupying 31,416 square meters. This area on average contains 15% green space, 4% parking space, 13% infrastructure, 38% open space, 3% water features and 26% build-up area (a complete overview of statistics is given in table A4 in the appendix).

Figure 1A: Satellite image of a local living environment of one observation unit (marked) (Googlemaps)

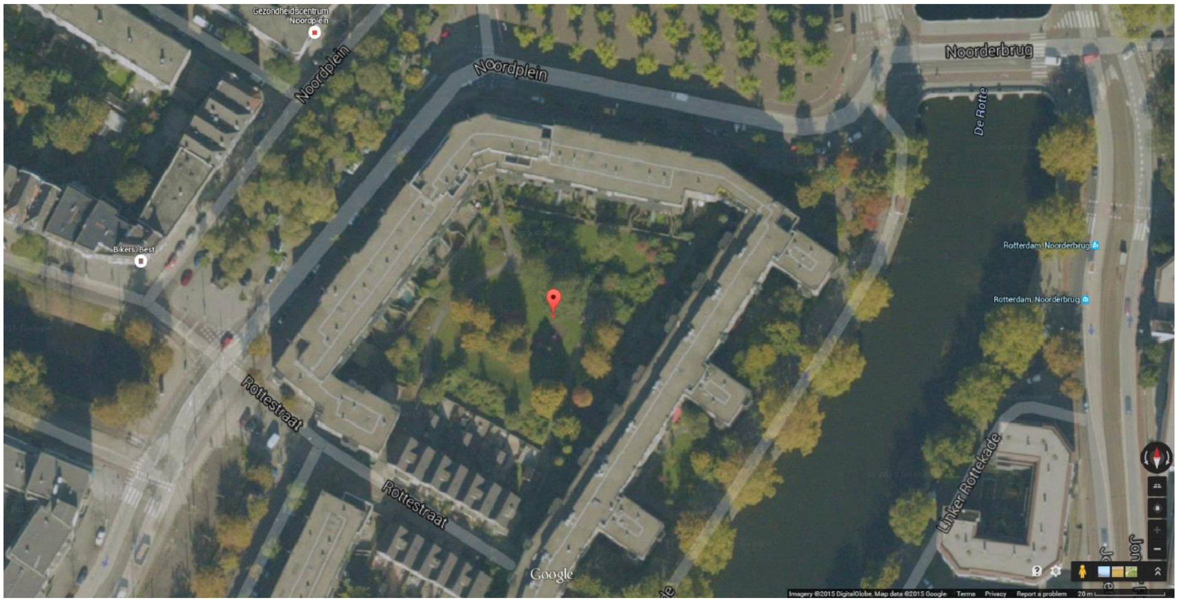
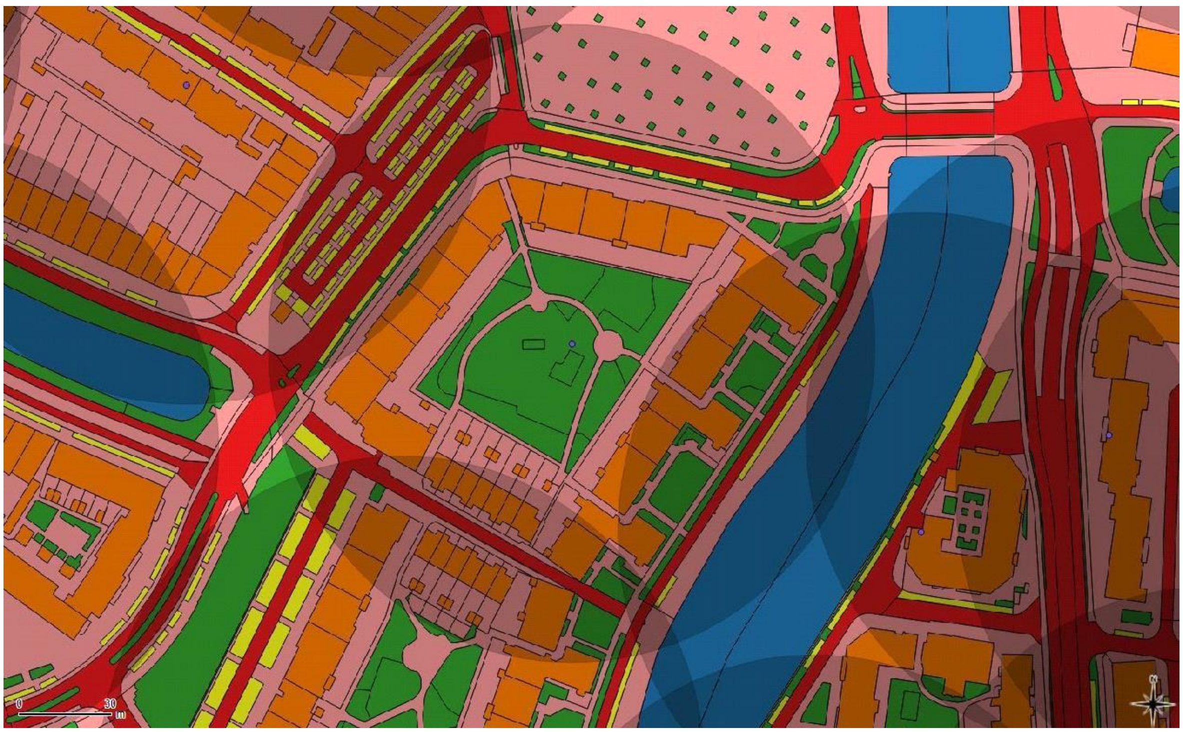


Figure 1B: Study area of the same observational unit with classified land-use categories (QGIS 2.6 Brighton)



Legend

Build-up area	Green spaces	Infrastructure
Open spaces	Waterbodies	Parking spaces
Unit of observation		

Spatial analysis issues

For some factors presumably influencing housing prices and even the (unequal) distribution of housing prices across space are no data available on the block level and neighborhood level (income, ethnicity, level of local social services). To account for these missing characteristics (potential omitted variables) of matter dummies are used to represent sub-municipalities. Except for the level of local services, which indeed is sub-municipality based, there is of course some degree of "misplaced" allocation of the presumed effects due to legislative borders. In other words, a household at the edge of a sub-municipality experiences the living area different compared to a household more in the center of that same sub-municipality. This is a good example of a wide-known spatial issue called the Modifiable Areal Unit Problem (MAUP). However, for most observations the specific area that matters regarding various unobserved factors, and these vary in size for different factors (Galster, 2001), completely lies within the sub-municipality boundary.

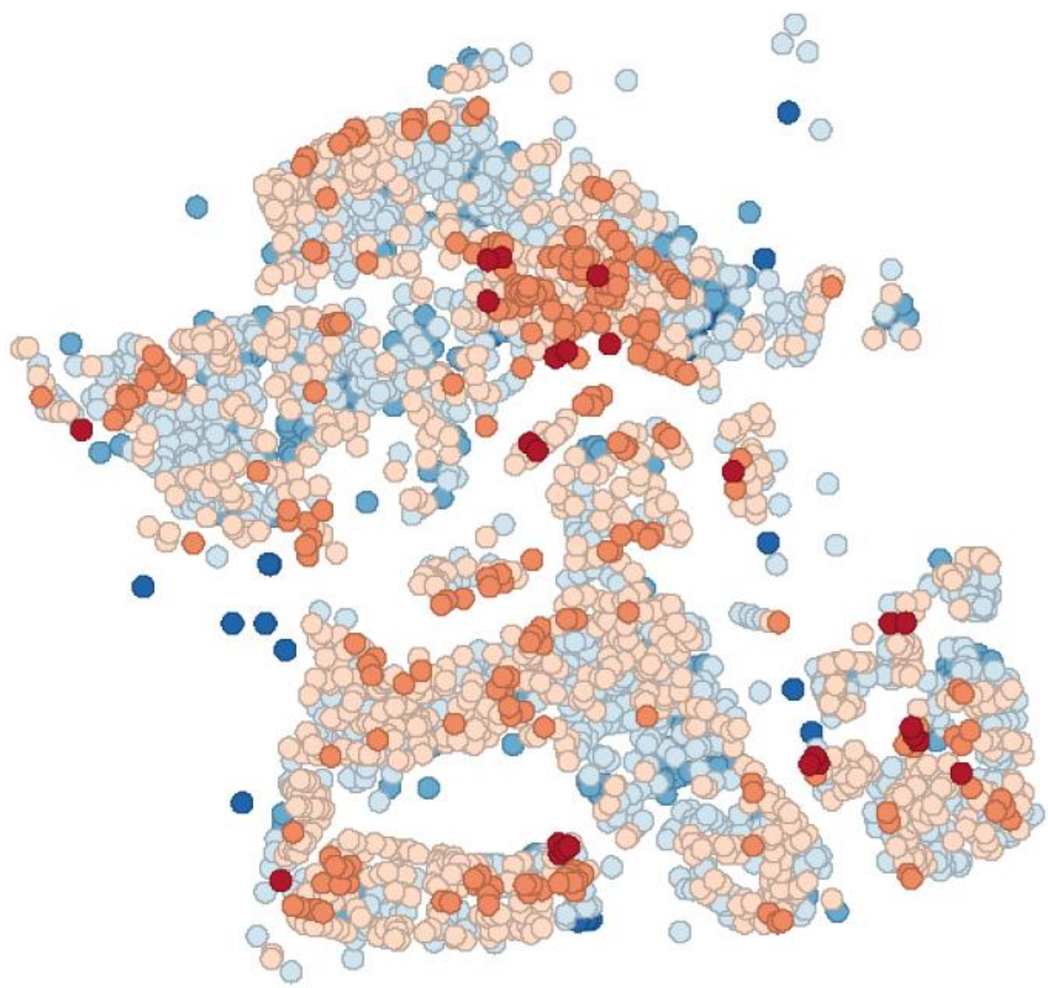
A typical problem that arises with spatial data analysis is that of spatial autocorrelation: observations contain spatial dependent features which have similar values compared to other nearby observations' features. "This phenomenon follows Tobler's (1970) ''First Law of Geography'': Everything is related to everything else, but near places are more related than far places…" (in Oakly & Tsao, 2007, p. 44). The assumption of independence of observations in regression analysis is thereby violated.

Detection of spatial autocorrelation is possible at the hand of Moran's Index (Moran's I). This is a statistic that measures the degree of spatial autocorrelation ranging from -1 (negative spatial autocorrelation) to 1 (positive spatial autocorrelation). The former means that similar spatial features tend to locate away from each other (dispersion) while the latter means clustering of spatial features. A random distribution takes on the value 0, which is the ideal situation regarding the distribution of the residuals (observed minus fitted values of the dependent variable). There is quite a strong association of positive spatial autocorrelation of the residuals from model 2 and 3 (the models which contain spatial land-use data) with a Moran's I value of 0.24 and 0.25 respectively (see the appendix for output from Geoda[14] and QGIS). This is not surprising because the urban landscape contains many continuous polygons that stretch over multiple buffer areas

[14] Geoda is also a free software program in which working with spatial data is possible.

(especially infrastructure land cover). In other words, the local environment of neighboring blocks are very similar (see figure x) and so the independent spatial variables take similar values which means that residuals tend to spatially correlate as well. This results in inefficient estimates of coefficients of land-use and mix variables (that depend on land-use variables), too small standard errors and too narrow confidence intervals leading to too low p-values which increases the chance of unjustified rejection of the null hypothesis of no effect (type 1 error).

Figure 2: Entropy index values for buffer areas (value increases from deep blue to deep red)



To partly counter this problem the models will use cluster robust standard errors that allows intragroup correlation of residuals. In addition, there is automatically corrected for possible heteroskedasticity of the error terms as well as they have the robust form (White, 1980). The research area consists of 56 neighborhoods which are used as cluster type. One scale level bigger (sub-municipalities) would not capture the cluster effect and one scale lower would have been inefficient. Some adjustments were made however in order to have clusters at least containing ten blocks. So a number of observations were assigned to the nearest neighborhood.

Problems relating to possible endogeinity need some discussion as well. According to Irwin & Bockstael (2001) and Irwin (2002) this problem mainly occurs when privately developable space is present but not accounted for. This effect would be locked in the error term and so the assumption of random error terms would be violated. Fortunately, the open space land-cover in the research area is mainly public property. Therefore open spaces here are considered exogeneous and are not subject to market forces. However, for smaller buffers the proportion of private land plots within blocks can be quite large in some part of the research area. This must be held in mind while interpreting the regression results.

Construction of the models

The first model serves as control model which contain factors that according to the literature should be accounted for in predicting residential property price. Model 1 has the following shape:

$$(1) \qquad Ln(P) = a + b_1 * H + b_2 * X\ (i) + b_3 * L\ (i) + M_{1...7}\ (i) + e\ (i)$$

Where P is an (N * 1) vector of property price, H is an (N * 2) matrix controlling for house characteristics on block basis, X is an (N * 8) matrix of socio-economic characteristics of block i, L is an (N * 4) matrix of accessibility features of a block, M stands for one of the seven sub-municipalities in which a block is located and e is an error term.

In the subsequent models quantitative data on different land-use types and mix indices composed of the land-use types are added.

$$(2) \qquad Ln(P)(i) = a + b_1 * H + b_2 * X\ (i) + b_3 * L\ (i) + M(i) + b4 * E\ (i) + e\ (i)$$

Here E is an (N * 6) matrix of land-use proportions within the total buffer area (100 meter radius) around the center point of a block.

(3) $Ln(P)(i) = a + b_1 * H + b_2 * X(i) + b_3 * L(i) + M(i) + D(i) + e(i)$

Here D represents diversity and fragmentation indices calculated by plugging in the various land-use aspects into the Shannon Entropy Index formula and Edge-to-Interior ratio outlined above.

