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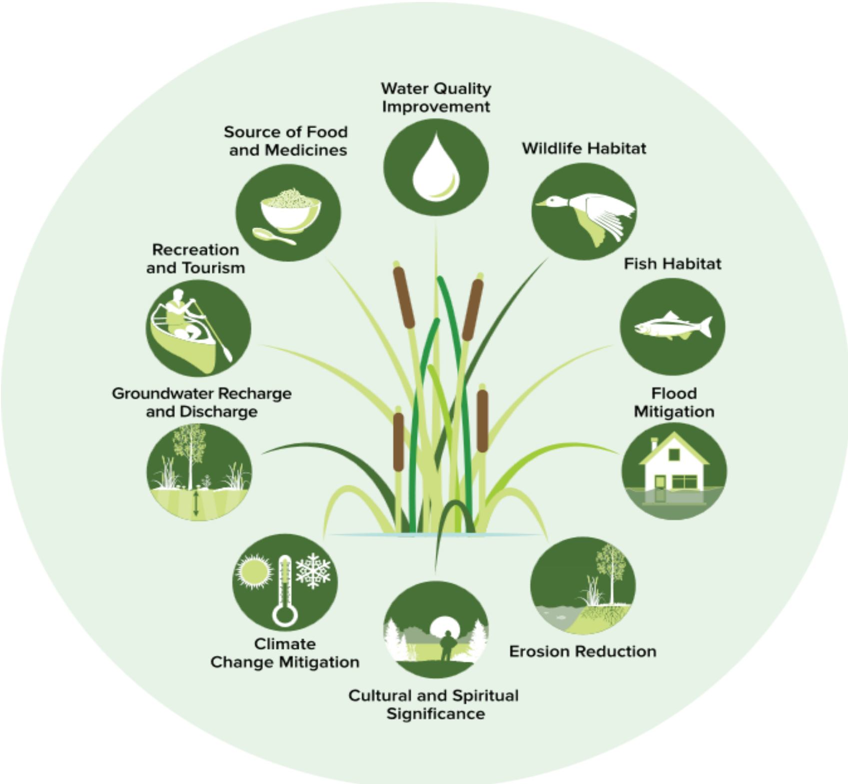
Assessment of ecosystem services in estuaries and urban areas



Leonie Josefine Ratzke

Hamburg 2023

Berichte zur Erdsystemforschung
Reports on Earth System Science

271
2023

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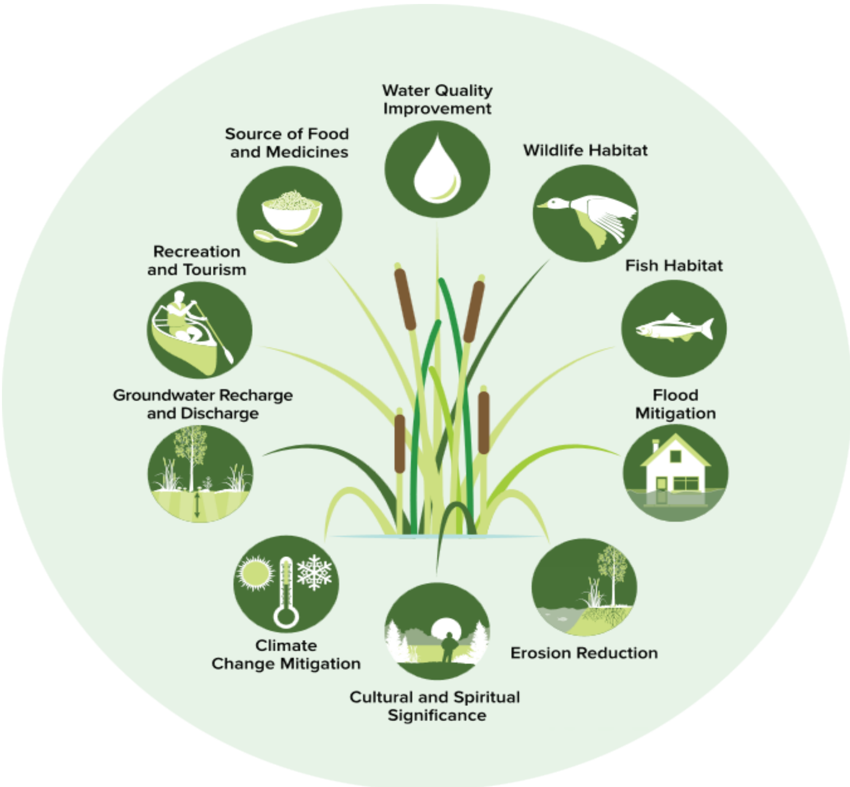

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Tag der Disputation: 25. April 2023

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Titelgrafik: *Ontario Ministry of Natural Resources and Forestry. 2017. A Wetland Conservation Strategy for Ontario 2017–2030. Queen's Printer for Ontario. Toronto, ON. 52 pp.*

Berichte zur Erdsystemforschung / Max-Planck-Institut für Meteorologie 271
Reports on Earth System Science / Max Planck Institute for Meteorology 2023

ISSN 1614-1199 - doi: 10.17617/2.3531745

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Acknowledgements

Writing this dissertation would not have been possible without the support of several people. First, I would like to thank my supervisor Prof. Dr. Grischa Perino for giving me the chance to work at his chair. I have enjoyed the freedom he gave me to work on my research, and am grateful for his support. Furthermore, I would like to thank my colleagues Henrike, Michael and Max for their support, friendship and useful comments. Special thanks goes to Michael Tanner for the great team work, fruitful discussions and connection that developed from them.
I am also grateful for financial support, as well as the support and training provided by the International Max-Planck Research School on Earth System Modelling of the Max-Planck Institute of Meteorology in Hamburg. I thank Prof. Dr. Heinke Schlünzen and Prof. Dr. Uwe Schneider for their professional supervision in my Advisory Panel.

Work is not everything and I am greatly thankful to Gustaf, for continuously loving, supporting and challenging me, for standing by my side through thick and thin and for reminding me to leave the desk at times. Last but certainly not least, I thank my brother Justus, my aunt Imme and my friends for having my back and supporting me through the challenges life presents and for being my rock.

Dedicated to the memory of my parents.

Abstract

This dissertation investigates research questions concerning ecosystem services and biodiversity in urban areas and estuaries. Drawing on a detailed hedonic pricing study, based on sales and rental offers coupled with relevant spatial variables from Hamburg, Germany, and using an internal instrumental variable approach, the first contribution of this dissertation investigates endowment, as well as willingness to pay (WTP) for access to urban green across income groups. The findings of the research show that per capita urban green is unequally distributed across income groups and confirm that income and environmental inequalities are interrelated. The findings suggest the need for additional or reformed integrated socio-environmental policies.

The second contribution investigates heterogeneous preferences for urban biodiversity as an environmental good, using a similar revealed preference approach as the first contribution. It relies on the same initially compiled dataset but additionally includes three spatially resolved biodiversity indicators. In the analysis, I find that WTP for biodiversity as an environmental good is positive and economically relevant. Urban biodiversity conservation and enhancement might thus result in co-benefits for the local urban population. In a convergent validity assessment, I identify a novel satellite-based biodiversity indicator as a potentially suitable alternative to a conventional species richness indicator. This is relevant for primary biodiversity valuation studies and benefit transfer studies in data-scarce regions.

In the third contribution, my co-author and I analyze how the transfer of property rights to local and indigenous peoples in coastal Ecuador affects mangrove deforestation. Specifically, we examine the mechanisms that contribute to the effectiveness of the policy measure and analyze the role that external institutions play in this process. Based on a theoretical model, we develop an instrumental variable estimator and regression discontinuity design to assess changes in mangrove forest area in the first twelve years after policy adoption and analyze the effect of the presence of nongovernmental organizations (NGOs) on the duration of the measure. The research demonstrates that significantly less mangrove forest was cleared in coastal Ecuador following the transfer of property rights to local and indigenous communities. In this context, the presence of NGOs funded by foreign aid increases the likelihood that property rights are transferred and held permanently. We calculate that the intervention prevented additional emissions of more than 1.55 million $tCO2$ and quantify the additional fisheries resources attributable to the transfer of property rights. Our work highlights the importance of local and indigenous people and civil society as stakeholders for sustainable land management in future climate policy.

In general, the dissertation sheds light on the importance of identifying feedback loops and interlinkages in socio-environmental processes that lead to the degradation of ecosystem services. This identification is the first necessary step for implementing informed regulation to reach the Sustainable Development Goals the international community defined to achieve well-being for the global population while reducing the probability that planetary boundaries are overstepped.

Zusammenfassung

In dieser Dissertation werden Forschungsfragen zu Ökosystemleistungen und Biodiversität in städtischen Gebieten und Flussmündungen untersucht. Der erste Beitrag dieser Dissertation beruht auf einem hedonischen Preismodell und verwendet Verkaufs- und Mietangebote aus Hamburg gekoppelt mit relevanten räumlichen Variablen für eine interne Instrumentvariablenschätzung. Fokus der Analyse ist die pro-Kopf Ausstattung sowie die Zahlungsbereitschaft (WTP) für den Zugang zu städtischem Grün über Einkommensgruppen hinweg. Die Ergebnisse der Untersuchung zeigen, dass der Zugang zu Grünanlagen ungleich über Einkommensgruppen verteilt ist und bestätigen, dass Einkommens- und Umweltungleichheiten sich bedingen. Die Ergebnisse legen nahe, dass zusätzliche oder reformierte integrierte Sozial- und Umweltpolitikmaßnahmen notwendig sind, um bereits definierte Ziele auf politischer Ebene zu erreichen.

Der zweite Beitrag untersucht heterogene Präferenzen für urbane Biodiversität als Umweltgut, wobei ein ähnlicher Ansatz der "revealed preferences" wie im ersten Beitrag verwendet wird. Er stützt sich auf denselben ursprünglich zusammengestellten Datensatz, umfasst aber zusätzlich drei räumlich hochaufgelöste Biodiversitätsindikatoren. Ich belege, dass die WTP für städtische Biodiversität als Umweltgut positiv und wirtschaftlich relevant ist. Die Erhaltung und Verbesserung der biologischen Vielfalt in Städten könnte somit zu einem Zusatznutzen für die lokale städtische Bevölkerung führen. In einer Bewertung der Kriteriumsvalidität von relevanten Biodiversitätsindikatoren identifiziere ich einen neuen, satellitengestützten Biodiversitätsindikator als eine potenziell geeignete Alternative zu einem herkömmlichen Biodiversitätsindikator. Dies ist besonders für zukünftige primäre Biodiversitätsbewertungsstudien und Nutzentransferstudien in datenarmen Regionen relevant.

Im dritten Beitrag analysieren mein Mitautor und ich, wie sich die Übertragung von Eigentumsrechten an lokale und indigene Völker in der Küstenregion Ecuadors auf die Abholzung von Mangroven auswirkt. Insbesondere untersuchen wir die Mechanismen, die zur Wirksamkeit der politischen Maßnahme beitragen und analysieren die Rolle, die externe Institutionen in diesem Prozess spielen. Auf der Grundlage eines theoretischen Modells entwickeln wir einen Instrumentvariablenschätzung und ein Regressionsdiskontinuitätsdesign, um Veränderungen in der Mangrovenwaldfläche in den ersten zwölf Jahren nach Verabschiedung der Politikmaßnahme zu bewerten und die Wirkung der Präsenz von Nichtregierungsorganisationen (NGOs) auf die Dauer der Maßnahme zu analysieren. Konkret belegt die Forschungsarbeit, dass nach der Übertragung von Eigentumsrechten an die lokale und indigene Bevölkerung an den Küsten Ecuadors deutlich weniger Mangrovenwälder abgeholzt wurden. Die Anwesenheit von NGOs, die durch ausländische Hilfe finanziert werden, erhöht dabei die Wahrscheinlichkeit, dass Eigentumsrechte übertragen und dauerhaft gehalten werden. Wir berechnen, dass die Maßnahme zusätzliche Emissionen von mehr als 1,55 Millionen tCO2 verhindert hat und quantifizieren die zusätzlichen Fischereiressourcen, die auf die Übertragung von Eigentumsrechten zurückzuführen sind. Unsere Arbeit unterstreicht die Bedeutung der lokalen und indigenen Bevölkerung und der Zivilgesellschaft als Akteure für eine nachhaltige Landbewirtschaftung in der zukünftigen Klimapolitik.

Generell beleuchtet die Dissertation, wie wichtig es ist, Rückkopplungsschleifen und Verflechtungen in sozio-ökologischen Prozessen zu erkennen, die zur Degradierung von Ökosystemleistungen führen. Dies ist der erste notwendige Schritt zur Umsetzung einer sachkundigen Regulierung, um

letztendlich die Ziele für nachhaltige Entwicklung zu erreichen, die die internationale Gemeinschaft definiert hat, um Wohlstand für die Weltbevölkerung zu erreichen und gleichzeitig die Wahrscheinlichkeit zu verringern, dass die planetaren Grenzen überschritten werden.

List of included essays

Chapter 2:

Inequitable Access to Urban Green Spaces and Related Trade-Offs Across Income Groups.

