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Does Tiling Gardens Have an Impact on the Attractiveness of Neighbourhoods?

The effect of Tiles in Gardens on Neighbouring Property Values

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Abstract

This study examines the external effect of tiles in gardens on housing transaction prices of surrounding properties in Amsterdam. Data on the vegetation level of gardens is constructed in QGIS (Quantum Geographical Information System) through the calculation of the Normalized Difference Vegetation Index (NDVI) using Infrared satellite images of the summer periods of 2017 and 2021 of Amsterdam from satellietdataportaal.nl. A hedonic pricing analysis is performed with internal characteristics and spatial attributes using data from the NVM database and the municipality of Amsterdam. A decrease in appreciation for tiles has been found, as there are 27 percentage point less gardens tiled for 90-100% in 2021 compared to 2017. The marginal willingness to pay of households for tiles within gardens of surrounding properties ranges from 0.0% to -0.3% at the statistically significant 1% level, the higher the percentage neighbourhood (pc4 area). It can be concluded that the more tiles within gardens per neighbourhood the bigger the negative external effect on the transaction prices of surrounding properties. The implied total public costs are estimated at 18,050.00 euros and the implied total private costs of 237.50 euros. Hereby, it can be concluded that tiles within gardens have a sizeable external effect on the housing transaction prices of surrounding properties in Amsterdam for the public. Especially by comparing these costs with the total private costs, it can be concluded that is valuable to experiment with incentives against tiling gardens.

Keywords: Private gardens, green space, urban amenities, public/private dilemma, Amsterdam

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1. Introduction

Apart from well-maintained gardens being a valuable neighbourhood amenity, filled with greenery they are also valuable for human and environmental health. Stichting SteenBreek, founded in 2015, is an initiative that is committed to greening gardens in the Netherlands for these considerations. They calculated that all gardens in urban environments in the Netherlands together have the size of the 'IJselmeer'. Approximately 60% of these gardens are filled with tiles of which 37% is tiled for more than 50% (Dijk, 2019). If all those gardens in the urban environments in Netherlands are filled with greenery, this adds up to a considerable area that matters in the bigger picture and benefit the environment and human health especially in cities. In other words: *"Little drop of water, Little grains of sand, Make the might ocean And the pleasant land."* – J. F. Carney (1845).

Awareness about the importance of a green infrastructure in urban environments and the role private gardens have in this is slowly boiling down from researchers to policy makers to citizens (Beumer, 2018). A large body of literature focusses on greening public spaces as they are linked to public concerns, such as health, water drainage, temperature regulation, and clean air. Although private spaces matter, there is a gap between public concerns and private investments. The so-called public/private dilemma (Beumer, 2018).

Over the past years public concerns have raised several initiatives that aim to bridge this gap and intend to provide policy makers and urban planners with levers to experiment with incentives against the tiling gardens (Dijk, 2019). The goal of this study is to contribute to the rapidly emerging field that aims to bridge this gap by finding evidence to support the initiatives against tiling gardens.

Hereby, this study focusses on Amsterdam as it is the city with the most tiled gardens, merely 11% of the gardens are covered with greenery. The first aim is to examine whether awareness about the importance of green gardens is boiled down in Amsterdam as well by measuring the change in vegetation level of gardens between 2017 and 2021 using data constructed in QGIS.

The second aim is to examine whether the importance of green gardens is reflected in house prices as well by performing a hedonic pricing analysis using the NVM database. The following research question is formulated:

"Does tiling gardens have an impact on the attractiveness of neighbourhoods ***in Amsterdam****?"*

There is expected to be a direct external effect on the house prices of surrounding properties when neighbours' gardens are tiled because it is expected to decrease the quality of that neighbourhood. Further, the marginal willingness to pay for the external effect is calculated and compared to the marginal willingness to pay of the direct effect of tiles in gardens on housing transaction prices. These results are used to compare the social costs with the private costs to be able to give a conclusive answer about the gap between public concerns and private interests.

Evidence has been found that the total number of tiles decreased between 2017 and 2021 indicating that the appreciation for tiles lowered substantially in Amsterdam. In 2017 61% of the gardens were tiled for 90-100% while in 2021 34% of the gardens were tiled for 90-100%. That is a reduction of 27 percentage point. Further, the marginal willingness to pay for properties in tiled neighbourhoods ranges from 0.0% to -0.3% at the statistically significant 1% level the higher the percentage tiles within gardens per neighbourhood. Finally, the implied total public costs are estimated at 18,050.00 euros and the implied total private costs of 237.50 euros.

The remainder of the paper is organized as follows: chapter two presents to theoretical framework that lead to the formulation of the hypotheses; chapter three and four presents, respectively, the methodology and the data sampling with descriptive statistics; chapter five presents the results that are followed by chapter 6 and 7 that present, respectively, the conclusion and discussion.

2. Literature review

The hypotheses to the research question will follow from this chapter by zooming in on the importance of green private gardens in cities from a broader perspective. By zooming is from a broader perspective, a complete picture arises from which the importance of green gardens can be extracted. Firstly, the paradoxical role of cities is explained from which the concept Sustainable Urban Development arose. This concept emphasizes the importance of increasing the green infrastructure in urban environments. After explaining this based on empirical evidence, there is zoomed in on the contribution that private gardens have in this.

2.1 The Paradoxical Role of Cities

All the "good" and the "bad" of human existence comes together in cities. On the one hand, urban development is associated with a great amount of land use change that affects the natural resources and biodiversity. On a global scale land is turned into sealed surface for housing, industry, and parking lots (Beumer, 2018). In 2006, the Netherlands is at the forefront with respect to their sealing rate, compared to other EU member states: land transformed faster into sealed surfaces than its population grew (Directorate-General for Environment (European Commission) et al., 2011).

On the other hand, urban development, the transformation of a country from a rural agriculturally based economy to an industrial service-based economy, results in agglomeration economies from firms and workers that cluster in space, such as economies of scale and knowledge spill overs (Henderson, 2003). This stems from Marshall's (1890) theory on localized economies of scale in manufacturing and services and provides great opportunities for increasing sustainable urban development, due to the creativity and potential of humans that emerges from urban living (Beumer, 2018).

This creativity is also reflected in the Netherlands that has implemented measures for mitigating the land transformation. There has for instance been an improvement of quality of life in urban centres with the "Randstad" program that puts emphasis on improving the attractiveness of inner urban areas in the metropolitan agglomeration of Amsterdam, Rotterdam, and The Hague. Also, designated "green and blue" landscapes are protected from infrastructure developments. Quantitative limits for annual land take exist that are indicative and used as monitoring tools (Directorate-General for Environment (European Commission) et al., 2011).

So, urban development represents a sectoral shift within an economy, but the productivity of growth is strongly affected by the form that urbanization takes, or the degree of urban concentration. There is an optimal degree of urban concentration, which balances the gains from enhanced concentration such as knowledge accumulation against the losses such as depletion of natural resources and loss in biodiversity (Henderson, 2003). Beumer (2018) points out that the creativity and human potential that emerges from knowledge accumulation, fostered by urban living, can also be used to reverse the losses, and design Sustainable Urban Development measures (Beumer, 2018).

2.2 Sustainable Urban Development

Sustainable urban development and design is a key issue for global policy and civil action for the nature of the 21st century. It is a broad interpretable concept, but an all-encompassing definition is given by UN Habitat (2015):

"Sustainable urban development can be defined as the spatial manifestation of urban ***development processes that creates a built environment with norms, institutions and governance systems enabling individuals, households and societies to maximize their potential, optimize a vast range of services so that homes and dynamic neighbourhoods, cities and towns are planned, built, renewed and consolidated restraining adverse impacts on the environment while safeguarding the quality of life, needs and livelihood of its present and future populations (UN Habitat, 2015)****."*

Sustainable cities are called Biophilic cities by Timothy Beatley (2011), professor at the Urban and Environmental Planning department at the University of Virginia School of Architecture. He draws from theory and research associated with biophilia and argues that there is a need to reimagine cities as biophilic cities. That is a city that is abundant with nature, which looks for opportunities to repair and restore and creatively inserts nature wherever it can. Urban nature, therefore, refers to all inherently human impacted or influenced, nearby and nuanced nature, not the distant and pristine wilderness (Beatley, 2011).

Beatley (2011) argues how for most young adults' nature has become abstract and general. According to him the current generations of young adults that grew up with video games, indoor living, and diminished free time, are disconnected from nature. This disconnect is linked to health concerns about overweight children, but also led to a generation that does not inherently care about nature anymore (Beatley, 2011). This is supported by Carijn Beumer, Assistant Professor in Global Health at the University of Maastricht, who observed a clear trend of paving gardens during her dissertation research in 2014. The main explanation she finds is that people find maintaining a garden too time-consuming and they indicate that they do not have a green thumb (Beumer, 2014; Mulder, 2020).

But biophilia also describes the extent to which humans are hardwired to need connection with nature and other forms of life. According to Beatley (2011) it is unlikely that this need disappeared for the generations of people that have existed in urban environments, and he concludes that nature is therefore essential, rather than optional in urban living.

2.3 Empirical Evidence on the Positive Human and Environmental Health effects of exposure to Urban Nature

There is sufficient empirical evidence on the effects of direct and indirect exposure to nature to support this statement. Sjerp de Vries, environmental psychologist and scientist at Wageningen University & Research, studied the effects of green on human health. He researched 147 studies and finds a positive effect through stress reduction. A green environment can be a garden, park, agricultural area or blue (water) area. This is also confirmed by another studies that show nature's ability to reduce stress, enhance a positive mood, improve cognitive skills and academic performance, and help in moderating the effects of ADHD, autism, and other childhood illnesses (Chiesura, 2004; Hartig et al., 2003; Van Den Berg et al., 2007).

It is argued that spending time in or just seeing a green environment has a relaxing and calming effect, it can reduce mental fatigue and improve moods (Bouwman, 2021; Chiesura, 2004). The passage through a natural environmental, although briefly, interrupts a process of resource depletion. In the long-run brief restorative experiences offer cumulative benefits. This is especially relevant in cities, where nature exists in smaller and more discontinuous ways. It indicates that the smaller green features that can be incorporated in cities, both indoors and outdoors, are worthwhile (Beatley, 2011). Besides, it can lead to leaving the house more often, exercising more often, meeting neighbours, and having social contact. All factors that positively influence people's health and well-being (Bouwman, 2021).

Urban green features have effects on environmental health as well. Trees and green rooftops, for instance, mitigate urban heat, addressing the urban heat island effect. Urban heat island effect causes heat-related stress and illness in cities and lowers worker productivity (Zhang et al., 2019). An increasing concern given climate change. Besides, urban green features provide air quality benefits. Evidence has been found that they significantly reduce air pollutants (Roy et al., 2012; Yang et al., 2005).

2.4 Empirical Evidence on the Growing Awareness Among Policy Makers and Citizens

These positive environmental and human health effects all provide reasons confirmed why strengthening the green infrastructure in cities is so important. Awareness is slowly tickling down from global research to policymakers to citizens. Research by research bureau ‘Motivaction’ shows that three out of four Dutch people believe that investing in green should be part of the recovery plans after the Covid-19 pandemic. The same study also shows that 62% of the Dutch people got through the lockdown period better because it gave them the chance to escape into nature. This indicates that the corona pandemic has contributed to citizen’s understanding of the importance of green (Bouwman, 2021).