All specified models contain a group of variables that together creates perfect collinearity, i.e. such a group has some specific information about the observations in the dataset in a way that one of the variables can be left out without loss of information. Variables indicating percentage of some type of dwelling and land-use together with the dummies representing sub-municipalities are cases of such groups. The variable that is dropped automatically forms the reference point to which the outcomes (the estimated coefficients) of the other variables from the same group are compared. Take for example the variables indicating percentages of land-use cover within the 100 meter radius. With information on proportions of water bodies, green spaces, open spaces, parking space and infrastructure cover, together with the fact that all land-use cover within the buffer will be accounted for, the proportion of build-up area is simply derived by extracting the percentages from 100%. This is actually the way the proportion of build-up area was calculated. Because build-up area forms the most typical physical element within the urban landscape it is chosen as reference land-use type. Interpretation of the coefficients with respect to the other land-use types is as follows: the impact when one unit proportion of land-use type x (e.g. green space) would be replaced by or takes the place of the same amount of build-up area.
Single family housing serves as reference among dwelling types and sub-municipality “Centrum” will function as reference area for the other sub-municipalities.

Resources and research context

- The research area encompasses seven sub-municipalities largely located within the Rotterdam Ring or Rotterdam “diamond-shaped” area (in Dutch: Rotterdamse ruit). It is the biggest and busiest beltway in the Netherlands consisting of four sections of national highways (A4, A15, A16 and A20). The sub-municipalities “Centrum”, “Delfshaven”, “Kralingen-Crooswijk” and “Noord” are located north of the river Maas while the other three (“Charlois”, “Feijenoord” and “IJsselmonde”) are at the south side of the river (see figures x and y for an overview).

- Block level information on house characteristics (including tax values) and average percentages of rental housing units and types of dwellings is obtained from the city Rotterdam.
- Data on land-use cover comes from the municipality as well and is edited with QGIS versions 2.2 (Valmiera) and 2.6 (Brighton).
- Dummies for sub-municipalities and neighborhood clusters were obtained by free download of a map containing quarters and neighborhoods (Wijk- en buurtkaart, 2012, CBS) and this was imported in QGIS.
- The remaining data (distance-related variables concerning parks, ramps, city centers and train stations) is created by using Google.maps, a coordinate converter[15] and the distance matrix tool in QGIS.

[15] http://www.gpscoordinaten.nl/converteer-rd-coordinaten.php

Figure 3A: Research area in regional context (OpenStreetMap, QGIS)

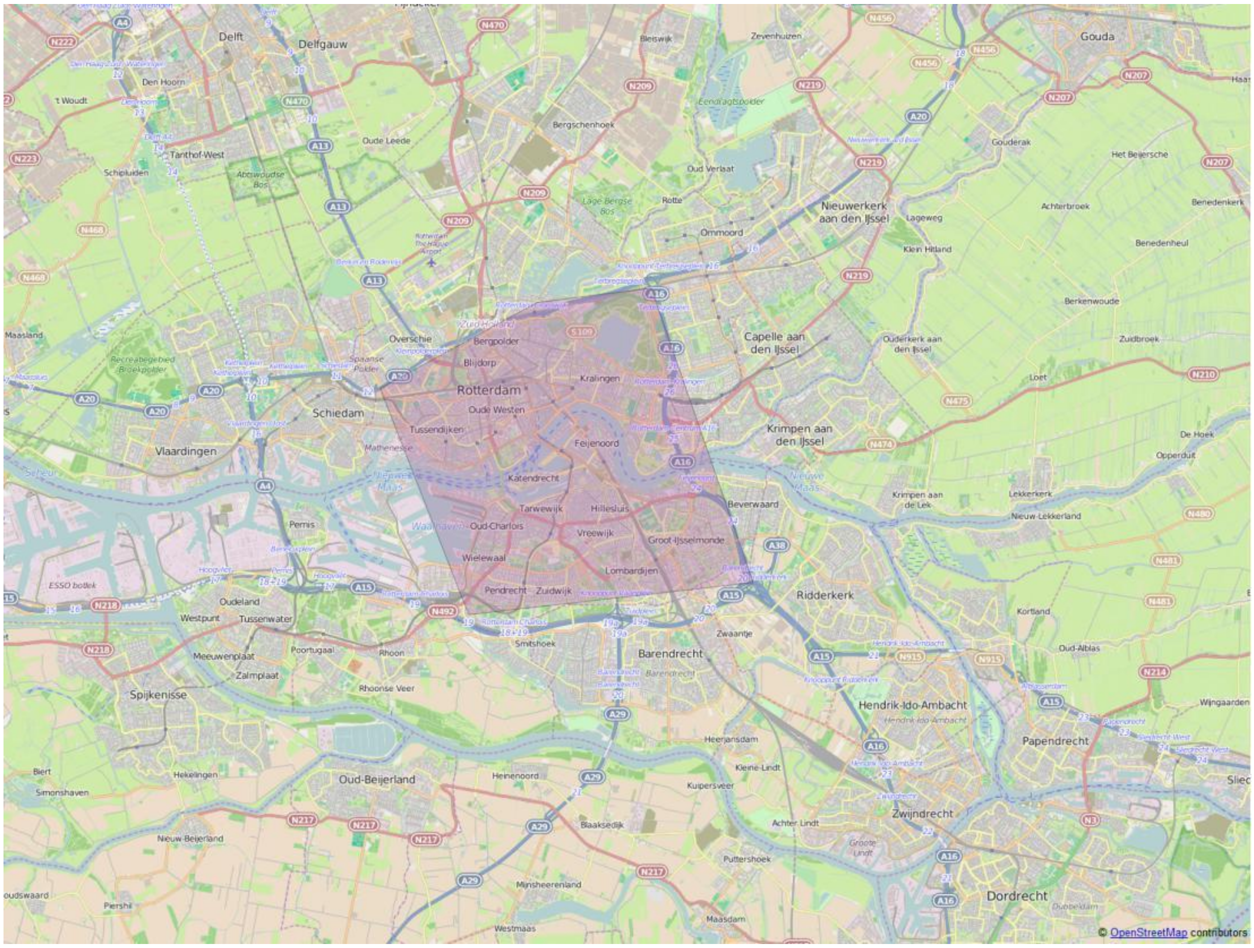
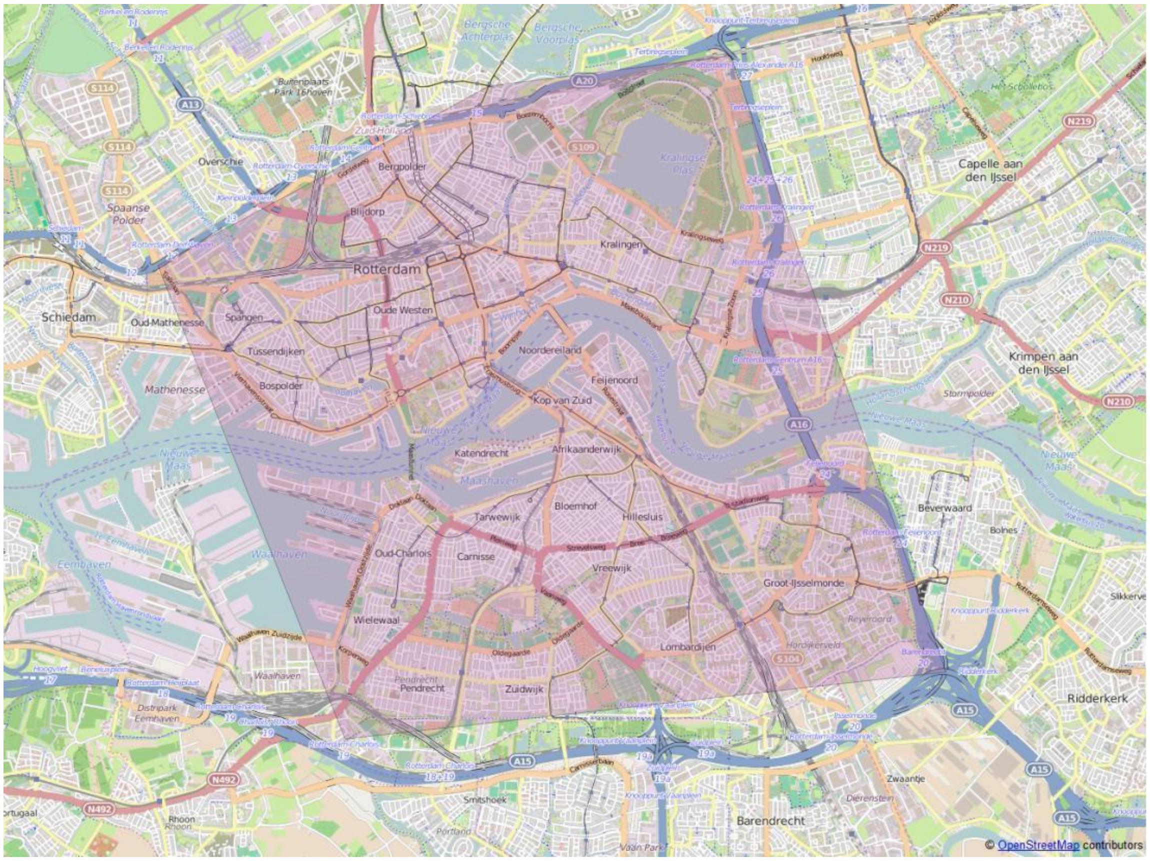


Figure 3B: Research area, close-up (OpenStreetMap, QGIS)



§ 4.4 - Summary of approach

By means of semi-log multiple regression models the impact of physical mix and arrangement and elements of the mix on residential property tax value (as proxy for price) per square meter is investigated. The natural logarithm is hereby taken of the dependent variable values. Land-use information (square meter and total perimeter for six land-use types) is aggregated at 100 meters around the center points of blocks. In the models there is controlled for structural, socio-economic and accessibility characteristics to isolate the possible effects of land-use types and the way the direct living environment is physically mixed and arranged. Dummies for sub-municipality are included to control for fixed (and unobserved) effects are added. The models are corrected for heteroskedasticity (if present otherwise) and partially corrected for spatial autocorrelation by clustering observations at the neighborhood level. There are 2488 blocks remaining after dropping outliers and incomplete observations within the research area.

Chapter 5 – Analysis of results

In this part results from the hedonic regression models outlined in the previous chapter are given and interpreted.

Model 1 stands for the control model, including block characteristics (structural and socio-economic), location variables and dummies for the sub-municipalities. Model 2 contains the variables indicating land-use proportions in the 100 meter buffer. Model 3 focuses on diversity and fragmentation indices. In all the models percentage of single family dwellings and sub-municipality "centrum" are omitted because of multicollinearity and automatically form the reference categories. In the model that contains variables regarding land-use proportions (model 2) the land-use type "build-up area" is omitted because of multicollinearity. More detailed information about residuals and other statistical tests are placed and discussed in the appendix.

In addition there is an inspection of possible non-linearities in the decay function. In other words the same analysis is done for land-use proportions and diversity/fragmentation within 100 meters but extended by another ring of 100 meters on top of the first ring to examine if there is a shift in valuation of different land-use elements and diversity measures (models 4 and 5). There is this possibility that residents differ in their preferences (to the extent that they can afford to choose in accordance with their desires) regarding direct living environments. So the analysis continues with an investigation to possible heterogeneity in effects of diversity and pattern of the physical living environment between sub-municipalities by including interaction-terms of the former with the latter (model 6). Here the assumption is made that preferences of residents within the same sub-municipality are similar.

§ 5.1 – Main results

Table x shows the regression results of the first three models. We can see that in all three the models the block characteristics are significant at the 0.01 level: they add significant explanatory power to the models presenting factors affecting residential property prices. The number of rooms exerts a negative effect on tax value per square meter. If the dependent variable was (the natural logarithm of) total tax value then this effect would be surprising. But since the effect is converted to a square meter rate the negative sign may make sense. When a property is divided by more rooms but still has the same overall size, space would be less valued.

The age of a house negatively affects the average tax value per square meter. Blocks that are one year older are, on average, almost a half percent cheaper, ceteris paribus. There is a very small quadratic effect of age (slight curvilinear relationship) which means that for very old properties the positive effect of status or aesthetics outweighs the negative effect of depreciation when a house gets older (it is such a small effect that it is not visible in the table as the coefficients are rounded up to four decimals). This is known as the “vintage” effect (Margolis, 1982). Take for example a ten year old property situated in some setting in one of the models. The total effect of age would be $10*-0.487\% + 10^2*0.004\% = -4.47\%$, ceteris paribus (mind that the correct way of measuring the effect is by multiplying the two coefficients of age and age squared by 100 due to the log-linear relationship). The same effect for a similar house but ten years older is -8.14%, ceteris paribus. So the total effect of age on the older house is not twice as large (no linear relationship) as it is on the younger house. Instead, it is less than that.

An increase in proportion of any other dwelling type rather than single family housing in a block yields significant negative, albeit small, effects. In compliance with the referred literature, the percentage of rental housing units in a block exerts a negative impact. A one unit increase (i.e. one percentage point) in proportion of rental units corresponds with a decrease of around 0.25 percent of average tax value per square meter.