Author: Leonie Ratzke
Available at SSRN: http://dx.doi.org/10.2139/ssrn.4247621

Chapter 3:

Revealing preferences for urban biodiversity as an environmental good

Author: Leonie Ratzke
Journal: Ecological Economics,
Volume 212, 2023, 107884,
Available at: https://doi.org/10.1016/j.ecolecon.2023.107884

Chapter 4:

Deforestation, Institutions, and Property Rights: Evidence from land titling to indigenous peoples and local communities in Ecuador

Authors: Leonie Ratzke and Michael Tanner
CAF working paper series, 2022, December 21
Available at: https://scioteca.caf.com/handle/123456789/1995

Contents

List of Figures

List of Tables

Abbreviations

AD	Anderson-Darling
AUSCM	Acuerdos de uso sustentable y custodia de manglar
CBD	Central business district
CI	Confidence interval
CM	Cambisols
CPUE	Catch per unit effort
CV	Coefficient of variation
DHI	Dynamic Habitat Index
ES	Ecosystem services
GPP	Gross Primary Productivity
HH	Households
IPLCs	Indigenous peoples and local communities
IV	Instrumental variables
KGS	Kolmogorov-Smirnov
LATE	Local average treatment effect
MWTP	Marginal willingnes to pay
NRMSE	Normalized root mean square error
NGO	Non-governmental organization
OLS	Ordinary least squares
PA	Protected areas
Ple	Planosoils
PP	Purchasing power
RDD	Regression discontinuity design
RoM	Ratios of median
SCC	Social cost of carbon
SDG	Sustainable Development Goal
tCO2	Tons of carbon dioxide
UGS	Urban green space
USAID	United States Agency for International Development
WTP	Non-marginal willingness to pay

1. Introduction

Ecosystems represent an important supplier of ecosystem services (ES) such as food, flood protection, carbon sequestration and climate regulation as well as aesthetic enjoyment and spiritual fulfillment to an increasing global population (MEA, 2005). Especially in the past, the key role of ecosystems and biodiversity in enabling continued human existence and well-being on the planet (Costanza et al., 1997; MEA, 2005; UNEP, 2010; Cardinale et al., 2012) was not sufficiently represented in collective decision-making processes and often taken for granted (Costanza et al., 1997; Daily et al., 2000).

Treating ES as essentially "free", seemingly infinite input factors in diverse production and planning processes has led to their degradation and masked trade-offs between conventional economic development, often involving land-use change, and the level and continuous supply of ecosystem services for present and future generations (Costanza et al., 1997; Daily et al., 2000; UNEP, 2010; Groot et al., 2012; Bateman et al., 2013).

The international community has defined 17 Sustainable Development Goals (SDGs) to achieve well-being for the global population while reducing the probability that planetary boundaries are overstepped (Vasseur et al., 2017; Wood et al., 2018). The goals acknowledge the crucial role of the environment and ecosystems in human existence and sustainable development (UNEP, n.d.). According to Kroll et al. (2019), the success of the agenda, however crucially depends on whether decision makers will be able to identify trade-offs between the SDGs, potentially resolve them and maximize the existing synergies between the SDGs.

According to Wood et al. (2018), the integration of the concept of ecosystem services into strategies within the sustainable development framework can help to achieve sustainable development goals and carve out potential synergies and trade-offs between environmental protection and human development. The inherently anthropocentric concept of ES stresses the relation of ecosystems and human well-being and highlights the need to explicitly account for the value of ES as input factors in the production of (environmental) goods and serves as a basis for valuation. According to Bateman et al. (2011b, p. 182) ES are "the flow of services (outcomes of structure and processes) provided by ecological assets in some assessment period[...]". A final ecosystem service, stemming from a sequence of processes of ecosystem functions then takes part in the production of goods which generate human well-being. The benefit value of the respective good is context dependent and can hence vary in space and time (Bateman et al., 2011b).

This definition of ecosystem services further directs the focus of research and enables identification of potential hot-spots for research: Some ES such as carbon sequestration, are relevant at a global scale and affect humans and their well-being even if there is a considerable spatial distance between ecosystem and an individual. Other services, especially cultural services require spatial proximity of the respective ecosystem and the benefiting individual or even direct contact to it (Broitman et al., 2018). This puts urban areas as well as ecosystems with especially pronounced regulating potential on the agenda of research and policy-making. The first, because of a growing global urban population who derive benefits because of direct contact to urban ecosystems as well as by benefiting from local regulating services[1]. The second, because ecosystems can serve as valuable carbon sinks, essential to reach global commitments made in international agreements such as the Paris agreement (Holden et al., 2018; Keenan and Williams, 2018; Lal et al., 2018). Many ecosystems with a high regulating potential are situated in coastal areas and estuaries which historically have been of great importance for economic activity, e.g. because of the significance of waterways in transportation and access to fisheries (Baird, 2005; Barbier et al., 2011b). Therefore, these hot-spots often overlap and are a location where trade-offs and synergies between the SDGs become manifest. Hence, this dissertation focuses on addressing research questions concerning ecosystem services and biodiversity in urban areas and estuaries.

In cities, Urban green spaces (UGS) represent an important supplier of ecosystem services (Wüstemann et al., 2017; Bertram and Rehdanz, 2015; Grunewald et al., 2017). With the ongoing urbanization trend, the already considerable opportunity costs of land are likely to increase in the future. With this increasing pressure on UGS, it is not surprising that they can be considered a scarce environmental good within urban areas. Thus, the equitable access to urban green in the vicinity of the home is an explicitly stated sub-goal of SDG 11, "Sustainable cities and communities" (BMZ, 2021).

Despite this, valuation studies quantifying the benefits city dwellers derive from UGS and at the same time addressing distributional aspects are scarce. The second chapter of this dissertation with the title "Inequitable access to urban green spaces and related trade-offs across income groups" seeks to fill this gap. Drawing on a detailed hedonic pricing study based on sales and rental offers from Hamburg, Germany, it seeks to quantify willingness to pay (WTP) for and distribution of per capita access to urban green across income groups. Based on the estimated WTP, I investigate the trade-offs households of different income groups face between urban green space endowment and private housing attributes.

The results of the analysis show that per capita urban green is unequally distributed across income groups and that low-income households face a trade-off between access to the ES of parks and square footage of their housing unit as well as with private green in the form of garden area. The results of Chapter 2 imply that existing policy instruments do not seem to be sufficient to reach SDG 11 and confirm that income and environmental inequalities are interrelated. The latter finding highlights a potential for synergies between SDGs 11 and 10, "Reduced inequalities".

Moreover, the findings of the chapter could be interpreted as an indication that reducing income inequality has the potential to foster diverse synergies with further SDGs such as 3 ("A healthy life") and 13 ("Climate action"), but could also involve trade-offs with "Economic growth" (SDG 8), depending on which policy instruments would be selected to reduce existing inequalities. The interrelation of SDGs 10 and 13 is supported by Adua (2022), who state that measures implemented to reduce inequalities, be it income or wealth-related inequalities, may ultimately pay off as climate mitigation dividends. It is also broadly in line with Drupp et al. (2018), who show that more equal societies have a higher valuation for environmental public goods, which might also manifest in democratic processes and policy decisions, while inequality is linked to less ambitious environmental policy (Drupp et al., 2021a).

If however the issue of income inequality is not addressed, this might mean that existing obstacles in securing the SDGs and environmental preservation are reinforced (Idrees and Majeed, 2022). Theodossiou and Zangelidis (2020) identify a self-reinforcing mechanism of inequality and political

[1] Examples for regulating services with a high local relevance are flood regulation and air purification.

participation. In their review including a causal assessment using data from a panel of 28 OECD and European countries, the authors find that income inequality decreases political participation rates, which in turn increases inequality. This implies a downward spiral, involving the degradation of democratic processes and and erosion of the legitimacy of future policy-making and represents a link to SDG 16 ("Peace, justice and strong institutions").

While the second chapter of this dissertation majorly focuses on how urban nature is distributed across income groups in quantitative terms and thus mainly touches upon the links between SDGs 11 and 10, it does not address the interplay of urban biodiversity and cultural ES, i.e. the amenity value of urban nature in relation to quantitative measures of environmental quality. Biodiversity and ES can be synergistic, but especially in urban areas, little is understood on which role biodiversity plays within the biodiversity and human well-being nexus and how this relates to the overarching SDGs.

Urbanization is a prominent driver of biodiversity loss (Spotswood et al., 2021; McDonald et al., 2020) and for a long time, following a "nature for itself" or "nature despite people" paradigm, biodiversity conservation efforts mainly focused on safeguarding biodiversity in non-urban landscapes (Mace, 2014; Faeth et al., 2011; Dearborn and Kark, 2010), e.g. in the form of National Parks (Bonn et al., 2020). Due to its inability to reach long pursued conservation aims manifest in several policy goals, the paradigm has since then developed over a "nature for people" to a "people and nature" paradigm. This development acknowledged the complex, dynamic relationships between human well-being and nature and the need to account for this in research and decision processes (Mace, 2014).

During this development, the more complex relationship between urbanization and nature has been highlighted as well, including the previously little recognized role of urban areas in global biodiversity conservation (Dunn et al., 2006; Dearborn and Kark, 2010; Broitman et al., 2018; Spotswood et al., 2021; Rega-Brodsky et al., 2022). First, strategies for urban biodiversity conservation have a direct impact on conserving local biodiversity. As stated above, human settlements have historically often emerged in estuaries, which are mostly rich in biodiversity and endemic species, due to their mosaic-like habitat structure (Shokri and Gladstone, 2013). This represents a potential direct link of urban biodiversity policies to SDG 14 "Life below water" and SDG 15, "Life on land". Nevertheless, many species and ecosystems will most likely not be directly preserved within cities. This however does not mean that urban biodiversity has little relevance for conservation of ecosystems with a high regulating potential and global biodiversity. Dunn et al. (2006), summarize an indirect link of urban biodiversity and global conservation under the label of the "pigeon paradox". This theory connects urban dwellers' preferences for environmental conservation and action with global conservation outcomes: Since the global population is increasingly concentrated in urban areas, city dwellers have significant influence on policy-making through donations, votes or by working in positions where they directly influence policy-making. If urban biodiversity is continuously degraded, the likelihood of encounters with dominant species such as pigeons, which are often perceived as nuisances, increases. According to Dunn et al. (2006), this can bear the danger that city dwellers develop an aversion to interactions with nature which could ultimately reduce pro-environmental behavior and action and thus influence policy making on a national level through the mentioned pathways. The theory thus links urban biodiversity to SDGs 13 ("Climate action") and 17 ("Partnerships for the goals").

Despite urban biodiversity's relevance, little is known about how urban biodiversity influences observed behavior in markets such as the housing market, and the evidence in the literature on whether biodiversity increases or decreases cultural ES and related human well-being is mixed.

The third chapter with the title "Revealing preferences for urban biodiversity as an environmental good" thus seeks to fill this gap and assesses the status quo by quantifying city dwellers WTP for urban biodiversity.
I find no evidence that urban dwellers in Hamburg perceive biodiversity as a nuisance, which would manifest in negative capitalization effects in the housing market. In contrast, the results point towards a synergistic nature of urban biodiversity and recreational preferences and hence highlight potential synergies of SDG 3, 11 and 15. This can be interpreted as an indication that in the current sample, positive encounters with (urban) biodiversity still prevail and that it is not too late to safeguard and improve urban biodiversity in Hamburg with adequate policy instruments, including ongoing educational campaigns. Since especially bird richness depends on suitable habitats and environmental quality, it is likely that the interlinkages between income and environmental inequality shown in Chapter 2 also manifest in an inequitable likelihood of interacting with fauna perceived as pleasing, as for instance shown by Strohbach et al. (2009). The latter thus represents a link between SDGs 10 and 15.
While these findings are a start in unraveling the complex theoretical mechanisms at work, more research is necessary to fully disentangle the pigeon paradox. Data on biodiversity, such as species (richness) data, is however not always readily available due to an expensive and time-consuming data collection process (Kallimanis et al., 2012). To improve the starting position of future research, the third chapter further contributes to the literature by introducing a relatively novel biodiversity indicator, the freely accessible, satellite-based Dynamic Habitat Index (DHI) provided by Hobi et al. (2017) to the economic valuation literature. In a convergent validity assessment, I find that while the results produced with the alternative indicator are not perfectly in line with the results derived with the conventional species richness indicator, the DHI represents a suitable biodiversity indicator for large-scale assessments, for applications in data-scarce regions or for research contexts with limited funding.

Chapter 4 has the title "Deforestation, Institutions, and Property Rights: Evidence from land titling to indigenous peoples and local communities in Ecuador". It investigates the effect of assigning property rights to local and indigenous peoples in coastal Ecuador with the goal of preventing deforestation of mangrove forests. Special focus is directed to the relevance of local provisioning services and resulting local benefits in the form of fisheries as well as the role of external institutions financed by foreign aid in policy effectiveness.
Provisioning services and regulating services can have a synergistic nature, but, especially where opportunity costs of regulating services are high, trade-offs between ES pose an issue. Mangrove forests are an example of an ecosystem with high regulating potential which has been continuously degraded as a result of prioritizing selected provisioning services - in this case shrimps bred in aquaculture[2].
In Ecuador, shrimp-farming started in the late 1960's, and was promoted both by the state and international development agencies. Due to a continuous growth of the industry, its aquaculture expanded and encroached on mangrove ecosystems and the traditional lands of indigenous peoples and local communities (IPLCs) (Rodríguez, 2018; Beitl, 2011; Veuthey and Gerber, 2012a). Apart from the loss of regulating and cultural ES, the resulting mangrove degradation had direct impacts on local communities as traditional users of the mangroves' provisioning services. As communities were themselves not profiting from the economic benefits of shrimp farming, the destruction of

[2] Mangroves are inter-tidal forests occurring along tropical, subtropical and some temperate coasts and estuaries (Duke et al., 2007a; Richards and Friess, 2016a)

mangrove ecosystems resulted in a loss of subsistence for these communities who traditionally rely on the naturally occurring provisioning services of intact mangrove ecosystems, i.e. fisheries (Rodríguez, 2018; Veuthey and Gerber, 2012a; Beitl, 2014a).