But even before the Covid-19 pandemic, citizens around the world have contributed to greening public spaces. For instance, traditional parks are turned into small urban farms to grow herbs and vegetables, and urban niches and roadsides are decorated with plants and flowers. There are insect hotels, green roofs, and green walls (Beatley, 2011; Beumer, 2018).

Characteristic to these initiatives of increasing the green infrastructure for biodiversity and sustainability is that they all target public spaces, as they are directly and most obviously related to the public concern, such as human and environmental health (Beumer, 2018).

2.5 Empirical Evidence on the Role of Private Spaces in the Creation of Urban Nature

All private gardens in urban environments in the Netherlands together have the size of the ‘IJselmeer’. Approximately 60% of these gardens are filled with tiles of which 37% is tiled for more than 50% (Dijk, 2019; Vries et al., 2023). Of all cities in the Netherlands, Amsterdam has the most tiled private gardens, merely 11% of the gardens are covered with vegetation (Dijk, 2019). Private gardens therefore have great potential to increase the green infrastructure of cities and mitigate the negative human and environmental health effects of urbanization.

However, gardens are often beyond the impact and reach of policymakers, potentially creating the gap between the trend of de-greening in private spaces and the public interests for increasing the green infrastructure. Mitigating this gap will unlock all potential for increasing the green infrastructure in cities (Beumer, 2018).

There is a young field of studies available on the contribution of private spaces, such as gardens or green roofs, in increasing the green infrastructure of cities. A study by Zhang, Fukuda, & Liu (2019) investigates households’ willingness to pay for green roofs in mitigating the urban heat island effect in Beijing through a contingent valuation survey. The results are positive and statistically significant, they find that the average household is willing to pay 20.55 US dollar per year. Also, they find that factors, such as attitude, perceived behavioural control, and social norm, play a significant role in households' willingness to pay. Hereby, suggesting that government credibility is of great importance in promoting participation (Zhang et al., 2019).

Another study by Lin, Jensen, and Wachter (2022) examined the effects of greening vacant lots on nearby housing transaction prices, by performing a difference-in-difference analysis using data from a longstanding program in Philadelphia and show how neighbourhood attributes matter to these outcomes. They investigate vacant lots that are treated by the Philadelphia LandCare program and find that prices for houses within 1,000 feet of a greened vacant lot rise by about 4%, with the effect size increasing over time. They also find that the size of the effect is dependent on the type of neighbourhood in terms of the share of vacant land and household income. By relaxing the assumption of a constant greening effect, they estimate an effect of 9% for neighbourhoods with a higher-than-average income and an average level of vacant land share with peak estimates at 19% for high-vacancy neighbourhoods. Support for these substantial percentages can be found in a similar study by Voico and Been (2008) that estimates the impact of community gardens on house prices of surrounding properties in New York City, performing a difference-in-difference specification of a hedonic pricing analysis (Voicu & Been, 2008).

Empirical studies on the effects of green gardens are also performed in the Netherlands. Although, the aim is to investigate the impact on human health, rather than house prices. The study "A green garden, a healthy garden", investigates the effect of a green garden on human health in 184 Dutch municipalities. So far, a positive correlation is found, but causation has not yet been established (Bouwman, 2021; de Vriens, 2020).

2.5 Hypotheses

There is a large body of literature that find evidence that a green infrastructure in urban environments is good for human and environmental health considerations (Beatley, 2011; Beumer, 2018; Chiesura, 2004; de Vriens, 2020; Hartig et al., 2003; Roy et al., 2012; Van Den Berg et al., 2007; Yang et al., 2005) because it improves cognitive skills, reduces stress, increases biodiversity, and improves water drainage.

In the Netherlands, awareness about the importance of a green infrastructure in urban environments is slowly boiling down from researchers to policymakers to citizens (Bouwman, 2021; Buiter, 2023; Mulder, 2020). There is a small body of literature that finds evidence that the awareness among citizens is reinforced quite recently by the Covid-19 pandemic (Bouwman, 2021; Vries et al., 2023). Therefore, it can be implied that the level of vegetation within urban gardens is an increasingly important neighbourhood amenity in the Netherlands that might be reflected in house prices.

This study aims to examine the external effect of the percentage tiles within gardens as a neighbourhood amenity on housing transaction prices in Amsterdam. It is expected that there is a direct negative external effect on house prices of surrounding properties when neighbours' gardens are filled with tiles, because it is expected to lower the amenity level of the neighbourhood.

As found by Zhang et al. (2019) factors such as attitude and social norms, play a significant role in households' willingness to pay. Hence, it is important fist to examine whether awareness about the importance of green gardens is boiled down to citizens in Amsterdam to be able to assume an external effect present. Hereby, the change in vegetation level within gardens between 2017 and 2021 using data constructed in QGIS is measured.

The following hypotheses have been formulated: Firstly, it is expected that more households in Amsterdam recognize the importance of green in their garden and invested accordingly:

Hypothesis 1: The percentage tiles within gardens in Amsterdam has decreased between 2017 and 2021.

Secondly, it expected that households are willing to pay less for a house in a neighbourhood where gardens are filled with tiles:

Hypothesis 2: Tiles within gardens have a negative external effect on the house prices of surrounding properties in Amsterdam between 2016 and 2021.

3. Methodology

3.1 The Hedonic Pricing Methodology

The price attached to a housing transaction is an implicit value and determined by both internal characteristics of the house and external factors that affect it. Determinants of house prices are, for instance, the moment and type of transaction, the structural characteristics of the house, and its spatial characteristics. Characteristics that are also enjoyed by surrounding properties and affect the transaction price are called external effects.

The hedonic pricing method estimates this implicit value of non-tradable characteristics of a heterogeneous good by comparing the implicit value with the observed value that incorporates all or part of the non-tradeable characteristics. So, the hedonic pricing methodology makes it possible to estimate the monetary value of a specific internal characteristic of a house or an external effect of a specific characteristic that is also enjoyed by the surrounding properties (Dekkers & Koomen, 2008).

Rosen (1974) was the first to describe the hedonic pricing methodology in a general framework. He made the link to standard micro-economic theory and showed that the first derivative of the hedonic price function with respect to a specific characteristic can be interpretated as the marginal willingness to pay of households for that characteristic (Koster & Rouwendal, 2023).

To be precise, the hedonic price function estimates the marginal willingness to pay of households for non-tradeable characteristics of tradeable goods. It is a description of the equilibrium prices of varieties of a heterogenous good, which is influenced by supply and demand. It can be implied if preferences, quantities or qualities of a heterogeneous good change that the hedonic price is also likely to change. The main advantage is that the marginal willingness to pay of households represents a quantification of the benefits or costs of the non-tradable characteristic of a good. This methodology is therefore often used for cost-benefit analysis in policy relevant research to investigate the welfare consequences of external effects and public goods for which no market exists (Koster & Rouwendal, 2023).

In this study the logarithmic version of the standard hedonic pricing methodology is used to quantify the external effect of tiles in gardens on the housing transaction price of surrounding properties. A limitation of this methodology is that it assumes a simplification of reality, where there is perfect competition, perfect information, an no transaction costs. Therefore actual house prices can deviate from theoretical house prices (Dekkers & Koomen, 2008). Other limitations of this methodology and its implications can be found in Chapter 7 ‘Discussion’.

A limitation that is being addressed in this study is that the model can be criticized on the grounds of being too "parametric". In other words, the model can be criticized on making too strong assumptions on the nature of the relationship. In practice households are heterogeneous in their preferences, implying the functional form might not be linear. As a result of such misspecification the estimated coefficients may be inconsistent (Chen et al., 2013; Koster & Rouwendal, 2023).

There are models that allow for more flexible specifications that reduce this misspecification bias. The so-called non-parametric model and the semi-parametric model. The semi-parametric is an extension of the non-parametric model and allows for the inclusion of additional control variables in parametric components, while the variable of interested is included non-parametrically (Acar, 2020; Chen et al., 2013; Koster & Rouwendal, 2023; van Ruijven & Tijm, 2022).

Therefore, the semi-parametric model can be described as a model that is "the best of both worlds". It allows for the examination of the effect of each variable on the dependent variable by including both the non-parametric and parametric parts in one model at the same time, eliminating problems, such as misspecification bias and omitted variable bias, that arise by performing both approaches one by one (Acar, 2020; Chen et al., 2013).

In this study, the semi-parametric model with Yatchew's weighting matrix will also be performed with the variables of interest included non-parametrically and the control variables parametrically. Chapter 3.2 'The Empirical Strategy' will elaborate on the empirical strategy of this model.

3.2 The Empirical Strategy

Firstly, to investigate whether tiles within gardens have an impact on the attractiveness of neighbourhoods a standard hedonic pricing analysis is performed. The analysis is performed on a number of years to (i) have enough observations to be able to draw conclusions, and to (ii) be able to control for changes over the years. The estimation of the hedonic price function relies on an Ordinary Least Squares (OLS) regression technique, regressing the housing transaction price on its characteristics. Both a linear functional form and quadratic functional form is considered to account for the fact that households may not be homogeneous. The regression models are formulated as follows:

$$Ln(P_{i,n,t}) = \beta_0 + \beta_1 EET_{i,n,t} + \beta_2 X_i + \beta_3 S_{i,t} + \eta_n + \lambda_t + \varepsilon_i \qquad (1)$$

and

$$Ln(P_{i,n,t}) = \beta_0 + \beta_1 EET_{i,n,t}{}^2 + \beta_2 X_i + \beta_3 S_{i,t} + \eta_n + \lambda_t + \varepsilon_i \qquad (2)$$

, where the dependent variable $Ln(P_{i,t,n})$ refers the transaction price of property $\boldsymbol{i}$, with year of transaction $\boldsymbol{t}$, located in postal code $\boldsymbol{n}$. The independent variable of interest, '$EET_{i,t}$' (External Effect Tiles), is a continuous variable of the percentage tiles within gardens per pc4 area, hereafter called neighbourhood. A continuous variable is chosen considering tiling, or the opposite, greening of gardens is a continuous process. The other independent variables, X_i and $S_{i,t}$, refer to vectors of, respectively, transaction & property characteristics, and spatial attributes that are considered to be important determinants of house prices according to previous studies (Dekkers & Koomen, 2008; Koster & Rouwendal, 2017). η_n and λ_t refer to, respectively, postal code fixed effects, to control for time-invariant differences between postal codes, and year fixed effects. This avoids having to compare properties of different neighbourhoods, which accordingly avoids bias that might be introduced by any systematic differences between neighbourhoods (Voicu & Been, 2008). Finally, β_1, β_2, and β_3 are the parameters to be estimated, β_0 is the constant, and ε_i is the error term (van Ruijven & Tijm, 2022; Verbeek, 2021).

A log-level functional form is chosen because (i) price changes are represented in percentages instead of absolute values, which is convenient for interpretation, and (ii) the error term is closer to the normal distribution (Verbeek, 2021). The control variables are either dummy variables or continuous variables. The values of the continuous variables are transformed into logarithmic values to normalize the data. Chapter 4 'Data' provides a table of descriptive statistics of all independent variables that are used in this analysis.