Table 4: Estimation results models 1-3 (dependent variable: ln tax value per square meter)

	Model 1 Coef./std.~s	Model 2 Coef./std.~s	Model 3 Coef./std.~s
Average number of ~s	-0.0525***	-0.0555***	-0.0525***
	(0.015)	(0.015)	(0.015)
age	-0.0049***	-0.0047***	-0.0050***
	(0.001)	(0.001)	(0.001)
age2	0.0000***	0.0000***	0.0000***
	(0.000)	(0.000)	(0.000)
% rental dwellings	-0.2559***	-0.2480***	-0.2577***
	(0.021)	(0.021)	(0.021)
% multi family (el~)	-0.0022***	-0.0021***	-0.0021***
	(0.000)	(0.000)	(0.000)
% multi family (no~)	-0.0038***	-0.0036***	-0.0038***
	(0.000)	(0.000)	(0.000)
% other multi family	-0.0034***	-0.0031***	-0.0033***
	(0.000)	(0.000)	(0.000)
% unknown dwelling~e	-0.0013***	-0.0013***	-0.0013***
	(0.000)	(0.000)	(0.000)
lncenter	0.0629**	0.0512*	0.0631**
	(0.030)	(0.030)	(0.030)
lnhospital	-0.0355	-0.0374	-0.0380
	(0.023)	(0.023)	(0.023)
lnpractitioner	0.0324***	0.0229**	0.0316***
	(0.011)	(0.011)	(0.011)
lnramp	0.0529**	0.0449**	0.0527**
	(0.022)	(0.021)	(0.022)
lntrain	-0.0002	-0.0031	-0.0013
	(0.018)	(0.019)	(0.018)
Park500	0.0389*	0.0412*	0.0388*
	(0.022)	(0.023)	(0.022)
Charlois	-0.3608***	-0.3334***	-0.3528***
	(0.064)	(0.064)	(0.063)
Delfshaven	-0.2343***	-0.2292***	-0.2285***
	(0.063)	(0.062)	(0.063)
Feijenoord	-0.3333***	-0.3186***	-0.3279***
	(0.060)	(0.058)	(0.060)
IJsselmonde	-0.3035***	-0.2715***	-0.3009***
	(0.067)	(0.064)	(0.066)
Kralingen-Crooswijk	0.0151	0.0261	0.0223
	(0.065)	(0.062)	(0.066)
Noord	-0.0364	-0.0323	-0.0306
	(0.058)	(0.054)	(0.059)
%Green100		-0.0002	
		(0.001)	
%Parking100		-0.0063*	
		(0.004)	
%Infra100		-0.0018	
		(0.002)	
%OS100		0.0011	
		(0.001)	
%Waters100		0.0048***	
		(0.001)	
ENT100			-0.3226
			(0.232)
Frag100			-0.0568
			(0.079)
ENTFrag100			0.0541
			(0.102)
Constant	7.6360***	7.8297***	7.9531***
	(0.356)	(0.352)	(0.398)
No. of Obs.	2488	2488	2488
R-Squared	0.60	0.61	0.60

* p<0.10, ** p<0.05, *** p<0.01

The distance to the nearest center (north or south) is in model 1 and 3 significant at the five percent level and in model 2 at the ten percent level. If, for example, distance increases from 500 to 550 meters (an increase of ten percent) then tax value per square meter is found to be 0.6 percent higher, ceteris paribus. Thus, residences located more to the edge of the research area are more valued. One logical explanation is that areas further away from the center area have lower building densities. Additionally, living in the densely built and populated center area entails high chances of negative spillover effects from surrounding land-uses, like pollution, noise and criminal activities. For many household types, which the current research could not account for unfortunately, this kind of place is not suitable and acceptable as a place of residence.

Compared with the ones located in sub-municipality “Centrum”, blocks found in sub-municipalities in the southern part of Rotterdam and “Delfshaven” experience a discount. Blocks located in “Kralingen-Crooswijk” and “Noord” are not significantly different from those located in the center. So in these cases a sub-municipality effect does not appear to exist as there are no differences in non-observed effects.

When living within the city of Rotterdam it seems that the place of residence relative to a train station does not have an effect on average tax value per square meter. The distribution of effects across several distances to train stations is not accounted for here but as outlined by Bowes & Ihlanfeldt (2001) the immediate area around a station can suffer from crime related activity so that local housing prices are lower. On larger distances the presumably positive effect of accessibility might not be experienced anymore and therefore controlling for the impact of a train station at straight distances for every observation (so distance varies among observations) can yield insignificant results. Proximity to the nearest highway ramp does have a negative effect on the five percent level: ten percent closer means a drop of around 0.5 percent. Factors that are accounting for this negative impact are side-effects of noise, bad view, air pollution and congested roads nearby[16].

[16] A regression without sub-municipalities shows a significant negative effect of distance to the nearest train station and changes the sign of distance to the nearest ramp to negative. This is intuitively to be expected because now the location effect is to a larger extent incorporated within these two variables and external accessibility now takes the upper hand as opposed to negative externalities.

If an urban park is located within 500 meters of a block it would increase the average tax value per square meter by four percent.

There are some effects noticeable regarding health services. While distance to the nearest hospital impose no significant effects, blocks located 10% further away from a practitioner are worth around 0.3 percent more per square meter. So these are small or insignificant effects and one explanation could be that people presume health services are present in abundance in the city and thus do not consider these kind of facilities as first-order factors in finding a place to live.

What can we say about the role of specific land-uses in explaining the price per square meter? The amount of water bodies around houses positively affects average tax value per square meter. When the proportion of water surface within 100 meters increases from five percent to fifteen percent (ten percentage points) at the expense of buildings, the tax value per square meter increases with almost 0.05 percent, ceteris paribus. Also in the other models aggregating land-use information in different buffer areas, water clearly has a positive effect.

Parking space on the contrary negatively affects average tax value per square meter. If within 100 meters the total amount of parking space increases by ten percent points, this would lead to a decrease of 0.06 percent if alpha is ten (this is of course a somewhat exaggerated example but it is just for the sake of comparison). This effect is logical in the sense that people only want enough space to park their own vehicle. If a great portion of the remaining space would also provide parking spaces (and most likely these spaces are occupied in a crowded city like Rotterdam) the direct living environment would be less appreciated and more useless through the eyes of local residents.

As can be derived from the corresponding p-values, the presence of green parcels, infrastructure and open spaces within 100 meters does not appear to have any effect in general. On average the main infrastructure elements that were expected to decrease prices (like busy roads) are less present within the buffer areas than other "light" elements that fall under this category (like bicycle lanes). Combining those different forms of infrastructure is probably the reason for the insignificance. An explanation for the insignificance of green space and open space is that in the first hundred meters many gardens of other houses within a block are included. Residents can decide for themselves if they want much green or pavement at their own plots. These land-use types in other gardens within the same block (which thus still belongs under one observation in this research set-up) are practically not part of the direct living environment simply because they are owned and not fall under public space. Also, these spaces largely lay out of sight due to placed walls and hedges so every household in a block has not a good view of green and open spaces from their neighboring parcels. The total effect is thereby canceled out.

Results from the models with diversity indices implicate that people do not really care whether the physical environment is highly mixed and fragmented or not. Performing the WALD test confirms this observation as the indices are jointly non-significant different from zero.

Overall the models are significant and explain around 60 percent of the variance in average tax value per square meter.

§ 5.2 – Controlling for interactions and non-linearities

The additional models that focus on non-linearities in effects of land-uses and diversity (models 4 and 5 respectively) and interactions with sub-municipalities (model 6) are displayed below. Some interesting results should be mentioned. Regarding green and open spaces, the findings coming from model 4 (concentric ring of 100 meters added) and from the models with buffer areas of 50 and 200 meters (see appendix) support the line of thought about the direct living environment made earlier. Within the smaller buffer the effects of the two land-use types are more insignificant (more private developable space) and at larger distances, where more public space is in potential more present than build-up area, significant positive effects are detected.

Green and open spaces impose an effect in the concentric ring. Water bodies are significant as well but now do not have an effect in the first 100 meters as opposed to model 2. Perhaps the 100-200 meter ring still belongs to the direct living environment where residents more likely want to see natural elements and free walking space than other build-up area providing facilities and services. Water elements do not necessarily have to be present in the *immediate* neighborhood when a larger surrounding area is considered however. Residents likely bear in mind that living next to water is not in line of reasonable expectations when living in a dense urban area. Parking space still negatively affects the variable to be explained within 100 meters and for the same reasons as just outlined. In the next ring there is no effect detected. Infrastructure, not surprisingly, becomes a negative factor in the first 100 meters when land-use data in the extra ring is considered as well. Negative side-effects of noise and pollution but also safety issues play a part in this. Although the road network and transportation facilities serve internal access to services and facilities located further away, in the first 100 meters these advantages do not hold. Two possible arguments in favor of build-up areas instead of infrastructure are: 1) the services contained within buildings next or below residential properties; and 2) the preference for having neighbors for social interaction and control. A side note to make is that annexes or outbuildings, like sheds, belong to build-up area as well what means that some extra proportion of this land-use type is owned for private usage and add up to total land plot size (which is valued accordingly).

Again, the diversity and fragmentation indices overall have no impact on residential property price (model 5). However, there are some subtle differences noticeable after the indices are interacted with the sub-municipalities (model 6). Blocks located in "Kralingen-Crooswijk" and "Charlois" are particularly against diversity in the urban physical environment. The first mentioned is a typical area where the environment looks more natural (it is the most green part of Rotterdam) and less "planned" compared to the center area which is more structured and modernly designed after World War II. "Charlois" is also considerably old but why residents specifically do not like diversity remains unclear. When a ten percent significance level is considered the effect of diversity on blocks located in sub-municipality "Noord" would also be significantly negative.

Table 5A: Regression results of model 4

```
Linear regression                                      Number of obs =    2488
                                                       F( 30,    46) =  178.11
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6247
                                                       Root MSE      =  .16286

                          (Std. Err. adjusted for 47 clusters in neighborhood)
```

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0582799	.0152495	-3.82	0.000	-.0889754	-.0275843
age	-.0043746	.0009101	-4.81	0.000	-.0062064	-.0025427
age2	.0000376	7.45e-06	5.05	0.000	.0000226	.0000526
avgrent	-.2432664	.0199446	-12.20	0.000	-.2834129	-.20312
percmultil	-.0021618	.0003273	-6.61	0.000	-.0028205	-.001503
percmultin	-.0036471	.000246	-14.83	0.000	-.0041422	-.003152
percothermulti	-.003086	.0003781	-8.16	0.000	-.003847	-.002325
percunknown	-.0013531	.0004191	-3.23	0.002	-.0021967	-.0005095
lncenter	.0374341	.0283521	1.32	0.193	-.0196357	.0945038
lnhospital	-.036568	.0226309	-1.62	0.113	-.0821216	.0089856
lnpractitioner	.0139442	.0112988	1.23	0.223	-.008799	.0366874
lnramp	.047573	.0215284	2.21	0.032	.0042386	.0909074
lntrain	-.0028781	.0189717	-0.15	0.880	-.0410662	.03531
Park500	.0334744	.0220073	1.52	0.135	-.010824	.0777728
Charlois	-.3317479	.0598486	-5.54	0.000	-.4522169	-.2112788
Delfshaven	-.2189846	.058578	-3.74	0.001	-.336896	-.1010731
Feijenoord	-.3231922	.0515646	-6.27	0.000	-.4269863	-.2193981
IJsselmonde	-.2639115	.0592087	-4.46	0.000	-.3830925	-.1447305
KraCro	.0376593	.0582399	0.65	0.521	-.0795716	.1548902
Noord	-.0140156	.050618	-0.28	0.783	-.1159043	.0878731
pGreen100	-.0009855	.0008229	-1.20	0.237	-.0026419	.0006708
pParking100	-.0059142	.0033079	-1.79	0.080	-.0125727	.0007443
pInfra100	-.0027813	.0014313	-1.94	0.058	-.0056623	.0000998
pOS100	.0000883	.001321	0.07	0.947	-.0025708	.0027474
pWaters100	.0017189	.0011813	1.46	0.152	-.000659	.0040968
pGreen200100	.0017825	.0010689	1.67	0.102	-.0003691	.0039341
pParking200100	-.0046284	.006045	-0.77	0.448	-.0167962	.0075395
pInfra200100	.0023774	.0017139	1.39	0.172	-.0010725	.0058272
pOS200100	.0030789	.001448	2.13	0.039	.0001642	.0059935
pWaters200100	.0047234	.0012571	3.76	0.000	.002193	.0072537
_cons	7.839464	.3586192	21.86	0.000	7.117602	8.561327

Table 5B: Regression results of model 5

```
Linear regression                                      Number of obs =    2488
                                                       F( 26,    46) =  115.74
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6026
                                                       Root MSE      =  .16746

                          (Std. Err. adjusted for 47 clusters in neighborhood)
```

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0535078	.015083	-3.55	0.001	-.0838684	-.0231473
age	-.0049092	.0009595	-5.12	0.000	-.0068407	-.0029778
age2	.0000407	7.51e-06	5.43	0.000	.0000256	.0000559
avgrent	-.2582079	.0202721	-12.74	0.000	-.2990135	-.2174023
percmultil	-.0021485	.0003183	-6.75	0.000	-.0027893	-.0015077
percmultin	-.0037557	.0002478	-15.16	0.000	-.0042545	-.0032569
percothermulti	-.0032673	.0004009	-8.15	0.000	-.0040742	-.0024604
percunknown	-.0014458	.000392	-3.69	0.001	-.0022349	-.0006567
lncenter	.0644578	.0296296	2.18	0.035	.0048166	.1240991
lnhospital	-.0445584	.0235926	-1.89	0.065	-.0920477	.002931
lnpractitioner	.0292726	.0113491	2.58	0.013	.006428	.0521173
lnramp	.0535864	.0219979	2.44	0.019	.009307	.0978658
lntrain	-.0005701	.0178909	-0.03	0.975	-.0365826	.0354423
Park500	.0355675	.0220373	1.61	0.113	-.0087912	.0799263
Charlois	-.3491904	.0627693	-5.56	0.000	-.4755385	-.2228424
Delfshaven	-.2195965	.0634173	-3.46	0.001	-.347249	-.0919441
Feijenoord	-.3249885	.0599498	-5.42	0.000	-.4456611	-.2043158
IJsselmonde	-.3022665	.0669319	-4.52	0.000	-.4369934	-.1675396
KraCro	.0311434	.0667335	0.47	0.643	-.1031842	.165471
Noord	-.0209482	.0598416	-0.35	0.728	-.1414032	.0995067
ENT100	-.2674175	.2423681	-1.10	0.276	-.7552792	.2204442
Frag100	-.0568556	.0791987	-0.72	0.476	-.2162742	.1025631
ENTFrag100	.0623327	.1019373	0.61	0.544	-.1428564	.2675217
ENT200100	-.0753171	.3688118	-0.20	0.839	-.8176967	.6670625
Frag200100	.0568901	.1415477	0.40	0.690	-.2280307	.3418109
ENTFrag200100	-.1015027	.1809092	-0.56	0.577	-.4656541	.2626487
_cons	8.048058	.5564647	14.46	0.000	6.927953	9.168163