To halt mangrove deforestation and prevent resulting conflicts involving violence, expropriation and encroachment of IPLCs, property rights, through land titling, were proposed as a policy instrument to achieve environmental, as well as development goals with potential benefits ranging from carbon sequestration and poverty reduction to food security (Liscow, 2013a; BenYishay et al., 2017a; D. C. Miller et al., 2021). Chapter 4 focuses on evaluating said policy and quantifying its effect on global regulating services as well as on local provisioning services. The study adds to several strands of the literature, including the literature on policy evaluation and causal methods in tropical deforestation (Sims, 2010a; Ferraro et al., 2012b; Liscow, 2013a), the literature investigating the role of the non-profit and non-governmental sector in fostering environmental preservation (Usmani et al., 2021; L. Grant and Grooms, 2017; Deaton, 2010a) as well as the literature on common pool resources and endogenous institutions in decentralized environmental and climate change policy (**Ostrom.2014**; Dietz et al., 2003a).

The findings of the chapter show that assigning property rights to IPLCs significantly decreases mangrove deforestation. This entails avoided emissions of more than 1.55 Million $tCO2$ over a period of twelve years and additional provisioning services, i.e. fisheries, leading to positive income effects for IPLCs. The chapter represents a case study showing that synergies between the SDGs 1 ("No poverty"), 2 ("Zero hunger"), 13 ("Climate action"), 14 ("Life below water") and 16 ("Peace, justice and strong institutions") are possible, if the maximization of a single provisioning service, i.e. shrimp breeding, is relinquished. It furthermore highlights the role of international North-South transfers, as well as the importance of local and indigenous peoples and civil society as actors in significantly increasing the probability of policy adoption and permanence. Thus, it highlights a link to SGD 17 ("Partnership for the goals"). As stated above, the relevance of urban biodiversity in global climate action also touches upon SDGs 13 and 17 and hence represents an indirect link between Chapters 3 and 4.

In general, the dissertation sheds light on the importance of identifying feedback loops and inter-linkages in socio-environmental processes that lead to the degradation of ecosystem services. This identification is the first necessary step for implementing informed regulation to reach the SDGs. This entails understanding the underlying mechanisms at work and identifying relevant actors, as well as taking the distribution of benefits resulting from ecosystem services into account. The dissertation provides insights into a several such inter-linkages. It is however likely that further such inter-linkages, manifesting in synergies and trade-offs between SDGs, are present. For instance, the dissertation does not directly investigate or delve into research questions related to gender inequality, ethnic inequality or broader implications of the findings for economic growth, industry, innovation and infrastructure, nor does it investigate or quantify regulating services other than carbon sequestration. Furthermore, it only briefly mentions the intergenerational conflict both inherent in the global climate change debate as well as in local equilibrium outcomes in the housing market.

In the case of Chapters 2 and 3, the chosen revealed-preference method is initially a black box and the assessments rely on several assumptions and previous theoretical work to shed light on the mechanisms potentially driving equilibrium outcomes. The method cannot however directly elicit detailed questions on perception and use of urban nature as it quantifies ex-ante WTP, nor can all theoretical mechanisms described by the pigeon paradox be tested with the available data.

Since several data sources were combined to empirically investigate the research questions posed in this dissertation, data resolution and data privacy concerns represent a limitation to perfect matching of different data products. Furthermore, the use of parametric estimation methods applied in this dissertation might involve a trade-off between a straightforward interpretation of model results and goodness-of-fit. The prior aim is clearly prioritized in this dissertation. Apart from these limitations, the estimation of the prevented emissions in Chapter 4 do not account for uncertainties in the carbon cycle (Holden et al., 2018).

The dissertation discusses several interrelations and potential feedback loops between (income) inequality and environmental and development outcomes. With two of the contributions focusing on a study region in the global North, I unwittingly take part in reproducing a different kind of inequality, i.e. inequalities of knowledge generation and data availability between the Global North and South (Collyer, 2018), which represent a barrier to reaching the SDGs (Fisher and Fukuda-Parr, 2019). On the other side of the coin, I hope that this research contributes to reducing said inequalities, e.g. by highlighting the interconnection between local processes relating to SDGs both in the Global North and Global South and providing evidence for the suitability of a freely accessible biodiversity indicator with global coverage. The authors of Chapter 4 furthermore did their best in avoiding so called "helicopter research practices" (Haelewaters et al., 2021), both with respect to authorship, involvement of local actors, future local dissemination of the research findings and by adhering to equal partnership and work ethics.

2. Inequitable access to urban green across income groups and related trade-offs

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Abstract:
Urban green spaces (UGS) provide a magnitude of ecosystem services to city dwellers and the issue of equitable and sufficient access to urban green has been a policy goal for several years. Nevertheless, valuation studies in the urban green space literature focusing on distributional aspects are scarce. Hence, I investigate endowment with, as well as willingness to pay for different types of UGS across income groups, drawing on a detailed hedonic pricing study, based on sales and rental offers from Hamburg, Germany. First, I document that per capita endowment with UGS is unequally distributed across income groups. This finding is robust across a wide range of inequality measures. Subsequently, I investigate the trade-offs households (HH) from different income groups face between UGS endowment and private housing attributes. Low-income HH face a trade-off between the square footage of their housing unit and the area of all UGS types except cemeteries. Low-income HH equally face a trade-off between private green, in the form of garden area, and public park as well as playground area. The results imply a hierarchy of green spaces with parks being the most in demand followed by playgrounds and cemeteries. The findings underline the interrelation between environmental and income inequality. Furthermore, they provide nuanced insights for the design of policies that seek to alleviate environmental inequalities within urban areas. The findings suggest the need for integrated socio-environmental policies, such as issuing rights of occupancy, low-income housing provisions coupled with a reform of the existing social assistance policies as well as long-term transformations in the mobility system. Based on the findings, I discuss the potential synergies and trade-offs between selected sustainable development goals implemented on a national scale.

2.1 Introduction

More than half of the world's population lives in urban areas. Germany is no exception, with more than 75% of people residing in cities and with this figure set to increase in the future (United Nations, 2014; Schlünzen et al., 2018). In densely populated areas, urban green spaces (UGS) represent an important source of diverse benefits to an increasing number of inhabitants (Perino et al., 2014). The ecosystem services (ES) UGS provide to city dwellers span from climate regulation and local air quality improvements to positive effects on mental and physical health and improved life satisfaction (Wüstemann et al., 2017; Bertram and Rehdanz, 2015; Grunewald et al., 2017). As the already substantial opportunity costs for UGS are expected to increase further in the future due to growing population densities and economic activity, there is an urgent need for research providing essential information concerning the benefits city dwellers derive from UGS. This information helps to prevent policy failure such as the under-provision of UGS (Hansjürgens et al., 2018).

The available investigations quantifying willingness to pay (WTP) for the mean provision of UGS in cities mostly focus on efficiency. Distributional aspects of access to urban green and the related inherent question of whether ecosystem services of UGS are equally distributed across income groups or classes is, however, comparatively understudied in the economic valuation literature. This is surprising given that the universal access to a safe, inclusive and accessible green area for all age and socio-economic groups is explicitly stated as a sub-goal of the United Nations' Sustainable Development Goal (SDG) 11 (BMZ, 2021). On a national level, policymakers acknowledged the need to improve access to high-quality public green within an adequate walking distance of peoples' dwellings in the German national biodiversity strategy of 2007, and discussed the need for more equitable access to urban green even before the adoption of SDG 11 (Dosch et al., 2015).[1]

Economic theory suggests that the utility an individual derives from UGS availability and resulting revealed WTP, depends on the characteristics of the site such as its size and reachability, the availability of substitutes as well as characteristics of the valuing individual, such as income or demographics (Bateman et al., 2011a). Previous studies in the urban green space and environmental valuation literature provide a substantial body of evidence on the marginal willingness to pay (MWTP) for access to UGS, mostly relying on distance or density-based proxies for UGS endowment (e.g. Palmquist (1992), Czembrowski and Kronenberg (2016), Engström and Gren (2017), Liebelt et al. (2018) and Blanchette et al. (2021)), including investigations of preference heterogeneity for UGS among valuing individuals (e.g. Allen Klaiber and Phaneuf (2010) and Panduro et al. (2018)). Comparatively fewer studies in the related environmental justice literature have focused on distributional aspects and the question of whether access to UGS differs across income groups or classes (e.g. Pham et al. (2012), Wüstemann et al. (2017), and Chen et al. (2022)). The same is true for the question of how households (HH) trade-off UGS area with private goods, such as square footage of a housing unit and private green. An example for a study analyzing the latter question is a survey-based analysis by Schindler et al. (2018) in Brussels. Further examples are a choice experiment by Tu et al. (2016) focusing on peri-urban forests and their potential substitutes, or Lewis et al. (2009) who explore the degree of substitutability between lot size and nearby protected

[1] In its program "Zukunft Stadtgrün"(Future Urban Green), the Federal Ministry for Construction again emphasized the need for the aforementioned aim for equitable access to high-quality green spaces within urban areas (BMWSB, 2017). Despite these repeatedly stated policy goals, no suitable indicator or monitoring strategy for equitable green space provision have so far been designed in Germany (Wüstemann et al., 2017).

open space, as well as the degree of complementarity between open space and the numeraire good in households' preferences.

To my knowledge, there is no valuation study integrating the valuation of ES with an equity assessment, i.e. a study investigating how per capita UGS endowment[2], as well as WTP for ES of UGS and the trade-offs between private goods and UGS households face, differ across income groups. This is in line with recent calls from the literature pertaining the need to study the valuation of environmental goods such as UGS and the distribution of income at the same time (Drupp et al., 2018). Hence, this study seeks to contribute to the environmental valuation and environmental justice literature, with a focus on urban green spaces. It specifically focuses on investigating the distribution of per capita access to urban green across income groups and the trade-offs households of different income groups face between UGS endowment and (i) square footage of their housing unit as well as with (ii) access to private green in the form of garden area. I provide theoretical arguments suggesting that inequitable access to urban green is an expected outcome in an unregulated environment. Based on the theoretical mechanisms and referring to the concept of ecosystem services as well as to the empirical results of previous (qualitative) studies, I derive hypotheses. To estimate WTP for urban green and test the hypotheses, I apply the hedonic pricing method (HPM) to estimate MWTP in a first step. For this purpose, I use data on more than 150 K rental and sales offer prices of both flats and houses rented or sold in the city of Hamburg, Germany. In a next step, I assume a structural form of the utility function to estimate WTP. To account for endogeneity caused by omitted variables, self-selection of households in the respective housing units, as well as potential measurement error, I use spatial fixed effects combined with an internal instrumental variable approach as an identification strategy. I do not pool UGS of different categories, but estimate WTP for endowment with three UGS types. With the resulting estimates as well as spatial data on green space endowment, I test if access to UGS of the median citizen of each income group differs significantly across income groups and provide estimates of several inequality measures as a robustness check. In a third step, I use the estimated WTP for UGS to (i) analyze if the resulting distribution of WTP across income groups is in line with the conjectured underlying theoretical mechanisms and (ii) quantify trade-offs with selected private goods as well as (iii) estimate UGS type and income-group-specific income elasticities of WTP using purchasing power as a proxy for income.

The findings show that per capita urban green is unequally distributed across income groups. While high-income HH have the highest per capita endowment with urban green, low-income HH face a trade-off between UGS area and the square footage of their housing unit for all UGS types, except cemeteries. Low-income HH equally face a stronger trade-off between private green and both park and playground area. HH of all income groups consume garden and cemetery area in a complementary relationship. The results imply a hierarchy of green spaces with parks being the most in demand followed by playgrounds and cemeteries. Furthermore, the results imply that existing policy instruments do not seem to be sufficient to reach the goal of equitable access to ecosystem services of urban green, and confirm that income and environmental inequalities are interrelated. My findings suggest the need for additional or reformed integrated socio-environmental policies. With reference to the literature, I discuss several policy measures and categorize them in short- and mid-term vs. long-term measures.

[2] To calculate the per capita endowment, the total area of each green space type within a 1 km radius of each housing unit was divided by the population density within the respective spatially and temporally overlapping raster pixel of the data described in Section 2.3.

This paper is organized as follows: In Section 2.2.1, I present theoretical concepts and mechanisms for the present application. Next, I derive hypotheses in Section 2.2.2. In Section 2.3.1, I describe the data preprocessing as well as compilation, which is followed by Section 2.3.2, further describing the identification strategy. In Section 2.4, I present the results of the analysis and discuss the findings as well as their policy implications in Section 2.5.

2.2 The economic framework and hypotheses

2.2.1 Quantifying willingness to pay for urban green and related trade-offs across income groups in a hedonic equilibrium framework

Hedonic pricing is anchored in the theory of consumer behavior and relies on the notion that the utility an individual derives from consuming a good is based on its composite attributes (Lancaster, 1966). The method is based on a general theoretical framework developed by Rosen (1974) which was applied to environmental goods shortly thereafter by Freeman (1974). According to this theory, the value of a specific characteristic x of a housing unit i is reflected in the price of the differentiated product, i.e. the price of each housing unit p_i. In a market transaction, a home buyer or renter hence reveals her willingness to pay for a bundle of observable characteristics x_i including structural housing characteristics, access to public goods and ecosystem services as well as for unobservable housing characteristics $\phi_{i,sp}$[3], by sorting into a specific housing unit in the urban space. Assuming a fixed supply, the implicit price for each housing characteristic is thus determined in a sort of bidding process depending on city dwellers' preferences and available income. Implicit prices may be distinct from each other in different housing market segments, or submarkets (Freeman, 1974; Poudyal et al., 2009; Liebelt et al., 2018). The so-called hedonic price schedule of each submarket m thus represents an equilibrium outcome determined by the interaction of a large number of buyers and sellers represented by a hedonic price function (Bajari and Kahn, 2005) which can be used to recover marginal willingness to pay (MWTP) for urban green. The composite price p of a housing unit i in submarket m is hence dependent on observable and unobservable housing attributes x_i and $\phi_{i,sp}$:

$$p_i = \mathbf{p_m}(\mathbf{x_i}, \phi_{i,sp}) \tag{2.1}$$

In a first stage, I thus recover the implicit prices for the housing characteristics of interest by estimating the hedonic price schedules of Equation 2.1 with the specification presented in Section 2.3.2.