Secondly, to relax the assumptions made on the functional form a semi-parametric model is performed. To be precise, the partial linear regression model with Yatchew's weighting matrix using OLS regression technique is performed. A semi-logarithmic functional form is chosen for the same reasons the logarithmic version of the standard hedonic pricing analysis is chosen. The regression model is formulated as follows:

$$Ln(P_{i,n,t}) = \beta_1 X_i + \beta_2 S_{i,t} + m(EET_{i,n,t}) + \varepsilon_i \qquad (3)$$

, where X_i, $S_{i,t}$ and $EET_{i,n,t}$ are the independent variables referring to, respectively, two vectors of parametric control variables and one non-parametric variable. The control variables used for this analysis are the same as used in the hedonic pricing analysis. β_1 and β_2 are the parameters to be estimated, and m(.) is the function of $EET_{i,n,t}$, which is the continuous variable of the percentage tiles within gardens per neighbourhood. ε_i is the, constantly normally distributed, error term. Finally, the model controls for fixed effects by treating them as nuisance parameters (Acar, 2020; Chen et al., 2013).

Thirdly, to be able to contribute to the rapidly emerging field that aims to bridge the gap between public concerns and private interests the exact same empirical strategy is performed again with '$DET_{i,t}$' (Direct Effect Tiles) as variable of interest. That is a continuous variable of the percentage tiles within gardens.

3.3 Spatial Variables

The spatial variables included in the regression analysis are constructed in QGIS (Quantum Geographical Information System) using maps and infrared satellite images from, respectively, the municipality of Amsterdam and Satellietdataportaal.nl.

For the variable of interest infrared images from satellietdataportaal.nl are used. Satellietdataportaal.nl provides images in Infra-Red-Green (IRG) colour combinations. The colour bands of these images are displayed as false colours and show all types of vegetation in red, especially useful in this study that aims to distinguish tiles from green within Amsterdam's private gardens.

The images are chosen based on three criteria: the images must (i) have high-quality resolution to create a detailed dataset, (ii) have lowest possible cloud cover, and (iii) have been taken during the summer period, the months June, July, and August, to be certain that most vegetation is in bloom. This resulted in images from the summer period of 2017 and 2021.

To be precise, the year 2017 is chosen because the resolution is sufficient to conduct detailed analysis. Further back in time the resolution is significantly less which would make the analysis less precise. The year 2021 is chosen because it has the lowest possible cloud cover compared to the other years after 2017. Both years needed two images to cover the whole of the municipality of Amsterdam: the year 2017 consists of a satellite image of 01-06-2017 and 06-07-2017 and the year 2021 consists of a satellite image of 14-06-2021 and 17-06-2021.

It is important to mention that the images have different resolution: images of 2017 have a resolution of 0.8m and images of 2021 have a resolution of 0.5m. In other words, the pixel sizes are, respectively, 80x80cm and 50x50cm. To be able to compare both years, the raster images are aligned to a 0.8m resolution to make the analysis as accurate as possible.

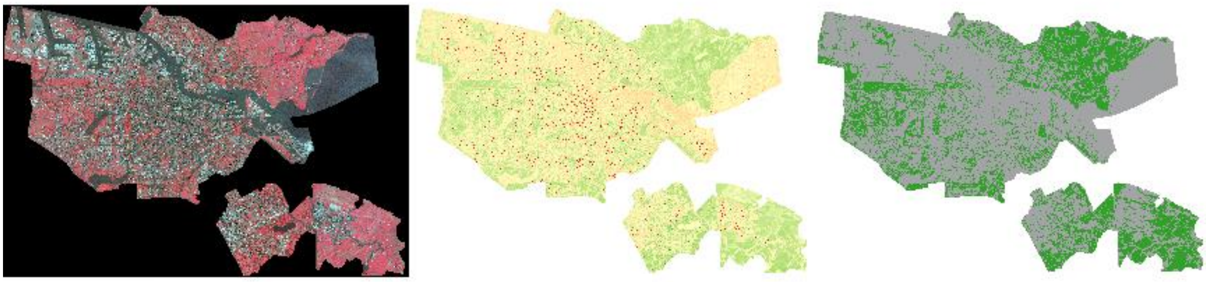
After selecting, acquiring, merging, aligning, and clipping the images to the region of interest, Amsterdam, the Normalized Difference Vegetation Index (NDVI) is calculated. That is a measurement indicating the density of vegetation. The formula of the NDVI is the following:

$$NDVI = \frac{NIR - Red}{NIR + Red} \qquad (4)$$

, where ***NIR*** and ***Red*** refer to the colour bands of the raster images. These bands represent different wavelengths of reflected light. The Infrared satellite images are shown in Figure 1 below.

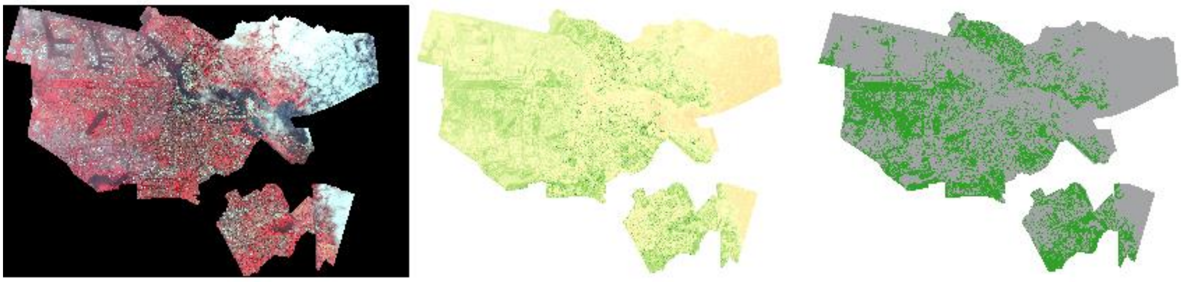
The layer generated with this formula shows a black and white image with continuous values within the range of -1 and 1. For the ease of interpretation the colour symbology is changed to red and green. The NDVI ranges are classified to distinguish between non-vegetated areas and vegetated areas. It is important to note that the measured vegetation is a projection of vegetation onto the ground surface. With trees, for instance, the tree crown is measured. It is not known whether the surface under the tree crown is vegetated or non-vegetated. The classification range used to distinguish between non-vegetation and vegetation is based on previous academic research from Australia (Aryal et al., 2022). Subsequently, to match satellite images of the Netherlands the range is slightly altered, based on visual inspection (Aryal et al., 2022; Mulder, 2020; Vries et al., 2023). The results and the classification range are shown in, respectively, Figure 1 and Table 1 below.

Figure consisting of, respectively, the Infrared Satellite images, NDVI, and NDVI classification for both years of Amsterdam



(i) (ii) (iii)

2017



(iv) (v) (vi)

2021

Figure 1: A table consisting of, respectively, the Infrared satellite images, NDVI, and NDVI classification of both years for Amsterdam. Subfigures (i) and (iv) show the Infrared satellite images, where everything coloured red indicates vegetation. Subfigures (ii) and (v) show the NDVI that ranges from -1 (red) to 1 (green). Subfigures (iii) and (vi) show the NDVI classification that only distinguished between non-vegetation and vegetation. The observations of housing transactions that are located under the clouds (a total of 642) are deleted from the dataset. It is striking to see that 2021 seems to be significantly greener than 2017, as it shows more green and less red pixels.

Table 1: NDVI ranges and classes. Classification (1) refers to non-vegetation and classification (2) refers to vegetation. The distinction between vegetation and non-vegetation is based on previous academic research and own altering through visual inspection.

Class	NDVI range	NDVI classification
Non-vegetation	<= 0.2100	Grey
Vegetation	> 0.2100	Green

The NDVI classification raster layers are appended to the polygon layer that consists of all garden plots of Amsterdam. This map considers buildings, such as garages, in gardens and excludes them from the surface of the plot. The new layers represent counts of each unique value, in this case the values associated with classes non-vegetation and vegetation, from the classified NDVI raster layers (numbers (iii) and (vi) from Figure 1) contained within each garden plot defined as polygon. In other words, it is calculated at a 0.8m resolution how much grey and green pixels exist within each garden plot in Amsterdam. The percentage tiles within gardens to examine the Direct Effect of Tiles (DET) in gardens on housing transaction prices is calculated as follows:

$$DET = \frac{Grey\ pixels\ within\ gardens}{Total\ amount\ of\ pixels\ within\ gardens} * 100\% \qquad (5)$$

To examine the External Effect of Tiles (EET) in gardens on surrounding housing transaction prices, the polygon layer of the garden plots with the data on grey and green pixels is appended to the polygon layer of the pc4 areas of Amsterdam. In other words, it is calculated how much grey and green pixels within gardens exist per pc4 area. The percentage tiles within gardens per pc4 area is calculated as follows:

$$EET = \frac{Grey\ pixels\ within\ gardens\ per\ pc4\ area}{Total\ amount\ of\ pixels\ within\ gardens\ per\ pc4\ area} * 100\% \qquad (6)$$

Table 2 in Chapter 4 ‘Data’ shows the summary statistics of this and other spatial variables. The spatial control variables are constructed by calculating the Euclidean distance between each house and the nearest spatial polygon / point. First, “# Public Trees per PC4 area” refers to the number of public trees per pc4 area conditional on the requirement that the year of planting of the tree is before year of transaction. Second, “Distance to Park / Plantsoen” and “Distance to Tram / Metro” refers to the Euclidean distance between each house and the nearest spatial polygon of a park / plantsoen or point of a Tram / Metro stop. For the construction of “Distance to Tram / Metro” two datasets are used from different years to correct for the tram / metro stops that have been added / removed in the meantime.

4. Data

4.1 Data sampling

The municipality of Amsterdam has seven districts: Centre, New-West, North, East, West, South, South-East, and one urban area: Weesp (Gemeente Amsterdam, 2023b). The urban area Weesp became officially part of the municipality of Amsterdam per 24-03-2022 (CBS, 2022).

Amsterdam is chosen to study because it is the largest city of the Netherlands with the most active real estate market in absolute terms, the municipality is very transparent regarding their data, and it is the city with the most tiled gardens of the Netherlands according to Stichting Steenbreek (Dijk, 2019). Besides there is continuous pressure on existing public green and/or undeveloped land, implied by its history of housing shortage. This continuous pressure could potentially influence the valuation of private green, making it interesting to examine changes in preferences over time (Verbeek, 2021).

The data required for performing the hedonic pricing analysis is partly obtained from the NVM (Dutch Association of Real Estate Brokers), the largest real estate agent coving about 75% of all housing transactions. This dataset consists of micro-data on housing transactions within the municipality of Amsterdam for the sample period between January 2016 and December 2021. Variables included in this dataset are on transaction prices, housing characteristics, and the exact location of the properties.

The spatial data is constructed in QGIS using data from the municipality of Amsterdam Satellietdataportaal.nl and consists of vector layers and raster layers. Chapter 3.3 'Spatial Variables' describes how the spatial variables are constructed. It is assumed that the values generated for 2017 apply for the years 2016-2018 the values generated for 2021 apply for the years 2019-2021. Since it is not known when the vegetation level of gardens changed this may not be accurate in practice and affect the results.