Table 5C: Regression results of model 6

Linear regression

Number of obs =	2488
F(35, 46) =	182.32
Prob > F =	0.0000
R-squared =	0.6084
Root MSE =	.16652

(Std. Err. adjusted for 47 clusters in neighborhood)

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0539191	.0147707	-3.65	0.001	-.083651	-.0241873
age	-.0049851	.0009565	-5.21	0.000	-.0069104	-.0030599
age2	.0000406	7.48e-06	5.43	0.000	.0000255	.0000557
avgrent	-.2499476	.0195764	-12.77	0.000	-.2893529	-.2105423
percmultil	-.002216	.0003101	-7.14	0.000	-.0028403	-.0015917
percmultin	-.0037393	.0002453	-15.24	0.000	-.0042331	-.0032455
percothermulti	-.0032887	.0003931	-8.37	0.000	-.00408	-.0024974
percunknown	-.0013988	.0003948	-3.54	0.001	-.0021936	-.0006041
lncenter	.0537124	.0306479	1.75	0.086	-.0079785	.1154033
lnhospital	-.0424457	.0220025	-1.93	0.060	-.0867343	.0018429
lnpractitioner	.0287108	.0103875	2.76	0.008	.0078019	.0496198
lnramp	.0509758	.0209803	2.43	0.019	.0087447	.0932068
lntrain	-.0012907	.0175296	-0.07	0.942	-.036576	.0339946
Park500	.037208	.021263	1.75	0.087	-.0055921	.0800081
Charlois	.4923075	.3170052	1.55	0.127	-.1457908	1.130406
Delfshaven	-.2652767	.2303369	-1.15	0.255	-.7289208	.1983675
Feijenoord	.0201608	.2384309	0.08	0.933	-.4597758	.5000973
IJsselmonde	-.1812839	.1699028	-1.07	0.292	-.5232805	.1607128
KraCro	.7253068	.2842867	2.55	0.014	.1530673	1.297546
Noord	.3972735	.2538857	1.56	0.124	-.1137719	.9083189
ENT100	.1657325	.2936599	0.56	0.575	-.4253743	.7568393
Frag100	-.0402059	.0977205	-0.41	0.683	-.2369071	.1564952
ENTFrag100	.0347438	.1181632	0.29	0.770	-.2031065	.2725941
CharloisENT100	-.8762362	.2781946	-3.15	0.003	-1.436213	-.3162596
DelfshavenENT100	-.015356	.2571656	-0.06	0.953	-.5330036	.5022916
FeijenoordENT100	-.3514152	.2965145	-1.19	0.242	-.948268	.2454375
IJsselmondeENT100	-.2307457	.1748074	-1.32	0.193	-.5826148	.1211234
KraCroENT100	-.8542342	.2799795	-3.05	0.004	-1.417804	-.2906646
NoordENT100	-.5086848	.2761269	-1.84	0.072	-1.064499	.0471297
CharloisFrag100	-.0565653	.0534636	-1.06	0.296	-.1641818	.0510513
DelfshavenFrag100	.0232208	.0307827	0.75	0.454	-.0387416	.0851832
FeijenoordFrag100	-.0246064	.0240838	-1.02	0.312	-.0730846	.0238717
IJsselmondeFrag100	.0370213	.0289619	1.28	0.208	-.0212761	.0953186
KraCroFrag100	.0007262	.0283461	0.03	0.980	-.0563316	.057784
NoordFrag100	-.0045844	.0273471	-0.17	0.868	-.0596313	.0504624
_cons	7.6878	.4089608	18.80	0.000	6.864605	8.510996

Chapter 6 – Conclusions, discussion and future research

This paper had the goal to answer the following question: *What effect does mixed land-use have on residential property prices?* The analysis has not found an effect of physical mix on residential property price within distances varying from 100 to 200 meters from centers of blocks in seven sub-municipalities in Rotterdam. Besides some minor cases of blocks in sub-municipality "Kralingen-Crooswijk" or "Charlois", the overall picture shows that residents do not mind how the physical environment is mixed and arranged in their direct living environment. The finding that physical mix in terms of entropy and fragmentation is not a relevant aspect of the direct living environment of residents is almost in coherence with Geoghegan et al. (1997) who only were able to find a significant effect when both aspects were jointly tested at a significance level of ten percent (there were however some effects detected when interactions with distance to Washinton DC were included, but this research had the focus on a pure urban area and no suburban areas). It might be the case that the combination of all types of land-uses causes the insignificance. There is no distinction made between types of mix (built environment and natural environment) as Baranzini & Schaerer (2011) did. Fausold & Lilieholm (1999) pointed to the essence of accounting for positive, negative and overall effects of open spaces. In this case all the positive effects of the natural elements within the mix are combined with negative effects mostly accounted for by parking space and infrastructural elements. So in this research set-up the mix-variable forms a combination of different types and nature of effects which explains why no direct relationship could be detected with residential property price.

Indeed the effects of different land-use types distinguished in this paper were "mixed". Natural elements like water and a green urban park are more valued by residents living in a dense urban area with much build-up area. Most important factors are the associated relief from urban stress and recreation opportunities. The results regarding water bodies are in accordance with Luttik (2000) who found positive effects of water surface and view of water at different research locations in the Netherlands. Here the consistency of the positively valued element of water is represented at various distances around residential properties. Also open spaces in the form of squares and pavements are significantly more valued than build-up areas at greater distances as this type of land-use does not indicate density. Infrastructure and parking space have a negative effect likely caused by noise and bad view.

The findings have some implications for urban developers and planners. Considering the natural elements of water and green in the form of a park the municipality would gain more tax revenues if those two elements were combined. The results were not in favor of basic green elements scattered across the area of interest but thus more in favor of a park located in vicinity (500 meters or so). This is contradictory with the statement Cho et al. (2008) made. Water is an element highly valued among residents but sometimes difficult for urban planners to incorporate in the urban fabric because of conflicting interests relating to missed revenues of for example retailers. Water (elements) should be present within or at the border of an urban park, like the case of "Vroesenpark" located in the neighborhood "Blijdorp", sub-municipality "Noord". Luttik (2000) made a similar conclusion of combining these elements to extract the highest rents from nearby residences. And at the same space is used efficiently as the uses are complementary.

There are some shortcomings and remarks that should be mentioned. There were some imprecise measurements and incorrect classifications in the original land-cover dataset of Rotterdam. But compared to the total research area these numbers were not problematic. The focus was on land cover in two-dimensional space. View is one of the most important aspects in experiencing the neighborhood (Hui et al., 2007) and residents of high-rise buildings have greater perceived neighborhood environments (three-dimensional space) which is not accounted for. There still may be omitted variables in the model including mix and fragmentation indices (indicated by the Ramsey reset-test). One possible feature can be the proportion of view.

Another potential omitted variable (and a second limitation) is accessibility of employment. For many people the location of residence is much dependent on the location of work. Not including this factor could lead to bias in estimates of physical environment variables. In an extreme situation one may pay much for a house that is located near the place of work which leads to overestimation of present physical elements.

One very important issue in this entire research is that of the pure spatial character of the analysis in general and of the land-use and mix variables in particular. Although spatial autocorrelation is partly corrected for via clustering of observations, the analysis really calls for a geographically weighted regression that in this context performs better than an ordinary least squares regression because the former controls for spatial dependence of effects of variables (Redfearn, 2009; Gao & Li, 2011). In particular, the main advantage of such a method is that for each observation a separate estimation model is calculated, meaning that coefficients of explanatory variables are estimated separately (and not averaged out) and hence more precise results closer to the "real" causation. This forms both a limitation of the current research and a suggestion for future research.

A couple of other suggestions are worth mentioning. What might be interesting to consider is distinction in quality levels of land-plots (within each land-use type). Some studies already distinguish in different forms and qualities of green spaces (see for example Anderson & West, 2006), but also infrastructure is a type of land-use which can be subdivided, for example in 'heavy' elements (railroads and highways) and in 'light' elements (bicycle lanes).

Although heterogeneity in willingness to pay for diversity and fragmentation across sub-municipalities is considered, there might be variation *within* sub-municipalities as well. Moreover, as sub-municipalities can control for formal sub-municipality effects, other characteristics that are of influence on the measured impact are transboundary and these are based on for example income (richer people may have different tastes and demands regarding their living environment) or age of residents. This distinction is relevant when particular neighborhoods with residents with specific characteristics form the target of revitalization projects. In this way the municipality can effectively arrange the physical environment in accordance with local demand.

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Appendix

Appendix A: Working process in QGIS/Excel

Table A1: Categorization of land-use types

Original land-use classification	**Aggregated land-use type**
Bedrijfsterrein	Build-up area
Begroeid	Green space
Bijgebouw	Build-up area
Bosplantsoen	Green space
Brug	Infrastructure
Buskom	Infrastructure
Cultuur Rozen	Green space
Getijdenwater	Water bodies
Gras	Green space
Greppel	Green space
Haag	Green space
Halfverhard	Open space
Hoofdgebouw	Build-up area
Klein Kunstwerk	Build-up area
Ligplaats	Build-up area
Muur	Build-up area
Onbebouwd	Open space
Onverhard	Open space
Opstal	Build-up area
OV-Baan	Infrastructure
Overig Groen	Green space
Overig Kunstwerk	Build-up area
Overige Verharding	Open space
Pad	Open space

Table A1 continued	
Parkeerplaats	Parking space
Plantenperken	Green space
Rijbaan	Infrastructure
Rijwielpad	Infrastructure
Sluis	Build-up area
Spoorbaan Metro	Infrastructure
Spoorbaantrein	Infrastructure
Standplaats	Build-up area
Struik	Green spaces
Tunnel	Infrastructure
Uitbouw op Maaiveld	Build-up area
Valdempende Ondergrond Kunstgras	Green space
Vaste Bak	Build-up area
Verhard	Open space
Viaduct	Infrastructure
Vlonder	Build-up area
Voetpad	Open space
Vrije Trambaan	Infrastructure
Water	Water bodies
Waterloop	Water bodies
Wegberm	Green space
Woonerf	Open space

Steps in QGIS

After adding the shapefile of Rotterdam in QGIS the first thing to do is to map all the locations of observations (centers of blocks) in a new layer.

- Import the CSV-file in QGIS by adding delimited text layer

- Choose the same Coordinate Reference System as project: EPSG:28992 - Amersfoort / RD New
- Select “comma” as delimiter
- Select field 2 for the X-coordinates and field 3 for the Y-coordinates (field 1 shows the case number of each observation)

With the land-use classification in table A1 (above) in mind, the original shapefile must be edited.

- Split the file into multiple files
  - vector > data management tools > split vector layer **>** select as criteria “by class”
- Combine similar land-uses
  - vector > data management tools > merge shapefiles to one.

The research area is formed by connecting the point-locations of the following ramps (clockwise): Knooppunt Terbregseplein – Knooppunt Ridderkerk – Poort van Charlois - Afrit 12 Spaanse Polder/ Delfshaven)

- Create polygon with the obtained coordinates from the online converter
  - pluggins > search python pluggins > points2one

Drop points that fall outside the research area

- vector > research tools > select by location
  - Select features in: *Coordinaten_alleblokken*
  - That intersect features in: *Research_area*
  - Invert selection in attribute table and remove the blocks outside the research area

Define buffer areas for each observation in order to capture an equal amount of information about land-use

- Create a buffer around each observation (total buffer area is π (pi) multiplied by radius squared, so for a buffer with radius 50, 100 and 200 the area of interest is $\pi * 50^2 \approx 7.854$ m^2, $\pi * 100^2 \approx 31.416$ m^2 and $\pi * 200^2 \approx 125.664$ m^2 respectively) and around the research area itself (see next step)

- vector > geoprocessing tools > buffer(s)
- Input vector layer -*coordinaten blokken binnen onderzoeksgebied*-
- Do not select "Dissolve buffer results"
- Delete points that have a buffer that is partly outside the Rotterdam region (manually search across the border of research area)
- For each distance the buffers around all relevant observations are saved as a separate shapefile

All together the amount of data is substantial > delete surface data that fall outside the research area

- For every land-use type shapefile cut the area of interest out the total Rotterdam surface
  - vector > geoprocessing tools > clip
  - Input layer: *Rotterdam_vlakken_KLASSE-"land-use function"*
  - Clip layer: "onderzoeksgebied"

Collect land-use data (i.e. types and amount of each type in square meters) within all buffer areas

- vector > geoprocessing tools > dissolve
  - Input vector layer:
  - Dissolve on field_1 (observation number)
- Capture the different land-use layers beneath the buffers and calculate total areas of every land-use type with
  - vector > geoprocessing tools > intersect
  - Input vector layer: clip land-use shapefile (for example green)
  - Intersect layer: buffer
  - Add geometry columns for automatically update area and perimeter

Calculate degree of mix by applying the different indexes and create a new variable

- Export all the tables from the attribute table with observations and accompanied measures of land-use areas and perimeters to an excel file (use vlookup to aggregate at observation level

    - Apply the Shannon Entropy Index and create a new variable.
    - Apply the Hirschmann-Herfindahl index
    - Apply the edge-to-interior ratio

- To control for factors other than mixed land-use and physical housing characteristics affecting residential property values, the literature often points to locational attainability to certain facilities, like public parks, public transport stations and ramps. These variables should be included in the analysis.
    - Find coordinates of “amenities” and other control variables (Again using Googlemaps and the converter and save as CSV-file) and make for each one a separate shapefile that contains the specific locations (in QGIS a pointlayer)
    - For every block find the distance to the nearest amenity and repeat this for every control variable
        - vector > analysis tools > distance matrix
        - InputID: *blokken binnen onderzoeksgebied*
        - TargetID: “*control variable”*
        - Find K=1 nearest neighbor

Appendix B: Preparations in STATA

After removal of the observations with missing values in some control variables, the dataset consisted of 2492 observations. Next thing to do is look at the distribution of the dependent variable lntaxvaluem2 and assess some diagnostics.