I assume that households act as price takers in only one housing market m. Their utility depends on the numeraire c_j, observed housing characteristics $\mathbf{x_i}$ and a bundle of unobserved characteristics $\phi_{i,sp}$:

$$U_{i,j} = U_{i,j}(\mathbf{x_i}, c_j, \phi_{i,sp}) \tag{2.2}$$

Households act as rational, utility-maximizing agents who choose the housing bundle that best fits their preferences given their income. Thus, the implicit prices for each characteristic represent the individual MWTP for those characteristics. Depending on their available income, households need to make trade-offs between consumption and proximity to and availability of local amenities

[3] The unobservable characteristics can be systematically clustered within spatial units sp.

(Banzhaf et al., 2019) as well as structural housing characteristics. Due to the resulting sorting process across the urban space, households with similar preferences for local amenities and with comparable means to afford them locate in spatially proximate housing units and thus form clusters. Since sociodemographic variables often correlate with preferences for local amenities, it is theoretically plausible that these clusters are at least relatively homogeneous in terms of income level and sociodemographic composition (Tiebout, 1956; Hachadoorian, 2016). In case residents additionally show a preference for living in proximity to neighbors with similar characteristics, e.g. a family with small children wanting to live close to kindergartens, UGS and schools as well as close to other families with similar socioeconomic status, this effect is reinforced (Clark and Fossett, 2008; van Gent et al., 2019).

Assuming the real estate market operates perfectly, theory suggests that the purchase price p_i is equal to the discounted sum of the stream of annual rents realizable from that property over its expected lifetime into the future (Day et al., 2007). Hence, I assume the same holds for the implicit prices of each product characteristic, and that the expected lifetime of a property is infinite to be able to express implicit prices as implicit rents by multiplying them with the discount rate ψ[4], in case it is a property (i this case the dummy variable d_{purch}=1 and d_{rent}=0), or with 12 in case it is a rental object (in this case the dummy variable d_{purch}=0 and d_{rent}=1):

$$\pi = d_{purch} \cdot \psi + d_{rent} \cdot 12 \tag{2.3}$$

The product $\pi * p_i$ thus represents annual spending for housing unit i. The optimal housing choice for each household with income y_j can hence be expressed as:

$$\max_{x,c_j} U_{i,j}(\boldsymbol{x_i}, c_j, \phi_{i,sp}) \;\; s.t. \;\; y_j = \pi \cdot p_i + c_j \tag{2.4}$$

Thus, the marginal cost for a continuous housing attribute k of $x_{i,k}$ is equal to the marginal rate of substitution with the numeraire good c_j when a housing bundle i is the utility-maximizing choice for a household j (Panduro et al., 2018).

If one assumes that all households are identical with respect to income and preference structure, the implicit price function itself is the inverse demand function for the respective characteristic (Freeman, 1979). In the case of non-marginal changes in the characteristic, it is however not possible to calculate welfare impacts. Since I want to quantify the flows of services for the current level of UGS, I use a thought experiment assuming that all UGS are canceled and developed for other purposes. This allows me to recover households' WTP to prevent these non-marginal changes in UGS area. To quantify households' WTP to preserve existing UGS, it is hence necessary to drop assumptions of preference and income homogeneity and instead estimate a WTP function in a second-stage estimation. Many researchers exclusively estimate the first stage of the hedonic model, as the second-stage estimation suffers from identification and endogeneity problems (Freeman, 1979; Epple, 1987; Zabel and Kiel, 2000; Freeman et al., 2014). The first issue can be resolved by estimating the first-stage hedonic price equation for different submarkets or by assuming a non-linear hedonic price function to introduce exogenous variation in the hedonic price schedules and enable identification of a WTP function in a second step (Zabel and Kiel, 2000). In this study, I rely on both sources of variation. Additionally, I include interaction terms between the variables of interest and variables indicating the presence of potential substitutes/complements, to allow for

[4] In this study I use 3% as discount rate.

spatial heterogeneity in the implicit prices of the variables of interest apart from the heterogeneity introduced by the functional form of the hedonic price schedule.

The problem of endogeneity arises because an individual chooses both the level of a characteristic, e.g. UGS area, as well as the implicit price for it while maximizing individual utility (Freeman et al., 2014). This in itself does not necessarily present a problem. It is however problematic if unobserved housing characteristics, including social factors such as the reputation of a neighborhood, which may or may not vary systematically across space are correlated with the variable of interest. To solve this second issue, an option is to apply two-stage least squares estimation with instrumental variables (IV) (Zabel and Kiel, 2000). Since finding suitable instruments is a considerable challenge, I revert to an econometric approach using an internal IV combined with spatial fixed effects further described in Section 2.3.2.

To recover non-marginal WTP for the ES provided by the current level of UGS, I base my second-stage estimation strategy on previous work by Chattopadhyay (1999), as it does not rely on restrictive assumptions of preference homogeneity and identical income. After recovering implicit prices from a first-step estimation procedure of the hedonic price schedule, I address the second-stage estimation problems in a cross-sectional setting by imposing structure on the unknown utility function of the observed individuals and by semi-parametrically recovering the bundle of unobserved characteristics $\phi_{i,sp}$ with spatial fixed effects. Additionally, potential remaining endogeneity resulting from unobservables not being systematically related across space or from measurement error is accounted for using an internal instrumental variable approach.[5]

Furthermore, I need to account for a non-linear budget constraint and the resulting estimation problems described in Day et al. (2007). I thus linearize the budget constraint by deriving a virtual income measure yv_j similar to Boyle et al. (1999)[6]:

$$yv_j = y_j - p_i + pp_i, \tag{2.5}$$

with income y_j, the price of a housing bundle p_i and the predicted price of the same housing bundle pp_i derived from the hedonic price function.

Bajari and Kahn (2005) show that if utility is continuously differentiable, monotonic in c_j, Lipschitz continuous in x_i and $\phi_{i,sp}$ and strictly increasing in $\phi_{i,sp}$, equilibrium prices are a function of the choice-specific characteristics independent of assumptions concerning the supply side.

I thus use a translog utility function as a flexible functional form in order to not prescribe additivity, homotheticity, or restrictions on the substitutability of housing characteristics. According to Christensen et al. (1975), the indirect translog utility function represents a local second-order approximation for any indirect utility function:

$$U_{i,j}(x_i, c_j, \phi_{i,sp}) = \ln c_j + \ln x_{i,k} \left(\alpha_k + \sum_{d=1}^{l} \alpha_{d,k} \ln D_{j,d} + \frac{1}{2} \sum_{k,w=1}^{n} \alpha_{w,k} \ln x_{i,w} + \alpha_{sp}\phi_{i,sp} \right), \tag{2.6}$$

with n housing characteristics and l socioeconomic characteristics D and where w can either represent all housing characteristics or selected housing characteristics including the characteristic of

[5] See Section 2.3.2.

[6] If the implicit price of an attribute is not constant due to non-linear hedonic price schedules, the budget constraint is also non-linear. In this case a HH's choice of attribute levels will depend not only on implicit prices but on all parameters of the respective hedonic price schedule. Thus, the demand function will not necessarily have the usual downward sloping properties in price-quantity space (Palmquist, 1988; Day et al., 2007). According to Palmquist (1988), this means that standard duality results no longer hold and that the budget constraint needs to be linearized to be able to recover and analyze hypothetical non-marginal changes in attribute levels.

interest to investigate the cross-price effects of interest. With reference to Day et al. (2007), I only include cross-price effects I consider relevant for this assessment or which others found to be relevant in previous research.

With a translog structure imposed on the utility function, the first-order condition for a maximum can be written as:

$$\frac{\delta \pi p_m(x_{i*})}{\delta x_{i,k}} = \frac{c_j}{x_{i,k}} \left(\alpha_k + \sum_{d=1}^{l} \alpha_{d,k} \ln D_{j,d} + \sum_{k,w=1}^{n} \alpha_{w,k} \ln x_{i,w} + \alpha_{sp}\phi_{i,sp} + \epsilon_i \right) \tag{2.7}$$

(Chattopadhyay, 1999). The error term ϵ_i is associated with those unobservable tastes of households that do not vary systematically with space or measurement errors in the housing attributes. While preference parameters $\alpha_{w,k}$ are assumed to be identical across consumers[7], I incorporate variation in preferences in three ways: First, by variation in observable household demographics D, which work as demand shifters. Second, by capturing households' heterogeneous choice bundles and third, by semiparametrically estimating a spatially distinct bundle of unobserved characteristics estimated with a spatial fixed effect. The latter is intended to capture common preferences for bundles of unobservable neighborhood characteristics, at a higher spatial scale than the individual housing unit. Due to the variation of implicit prices $\frac{\delta \pi p_m(x_{i*})}{\delta x_{i,k}}$ and variation between submarkets m, the preference parameters α_k, $\alpha_{d,k}$, $\alpha_{w,k}$ and α_{sp} can be identified. Households are assumed to be identical in their decision process.

Integrating the inverse demand function in Equation 2.7 allows me to calculate non-marginal WTP for the benefits city dwellers receive from the current endowment with UGS (Chattopadhyay, 1999). The ex-ante WTP for the chosen level of the respective attribute is thus given by:

$$WTP_{j,k} = \int_0^{x_{i,k}} \frac{\delta U_j / \delta x_{i,k}}{\delta U_j / \delta c_j} dx_{i,k} \tag{2.8}$$

For the chosen specification of the utility function this gives[8]:

$$WTP_{j,k} = c_j \ln x_{i,k} \left(\alpha_k + \sum_{d=1}^{l} \alpha_{d,k} \ln D_{j,d} + \sum_{k,w-k=1}^{n-k} \alpha_{w-k,k} \ \ln x_{i,w-k} + \alpha_{k,k} \frac{\ln x_{i,k}}{2} + \alpha_{sp}\phi_{i,sp} \right) \tag{2.9}$$

Although not flawless as it includes a structural assumption of the utility function, the present approach is useful as it decomposes the ex-ante WTP for access to different green space types t across income groups I as well as in relation to sociodemographic characteristics D and potential substitutes S in a third-stage estimation. The third-stage estimation allows for the separate estimation of the income elasticty of WTP $\epsilon_{t,I}$ as well as the trade-offs with selected housing characteristics $\alpha_{t,s,I}$ that households from different income groups I face and is thus essential for hypothesis testing. Furthermore, a parametric function potentially enables benefit transfer to other study sites in the form of function transfer. Hence, I regress the relevant variables on the natural logarithm of WTP for preserving the current level of UGS area of type t in separate models for each income group I:

[7] Random effects models applied e.g. by Bajari and Kahn (2005), are not appropriate here as the assumption of zero correlation between ϕ and $x_{i,k}$, does not necessarily hold. Park area could for instance be correlated with unobserved school quality.

[8] Please note that I us the inverse hyperbolic sine transformation instead of the natural logarithm since the natural logarithm of zero is not defined.

$$\ln WTP_{t,I} = \alpha_{t,I} + \epsilon_{t,I} \cdot \ln PP_i + \sum_d \alpha_{t,d,I} \cdot D_{i,d} + \sum_s \alpha_{t,s,I} \cdot \ln S_{i,s} + \sum_c \alpha_{t,c,I} C_{i,c} + q_{t,I} \quad (2.10)$$

In this context $\alpha_{t,I}$ represents the unexplained mean WTP for a bundle of ecosystem services of the respective UGS type t and income group I, while the coefficient vectors $\epsilon_{t,I}$ $\alpha_{t,d,I}$, $\alpha_{t,s,I}$, $\alpha_{t,c,I}$ represent explained heterogeneous variation in $WTP_{t,I}$ for three distinct income groups I and UGS types t. The error term $q_{t,I}$ represents the remaining idiosyncratic taste variation in each income group.

Based on Hanemann (2006, pp. 88-89), I define $S_{i,s}$ as substitute for t if an increase in its level decreases WTP for the UGS area of type t. Analogously, $S_{i,s}$ is consumed in a complementary relationship with UGS area of type t, if an increase in its level increases WTP. The coefficient estimate $\alpha_{t,s,I}$ thus informs about the trade-offs between selected private goods and consumption of green space area of different types each income group faces. Responding to Drupp et al. (2021b)'s call for an improved reporting of income elasticities in valuation studies, I quantify the income elasticity of WTP by estimating $\epsilon_{t,I}$ with purchasing power PP as a proxy for income. Estimating coefficient vector $\alpha_{t,d,I}$ can shed light on the heterogeneity of WTP between households with differing socioeconomic characteristics, while $\alpha_{t,c,I}$ can clarify the relationship with other control variables.