4.2 Data Description

The total dataset consists of 48,171 observations between January 2016 and December 2021 and meets the following criteria: there are (i) no duplicates, (ii) no extreme outliers after taking the logarithm, (iii) Transactional and Property characteristic variables winsorized at the 99.99th percentile, and (iii) observations located under clouds are dropped. Table 2 below shows the summary statistics for the internal characteristics and the spatial attributes. The number of obs, mean, stdev, min, and max are reported.

Table 2: Table showing summary statistics of the Transactional & Property Characteristics and Spatial Attributes.

Summary Statistics of Transactional Characteristics and Property Characteristics

Variable	Obs	Mean	Std. Dev.	Min	Max
Ln(Price)	48171	13.024	.55	11.225	15.926
Spatial Attributes:					
Number of public trees per pc4 neighbourhood	48171	3241.863	2286.722	0	11051
Distance Park/Plantsoen	48171	585.613	355.471	17.075	3204.808
Distance Metro/Tram	48171	370.855	487.133	11.02	3996.072
Maintenance Outside	48171	.771	.096	0	1
Maintenance Inside	48171	.758	.138	0	1
Structural Characteristics:					
Ln(Price List)	48152	12.969	.572	10.021	15.956
Ln(Size)	48171	4.394	.468	3.219	6.267
Number of Rooms	48171	3.549	1.598	1	24
PC4 area	48171	1059.984	26.817	1011	1109
Transactional Characteristics:					
Ln(Days on Market)	46794	3.387	.788	0	7.968
Year	48171	2018.413	1.747	2016	2021
Month	48171	6.719	3.361	1	12
Day	48171	15.54	8.754	1	31

Variable	Obs	Mean	Std. Dev.	Yes	No
Construction period:					
Before 1906	48171	.203	.402	9,769	38,402
[1906 , 1930]	48171	.256	.437	12,342	35,829
[1931 , 1944]	48171	.109	.312	5,251	42,920
[1945 , 1959]	48171	.046	.209	2,208	45,963
[1960 , 1970]	48171	.062	.241	2,976	45,195
[1971 , 1980]	48171	.03	.172	1,467	46,704
[1981 , 1990]	48171	.092	.289	4,445	43,726
[1991 , 2000]	48171	.073	.261	3,533	44,638
[2001 , 2010]	48171	.09	.286	4,343	43,828
[2011 , 2020]	48171	.037	.189	1,790	46,381
After 2020	48171	0	.022	24	48,147
Property type dummies:					
Apartment	48171	.855	.353	41,163	7,008
Terraced	48171	.101	.302	4,887	43,284
Semidetached	48171	.036	.185	1,712	46,459
Detached	48171	.008	.092	409	47,762
Garden	48171	.556	.497	26,798	21,373
Maintenance Good	48171	.871	.335	41,946	6,225
New built	48171	.011	.105	532	47,639

Table 3 below shows the summary statistics of the variable of interest, percentage tiles within gardens per neighbourhood, for 2017 and 2021 separately.

Table 3: Table showing summary statistics of the variable of interest, the percentage tiles within gardens per neighbourhood. It is striking to see how the mean percentage decreased from 73% to 50% and the minimum decreased from 47% to 22%.

Summary statistics of percentage tiles within gardens per neighbourhood for 2017 and 2021

Variable	Obs	Mean	Std. Dev.	Min	Max
Percentage tiles within gardens per pc4 neighbourhood for 2017	24665	72.933	11.206	47.135	95.408
Percentage tiles within gardens per pc4 neighbourhood for 2021	23506	50.148	17.833	22.326	99.131
Total dataset	48171	61.772	18.761	22.326	99.131

It is striking to see that the average percentage tiles within gardens per neighbourhood decreased from 73% to 50% and the minimum percentage tiles within gardens also decreased from 47% to 22%.

Table 4 below shows the frequency of observations per percentage category for the variable of interest. A visual representation of is shown in Figure 2 below.

Table 4: Table of summary statistics of the variable of interest split into categories. In total, there are 48,171 observations. In total 8 categories are made ranging from 20-30% to 90-100%. Table 3 shows that there is no percentage below approximately 22%, therefore the first category ranges from 20 to 30%.

Summary statistics of percentage tiles within gardens per neighbourhood split into 8 categories for the Total Dataset

	Frequency 2017	Frequency 2021
20-30%	0	1676
30-40%	0	2000
40-50%	287	2916
50-60%	1359	2372
60-70%	3338	1002
70-80%	3947	1505
80-90%	3353	938
90-100%	1495	610
Total obs	13779	13019

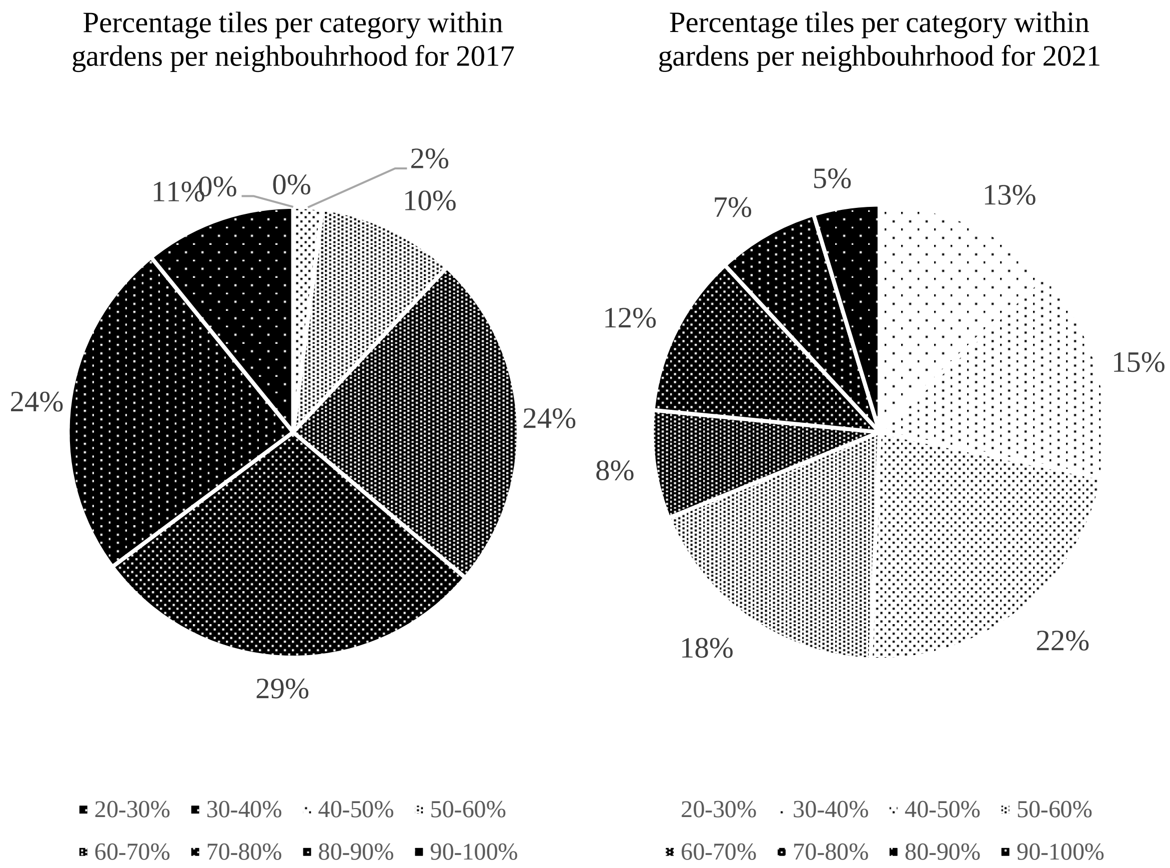


Figure 2: The percentage non-vegetation per garden by category for 2017 and 2021. It is striking to see how the percentage of gardens that are non-vegetated for 90 to 100% is approximately halved by 2021 and the percentage of gardens that are non-vegetated for 0 to 10%, 10 to 20% and 20 to 30% increased significantly.

Figure 3 below shows the percentage tiles for all neighbourhoods in Amsterdam. It is striking to see that the percentages are higher in 2017 compared to 2021 in most neighbourhoods.

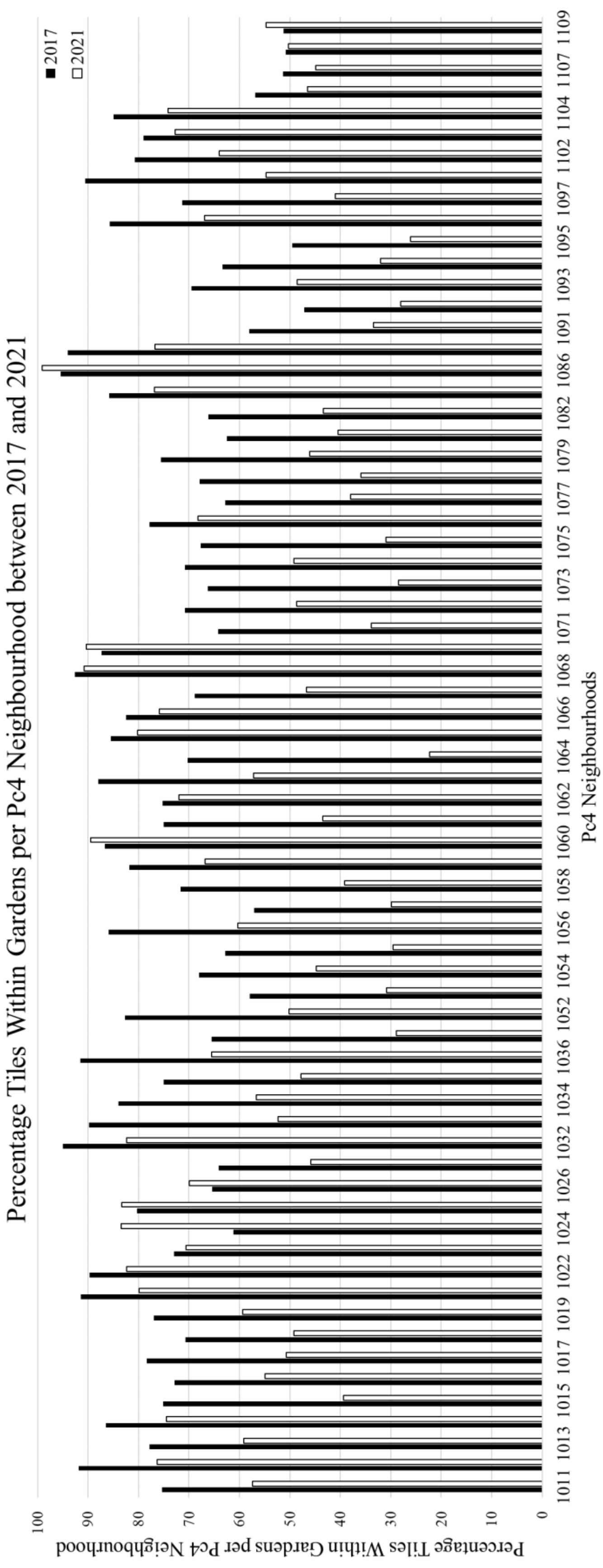


Figure 3: Figure showing the percentage tiles within gardens per neighbourhood for 2017 and 2021. It is striking to see how the lowest percentage tiles within gardens per neighbourhood is near 50% in 2017, while the lowest percentage in 2021 is near 20%.