Figure A1: Quatile plot dependent variable

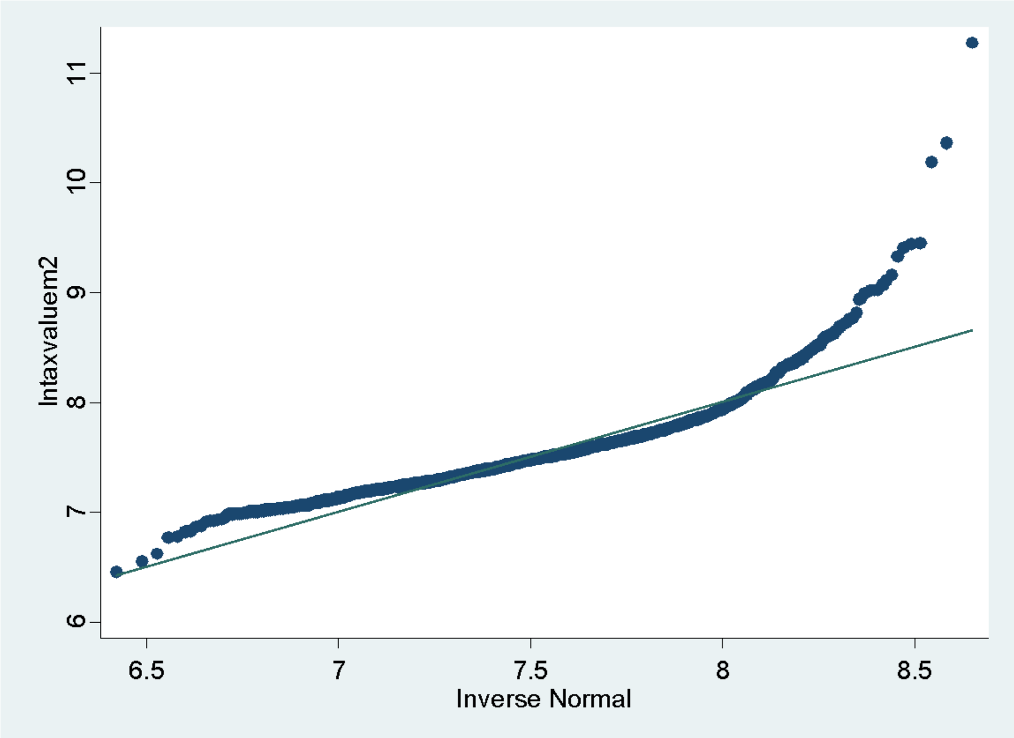


Table A2: Descriptives dependent variable

lntaxvaluem2

	Percentiles	Smallest		
1%	6.997395	6.450997		
5%	7.120472	6.55108		
10%	7.20786	6.614482	Obs	2492
25%	7.330075	6.763384	Sum of Wgt.	2492
50%	7.496884		Mean	7.53614
		Largest	Std. Dev.	.3322879
75%	7.674003	9.444837		
90%	7.875907	10.18867	Variance	.1104152
95%	8.123678	10.3588	Skewness	2.226906
99%	8.691822	11.26978	Kurtosis	16.25479

The distribution is clearly not normal. High positive skewness (right tail) and very high Kurtosis score (peaked in the middle). This also can be seen from the density curve compared to the normal distribution and the boxplot:

Figure A2: Distribution of dependent variable compared to normal distribution

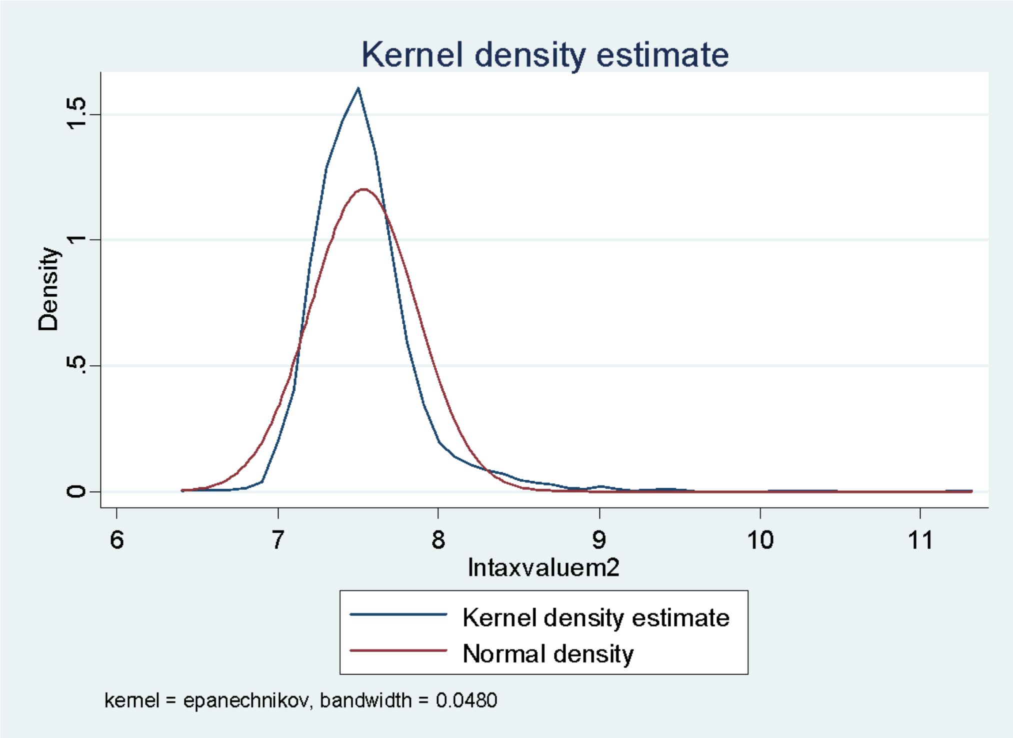
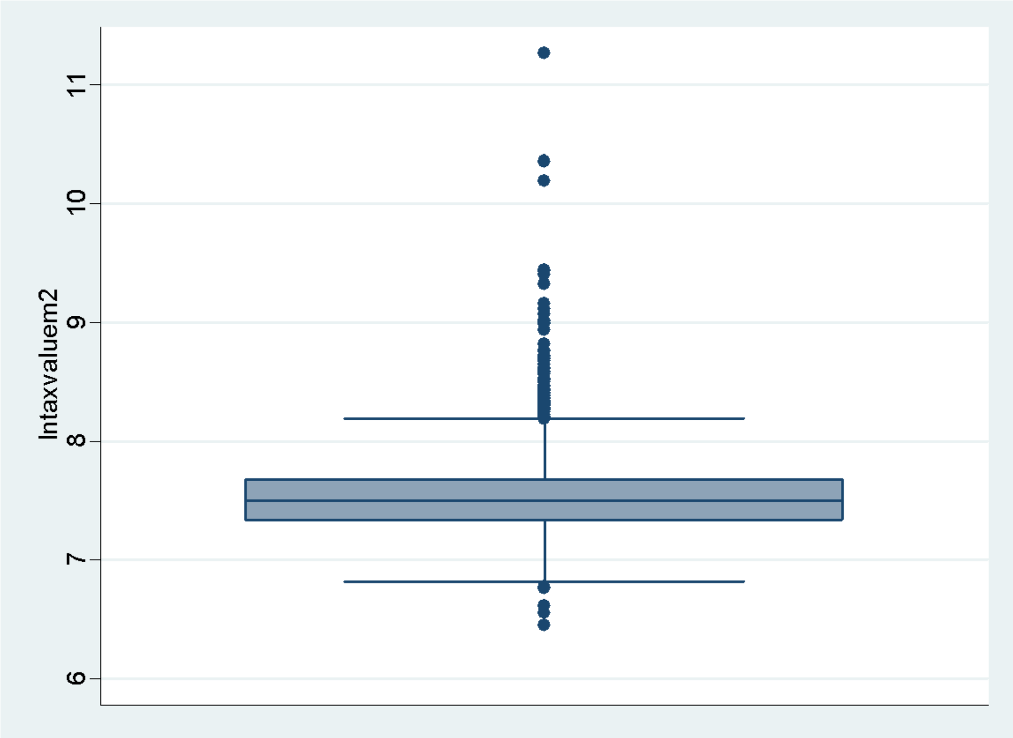


Figure A3: Boxplot dependent variable



After winsorizing the highest five percent of values and deletion of three extreme observations which were also non-typical locations of blocks compared to the rest of the dataset, the same diagnostics were obtained.

Figure A4: Quatile plot dependent variable

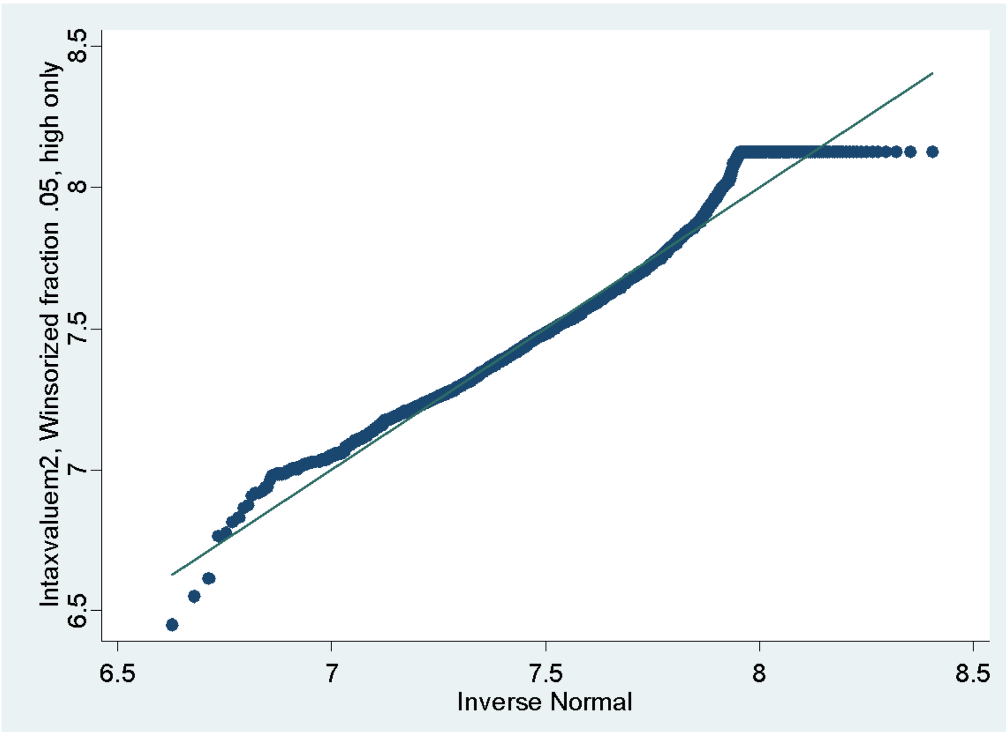


Table A3: Descriptives winsorized dependent variable

lntaxvaluem2, Winsorized fraction .05, high only

	Percentiles	Smallest		
1%	6.997395	6.450997		
5%	7.120472	6.55108		
10%	7.20786	6.614482	Obs	2489
25%	7.329962	6.763384	Sum of Wgt.	2489
50%	7.495679		Mean	7.516707
		Largest	Std. Dev.	.2652092
75%	7.672405	8.123678		
90%	7.873681	8.123678	Variance	.0703359
95%	8.114787	8.123678	Skewness	.3717106
99%	8.123678	8.123678	Kurtosis	3.104906

Figure A5: Distribution of winsorized dependend variable compared to normal distribution