2.2.2 Hypotheses

Within the framework presented in the previous section, households (HH) have heterogeneous income and preferences. Given that UGS types are heterogeneously distributed across space, I expect HH to sort across the urban space, depending on their willingness and ability to pay for amenities including UGS (Tiebout, 1956; Epple and Platt, 1998; Banzhaf et al., 2019), selecting a housing bundle with the structural housing attributes they prefer and can afford. In general, I would expect all or most households to want to live in a nice amenity-rich neighborhood. Since HH face a trade-off between consumption and the level of desired housing attributes including UGS, they reveal their willingness and ability to pay for UGS in the sorting process. High-income households have a higher budget at their disposal and will thus be able to *ceteris paribus* out-bid low-income HH in the housing market for environmental amenities including UGS (Banzhaf et al., 2019). Due to their comparably lower budget, low-income HH may have to prioritize necessary consumption goods like food and other structural housing attributes such as square footage and thus face a much stronger trade-off between those prioritized goods and access to UGS area. The likely resulting pattern in equilibrium is an imperfect clustering of HH by income levels (Epple and Platt, 1998) across UGS endowment levels with high-income HH living in larger dwellings within an environment that is richer in amenities compared to low-income HH. Based on the previous considerations and the conjecture that policy measures in place to alleviate environmental inequality are not sufficient to achieve equal access to UGS, I expect per capita access to urban green to significantly differ between high and low-income HH and derive the following hypotheses:

> ***H*1**: *UGS endowment of high-income households is significantly higher than that of low-income households.*

and

> ***H*2**: *The trade-off low-income households face between square footage and urban green area is significantly stronger than for high-income households.*

I test H1 with a two-sample median test under the null hypothesis that the median per capita endowment with UGS of the low and high-income sub-samples are equal (Sweet, 2020). H2 can be tested by inspecting $\alpha_{t,s,I}$ with s in this case representing square footage. If the confidence interval (CI) of the estimated coefficient for the low-income group is negative, lies below that of the high-income group and the CIs of significant coefficients do not overlap, I do not reject H2.
As HH not only have the option to consume public, but also private green, in the form of private gardens, the resulting endowment with public and private green in equilibrium depends on HH preferences, i.e. which type of green (private or public) they prefer. If private gardens were perfect substitutes for UGS, i.e. two green areas offering an identical bundle of ecosystem services, it would *ceteris paribus* be likely that HH would only want to consume the private good as a corner solution, as they would then have to share it with fewer users (in the case of flats) or even have exclusive access to it (in the case of houses)[9]. In equilibrium this would lead to a higher implicit price for private gardens than for UGS resulting from the same bidding process described above. However, assuming perfect substitutability seems to be a stretch, given that previous studies provide inconsistent findings with regard to household preferences for public and private green: V. Harris et al. (2018) who carried out a quantitative postal survey and asked 755 randomly selected households to state their preferences for different types and forms of urban greenery on a seven-point Likert scale. The authors provide evidence that preferences for public parks and private gardens are distinctly separated and that, opposite to the previous reasoning, survey respondents overall preferred parks to gardens. Coolen and Meesters (2012) used data from a large representative housing survey, the Woon Onderzoek Nederland 2006, to map and compare the meanings people attach to both private gardens and public UGS. Their results suggest that private gardens and UGS are not substitutes. These results are supported by Lewis et al. (2009), who explores the degree of substitutability between lot size as a proxy for garden size and nearby protected open space, using a discrete choice model, and found a complementary relationship between lot size and protected open space. These findings are however contrasted by Schindler et al. (2018), who carried out a survey investigating, among others, residents' willingness to substitute non-park pubic green and private green. Their results indicate that residents in Brussels did perceive private gardens and public green as imperfect substitutes and were more willing to substitute private green the higher the perceived quality of the public green space was.
From an ecosystem service (ES) perspective, one reason to assume imperfect substitutability and therefore challenge the previous and support the latter findings, is that residents who locate in dwellings with access to a garden or access to UGS, reveal preferences for spending time outside, or at least for the option of doing so. This service can be provided by all UGS types and equally by gardens.
Apart from this common characteristic, one could intuitively hypothesize that each UGS type, as well as private green, provides differing ES as potential activities carried out by UGS users might not be the same in the respective UGS categories such as playgrounds, cemeteries, parks and other green spaces (Engström and Gren, 2017; Grunewald et al., 2017). The overlap of services a garden and an UGS share (and the resulting degree of substitutability) thus depends on UGS category. Both a complementary and substitute relationship among private green and UGS is theoretically possible. This depends on whether specific households or socioeconomic subgroups prefer "spending time outside" and other services which can be provided by both gardens and specific UGS types, or whether they prefer services only a garden can provide (e.g. privacy (Coolen and Meesters, 2012)). However, at the mean, I expect the common services to drive results in equilibrium. Thus,

[9] This conclusion is based on a stylized model framework, factoring out preferences for social interaction.

I conjecture garden area and UGS to be imperfect substitutes.
Assuming convex preferences and that mean preferences with respect to private vs. public green do not differ systematically between high and low-income HH, I expect that at the mean, HH will prefer to consume a mix of UGS and garden area instead of a corner solution if gardens and UGS are imperfect substitutes. Based on V. Harris et al. (2018)'s findings, stating that survey respondents overall preferred parks over gardens, it could follow that at the mean high-income HH substitute park area (and potentially UGS area in general) with garden area to a lesser extent than the mean low-income HH. This could follow as prices for park area are bid up by high-income HH to a stronger degree than prices for private green are. I thus hypothesize the following:

> ***H*3**: *High-income households substitute UGS area with garden area to a significantly lesser extent than low-income households.*

I test H3 by inspecting $\alpha_{t,s,I}$ with s representing garden area. If the confidence interval (CI) of the estimated coefficient for the low-income group is negative, lies below that of the high-income group and the CIs of significant coefficients do not overlap, I do not reject H3.
Previous studies, often did not differentiate between UGS of different categories but pooled them in their analysis (Morancho, 2003; Liebelt et al., 2018; Schindler et al., 2018), thereby implicitly assuming that residents perception and WTP for UGS does not depend on UGS category. Due to the differences in ES each UGS category offers as discussed above, I conjecture that this assumption might not be warranted. Hence, I do not pool the UGS types into one category but repeat the analysis and hypothesis testing for the three distinct UGS categories *park*, *playground* and *cemetery*, to be able to spot potential systematic differences in the equilibrium outcome resulting from potentially differing bidding process for access to each UGS type.

2.3 Data compilation, preprocessing and econometric identification strategy

The study area is the city of Hamburg, situated in the north of Germany. With 1.83 million inhabitants and a size of 755 km^2, Hamburg is Germany's second largest city. As the city's population is projected to grow further in the coming decades, intensified trade-offs between different land-use types can be expected (Oelmann et al., 2014; Statistisches Amt für Hamburg und Schleswig-Holstein, 2017). With 56 km^2 of urban space reserved for recreational purposes, 185 km^2 of agricultural land, 56 km^2 forest and 63 km^2 waterbodies, almost half of the urban area is covered by green and blue urban spaces (Statistisches Amt für Hamburg und Schleswig-Holstein, 2017).

2.3.1 Variable selection and preprocessing

Real estate is a multidimensional, complex good and many factors influence differences in selling or renting prices. To derive the MWTP for UGS with econometric methods, the researcher should thus include information about housing attributes, neighborhood characteristics as well as environmental amenities associated with the housing unit (Geoghegan et al., 1997). Even though this assessment uses an internal instrumental variable approach to account for omitted variables, I include several explanatory variables as controls to enable comparison to previous research.
According to Belcher and Chisholm (2018), a selection of explanatory variables for a hedonic pricing analysis should rely on findings from previous research while taking the availability of data into con-

sideration. The following subsections thus describe the structural, neigbourhood and environmental variables of interest used in this study.

Real estate data on housing prices and structural attributes

Structural characteristics are acknowledged determinants of housing price worldwide (Belcher and Chisholm, 2018). A dataset comprising 235,335 unique entries of rental objects and objects of purchase was procured from F+B Forschung und Beratung für Wohnen, Immobilien und Umwelt GmbH in exchange for a procurement fee. The data set covers a period from 2005 to 2018 and was compiled from 127 data sources such as newspapers and the real estate web portal immodaten.net. It contains housing unit offer prices, structural attributes as well as addresses. As offer prices of sales objects are usually higher than actual transaction prices, the data provider adjusted these with a regularly updated transaction deduction. This study uses the adjusted prices. The data provider extensively checked the data for plausibility and duplicate entries with respect to address, slightly changed structural characteristics in multiple published offers for the same object, as well as with respect to plausibility of rental and sales prices. Hamburg's authorities use the resulting regularly updated dataset for preparing the offical rental guidelines.

Apart from explanatory variables such as size of living space, lot size, age, floor and object type, the dataset contains 71 categorical variables describing attributes and quality of the housing objects. Based on a review of the literature, I identified the structural characteristics which had a significant association with housing unit prices in previous research. A table of the identified structual characteristics used as control variables with references to previous studies using the same or similar controls are available in appendix table A.2.

In order to prepare the data for analysis, I merged the real estate dataset with the cadastral map ALKIS of 2018, an official, regularly updated dataset provided by the authority for geoinformation and land surveying, Landesbetrieb Geoinformation und Vermessung (2019a). Next, I dropped entries with incomplete adresses from the dataset, which resulted in the following sample sizes for five distinct housing unit groups: 8,837 single family homes for sale, 31,752 flats for sale, 380 multi-family homes for sale, 5,529 houses for rent and 173,139 flats for rent. The sample reflects the fact that there is a relatively higher share of rental objects than housing objects for sale on the German housing market (Voigtländer, 2009). Due to the relatively small sample sizes, I droped the observations in the submarket multi-family homes for sale as well as houses for rent. Using the full dataset spanning over 13 years enables statistical analysis for the remaining submarkets. Hence, I normalized housing prices using 2005 as the base year with an annual consumer price index for housing, water, electricity, gas and other fuels published by the German Federal Statistical Agency (Destatis, 2018). Since the building year of housing units is included in the dataset, instead of their age, I calculated the age based on year 2018. As there were a lot of missing values for the "floor" variable I excluded the variable from the analysis. Instead, I included a variable indicating if the housing unit is situated on the ground floor.

Variables of interest

In order to calculate urban green space area for each of the three green space types of interest, I first acquired spatial data on the presence of UGS from the cadastres of official urban green spaces (BUE, 2016b). In a second step, I intersected each of the UGS layers with a spatial buffer with a 1 km radius around the housing unit. I use the area of green spaces within a buffer for the UGS types park, playground, allotment garden and cemetery to quantify UGS area in the vicinity

of people's homes. According to Schipperijn et al. (2010) and Bertram and Rehdanz (2015) this measure of green space availability combines both the notion of availability as well as distance as predictors of actual UGS use. I use absolute area in this radius as a variable in the three-stage estimation procedure. Since valuation of UGS might be negatively impacted by increased crowding of UGS (Perino et al., 2014), I use the per capita endowment as an indicator when analyzing UGS endowment across income groups. As a further measure to quantify UGS endowment, I use the number of UGS of each type in a 1 km radius, as well as the size of the closest UGS of each type. To determine the latter, I first calculated the network distance to the centroid of the closest UGS for each UGS type and identified the UGS with the minimum distance. Next, I extracted the size of each of the closest UGS from BUE (2016b).
In order to be able to account for the spatially heterogeneous built-environment in connection with visible housing attributes such as lot size, private gardens and balconies or terraces, I include interaction terms of the UGS variables and the level of the respective attribute. As the available data set includes a dummy indicating the presence of a garden but not its size, I multiplied the nonbuilt-up area of each lot with the available dummy, in order to create a continuous garden size variable for the third-stage estimation. I calculated the nonbuilt-up area with spatial data taken from Hamburg's official land survey register (Landesbetrieb Geoinformation und Vermessung, 2019c) by spatially merging it with the coordinates of each observation in the available data set by F+B.

Selection and preprocessing of neigborhood variables as controls

Next, I identified neighbourhood variables which had a significant effect on housing prices in previous studies. The identified variables and references are available in table A.3. For instance, previous studies found a significant association of housing prices and proximity to green open spaces such as forests (Tyrväinen, 1997; Tyrväinen and Miettinen, 2000; Czembrowski and Kronenberg, 2016; Votsis, 2017). As the definition of UGS in this study does not include forests, sport and leisure facilities or other green spaces such as moors or grassland, I included the shortest network distance to each of the land use categories as a control variable[10]. Since most data is only available in a high resolution inside the administrative boundaries of Hamburg, I combined three data sources to control for green spaces outside the administrative boarder of Hamburg. Furthermore, I included the distance to the closest body of water as a further control variable (Tyrväinen, 1997; Engström and Gren, 2017; Liebelt et al., 2018). Please refer to Figure A.1 for an overview of the respective data sources, variable creation and pre-processing as well as green space categorization for the estimation of the hedonic price schedules.
Apart from designated green areas, street trees can also be viewed as urban green and impact housing prices (Donovan and Butry, 2011; Plant et al., 2017). Hence, I included the number of trees in a 100 m radius around each housing unit as additional control. I calculated this variable with 100 m buffers and the official street tree cadastres of 2016, provided online by the city of Hamburg (BUE, 2016c). Further controls, which do not represent urban green are for example the distance to the closest church, as previous research found a significant effect of proximity to

[10] Since the availability for the remaining green areas such as agricultural areas, marshes, forests etc. in the vicinity of housing units is zero for most observations in this sample, I use the network distance over the street grid to the closest of the remaining green spaces as control variables in the first-stage estimation procedure to avoid coefficient estimates largely driven by a few outliers. For the quantification of mean and median endowment with all present green types (please refer to Figures A.18 and A.18), I additionally calculated the densities in a 1 km radius as described in the previous subsection.

places of worship on house prices (Carroll et al., 1996; Thompson et al., 2012; Brandt et al., 2014). Furthermore, I included the distance to the central business district (CBD) as proxy for access to employment either as a continuous variable or in the form of dummy variables indicating the quartile of the distance to the city center variable calculated over the street grid.
This is initially based on the emphasisean "access-space" trade-off model which assumes a monocentric city structure, where residents chose their housing location based on a trade-off between commuting time to their place of employment and housing costs (Mills, 1972; Xiao, 2017). This variable is important in this study, as the distribution of UGS is not homogeneous in different parts of the city as depicted in Figures A.2 to A.4 and implicit prices might thus be heterogeneous across space.
The spatial data used to calculate spatial variables was reprojected to the ETRS 89/ UTM zone 32 N (zE-N) projection and preprocessed in QGIS. The necessary data layers were retrieved from Transparenzportal Hamburg. If not otherwise stated, I calculated all distances as shortest over a network retrieved from Geofabrik (2019) using the Qgis Network Analysis Toolbox 3 (Raffler, n.d.). After compiling variables of interest with structural and neighbourhood variables, I dropped rows with missing values. Missing values were mainly present for the structural characteristic *age*, resulting in a final pooled sample size of about 154.7 K.
The description of each variable is depicted in Appendix Table A.1 whereas Figures A.2 to A.4 show the spatial distribution of parks, playgrounds and cemeteries, as well as the respective zones of the CBD variable in Hamburg.