5. Results

The results of examining the external effect of tiles within gardens on house prices of surrounding properties in Amsterdam are discussed in this chapter. First, the results based on the spatial analysis is discussed. Second, the results based on the hedonic pricing analysis is discussed.

5.1 Results on Spatial Analysis

The map in Figure 4 shows how the vegetation level in Amsterdam changed between 2017 and 2021, respectively. Most interesting are the colours light green and red. They indicate a change from non-vegetated in 2017 to vegetated in 2021 and vice versa. It is striking to see how there seem to be more light green areas than red areas, which implies that the total amount of vegetation in Amsterdam increased in 2021 compared to 2017.

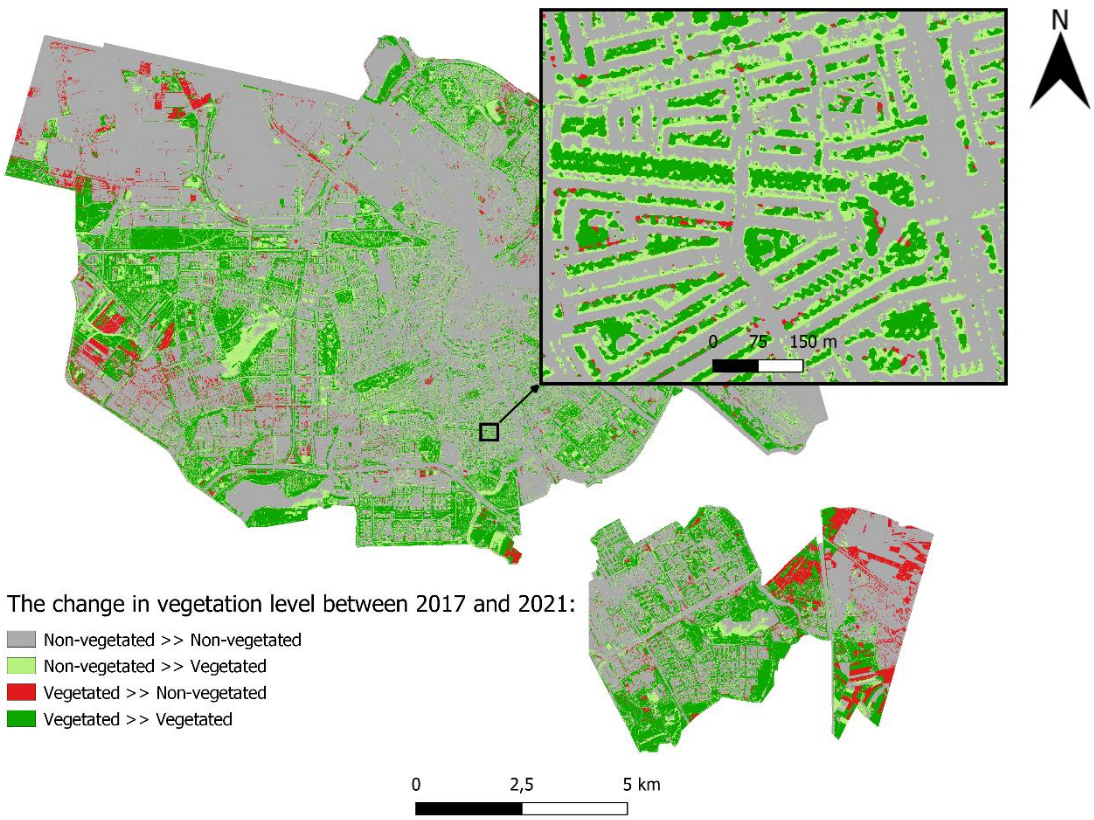


Figure 4: ***A map of the transition layer to show how the vegetation level has changed between 2017 and 2021, respectively. It is striking to see how there seems to be more dark green areas than white areas, indicating the overall amount of vegetation increased in 2021 compared to 2017.***

Since this study is interested in examining the external effect of the tiles within gardens solely on housing transaction prices it is necessary to have the exact plot of each private garden within Amsterdam. Figure 5 below shows a map of Amsterdam with its pc4 areas and its private garden plots. The precision of the garden plots is striking, for instances garages are not included in these plots. Therefore, it can be assumed that the area that is left is only designated for tiles or greenery.

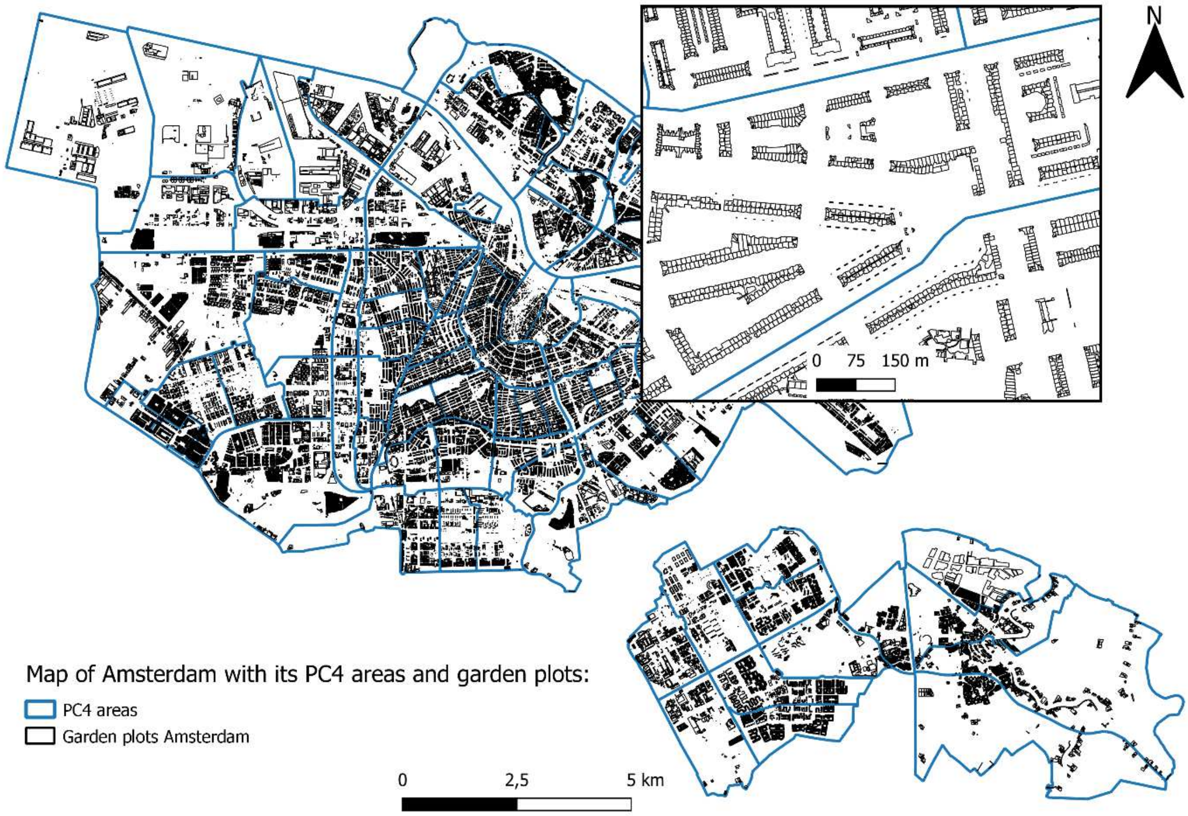


Figure 5: A map of Amsterdam with its pc4 areas and its garden plots. It is striking to see that garages are not included in the garden plots. Therefore, it can be assumed that the area that is left is only designated for tiles or greenery.

Both maps are appended to each other to construct a map that consist of the vegetation level per garden plot. This is visualised in Figure 6 and 7 below for part of, respectively, the most tiled and greenest neighbourhood of Amsterdam. To be precise, the figure shows a map of gardens and its vegetation transformation between 2017 and 2021 in the most tiled neighbourhood, pc4 area 1086, and the greenest neighbourhood, pc4 area 1064, of Amsterdam.

Figure 6: A map of gardens with vegetation transformation between 2017 and 2021 in the most non-vegetated pc4 area of Amsterdam

Figure 7: A map of gardens with vegetation transformation between 2017 and 2021 in the most non-vegetated pc4 area of Amsterdam

Finally, Figure 8 below show a graph on the percentage point difference in percentage tiles within gardens per neighbourhood. It is striking to see that the percentage tiles within gardens decreased in 63 out of the 70 neighbourhoods examined. A table with the exact percentages for both years and the percentage point difference between them can be found in Table 9 in Chapter 8 ‘Appendix’. Based on the graph below, it can be concluded that between 2017 and 2021 households have taken the initiative to remove tiles from their garden and substituted it for greenery.

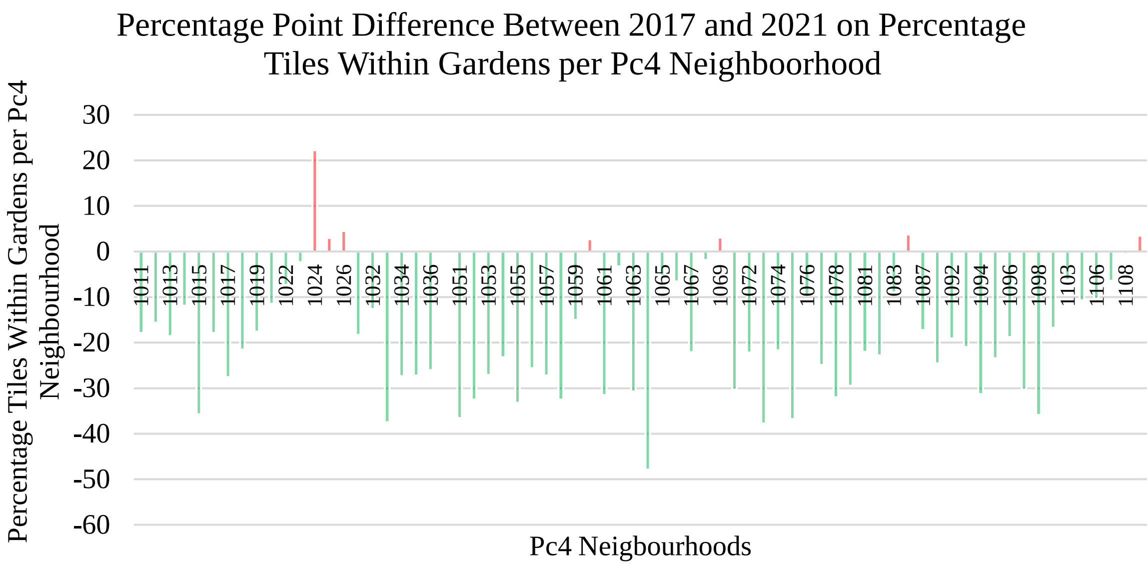


Figure 8: A graph of the percentage point difference between 2017 and 2021 on the percentage tiles within gardens per neighbourhood. It is striking to see that the percentage tiles within gardens decreased in 63 out of 70 neighbourhoods.