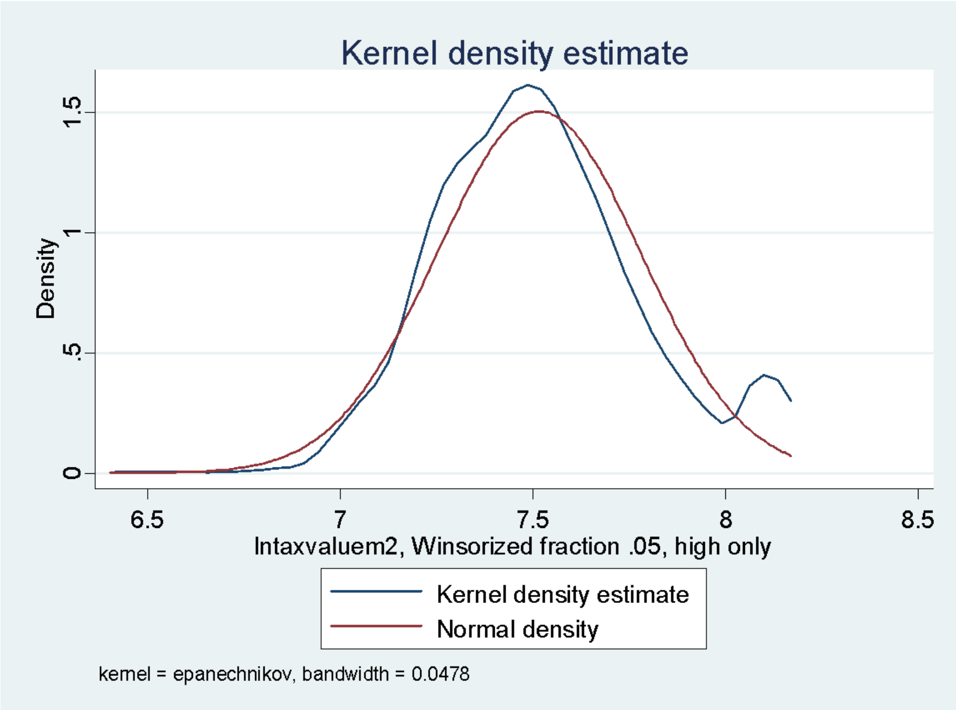
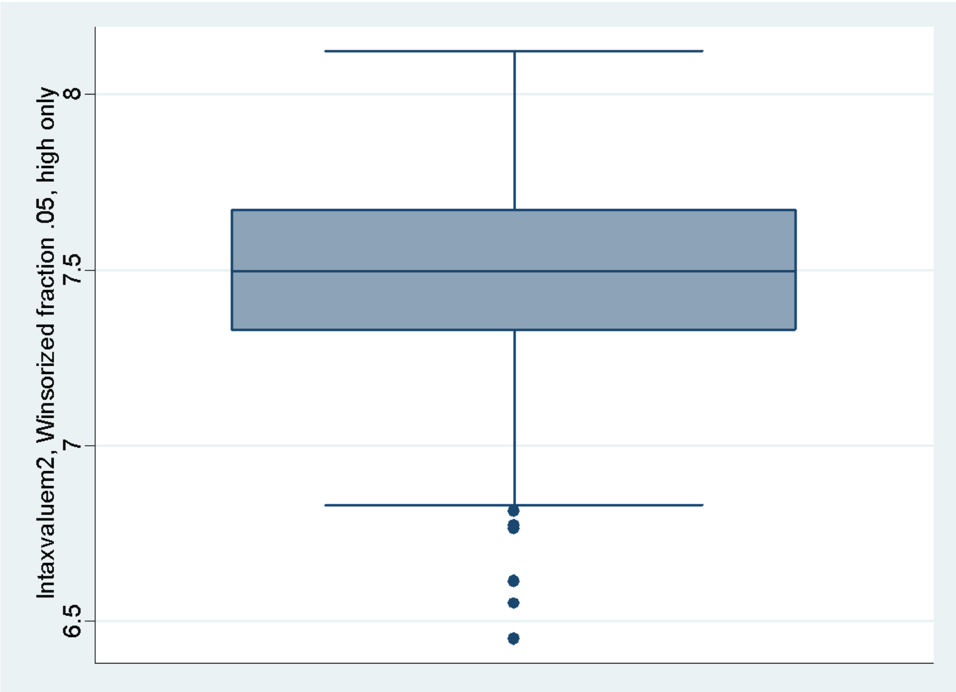


Figure A6: Boxplot dependent variable

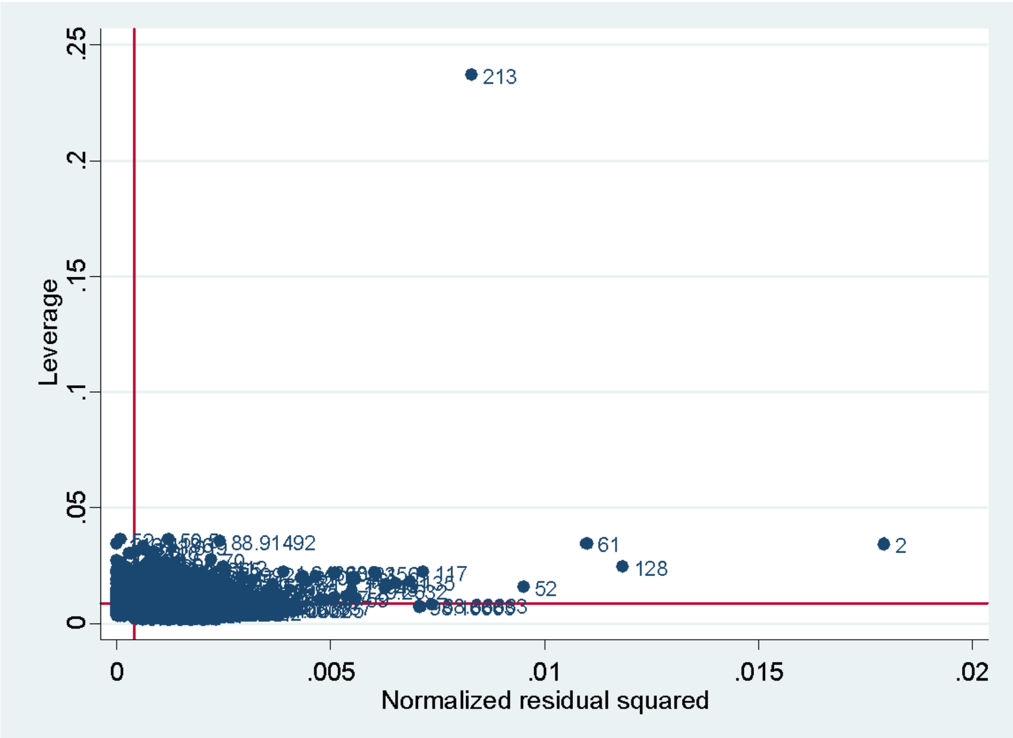


Below is the lvr2plot (leverage-versus-residual-squared plot) after a normal multiple regression:

Clearly, one observation with a very high leverage (the observation with the highest age by far of 213 years) compared to the rest of the data needs to be investigated. I use the Cook's D (Distance) approach. A simple rule of thumb tells us that when an observation has D > 1 it is a high influential point, in that it affects the magnitude of coefficients on its own. Another rule points to influential observations when D > 4/n, where n = number of observations.

There are quite a number of observations with D larger than 4/2489 but one has even a value of 1.263977 (which is higher than the threshold level of 1). This is the observation with the highest age and indeed it influences the coefficients of age and age squared. In a regression that includes this observation the variables "age" and "age2" have a coefficient of -.0038193 and .0000319 respectively and without the observation in question these take values of -.0048853 and .0000414 in the same order.

Figure A7: lvr2plot (numbers refer to age)



The dataset now contains 2488 observations. Descriptive statistics are presented below.

Table A4: Summary of statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lntaxvaluem2	2488	7.516337	.2642375	6.450997	8.114787
avgrooms	2488	3.668423	.8459768	1	8
age	2488	59.81742	28.24764	1	147
avgrent	2488	.6786809	.3242844	0	1
percsingle~m	2488	27.60114	40.17138	0	100
percmultil	2488	13.44543	29.45512	0	100
percmultin	2488	25.64365	32.42669	0	100
percotherm~i	2488	27.49185	30.85673	0	100
percunknown	2488	5.817929	17.54091	0	100
lncenter	2488	7.550357	.5580849	4.329151	8.526671
lnhospital	2488	7.043687	.5658792	3.85823	8.779893
lnpractiti~r	2488	5.600178	.6894271	2.4918	8.674916
lnramp	2488	7.352109	.5929871	4.343805	8.307213
lntrain	2488	7.240573	.6610318	4.276666	8.583543
Park500	2488	.2013666	.4011019	0	1
Centrum	2488	.0699357	.2550899	0	1
Charlois	2488	.187701	.3905517	0	1
Delfshaven	2488	.1270096	.3330507	0	1
Feijenoord	2488	.1575563	.3643977	0	1
IJsselmonde	2488	.2017685	.401401	0	1
KraCro	2488	.1378617	.3448241	0	1
Noord	2488	.1181672	.3228709	0	1
pGreen100	2488	15.55528	13.19502	0	87.37266
pParking100	2488	3.987325	2.193695	0	17.74982
pInfra100	2488	12.73856	4.620695	0	39.12752
pOS100	2488	38.32388	8.959782	2.861431	70.89707
pWaters100	2488	3.273546	7.113298	0	70.3382
pBuildup100	2488	26.12142	10.14654	.2618721	76.82113
ENT100	2488	.8127714	.0702104	.3387776	.9882629
Frag100	2488	2.382537	.6669024	.7991459	10.88188

Table A5: Variance Inflation Factor analysis after regression of model 2 (left) and model 3 (right). (Note: without interaction terms age2 and ENTFrag100 because of high correlation with age and ENT100 & Frag100 respectively)

Variable	VIF	1/VIF
IJsselmonde	8.46	0.118155
Charlois	6.57	0.152276
lncenter	5.94	0.168446
KraCro	4.90	0.204103
Feijenoord	4.80	0.208462
Delfshaven	4.52	0.221361
Noord	4.40	0.227330
pGreen100	3.52	0.284169
lnramp	3.12	0.320102
pOS100	3.05	0.328081
lnhospital	2.64	0.378805
lntrain	2.49	0.401579
percotherm~i	2.34	0.427115
percmultil	2.21	0.451852
percmultin	1.91	0.522833
pWaters100	1.79	0.557263
pParking100	1.73	0.576657
age	1.65	0.605680
avgrooms	1.62	0.618927
pInfra100	1.47	0.680524
percunknown	1.31	0.763578
avgrent	1.29	0.774648
Park500	1.27	0.789451
lnpractiti~r	1.25	0.800074
Mean VIF	3.09	

Variable	VIF	1/VIF
IJsselmonde	8.14	0.122853
Charlois	6.33	0.157862
lncenter	5.83	0.171552
KraCro	4.87	0.205168
Feijenoord	4.61	0.216965
Delfshaven	4.49	0.222771
Noord	4.35	0.229657
lnramp	3.03	0.330473
lnhospital	2.61	0.382924
lntrain	2.51	0.398876
percotherm~i	2.17	0.459819
percmultil	1.99	0.502657
percmultin	1.72	0.582598
age	1.64	0.609690
avgrooms	1.59	0.627160
ENT100	1.30	0.769711
Frag100	1.30	0.770926
avgrent	1.26	0.792728
Park500	1.23	0.815041
lnpractiti~r	1.21	0.827254
percunknown	1.20	0.832717
Mean VIF	3.02	

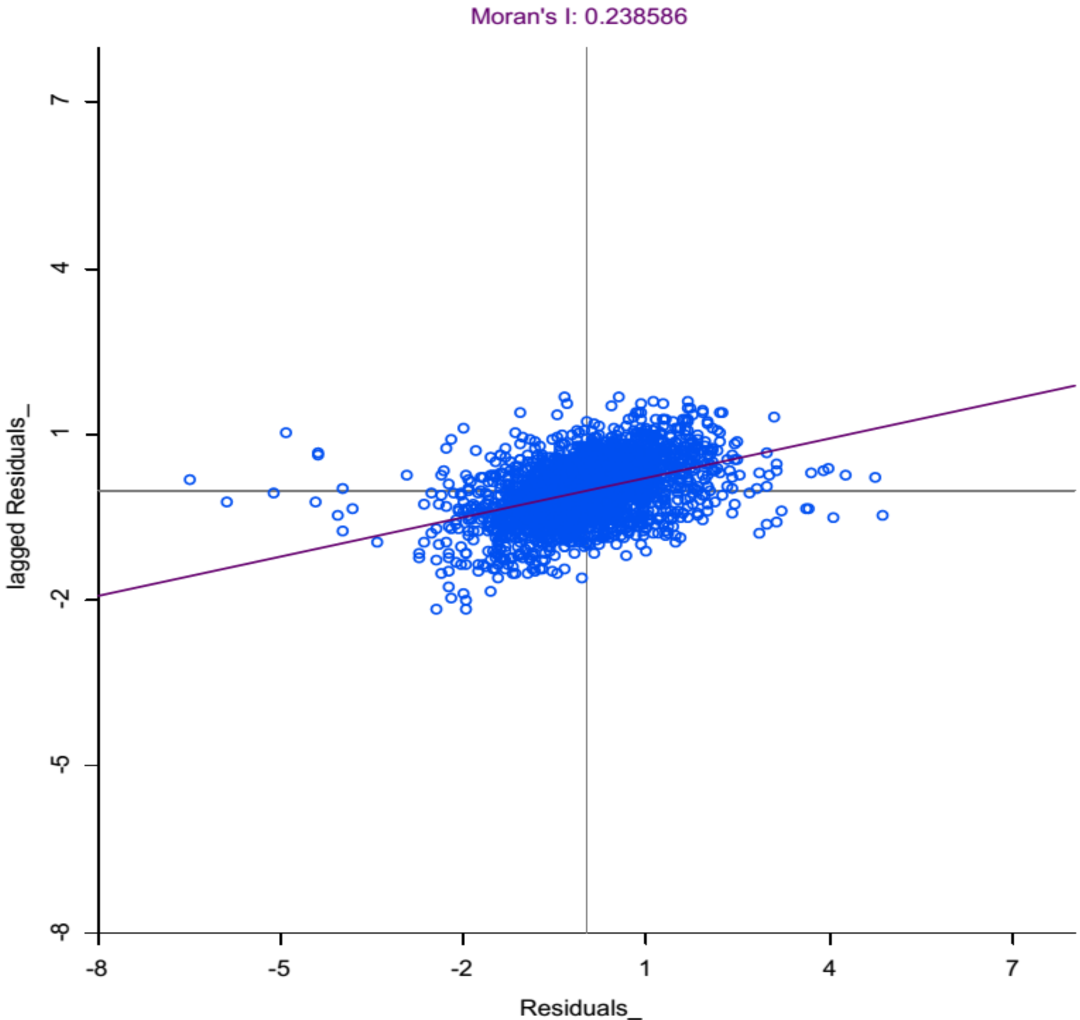
No VIF values larger than 10 and no mean VIF value larger than 6 are present. These threshold values are often used as a rule of thumb, although values larger than these do not necessarily imply severe problems related to multicollinearity (see O'brien, 2007).