Socioeconomic data

For the third-stage estimation, additional data on the socioeconomic characteristics of agents, i.e. households is necessary. Unfortunately, no dataset with exact coordinates is available due to protection of data privacy. Hence, I merged the data described in the previous subsections with a panel data grid provided by Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI and microm, 2019). The data is available for the years 2005 and 2009–2016 with a resolution of 1 square km and includes information on mean household age, share of singles, couples, families, unemployed people as well as number of children in the respective raster cell, as well as population density and purchasing power (PP)[11].

2.3.2 Econometric approach and identification strategy

As already stated previously, I need to account for endogeneity caused by omitted variables which can be systematically varying over space, as well as endogeneity due to measurement error. In this study, I use spatial fixed effects combined with an internal IV method using Gaussian copula by Park and Gupta (2012) to address these problems in all three estimation stages. The method resolves the endogeneity of the variable of interest by estimating additional regressors from the data using copulas (Zaefarian et al., 2017) to prevent correlation of the variable of interest with the error term. Similar to the control function approach by Petrin and Train (2010), the internal IV strategy estimates additional regressors $Z_p** = \phi^{-1}(H(Z_p))$ based on the marginal distribution $H(Z)$. By estimating the additional regressors, I can thus account for remaining endogeneity, e.g. due to unobservables that do not vary systematically over space and hence are not covered by the

[11] For a few raster cells, data on the PP is missing as the number of households the value is based on was not sufficient (min. 5 HH) to guarantee data privacy. Hence, observations assigned to missing PP values were dropped in the second and third-stage estimation.

spatial fixed effect recovering $\phi_{i,sp}$ (see Section 2.2.1) or resulting from measurement error. In order to obtain correct standard errors and confidence intervals, I use a bootstrapping procedure with 1,000 replications (Park and Gupta, 2012).[12]

I carry out the first-stage estimation of the hedonic price function for nine distinct *a priori* defined submarkets, across time and dwelling type, while I pool the data in the second and third-stage estimation. I assume that individuals between submarkets have systematically different demand structures or the structure of housing characteristics is systematically different. Furthermore, I assume that there is generally no mobility across market segments (Freeman et al., 2014). Including submarkets thus partly accounts for preference heterogeneity and is hence very likely to substantially reduce variance of house prices in the subsets compared to the whole data set. Furthermore, the differentiation by dwelling type enables comparison to previous studies in the UGS literature. To account for potentially varying macro dynamics over time, I divide each of the subsets differentiated by dwelling type into three time periods: Pre Euro-crisis years 2005-2009, a crisis and recovery period 2010-2013 and a post-crisis period from 2014-2018.

I assume that each submarket m is in equilibrium, housing is an approximately continuous good and that house prices are exogenous, meaning that the supply of housing units does not change considerably in the short-run, i.e. a period of several years. I argue that the size and position of UGS are fixed and exogenous at least in the short-term as urban planning and related urban land-use change is a lengthy bureaucratic process in Germany. The first-stage estimation is carried out on individual dwelling level i:

$$\begin{aligned}\ln p_{i,m} = \alpha_m + \sum_{s=1}^{s} \alpha_{s,m} \boldsymbol{S_{s,i}} + \sum_{n=1}^{n} \alpha_{n,m} \boldsymbol{N_{n,i}} + \alpha_{Pr,Pl,m} Pr_i \cdot Pl_i + \alpha_{Pr,A,m} Pr_i \cdot A_i + \alpha_{Pr,C,m} Pr_i \cdot C_i + \\ \alpha_{Pl,C,m} Pl_i \cdot C_i + \alpha_{Pl,A,m} Pl_i \cdot A_i + \alpha_{Pr,C,m} Pr_i \cdot C_i + \boldsymbol{UGS_{t,i}} \cdot \\ \left(\sum_{t=1}^{t} \alpha_{t,m} + \sum_{t=1}^{t} \alpha_{sc,t,m} sc + \sum_{t=1}^{t} \alpha_{th,t,m} th + \sum_{t=1}^{t} \alpha_{fr,t,m} fr + \sum_{t=1}^{t} \alpha_{L,t,m} L_i + \sum_{t=1}^{t} \alpha_{g,t,m} g_i + \sum_{t=1}^{t} \alpha_{b,t,m} b_i \right) + \\ \sum_{d=1}^{d} \alpha_{d,m} \boldsymbol{D} + \sum_{p=1}^{p} \alpha_{p,m} Z_p^{**} + \epsilon_i\end{aligned} \tag{2.11}$$

Matrix $\boldsymbol{UGS_{t,i}}$ includes the variables of interest, the area of UGS of the types t representing park, playground and cemetery within a 1 km radius around the housing unit, while $\boldsymbol{S_{s,i}}$ is a matrix of s structural housing characteristics and $\boldsymbol{N_{n,i}}$ a matrix of n neighborhood characteristics. In order to model spatial heterogeneity of the built environment and in implicit prices for the variables of interest, I include interaction terms with a set of dummy variables. I use the quartiles of a continuous variable indicating the walking distance from the respective housing unit to the city center measured over the street network as cutoffs to create the dummies (sc for the second ring, th for the third ring and fr for the fourth ring). To incorporate potential spatial heterogeneity within the thereby specified zones of the city, I include interaction terms with variables indicating the absolute endowment with UGS area of the UGS types park Pr, playground Pl, allotment gardens A and cemeteries C, as well as with lot size L, presence of a garden g as well as balconies or terraces b as generally observable housing characteristics also included as levels within the matrix $\boldsymbol{S_{s,i}}$. Additionally I include spatial fixed effects on district level $\boldsymbol{D}$ to recover α_{sp} (see Section 2.2.1) and the additional regressors Z_p^{**} estimated with the copula correction method to account for remaining endogeneity. The term ϵ_i represents the regression residuals.

[12] Please refer to Park and Gupta (2012) for more information on the two-stage estimation procedure.

Next, I use the implicit prices recovered in the first-stage estimation procedure together with data on socioeocnomic HH characteristics to recover non-marginal WTP in a second-stage estimation.[13] Since the data on socioeconomic characteristics is not available at the same spatial resolution as the housing unit offers, I have to assume that an individual household responding to the housing offer by sorting into a selected housing unit has similar socioeconomic characteristics as the existing population in a spatially overlapping 1 km^2 pixel providing the data on socioeconomic variables for a specific year. This assumption is in line with the assumed theoretical mechanisms and resulting clustering of HH with similar characteristics described in Section 2.2.1. As the data on socioeconomic characteristics is available in panel-data format, possible developments of the existing population over time are captured by the data, e.g. ageing of the local population, considerable increase in births and resulting mean number of children or change of civil status.

With reference to Chattopadhyay (1999), I rearrange Equation 2.7 to avoid heteroskedasticity of the structural error term by multiplying it with $\frac{x_{i,k}}{c_j}$.

For the chosen translog functional form of the utility function, the variables have to be logarithmized. Since several variables have true zero values, I use the inverse hyperbolic sine transformation (Burbidge et al., 1988; Pence, 2006), as an approximation to be able to keep zero values in the sample during the second-stage estimation procedure.

Please note that I can only identify the WTP of HH who actually consumed a non-zero amount of the good with this estimation procedure. With the preference parameters estimated with rearranged Equation 2.7, I calculate non-marginal WTP using Equation 2.9. In a next step, I carry out the third-stage estimation with Equation 2.10 to recover the respective effects for testing the hypotheses presented in Section 2.2.2. I use spatial fixed effects on district level to recover α_{sp} and use the internal IV method to account for remaining endogeneity both in the second and third-stage estimation. Additional regressors Z_p^{**} are marked with a double asterisk in the results tables in the Appendix. I define income groups I, by splitting the sample at the 33% and 66% percentiles of the income distribution.

2.4 Results

2.4.1 Hedonic price schedules and second-stage results

The results of the first-stage estimation of the hedonic price schedules of nine submarkets, *a priori* defined across dwelling type and for three time periods, are depicted in Appendix A.3. Please refer to Appendix A.2.1 for descriptive statistics of the variables in each submarket. From the first-stage estimation results, I calculated the marginal willingness to pay for an additional unit UGS. The densities of MWTP used in the second-stage estimation are displayed in Appendix Figures A.5 to A.7. The estimates for an additional hectare playground area are comparatively higher than for an additional hectare park or cemetery area since there is more scarcity of playground area compared to the other two UGS types[14]. Appendix tables A.24 to A.26 show the results of the second stage regressions used to calculate non-marginal WTP (see Equation 2.9). Please refer to density plots

[13] Negative implicit prices for UGS both defy theory and previous empirical findings and result most likely from the chosen parametric form of the utility function. Similar to Day et al. (2007) and Panduro et al. (2018), I thus set estimated negative implicit prices for selected dwellings to zero. The share of corrected values ranges from 0.02% of the WTP estimates for parks to 3% of the estimates for cemeteries.

[14] In this sample, the mean endowment with playground area is 3 *ha* compared to 27.3 *ha* park area and 17 *ha* cemetery area.

A.8 to A.10 showing the estimated WTP densities for the respective UGS types.

2.4.2 Willingness to pay and per capita endowment with urban green space area across income groups

In the following, I present results on the mean WTP per hectare green space across income groups and green space types as shown in Figure 2.1, as well as the median per capita green space area available to each income group in Figure 2.2.

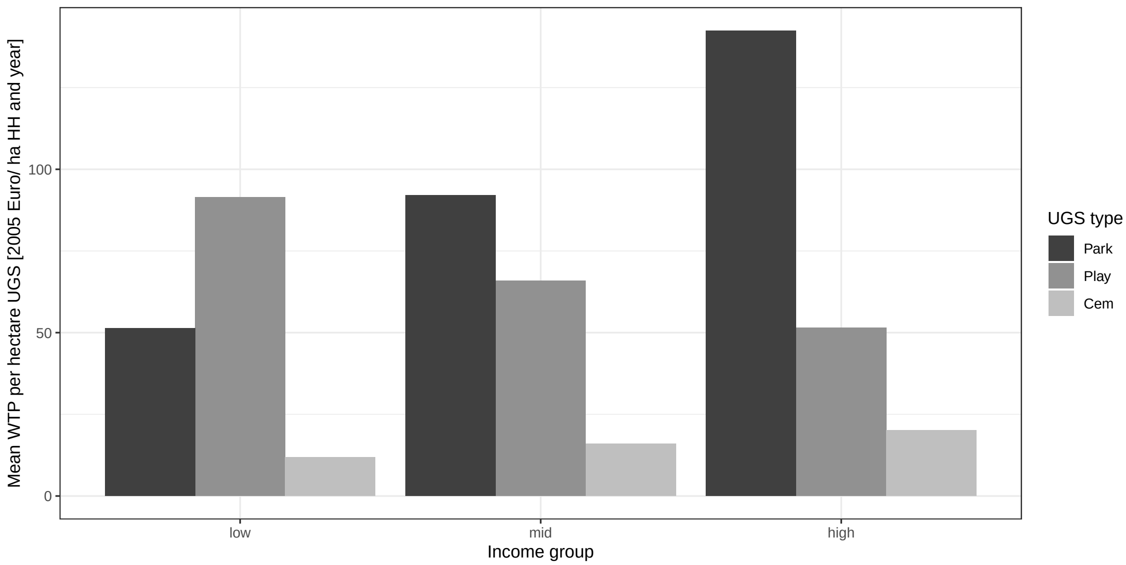

Figure 2.1: Mean non-marginal willingness to pay (WTP) per hectare urban green space (UGS) area in a 1 km radius across income groups and green space types measured in euros of 2005 per household and annum.

Mean WTP per hectare UGS, household and year increases with income in the case of parks, ranging from 51 €/ha for low-income households (HH) to 142 €/ha for high-income HH. In contrast, the mean WTP per hectare UGS, household and annum for access to playgrounds decreases across the income groups. With 91 €/ha, the WTP per hectare playground area for low-income groups is higher than the WTP for park area in the same income group. In the high-income group, however, the mean WTP for a hectare playground is more than 60 % less than the WTP for park area (52 €/ha)[15]. Mean WTP for cemetery area again increases across income groups and ranges from 12 €/ha in the low-income group to 20 €/ha in the high-income group.
These differences in WTP across income groups and UGS types are also reflected in the median per capita UGS area available to each income group in this sample. The median per capita UGS

[15] When dividing the WTP per hectare playground area by the average number of children within the defined spatial unit and time period, I find an average annual WTP of 431 Euro per hectare and child in the low-income group and 304 and 231 Euro in the mid- and high-income group respectively. The summary statistics in Table A.17 show that the average number of children in the low-income and high-income group are similar, i.e. 0.22 and 0.24. One could interpret this as an indication that low-income HH have less means to provide free-time activities for their children which is why they rely more on public playgrounds than high-income HH.