5.2 Results on the Hedonic Pricing Analysis

For the hedonic pricing analysis an OLS regression technique is performed to examine the effect of tiles in gardens on housing transaction prices of surrounding properties in Amsterdam. The variable of interest is a continuous variable that measure the percentage tiles within gardens per neighbourhood. The regressions analysis estimates the coefficient on the natural logarithm of the housing transaction price of a specific property. To control for endogeneity issues as much as possible the hedonic pricing model includes various control variables, as well as time-invariant fixed effects and time fixed effects.

Recall, the standard hedonic pricing analysis makes strong assumptions on the nature of the relationship. In practice, this relationship might not be linear, because households are heterogeneous in their preferences. Therefore, both a linear and a quadratic hedonic price function is estimated. To reduce potential misspecification bias, the semi-parametric model is also performed. The regression results on the relationship between the percentage tiles within gardens per neighbourhood on housing transaction prices for all three models are shown in Table 5 below.

Table 5: The regression results for the hedonic pricing model and the semi-parametric model with the continuous variable of the percentage tiles within gardens per neighbourhood. Both models included all observed control variables and fixed effects. For the semi-parametric model, the F test statistics is shown to determine whether the independent variable of interest reliably predicts the dependent variable.

VARIABLES	Linear Hedonic pricing estimation (3) Ln(Price)	Quadratic Hedonic pricing estimation (3) Ln(Price)	Semi-parametric estimation (3) Ln(Price)
Percentage Tiles Within Gardens per Pc4 Neighbourhood	-0.001* (0.0004)	-0.000* (0.0000)	F Test Stat: 2029 (0.000) Degrees of freedom: 46,774
Transactional and Property characteristics	YES	YES	YES
Spatial attributes	YES	YES	YES
Year FE	YES	YES	YES
Pc4 FE	YES	YES	YES
Constant	1.050** (0.282)	1.029** (0.2910)	
Observations	46,775	46,775	46,774
R-squared	0.982	0.982	0.651

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

All three models include all observed control variables and fixed effects. The regression results with less control variables and/or fixed effects are shown in Table 13 in Chapter 8 ‘Appendix. The estimation of the first two models resulted in a coefficient for the variable of interest. The estimation of the semi-parametric model did not result in a coefficient for the variable of interest, instead a graphical representation of the non-parametric part of the semi-parametric model is shown in Figure 9 below.

The sign of the relationship for the linear and quadratic hedonic price function is in line with expectations at a statistically significant 10% level. It is debatable whether conclusions can be drawn from a 10% confidence interval. The maximum probability for determining statistical significance is generally at the 5% level, determined by Fisher in 1925 in his book ***Statistical Methods for Research Workers*** (Cowles & Davis, 1982; Sedgwick et al., 2022). For the linear hedonic price function, the external effect of percentage tiles within gardens per neighbourhood on housing transaction prices is estimated at -0.1%. For the quadratic hedonic price function, the estimated coefficient drops approximately 0.0%.

For the semi-parametric model, the F test statistics is shown, to determine whether the percentage tiles within gardens per neighbourhood reliable predicts the housing transactions prices. It is striking to see that the predictability of the model reduced from 98.2% to 65.1%. This indicates that the variable of interest significantly predicts the outcome of the model.

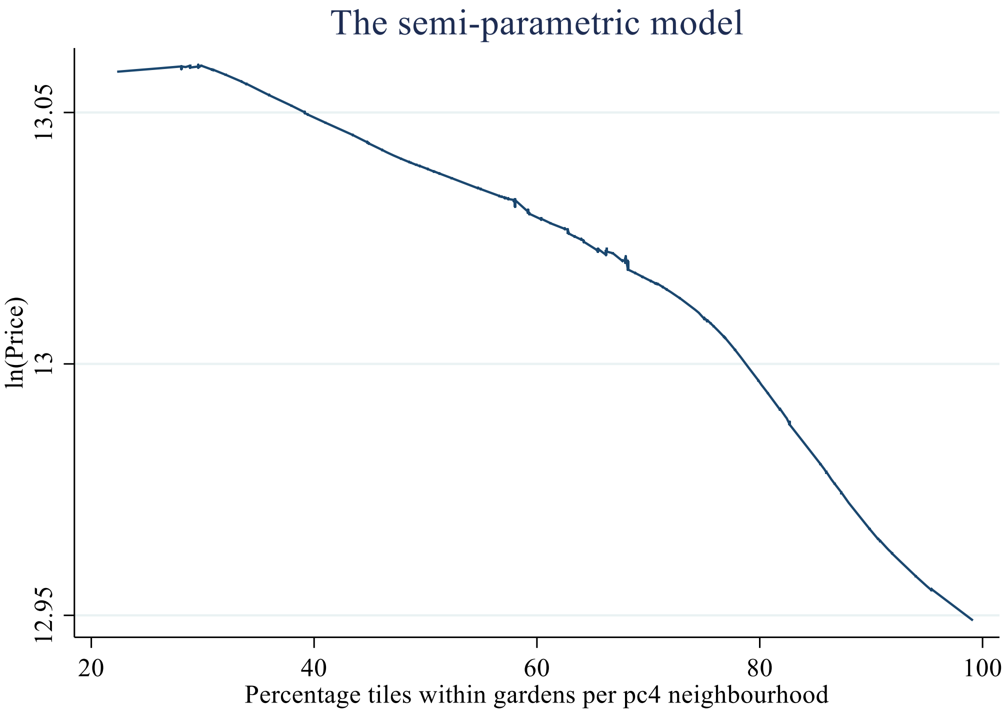


Figure 9: A graphical representation of the non-parametric part of the semi-parametric model. It is striking to see that the estimated functional form does not seem to be linear, indicating households are indeed heterogenous. Based on this graphical representation, the functional form seems to be concave downward sloping, which is more in line with the quadratic hedonic price function.

From this figure it can be implied that there is indeed misspecification bias in the linear hedonic pricing analysis as the functional form is not completely linear. The functional form implies a concave downward sloping price function because the slope seems to decrease the higher the percentage tiles per neighbourhood.

Two graphical representations in Figure 10 below show the non-parametric functional form with, respectively, the linear prediction and the quadratic prediction of the model.

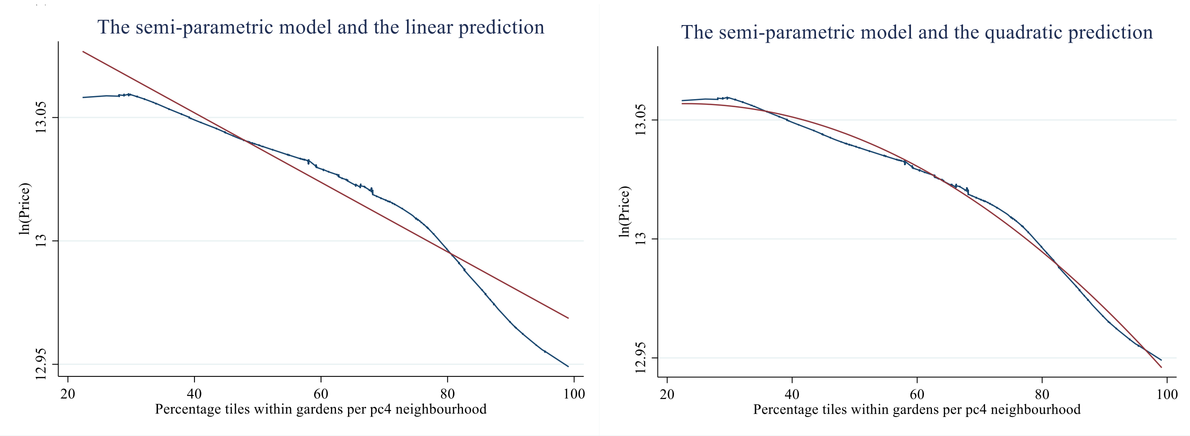


Figure 10: Two graphical representations of the non-parametric functional form with, respectively, the linear prediction and the quadratic prediction.

Based on the figure, the functional form of the estimated relationship is indeed not linear, but quadratic. Hereby, it can be implied that households are heterogeneous in their preferences on the percentage tiles within gardens per neighbourhood.

To test for heterogeneity the marginal willingness to pay for various intervals are estimated. The intervals are large enough to be able to draw conclusions and small enough that the effect is marginal. The results are shown in Table 6 below.

Table 6: Table showing the marginal willingness to pay of households for different percentages tiles within gardens per neighbourhood.

Percentage tiles within gardens per pc4 neighbourhood	Coefficient estimates	Marginal Willingness to Pay in percentages
20-30%	0.000***	0.01%
30-40%	-0.001***	-0.10%
40-50%	-0.001***	-0.10%
50-60%	-0.001***	-0.09%
60-70%	-0.001***	-0.12%
70-80%	-0.002***	-0.19%
80-90%	-0.003***	-0.30%
90-100%	-0.002***	-0.20%

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Firstly, from this table it can be concluded that households are indeed heterogeneous as the marginal willingness to pay differs per category. Secondly, it can be concluded that the functional form is indeed concave downward sloping as the estimated marginal willingness to pay decreases the higher the percentage tiles within gardens per neighbourhood.

The marginal willingness to pay ranges from 0.0% to -0.3% at the statistically significantly 1% level. Hereby, it can be concluded that the percentage tiles in gardens have a sizable negative external effect on the attractiveness of neighbourhoods the higher the percentage is.

To be able to compare the results of the external effect with the results of the direct effect, the marginal willingness to pay is also calculated for the direct effect of percentage tiles within gardens on housing transaction prices. The estimated marginal willingness to pay for various intervals are shown in Table 7 below. The summary statistics of this variable can be found in Table 2 in Chapter 4 'Data' and in Table 10 in Chapter 8 'Appendix'. The regression results and graphical representations of the functional form can be found in Table 11 and Figures 11 and 12 in Chapter 8 'Appendix'.

Table 7: Table showing the marginal willingness to pay of households for different percentages tiles

Percentage tiles within gardens	Coefficient estimates	Marginal Willingness to Pay in percentages
0-10%	0.00023***	0.023%
10-20%	0.00014***	0.014%
20-30%	0.00010***	0.010%
30-40%	0.00006***	0.006%
40-50%	0.00002***	0.002%
50-60%	-0.00016***	-0.016%
60-70%	-0.00019***	-0.019%
70-80%	-0.00020***	-0.020%
80-90%	-0.00018***	-0.018%
90-100%	-0.00015***	-0.015%

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Firstly, this table supports the conclusion that households are heterogeneous as the marginal willingness to pay differs per category. Secondly, it can be concluded that the functional form is a parabola as the marginal willingness is decreasingly positive and increasingly negative the higher the percentage tiles.

The marginal willingness to pay ranges from 0.023% to -0.020% at the statistically significantly 1% level. It is striking to see that the estimated marginal willingness to pay for the direct effect is approximately ten times smaller than the marginal willingness to pay for external effect. Hereby, it can be concluded that the direct effect for tiles within gardens is not sizable given the low percentage values and compared to the percentage values of the external effect.