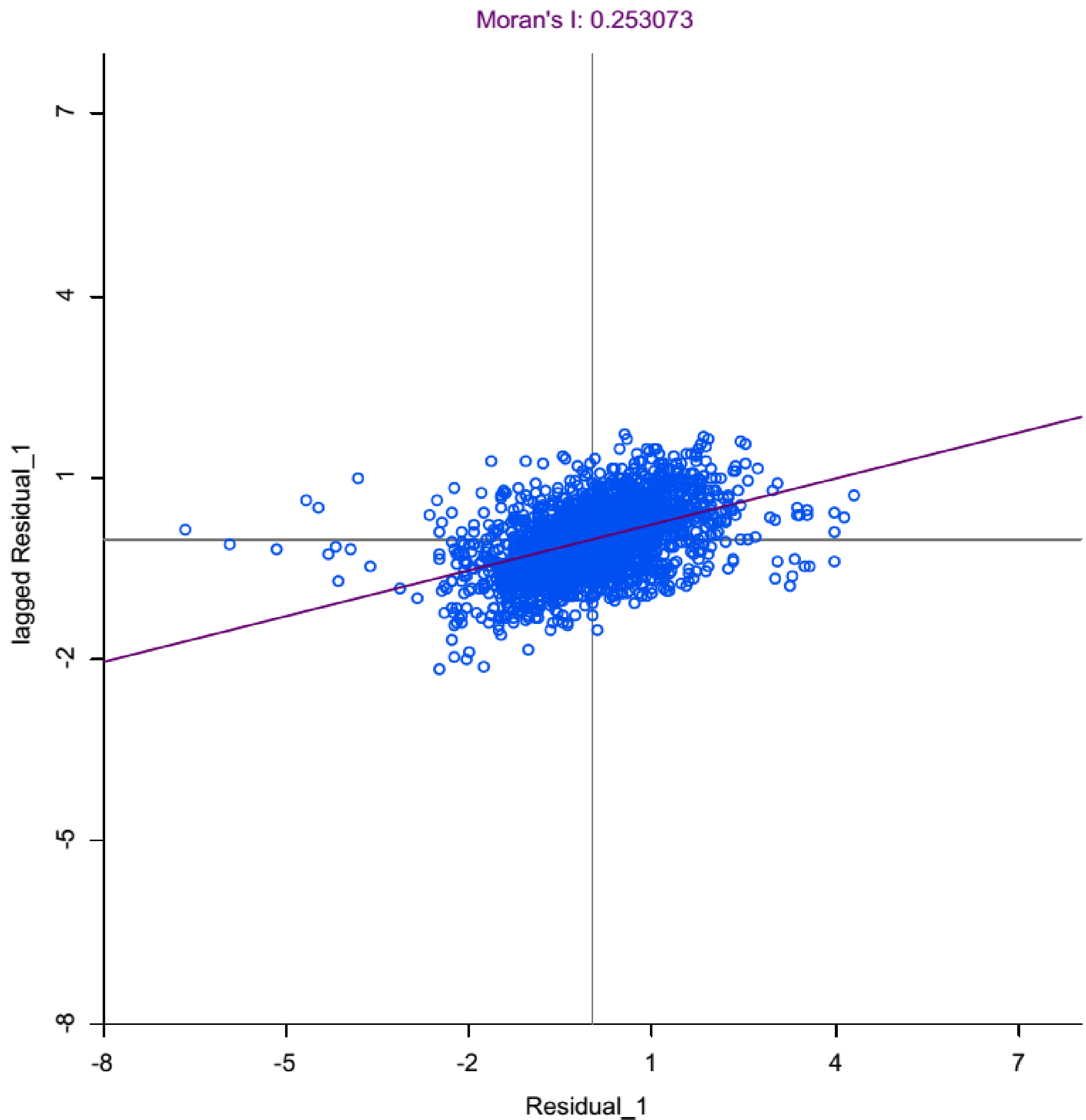
Appendix C: Testing for spatial autocorrelation

After a regression of model 2 and 3, the models with land-use information, the residuals were obtained and connected with the observations in the attribute table in QGIS. Then that file was imported in GeoDa in order to create a spatial weight matrix.

As the buffers are all of the same size and can have overlapping areas as well as form “islands” on their own the method of k-nearest neighbors is chosen to determine which observations are neighbors of each other and how the weights assigned to the observations are calculated. The mean number of buffer areas of other observations within one particular buffer around an observation is about 10. But then also marginal overlapping cases are counted as well and observations more isolated definitely have less natural neighbors than that. A rule of thumb suggests that each observation should have at least 8 neighbors () and so this number will be used accordingly.

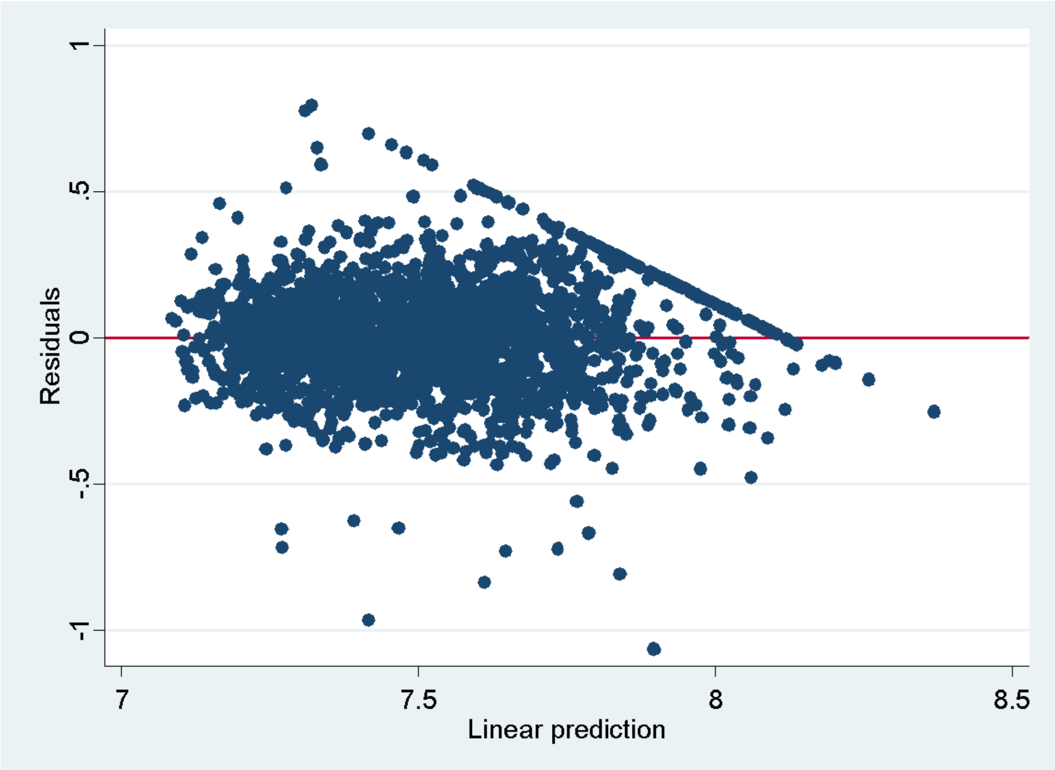
Figure A8: Moran's Index for spatial autocorrelation based on k=8 nearest neighbors (model 2 above, model 3 below)




Moran's I: 0.253073
lagged Residual_1
7
4
1
-2
-5
-8
-8
-5
-2
1
4
7
Residual_1

Appendix D: Post-regression testing and supporting output

Figure A9: Residuals vs predicted values model 2



The residuals do not show a particular pattern across the range of predictions and a great portion is actually clustered close around the zero-line. The straight line of points comes from those observations that have been winsorized.

Figure A10: Histogram of residuals model 2 (with normal curve)

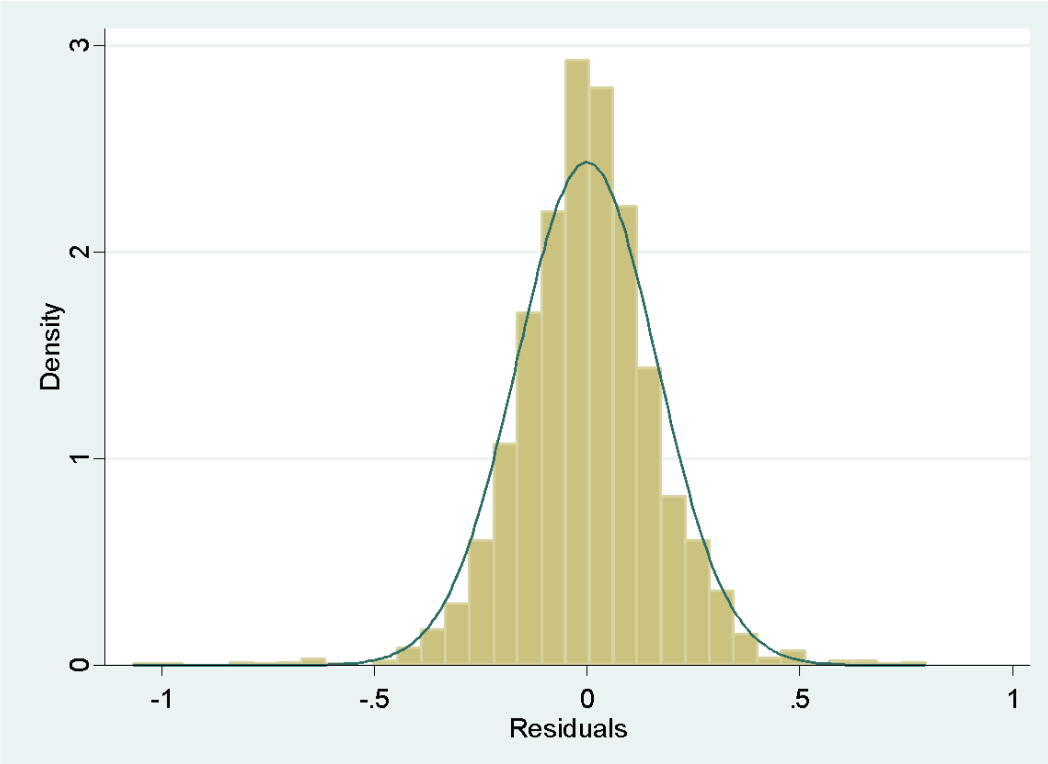


Table A6: Linktest model 2

Source	SS	df	MS
Model	106.791661	2	53.3958307
Residual	66.85434	2485	.026903155
Total	173.646001	2487	.069821472

Number of obs =	2488
F(2, 2485) =	1984.74
Prob > F =	0.0000
R-squared =	0.6150
Adj R-squared =	0.6147
Root MSE =	.16402

lntaxvaluem2	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_hat	1.006812	.8620746	1.17	0.243	-.6836461	2.697271
_hatsq	-.0004504	.0569861	-0.01	0.994	-.1121954	.1112946
_cons	-.0257395	3.25884	-0.01	0.994	-6.41606	6.364581

Table A7: Ramsey RESET test model 2

```
Ramsey RESET test using powers of the fitted values of lntaxvaluem2
       Ho:  model has no omitted variables
                F(3, 2459) =      2.52
                  Prob > F =      0.0562
```

The linktest points out that the model is specified correctly as the created variable _hatsq (i.e. the squared fitted values) is definitely insignificant. The Ramsey RESET test for omitted variables is also in favor of model 2 because there is no indication of missing variables that would significantly add explanatory power to the model (alpha five percent).

The same tests are carried out for model 3. The distribution of residuals look similar as the previous model.

Figure A11: Residuals vs predicted values model 3

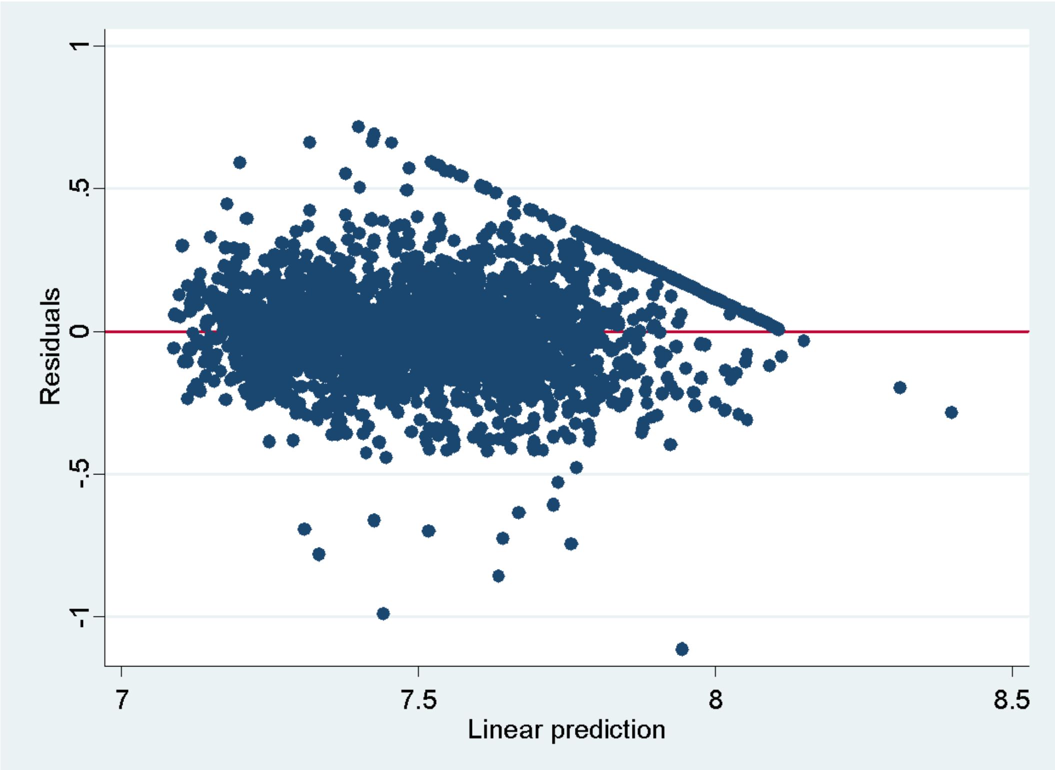


Figure A12: Histogram of residuals model 3 (with normal curve)