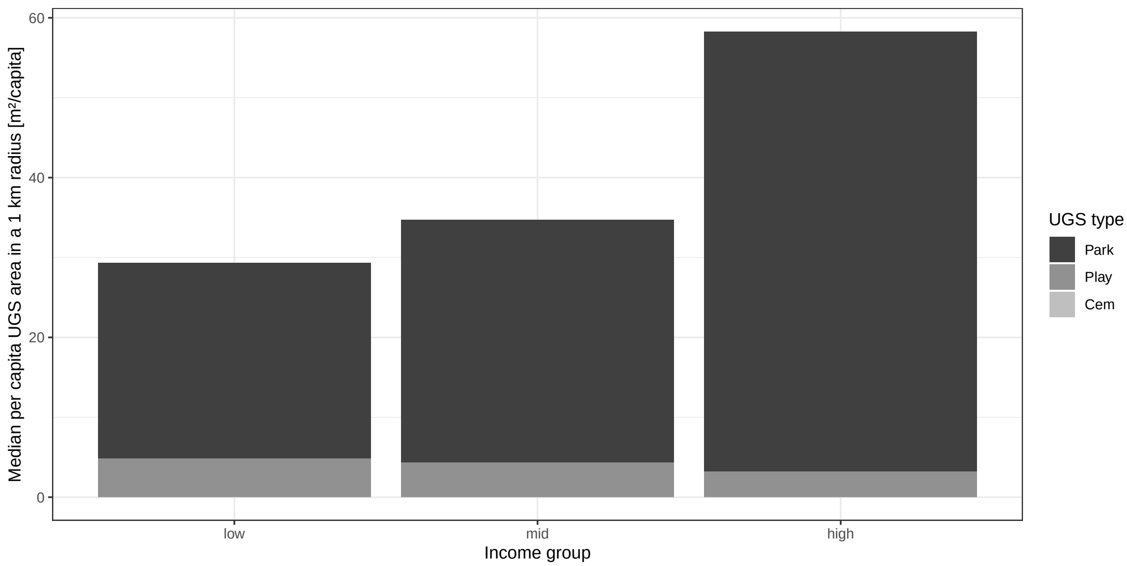

Figure 2.2: Median per capita urban green space area in a 1 km radius across income groups and green space types.

area within a 1 km radius around a housing unit amounts to 29 square meters in the low-income group, almost 35 sqm/c in the medium-income group and more than 58 sqm/c in the high-income group. A two-sample median test (Sweet, 2020) indicates that there is enough evidence to conclude that the median endowment with UGS between the low and high-income groups are different at a significance level of 0.1%. Thus, I do not reject hypothesis $H1$. In accordance with the differences in WTP across income groups shown in Figure 2.1, available median per capita park area is highest in the high-income group (55 sqm/c). Compared to the low-income group with a median endowment of 24 sqm/c, high-income HH have access to more than twice the amount of per capita park area in their close living environment. The median endowment with per capita playground area in the low-income group (4.9 sqm/c) is however higher than in the medium (4.4 sqm/c) and high (3.2 sqm/c) income groups, while median cemetery area is zero regardless of which income group I consider[16].
When comparing access to UGS across income groups in different parts of the city (please refer to Appendix Figures A.15 and A.16 showing median and mean per capita UGS area across income groups and for different walking distances to the city center), I find that at the mean the high-income group has access to more per capita UGS area than medium and low-income HH regardless of where they sort within the city. At the mean, a high demand for cemetery area in the high-income group

[16] When including allotment gardens, protected areas, woodland, moors, marshland, grassland, sports and leisure facilities, heathland, immission protection green, forests and agricultural areas as shown in Figure A.19, only allotment gardens have an impact for the median endowment. For all green types except for parks, playgrounds and allotment gardens, the median endowment is zero, regardless of the income group. At the mean, few HH with a large endowment of other green types, especially agricultural areas and forests represent extreme outliers and drive the results shown in Appendix Figure A.18. Since allotment gardens are not really completely accessible for the public, except for people who rent the garden or, at most, take a walk around the allotment garden, I exclude them from the assessment. In my mind, mean endowment is not a good indicator when considering distribution of green spaces, since it is not robust to outliers. Hence, I mainly refer to the results presented in Figure 2.2 in the following.

is mostly driven by Ohlsdorf cemetery (third quartile of walking distance variable). At the median, one can see that the high-income group has the largest UGS endowment in the city center and also in the second and third ring of the city. In the fourth ring, low-income HH can afford more UGS area and have access to more per capita UGS area than the medium and high-income groups. This, as well as a positive and significant coefficient[17] of the variable indicating the walking distance to the city center in Tables A.27 to A.29, indicate that all HH, but especially low-income HH, trade-off proximity to the city center and park area. Median per capita cemetery area consumed is zero (or very close to zero) in all rings and income groups.

When going more into detail and assessing the endowment ratio of per capita UGS area between low-income HH and high-income HH across the distribution of the green space variables (please refer to Figure A.17), it becomes clear that depending on the percentile of the park variable, the low-income group has 25% to 50% less park area per capita available than the high-income group. low-income HH consume considerably more playground area than high-income HH up until the 80% percentile. In the case of cemetery area, HH seem to consume either a lot of cemetery area per capita or none at all, as is indicated by a non-defined ratio for the percentiles below the 80% percentile. Above the 80% percentile, the endowment ratio shows a more than 75% larger endowment for high-income HH compared to low-income HH. Again, I propose that this latter finding is driven by Ohlsdorf cemetery.

These findings are based on the *a priori* definition of income groups by splitting the sample at the 33% and 66% percentiles of the income distribution. In the literature it is quite common to compare the endowment of an environmental (dis-)amenity of the top and bottom 10% of the income distribution with the inter-decile ratio or to use vertical inequality measures such as the Gini-coefficient and the coefficient of variation (CV)[18].

Table 2.1 thus shows the different inequality measures across UGS types. While the Gini coefficient and CV both indicate that cemetery area is most unequally distributed, followed by park and playground area, the ratios of medians (RoM) confirm that park area is distributed in favor of the high-income group, while it is the opposite for playground area, regardless of the definition of income groups. The RoM of cemetery area is not defined, as most households do not consume the environmental good: Only 30% in the low-income group consume at least some cemetery area compared to 22% in the high-income group [19].

[17] The variable increases with distance form the city center.

[18] The Gini-coefficient lies between zero and one, with larger values indicating greater inequality. The coefficient of variation has no upper bound, the higher the coefficient, the greater the inequality.

[19] I used the 10 and 90 percentiles of the purchasing power distribution to define the high and low-income groups in this case.

UGS	RoM	RoM	Gini	CV
Park	0.44	0.37	0.61	2.86
Playground	1.50	2.06	0.43	1.65
Cemetery	NA	NA	0.96	5.74
Income group cut-off	33% & 66%	10% and 90%	Full sample	Full sample

Table 2.1: Comparison of inequality measures across urban green space (UGS) types. With the Gini coefficient (Gini), the coefficient of variation (CV) and the ratio of medians (RoM) as inequality measures. The RoM equals the median per capita endowment with UGS area in a 1 km radius around housing units of the low-income group divided by the median per capita endowment of the high-income group.

In a nutshell, these results, including robustness checks using horizontal and vertical inequality measures, show that access to urban green in Hamburg is generally unequally distributed across income groups. They also indicate that most high-income HH prefer parks over playgrounds and that cemeteries seem to be least in demand among most HH except for Ohlsdorf cemetery which is a special case as it is a very large park cemetery.
I use the internal IV method and additionally control for sociodemographic characteristics and related preference heterogeneity in the third-stage regressions to assure that the trade-offs analysed in the following sections are not biased. Nevertheless, it might still be insightful to explore systematic differences in sociodemographic characteristics between the low and high-income group to understand which subgroups are mainly affected by environmental inequality. Hence, Appendix Table A.17 displays group comparisons between the high and low-income group for selected sociodemographic variables as well as for the size of the closest UGS of each type and the number of UGS in a 1km radius. It shows that at the mean, the share of above 60-year-old city dwellers as well as the share of families is considerably higher in the high-income group. The share of unemployed dwellers and singles with or without children is significantly higher in the low-income group. At the mean, the size of the closest UGS for low-income HH is significantly smaller than in the high-income group, but the number of UGS as well as the mean population density is higher, indicating more fractured and potentially more crowded green spaces around housing units of low-income HH.

2.4.3 How households across income groups trade-off access to urban green with private goods

In the following two subsections, I assess if and to what degree households in different income groups face a trade-off between access to urban green and the square footage of their apartment or house (following subsection) as well as between garden size and access to urban green (subsequent subsection) and test hypotheses $H2$ and $H3$ for each UGS type.

Trade-off between square footage and access to urban green

Figure 2.3 displays the effect of a 1% increase of square footage on the willingness to pay for park area in percent. It shows that low-income households face a trade-off between housing size and access to park area, while high-income HH consume both goods in a complementary relationship. Based on these results, I do not reject $H2$ for the UGS type *Park*. Income elasticities of WTP estimated with purchasing power as a proxy for income range from 1.3 for low-income HH and medium-income HH to 0.9 for high-income HH (please refer to Appendix Tables A.27 to A.29).

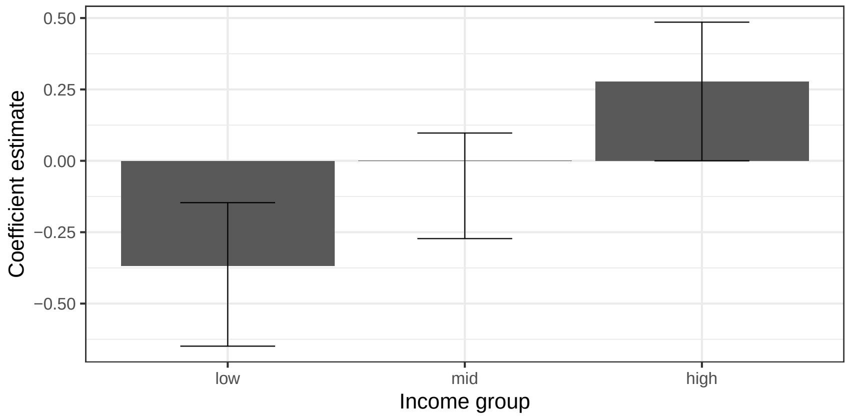

Figure 2.3: Effect of a 1% increase of square footage on the willingness to pay for park area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

In case of access to playground area, Figure 2.4 shows that only low-income HH substitute access to playground area with square footage from their housing unit. I did not find a significant effect for high-income HH, while mid-income HH seem to consume the square footage and playground area in a complementary relationship.
Based on these results, I do not reject $H2$ for the UGS type *Playground*. In case of access to cemetery area, Figure 2.5 shows that only mid-income HH substitute access to cemetery area with square footage from their housing unit. I do not find a significant effect for the other income groups. I reject $H2$ for the UGS type *Cemetery*. As shown in Appendix Figure A.20, in equilibrium, high-income HH consume higher mean living area/square footage than medium and low-income HH.

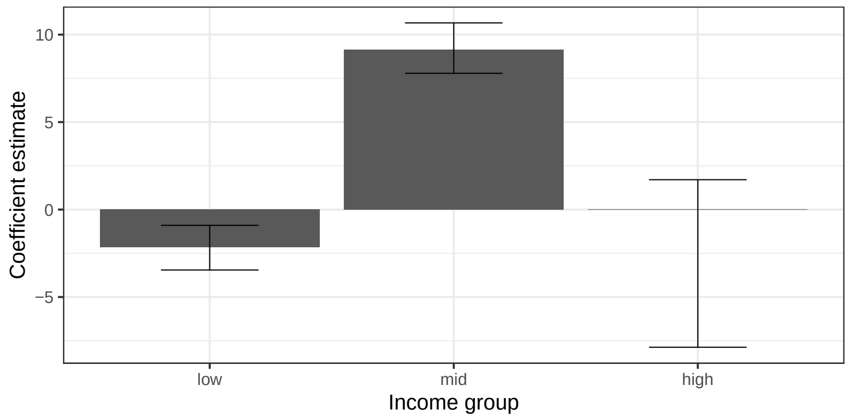

Figure 2.4: Effect of a 1% increase of square footage on the willingness to pay for playground area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

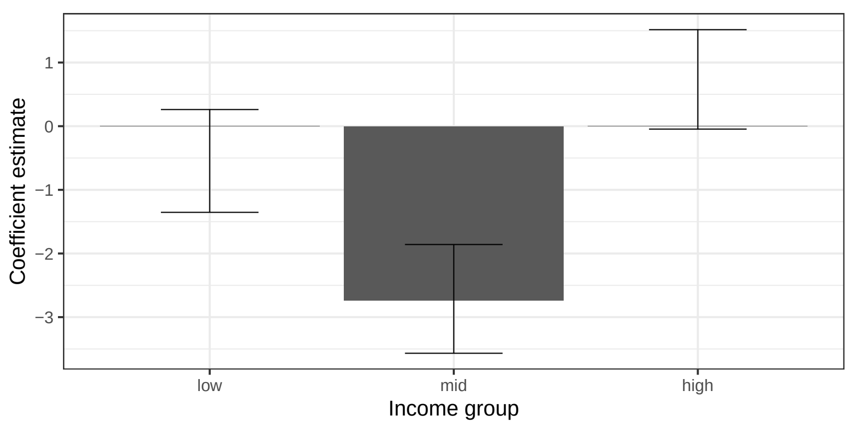

Figure 2.5: Effect of a 1% increase of square footage on the willingness to pay for cemetery area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

Trade-off between garden size and access to urban green

In case of the private good garden size, all HH trade-off garden size with park area in a 1 km radius. The trade-off for low-income HH is largest and the mean effect decreases the higher the income. Compared to the trade-off between square footage and park area, the effect is small (for example -0.4 % decrease in WTP for park area per 1% increase in square footage vs. 0.03 % decrease in WTP for park area per 1% increase in garden size in the low-income group). Based on these results, I do not reject $H3$ for the UGS category $Park$.