To be able to draw a conclusion on economic significance, the implied the total costs for tiles within gardens are calculated for the public and for private home owners that have a garden. The results are presented in Table 8 below.

Table 8: The implied total public and private costs for tiles within gardens in Amsterdam. *The Tiles "premium" is* ***defined by the predicted price with the actual percentage tiles less its predicted price when the percentage tiles equal zero. The total public costs are calculated assuming there are 475,000 houses in Amsterdam. That is the number of houses in Amsterdam per 1 January 2023 according to the municipality of Amsterdam (Gemeente Amsterdam, 2023a). The private costs are calculated assuming 237,500 houses in Amsterdam have a garden. This assumption is based on the garden/no garden*** *distribution of the dummy variable 'garden'* ***in the dataset used in this study. It is striking to see the difference in order of magnitude between the two. The total costs for the public are a significant amount, while the total costs for private homeowners with gardens is negligible.***

Total public versus private costs for tiles within gardens in Amsterdam

Public			***Private***		
Average MWTP	Tiles "premium"	**Total Costs**	Average MWTP	Tiles "premium"	**Total Costs**
13.021	-0.038	18,050.00	12.934	-0.001	237.50

Note: (i) the costs are in euros (€).

Firstly, the Tiles "premium" is defined by the predicted price with the actual percentage tiles less its predicted price when the percentage tiles equal approximately zero. Secondly, the total public costs are calculated assuming there are 475,000 houses in Amsterdam. This number is based on the statistics of the municipality of Amsterdam per 1 January 2023 (Gemeente Amsterdam, 2023a). Thirdly, the total private costs are calculated assuming 237,500 houses in Amsterdam have a garden. This assumption is based on the distribution of the dummy variable 'garden' in the dataset used in this study, which can be seen in Table 12 in Chapter 8 'Appendix'. It is striking to see the difference in order of magnitude between the two. The public concern is significantly higher than the private investment.

6. Conclusion

This study aims to answer the question whether tiles within gardens have an impact on the attractiveness of neighbourhoods in Amsterdam. Hereby, it measures the direct external effect of the percentage tiles within gardens as a neighbourhood amenity on house prices by performing a standard hedonic pricing analysis and a semi-parametric analysis using the OLS regression technique.

Two hypotheses have been formulated. The first regarding the change in percentage tiles within gardens in Amsterdam between 2017 and 2021. The second regarding the extent to which tiles within gardens affect households' marginal willingness of surrounding properties.

Firstly, it has been found that gardens are less tiled in 2021 than in 2017. Hereby, the first hypothesis that states the total amount of tiles in gardens of Amsterdam has decreased can be accepted. Most strikingly to see is the drop from 61% to 34% in gardens that are tiled for 90-100%. It can be concluded that awareness about the importance of green gardens is boiled down to the average citizen in Amsterdam. An explanation for this significant drop could be the covid-19 pandemic as before and during is examined in this study (Bouwman, 2021).

Secondly, the direct external effect of percentage tiles within gardens per neighbourhood is estimated at -0.10% and -0.00% for, respectively, the linear hedonic price function and the quadratic hedonic price function at the statistically significant 10% level. These results are in line with expectations in terms of sign. Hereby, it can be concluded that the hypothesis can be accepted at the statistically significantly 10% level.

However, as discussed in Chapter 5 'Results' the statistically significant 5% level is generally considered to be the maximum acceptable probability for determining statistical significance. Therefore, it is suggested that further research is necessary. Potential limitations to this study that can influence statistical significance are discussed in Chapter 7 'Discussion'.

For robustness reasons a semi-parametric model is also performed to remove potential misspecification bias in the estimated coefficients. A graphical representation is given of the non-parametric part of the model and compared to the linear and quadratic prediction of the model. It is striking to see that the functional form is concave downward sloping and in line with the quadratic hedonic pricing analysis.

The semi-parametric model is used to calculate the marginal willingness to pay in percentages to test for heterogeneity, as these results are least biased. The results show the marginal willingness to pay decreases the higher the percentage tiles within gardens per neighbourhood, ranging from 0.0% to -0.3%, at the statistical significance 1% level. Hereby, it can firstly be concluded that households are heterogeneous and have different preferences for different percentages tiles. Secondly, the results are in line with the quadratic hedonic pricing analysis and therefore support is found for the acceptation of the second hypothesis.

An explanation for the decreasing marginal willingness to pay can be that gardens are always paved to a certain extent for a garden path or terrace. As explained in Chapter 1 'Introduction', gardens are often used as a meeting place for neighbours, especially in the economically weaker neighbourhoods. In other words, it can be assumed that a garden defined as "green" by households is never 100% green, but for the excess part.

To be able to conclude on the economic significance, the implied total public costs are estimated and compared to the implied total private costs, considering the public/private dilemma firstly discussed in Chapter 1 'Introduction'. The implied costs are estimated at 18,050.00 euros and 237.50 euros, respectively. Firstly, it can be concluded that tiles within gardens have a sizeable negative external effect on the housing transaction prices of surrounding properties in Amsterdam. Secondly, it can be concluded that it is valuable to experiment with incentive against tiling gardens as the public concern is significantly higher than the private investment. To recall the words of J. F. Carney (1845): no matter how small the garden, together they make a substantial impact and contribute to the development of a sustainable, future-proof city.

7. Discussion

For this study, a hedonic pricing analysis is chosen to examine external effects of neighbours' tiled gardens on house prices. A hedonic pricing analysis provides the possibility to examine external effects of non-tradeable characteristics of a heterogeneous tradeable good through revealed preferences. With the increasing availability of large databases on real estate transactions, such as the NVM database used in this study, it is possible and believed to be better to examine external effects using revealed preference methods instead of stated preference methods. Stated preference methods asses value through surveys and choice experiments but may fail to reflect actual behaviour due to several behavioural biases (Lazrak et al., 2014).

Nevertheless, both methods have its own advantages and disadvantages, which suggest that both methods are comparable in terms of outcomes. Besides, both methods have the same conceptual roots. The study by Koning, Filatova, and Bin (2017) aims to bridge the gap between both method approaches by combining them in the flood-prone housing market in Greenville, NC in the US. The results do not provide a conclusive answer to which type of behavioural method is most accurate.

Yet, stated preference methods are prone to behavioural biases, such as hypothetical bias and strategic bias, which are expected to be an issue in this study. Households may answer that they are willing to invest in green in their gardens to increase the overall amenity level of the neighbourhood. In practice they may not do it because the maintenance is too time consuming or too expensive. Households may also answer strategically as the research question is linked to climate change, which is a sensitive topic and people do not like to be judged. There are also errors coupled to stated preference methods, for instance respondents do not read the questions carefully (Koster, 2022, p. 2).

The Revealed preference method in turn has its own disadvantages of collinearity between the dependent variable and the independent variable. Specifically for the hedonic price function, the main disadvantages are the issue of misspecification and the omitted variable bias.

The issue of misspecification bias is examined in this study by performing a semi-parametric version of the hedonic pricing analysis as well. However, omitted variable bias is still a potential issue. Although this study includes many control variables, there are control variables unobserved and therefore not included in the regression. For instance, other spatial attributes, such as distance to closed main road or highway and distance to city centre, are considered to be important control variables (Koster & Rouwendal, 2017). For future research, it would be interesting to include these variables as well to reduce potential bias in the estimated coefficients.

However, to mitigate the omitted variable bias as much as possible this study included year fixed effect and time-invariant fixed effects, next to the transactional and property characteristics and spatial attributes. For future research, it would also be interesting to perform analysis using the instrumental Variable (IV), first-differencing, and / or quasi-experimental approach to solve all omitted variable bias.

There are also potential flaws of sorting due to income differences between households. When a model includes demographic and socio-economic characteristics as well it considers that different type of households are not randomly selected across space (van Ruijven & Tijm, 2022). This phenomenon of non-random sorting of households was first recognized in relation to politics (Tiebout, 1956). Later a unified framework was developed for measuring households' preferences in the field of spatial economics (Bayer et al., 2007).

Households sort themselves to locations dependent on their own characteristics in terms of income, education, and migration background, among others (Bayer et al., 2007; van Ruijven & Tijm, 2022). In other words, certain demographic and socio-economic characteristics attract certain households. If these preferences for demographic and socio-economic characteristics of neighbourhoods are correlated with the variable of interest, the estimates of the marginal willingness to pay will only reflect the average of subpopulations (Chay & Greenstone, 2005). It can be assumed that this is the case in this study, as Beumer (2014) found evidence that the vegetation level of gardens is correlated with households' income level.

The most tiled gardens were found in the economically weaker neighbourhoods. For future research it would be interesting to apply the sorting model to this research question to estimate the marginal willingness to pay per income dependent subpopulation instead of the average of subpopulations.

Apart from the empirical model used, there are also points of discussion associated with the data constructed in QGIS. Firstly, the variable of interest only makes a distinction between tiles and green, the maintenance level of the garden or the type of greenery is not considered. When a garden is poorly maintained and filled with for instance weeds, the estimated coefficients may be biased. Similarly, Lin, Jensen, and Wachter (2022) investigate the Philadelphia LandCare (PLC) program that aims at fighting blighted properties including unattended vacant lots. They find that prices for houses within 1,000 feet of a maintained greened vacant lot compared to an unattended vacant lot rises by about 4%. That maintained greened vacant lots have positive external effects on house prices supports to the understanding that the maintenance level of the garden might be an important variable to control for (Lin et al., 2022).

Secondly, the assumption is made that the data constructed in QGIS for 2017 and 2021 can be applied to housing transactions that take place between, respectively, 2016-2018 and 2019-2021. This is assumption is made to perform the analysis on as many observations as possible and the Infrared satellite images from sattelietdataportaal.nl are not useable for all years due to cloud cover. However, in practise it is not clear when gardens are transformed, which could cause bias in the results.

Thirdly, no distinction is made between front yards and backyards. The analysis would be improved when this distinction is made, because gardens only externally effect housing transaction pricing when the surrounding neighbours enjoy them. Backyards are less visible and therefore less enjoyed by the surrounding neighbours. Back yards may therefore externally affect housing prices less that front yards. For future research, it would be interesting to performs the analyses again with only front yards to examine whether the estimated coefficients differ.

8. Appendix

Table 9: Table showing the percentage tiles within gardens per neighbourhood in Amsterdam for both years separately and the difference between the two years. The values are sorted from low to high based on the third column that indicates the difference between 2017 and 2021.