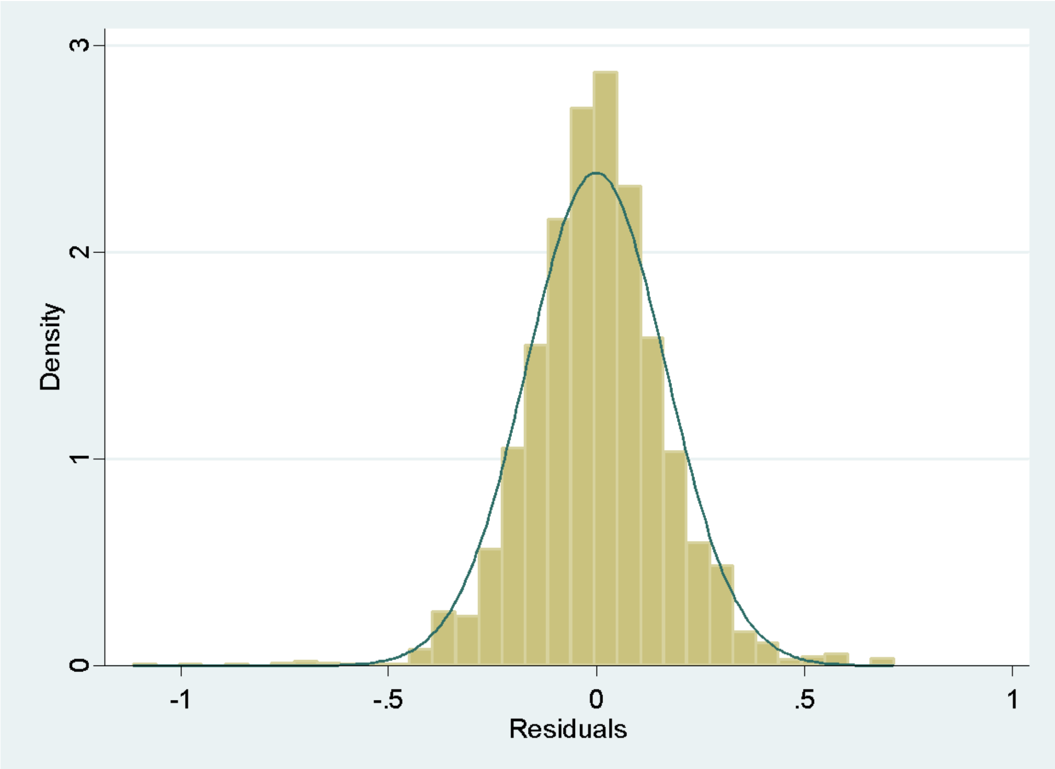


Table A8: Linktest model 3

Source	SS	df	MS
Model	104.163659	2	52.0818293
Residual	69.4823429	2485	.027960701
Total	173.646001	2487	.069821472

Number of obs =	2488
F(2, 2485) =	1862.68
Prob > F =	0.0000
R-squared =	0.5999
Adj R-squared =	0.5995
Root MSE =	.16721

lntaxvaluem2	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
_hat	-.7446547	.9158501	-0.81	0.416	-2.540563	1.051253
_hatsq	.1154928	.0606178	1.91	0.057	-.0033738	.2343594
_cons	6.583778	3.457774	1.90	0.057	-.1966366	13.36419

Table A9: Ramsey RESET test model 3

```
Ramsey RESET test using powers of the fitted values of lntaxvaluem2
       Ho:  model has no omitted variables
                F(3, 2461) =       5.23
                  Prob > F =       0.0013
```

We can see that the LINKTEST does not allow rejecting the null hypothesis (though it is a close call considering a five percent significance level) that the model is correctly specified. However, the Ramsey RESET test this time gives a clear signal that the model has omitted variables.

Appendix E: Regression output for 50 and 200 meter buffers

Table A10: Regressions for 50 meter buffers

```
Linear regression                                      Number of obs =    2488
                                                       F( 25,    55) =  124.47
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6075
                                                       Root MSE      =  .16638

                          (Std. Err. adjusted for 56 clusters in neighborhood)
```

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0545351	.0156322	-3.49	0.001	-.0858627	-.0232075
age	-.0049924	.0008838	-5.65	0.000	-.0067635	-.0032213
age2	.000042	7.37e-06	5.70	0.000	.0000273	.0000568
avgrent	-.2485012	.020599	-12.06	0.000	-.2897825	-.2072199
percmultil	-.0020374	.0003425	-5.95	0.000	-.0027237	-.0013511
percmultin	-.003607	.00031	-11.64	0.000	-.0042282	-.0029858
percothermu~i	-.003137	.0004227	-7.42	0.000	-.0039841	-.0022899
percunknown	-.0012397	.0004216	-2.94	0.005	-.0020846	-.0003949
lncenter	.0582917	.0302259	1.93	0.059	-.0022823	.1188658
lnhospital	-.0391532	.0245779	-1.59	0.117	-.0884084	.010102
lnpractitio~r	.0280578	.0117052	2.40	0.020	.0046001	.0515156
lnramp	.0485249	.0195743	2.48	0.016	.0092971	.0877526
lntrain	-.0016524	.0186313	-0.09	0.930	-.0389903	.0356855
Park500	.0376787	.0249893	1.51	0.137	-.012401	.0877584
Charlois	-.3429557	.0657175	-5.22	0.000	-.4746564	-.2112549
Delfshaven	-.2303552	.0640572	-3.60	0.001	-.3587287	-.1019816
Feijenoord	-.319928	.0616539	-5.19	0.000	-.4434852	-.1963708
IJsselmonde	-.2809987	.0697291	-4.03	0.000	-.420739	-.1412584
KraCro	.0226915	.0641138	0.35	0.725	-.1057955	.1511785
Noord	-.0318239	.0563062	-0.57	0.574	-.144664	.0810161
pGreen50	-.0137261	.0689695	-0.20	0.843	-.1519442	.124492
pParking50	-.287495	.1806291	-1.59	0.117	-.6494838	.0744938
pInfra50	-.1352077	.091236	-1.48	0.144	-.3180487	.0476333
pOS50	.0739557	.0847942	0.87	0.387	-.0959757	.2438871
pWaters50	.437064	.1385556	3.15	0.003	.1593923	.7147357
_cons	7.73322	.3367877	22.96	0.000	7.058283	8.408158

```
Linear regression                                      Number of obs =    2488
                                                       F( 23,     55) =  105.90
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.5996
                                                       Root MSE      =  .16799
```

(Std. Err. adjusted for 56 clusters in neighborhood)

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0533886	.0154109	-3.46	0.001	-.0842727	-.0225046
age	-.0050127	.0008789	-5.70	0.000	-.0067741	-.0032513
age2	.0000421	7.36e-06	5.71	0.000	.0000273	.0000568
avgrent	-.2569076	.0204325	-12.57	0.000	-.2978552	-.21596
percmultil	-.0021364	.000322	-6.63	0.000	-.0027818	-.0014911
percmultin	-.0037738	.0002912	-12.96	0.000	-.0043574	-.0031901
percothermu~i	-.0032822	.0004297	-7.64	0.000	-.0041433	-.0024211
percunknown	-.0013171	.0004193	-3.14	0.003	-.0021574	-.0004768
lncenter	.0639633	.0302565	2.11	0.039	.0033278	.1245987
lnhospital	-.0385419	.0245309	-1.57	0.122	-.0877029	.0106192
lnpractitio~r	.032982	.011741	2.81	0.007	.0094525	.0565115
lnramp	.0528367	.0200546	2.63	0.011	.0126463	.093027
lntrain	.0003571	.017741	0.02	0.984	-.0351968	.0359109
Park500	.0362524	.0244446	1.48	0.144	-.0127357	.0852405
Charlois	-.35708	.0646621	-5.52	0.000	-.4866658	-.2274941
Delfshaven	-.2319117	.0628711	-3.69	0.001	-.3579082	-.1059152
Feijenoord	-.331149	.0594506	-5.57	0.000	-.4502907	-.2120073
IJsselmonde	-.3033669	.0683593	-4.44	0.000	-.4403619	-.1663719
KraCro	.0199292	.0644564	0.31	0.758	-.1092443	.1491028
Noord	-.0347697	.0566669	-0.61	0.542	-.1483327	.0787932
ENT50	.0310759	.061446	0.51	0.615	-.0920646	.1542163
Frag50	.0382211	.0148302	2.58	0.013	.0085006	.0679416
ENTFrag50	-.0669557	.0245584	-2.73	0.009	-.1161718	-.0177397
_cons	7.65342	.343432	22.29	0.000	6.965167	8.341673

In this model fragmentation and the interaction of diversity with fragmentation have significant p-values. But due to large proportions of private space within the 50 meter buffers the land-use variables and with that the mix indices are likely to be endogenous. So further interpretation is not of use.

Table A11: Regressions for 200 meter buffers

```
Linear regression                                      Number of obs =    2488
                                                       F( 25,    55) =  114.88
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.6221
                                                       Root MSE      =  .16327

                          (Std. Err. adjusted for 56 clusters in neighborhood)
```

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0587078	.0161298	-3.64	0.001	-.0910326	-.026383
age	-.0043143	.0008435	-5.11	0.000	-.0060048	-.0026238
age2	.0000369	7.20e-06	5.13	0.000	.0000225	.0000513
avgrent	-.2433977	.0197148	-12.35	0.000	-.2829071	-.2038883
percmultil	-.0022644	.0003142	-7.21	0.000	-.002894	-.0016348
percmultin	-.0037234	.0002832	-13.15	0.000	-.004291	-.0031558
percothermu~i	-.0031434	.0004003	-7.85	0.000	-.0039457	-.0023412
percunknown	-.0013885	.0004231	-3.28	0.002	-.0022364	-.0005406
lncenter	.0359802	.0290568	1.24	0.221	-.0222508	.0942113
lnhospital	-.0359397	.0241233	-1.49	0.142	-.0842838	.0124044
lnpractitio~r	.0141006	.0116144	1.21	0.230	-.0091752	.0373765
lnramp	.0454641	.0197439	2.30	0.025	.0058964	.0850318
lntrain	-.0037631	.0190941	-0.20	0.844	-.0420284	.0345023
Park500	.0316886	.0243887	1.30	0.199	-.0171874	.0805647
Charlois	-.3354619	.0601793	-5.57	0.000	-.4560639	-.2148599
Delfshaven	-.2188336	.0595953	-3.67	0.001	-.3382654	-.0994019
Feijenoord	-.3257593	.0516734	-6.30	0.000	-.4293152	-.2222034
IJsselmonde	-.269887	.0626373	-4.31	0.000	-.395415	-.144359
KraCro	.0350621	.0585389	0.60	0.552	-.0822524	.1523767
Noord	-.0170905	.0507349	-0.34	0.738	-.1187655	.0845845
pGreen200	.0008774	.0011386	0.77	0.444	-.0014045	.0031593
pParking200	-.0109856	.0056813	-1.93	0.058	-.0223711	.0003999
pInfra200	1.58e-06	.0022554	0.00	0.999	-.0045183	.0045215
pOS200	.0033261	.0015268	2.18	0.034	.0002663	.0063858
pWaters200	.006011	.0013799	4.36	0.000	.0032457	.0087763
_cons	7.868381	.3568036	22.05	0.000	7.15333	8.583431

Linear regression

Number of obs	= 2488
F(23, 55)	= 92.68
Prob > F	= 0.0000
R-squared	= 0.6006
Root MSE	= .16777

(Std. Err. adjusted for 56 clusters in neighborhood)

lntaxvaluem2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
avgrooms	-.0534573	.0156599	-3.41	0.001	-.0848405	-.0220742
age	-.0049159	.0009068	-5.42	0.000	-.0067332	-.0030986
age2	.000041	7.48e-06	5.48	0.000	.000026	.000056
avgrent	-.2582696	.02013	-12.83	0.000	-.298611	-.2179283
percmultil	-.0021799	.0003246	-6.72	0.000	-.0028303	-.0015294
percmultin	-.0037835	.0002848	-13.29	0.000	-.0043541	-.0032128
percothermu~i	-.0033011	.0004281	-7.71	0.000	-.0041589	-.0024432
percunknown	-.001414	.0004177	-3.38	0.001	-.0022511	-.0005768
lncenter	.0635014	.0304578	2.08	0.042	.0024626	.1245403
lnhospital	-.0435804	.025535	-1.71	0.094	-.0947536	.0075929
lnpractitio~r	.0301124	.0116564	2.58	0.012	.0067525	.0534723
lnramp	.0533802	.0197212	2.71	0.009	.013858	.0929024
lntrain	.00047	.0176889	0.03	0.979	-.0349794	.0359194
Park500	.0355995	.024223	1.47	0.147	-.0129446	.0841435
Charlois	-.353058	.0638741	-5.53	0.000	-.4810645	-.2250515
Delfshaven	-.220722	.0640335	-3.45	0.001	-.349048	-.092396
Feijenoord	-.3258272	.0603928	-5.40	0.000	-.4468571	-.2047973
IJsselmonde	-.3027626	.0690097	-4.39	0.000	-.4410612	-.164464
KraCro	.0286876	.0660973	0.43	0.666	-.1037743	.1611495
Noord	-.0224085	.0584302	-0.38	0.703	-.1395053	.0946883
ENT200	.017699	.3813678	0.05	0.963	-.7465791	.7819771
Frag200	.0924238	.153134	0.60	0.549	-.2144635	.3993112
ENTFrag200	-.1547495	.1991897	-0.78	0.441	-.5539346	.2444356
_cons	7.749503	.5187156	14.94	0.000	6.709973	8.789032