Pc4 Neighbourhood	Percentage Tiles Within Gardens per Pc4 Neighbourhood	Percentage Tiles Within Gardens per Pc4 Neighbourhood	Difference between 2017 and 2021
1064	70.2151413	22.32589912	-47.8892
1073	66.26409912	28.46921349	-37.7949
1033	89.85777283	52.3645668	-37.4932
1075	67.68147278	30.93582916	-36.7456
1051	65.47409058	28.87451553	-36.5996
1098	90.6135788	54.71766281	-35.8959
1015	75.12463379	39.42277908	-35.7019
1055	62.77157593	29.60105896	-33.1705
1052	82.67832184	50.20387268	-32.4744
1058	71.6387558	39.17118454	-32.4676
1078	67.93190002	35.96604919	-31.9659
1061	74.98869324	43.45301819	-31.5357
1094	63.37252426	32.08249283	-31.29
1063	87.99333191	57.22731781	-30.766
1071	64.19911194	33.91606522	-30.283
1097	71.29606628	41.01347351	-30.2826
1079	75.59701538	46.10980225	-29.4872
1017	78.32086182	50.72579956	-27.5951
1034	83.98321533	56.6244812	-27.3587
1057	57.10139847	29.8560276	-27.2454
1035	75.02799988	47.8082695	-27.2197
1053	57.94721603	30.8321743	-27.115
1036	91.56774139	65.52072144	-26.047
1056	85.96987152	60.38095093	-25.5889
1077	62.8649559	37.9564209	-24.9085
1091	58.03794098	33.48902512	-24.5489
1095	49.49835205	26.08878899	-23.4096
1054	67.96841431	44.78050613	-23.1879
1082	66.19833374	43.40792084	-22.7904
1072	70.83677673	48.67537308	-22.1614
1067	68.81317139	46.6881218	-22.125
1081	62.49859238	40.4546814	-22.0439
1074	70.83768463	49.17206192	-21.6656

1018	70.70450592	49.15884781	-21.5457
1093	69.46459961	48.5215683	-20.943
1092	47.1354332	28.09567642	-19.0398
1096	85.72949982	66.95666504	-18.7728
1013	77.78927612	59.19462967	-18.5946
1031	64.14263153	45.83740616	-18.3052
1011	75.31009674	57.41907501	-17.891
1016	72.80805969	54.94474411	-17.8633
1019	76.91549683	59.32529068	-17.5902
1087	93.9987793	76.76437378	-17.2344
1102	80.73679352	63.97599411	-16.7608
1012	91.87794495	76.26526642	-15.6127
1059	81.81166077	66.81143951	-15.0002
1032	94.96424103	82.32859039	-12.6357
1014	86.42206573	74.52914429	-11.8929
1021	91.3799057	79.87609863	-11.5038
1104	84.92527008	74.20333862	-10.7219
1106	56.82656097	46.46487045	-10.3617
1076	77.77867126	68.16321564	-9.61546
1083	85.79112244	76.85902405	-8.9321
1022	89.73254395	82.38316345	-7.34938
1066	82.42386627	75.86514282	-6.55872
1107	51.32527161	44.91030121	-6.41497
1103	79.0619278	72.74784851	-6.31408
1065	85.44905853	80.15055084	-5.29851
1062	75.27609253	72.00598907	-3.2701
1023	72.96593475	70.60096741	-2.36497
1068	92.61998749	90.796875	-1.82311
1108	50.81431961	50.31723022	-0.49709
1060	86.72902679	89.43582153	2.706795
1025	80.33346558	83.31890869	2.985443
1069	87.31278992	90.36937714	3.056587
1109	51.24032974	54.7089653	3.468636
1086	95.40807343	99.13050079	3.722427
1026	65.38516998	69.89858246	4.513412
1024	61.21149063	83.44958496	22.23809

Table 10: Table of summary statistics of the variable of interest split into categories. In total, there are 48,171 observations. In total 10 categories are made ranging from 0-10% to 90-100%.

Summary statistics of percentage tiles within gardens split into 10 categories

	Frequency
0-10%	1813
10-20%	934
20-30%	1284
30-40%	1465
40-50%	1628
50-60%	1672
60-70%	1670
70-80%	1754
80-90%	1786
90-100%	34165
Total obs	48171

Table 11: The regression results for the hedonic pricing model and the semi-parametric model with the continuous variable of the percentage tiles within gardens. Both models included all observed control variables and fixed effects. For the semi-parametric model, the F test statistics is shown to determine whether the independent variable of interest reliably predicts the dependent variable.

VARIABLES	Linear Hedonic pricing estimation (3) Ln(Price)	Quadratic Hedonic pricing estimation (3) Ln(Price)	Semi-parametric estimation (3) Ln(Price)
Percentage Tiles Within Gardens	-0.0002*** (0.0000)	-0.0000*** (0.0000)	F Test Stat: 12074 (0.0000) Degrees of freedom: 26305
Transactional and Property characteristics	YES	YES	YES
Spatial attributes	YES	YES	YES
Year FE	YES	YES	YES
Pc4 FE	YES	YES	YES
Constant	0.7830 (0.4834)	0.7753 (0.4848)	
Observations	26,306	26,306	26,305
R-squared	0.9777	0.9777	0.9496

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

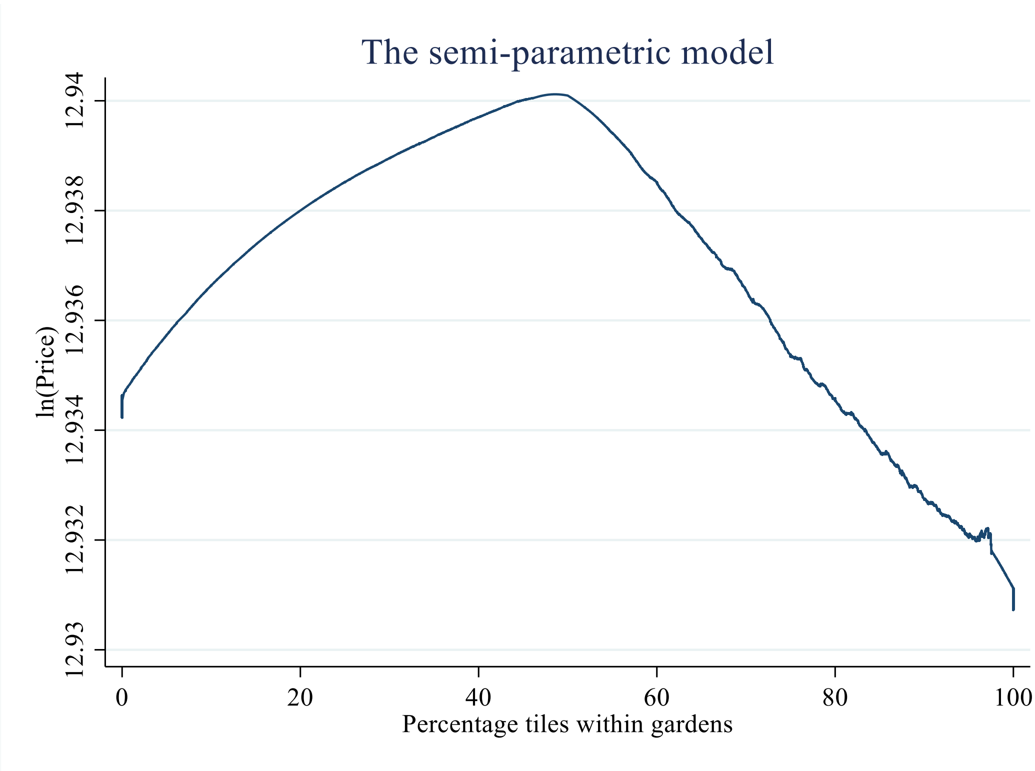


Figure 11: A graphical representation of the non-parametric part of the semi-parametric model. It is striking to see that the estimated functional form does not seem to be linear, indicating households are indeed heterogenous. Based on this graphical representation, the functional form seems to parabola, which is more in line with the quadratic hedonic price function.

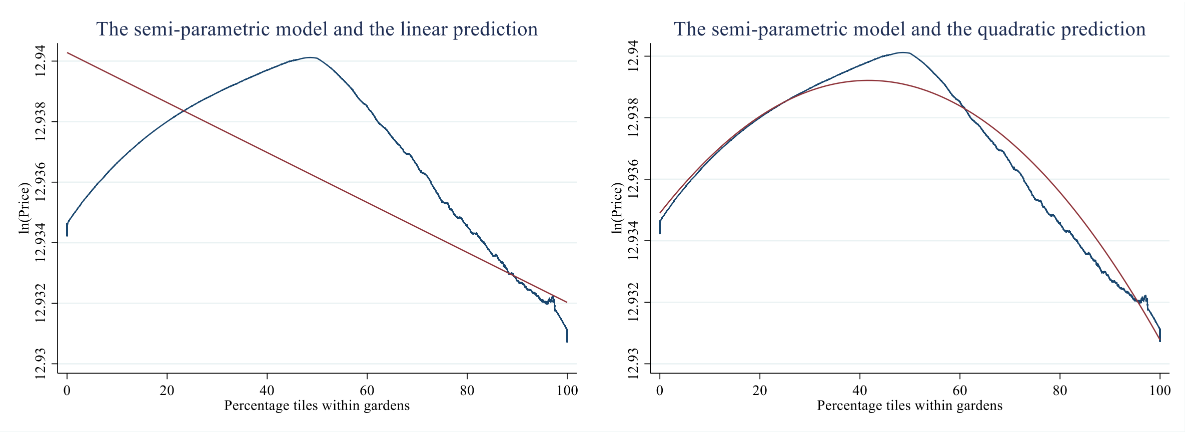


Figure 12: Two graphical representations of the non-parametric functional form with, respectively, the linear prediction and the quadratic prediction.

Table 12**: Tabulation of the dummy variable ‘garden’ used to determine the assumption **on the number of houses in Amsterdam with a garden for the calculation of the total private costs.

Tabulation of dummy variable ‘garden’

Garden	Freq.	Percent	Cum.
Yes	21373	44.37	44.37
No	26798	55.63	100.00
Total	48171	100.00	

*Table 13: **The regression results for the linear and quadratic hedonic pricing model** with less control variables of FE's.*

	Linear Hedonic Pricing Estimation			
	(1)	(2)	(3)	(4)
VARIABLES	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Price)
Percentage Tiles Within Gardens per Neighbourhood	-0.009**		-0.000***	
	(0.003)		(0.000)	
Percentage Tiles Within Gardens		-0.002*		-0.000***
		(0.001)		(0.000)
Transactional and Property characteristics	NO	NO	YES	YES
Spatial attributes	NO	NO	YES	YES
Year FE	YES	YES	YES	YES
Pc4 FE	YES	YES	NO	NO
Constant	13.603***	13.047***	1.308***	1.301***
	(0.179)	(0.062)	(0.032)	(0.047)
Observations	48,171	26,798	46,775	26,306
R-squared	0.404	0.388	0.984	0.980

	Quadratic Hedonic Pricing Estimation			
	(1)	(2)	(3)	(4)
VARIABLES	Ln(Price)	Ln(Price)	Ln(Price)	Ln(Price)
Percentage Tiles Within Gardens per Neighbourhood	-0.000**		-0.000***	
	(0.000)		(0.000)	
Percentage Tiles Within Gardens		-0.000**		-0.000***
		(0.000)		(0.000)
Transactional and Property characteristics	NO	NO	YES	YES
Spatial attributes	NO	NO	YES	YES
Year FE	YES	YES	YES	YES
Pc4 FE	YES	YES	NO	NO
Constant	13.366***	13.015***	1.308***	1.301***
	(0.104)	(0.070)	(0.032)	(0.047)
Observations	48,171	26,798	46,775	26,306
R-squared	0.404	0.387	0.984	0.980

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

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