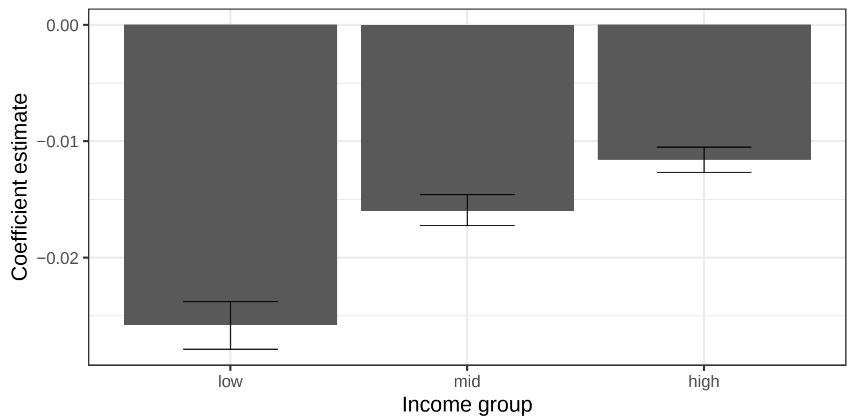

Figure 2.6: Effect of a 1% increase of garden size on the willingness to pay for park area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

The substitution behavior across income groups is very similar for playgrounds in qualitative terms, with the low-income group showing a stronger substitution behavior than the medium-income group, and the effect being insignificant for high-income HH. The effect is relatively comparable to that of park area and lies around -0.06% WTP for playground area per 1% increase in garden size in the low-income group. Just as it was the case for the UGS category $Park$, I do not reject $H3$. In the case of cemeteries, a complementary relationship between cemetery area and garden size can be found for all income groups. The effects are not significantly different between the low and high-income group as confidence intervals overlap. As there seems to be a complementary relationship between cemetery area and garden size, I reject $H3$ for the UGS category $Cemetery$.

As shown in Appendix Figure A.21, in equilibrium, high-income HH have larger gardens at the mean than medium and low-income HH. The difference in access to private green is however very likely even more prominent as more low-income HH in the sample sorted into apartments as opposed to houses compared to high-income HH (96% vs. 86%). Thus relatively more HH in the low-income group have to share the available garden with other inhabitants of the same housing unit.

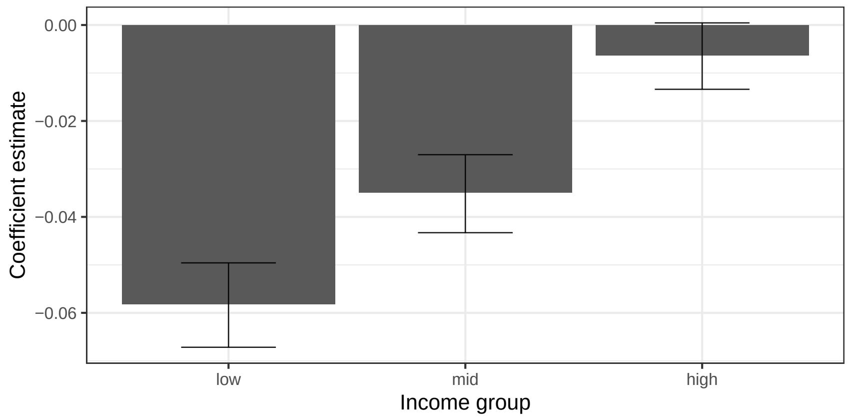

Figure 2.7: Effect of a 1% increase of garden size on the willingness to pay for playground area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

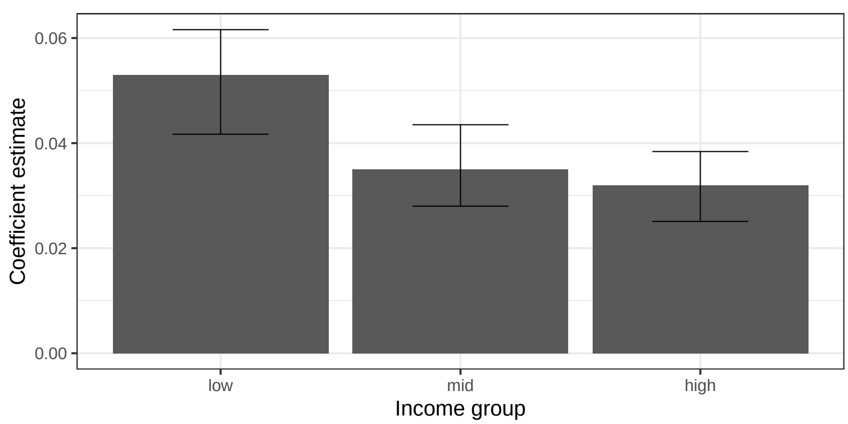

Figure 2.8: Effect of a 1% increase of garden size on the willingness to pay for cemetery area in percent. A negative coefficient indicates substitution behavior while a positive coefficient indicates a complementary relationship. The figure also displays the 95% confidence interval of each point estimate.

2.4.4 Synthesis and proposed underlying mechanism

From the results presented in the previous subsections, I conclude that per capita urban green area in Hamburg is unequally distributed across income groups and do not reject hypothesis $H1$. At the median, low-income households have less per capita UGS, garden and housing area at their disposal than medium and high-income HH. The findings are hence in line with the theoretical considerations made in in Section 2.2. From the findings concerning WTP for the three UGS types, the analyzed substitution behavior across income groups and the theoretical considerations made, I conclude that high-income HH bid up prices for access to parks so that low and medium-income HH have to prioritize other goods such as food and (as shown here by a significant substitution effect of low-income HH in line with $H2$) square footage over access to park area. As high-income HH show a considerably lower WTP per hectare playground area compared to the WTP per hectare park area, prices seem to be relatively more affordable for low and medium-income HH.

In line with $H3$, private green in the form of garden area seems to be an imperfect substitute for park and playground area and high-income HH trade-off park area with private green to a lesser extent than low-income HH, while there is no significant relationship for playground area. In the case of parks, it might be that the mechanism proposed in Section 2.2 is the underlying reason for this: Dwellers prefer parks over private green[20], and hence the implicit price for park area is higher than that of private green. Garden area would therefore be relatively more affordable for low-income HH, resulting in the stronger trade-off of private green and park area for low-income HH compared to high-income HH observed in equilibrium.

At the median, low-income HH consume more per capita playground area than high-income HH and WTP per hectare playground area is the highest in the the former income group. In case of cemetery area, a majority of 71% of the HH seem to prefer to not consume the environmental good at all. Nevertheless, WTP for cemetery area is highest in the high-income group but overall lies below that for other UGS types regardless of the income group. In a nutshell, I interpret the results as such that there seems to be a hierarchy of green spaces for the median citizen: Park $\succ$ Playground $\succ$ Cemetery. This interpretation makes sense from an ecosystem services perspective, as I would assume that parks offer a larger variety of cultural ecosystem services compared to playgrounds and cemeteries. From the systematically differing trade-offs city dwellers from different income groups face with the private housing characteristics *square footage* and *garden size*, as well as the differences in estimated WTP depending on UGS category, I deduce that UGS of different types are indeed perceived and valued differently by city dwellers. One reason for this might be the different bundles of cultural ecosystem services they offer, as proposed in Section 2.2. A conjecture that I can however not test with the present data set and method.

[20] At least inhabitants of apartments without exclusive access to the private green, which make up the majority of the sample.

2.5 Discussion: Putting inequitable access to urban green in a broader perspective and suggesting pathways to achieve sustainable development goals

In this study, I investigated the distribution of per capita access to urban green across income groups and the trade-offs households of different income groups face between urban green space endowment and square footage as well as garden area. My findings indicate an inequitable endowment with UGS in favor of high-income HH. Low-income HH face a trade-off between access to UGS and square footage or private green in the form of garden area except in the case of cemetery area where HH of all income groups consume garden and cemetery area in a complementary relationship. The WTP estimates for different UGS types significantly differ between income groups. The estimates for WTP seem to be in line with other estimates in the literature. In the pooled sample, the mean WTP of 1,316 EUR per year and HH for park area lies within the range of WTP between 774 EUR and 1396 EUR per year and HH estimated by Panduro et al. (2018) who used both a proximity and a density-based park variable to estimate WTP. In a quasi-natural experiment carried out in Australia, Breunig et al. (2019) find that a playground in a 300m radius of houses and flats for sale increases its property price by 4.6% in the mean. When converting the annual perpetuities of benefit flows of this study back to absolute price premiums for houses and flats for sale[21] and dividing it by the respective offer price, the results of this study indicate an average 5.9% price premium for access to the ecosystem services of playgrounds in a 1 km radius around houses and flats for sale. The estimates are comparable considering the fact that the playground variable in this study might include multiple playgrounds and is based on a larger radius around the housing unit. Findings by Czembrowski and Kronenberg (2016) indicate that cemeteries are seen as disamenities, while I find significant positive WTP for cemetery area at least for some HH, even though it is low compared to the WTP for parks and playgrounds. Many cemeteries in Hamburg are characterized by ample green spaces, in many ways adopting characteristics normally associated with parks, which might be driving the observed differences with the results by Czembrowski and Kronenberg (2016), who analyzed data from Poland. A further explanation might be aggregation bias, as I find considerable spatial heterogeneity in implicit prices for cemetery area which has not been accounted for in the mentioned study.

The results of this study indicate that households in the low and medium-income group in Hamburg have less than the German average endowment of freely accessible UGS for large cities of 46 sqm in relatively close vicinity of their housing unit available for their use. In contrast, high-income HH have comparable conditions as available to inhabitants of larger small cities in Germany (Mattanovich et al., 2017).

While this outcome may be efficient, given the present distribution of income, the question of how the political goal of equitable access to UGS as formulated in SDG 11 and adopted on national level can be reached in a city like Hamburg comes to mind.

In Section 2.4.4, I proposed a Tiebout like sorting behavior, resulting from a heterogeneous distribution of amenities, in this case UGS, as a likely underlying mechanism driving the equilibrium outcome observed in this study. In Tiebout's model, a "consumer-voter" picks the housing unit which best satisfies her preferences with regards to public good endowment subject to income (Tiebout, 1956). With reference to the results of this study, as well as other findings in the literature (Panduro et al., 2018), especially parks seem to be popular UGS. From an ecosystem services

[21] Annual WTP divided by the discount rate $\pi = 0.03$.

perspective, this makes sense as parks offer the largest variety of ecosystem services especially compared to playgrounds and cemeteries. Hence, neighborhood stratification results from high-income HH bidding up housing prices in places with a high park endowment, thereby rendering the respective housing blocks less affordable for low-income HH. According to Banzhaf et al. (2019), the resulting environmental inequality can thus be traced back to an underlying income inequality and is, as I have also displayed in Section 2.2.2, an expected outcome in an unregulated environment. This seems intuitive, as income inequality leads to an unequal ability to take part in the "bidding game" within the housing market. Current policies in place do not seem to sufficiently address this issue since a considerable environmental inequality can be observed in equilibrium. As I have shown in Subsection 2.4.3, membership in different income groups does not only seem to affect the resulting endowment with public green, but also results in a higher endowment with private green in the form of (larger) gardens that high-income HH enjoy. Additionally, it is likely that further potential substitutes for UGS such as nature protection areas and forests outside of Hamburg are also more accessible for high-income HH, as a higher income positively correlates with car ownership (Panduro et al., 2018) and results in a comparatively higher mobility. These considerations emphasize the previously made point that income inequality and environmental inequality, are closely intertwined[22], but also stresses that synergies between SDGs such as between goal 11 (sustainable cities and communities, including the equitable access to urban green as a sub-goal) and 10 (reduced inequalities) seem possible. As is well documented in the literature, income inequality is also closely connected to other social issues (in Germany) and related SDGs such as the goal of ensuring a healthy life (SDG 3). First, indirectly, through the environmental inequalities channel, since low-income HH have less immediate access to UGS and nature in cities and the potential related health benefits as for example discussed by Porcherie et al. (2021) and Dosch et al. (2015). Second, directly, by a perceived inequitable access to health care services, e.g. documented by Hoebel et al. (2017). A review of the related literature by Drupp et al. (2021b), suggests that the negative effects of reduced access to regulating services on health for low-income groups are in turn negatively affecting labor productivity and thus reinforcing income inequality. Addressing the issue of income inequality, might hence potentially offer the opportunity for multiple synergies between SDGS (or at least move ahead on the road to reaching them).

After acknowledging these considerations and assuming the mentioned bidding process as an underlying mechanism, it seems likely that the intuitive impulse of mandating environmental quality improvements such as providing additional or larger parks a policy maker might have, e.g. by imposing green space endowment rules in low-income districts, could lead to the unwanted effect of increasing housing prices and thus could even decrease affordable housing options for low-income households (Wolch et al., 2014; Banzhaf et al., 2019). In the long run, these improvements financed by tax-payers, would ultimately benefit wealthier property owners by increasing property values (Wolch et al., 2014). Additionally, this could fuel the already ongoing trend of increasing housing expenditures observable in Germany since the mid- 90s, with possible negative consequences for wealth accumulation in low-income groups, who are spending disproportionally more of their income on housing expenditures, compared to high-income households (Dustmann et al., 2018). Hence, simply improving access to UGS in low-income housing blocks without further regulation could ultimately lead to a widening of the income gap between the wealthy and those who are less well off, and as a result reinforce environmental inequality and thereby move further away from

[22] Please refer to Drupp et al. (2021b) for an in depth discussion of the theoretical mechanisms of the manifold inequality-environment interlinkages.

reaching the SDG, at least as long as UGS are a relatively scarce or rationed amenity.[23]
In a city like Hamburg, where in-migration increases the demand for housing annually, and soil sealing shares increase consistently (BUKEA, n.d.), it is unlikely that UGS will become so abundant that they are no longer scarce, at least under the current frame conditions. For this it would require more profound societal transformations, such as a far-reaching mobility transition including a reduced reliance on individual motorized private transportation. Under these new frame conditions, some streets and parking lots in Hamburg and other urban areas could potentially be transformed into open spaces, due to the decreased demand for motorized private transportation and related grey infrastructure. Even though Hamburg has plans to become at least partly car-free (BSW, 2020; Nieuwenhuijsen et al., 2019), it seems unlikely that this transformation is a realistic policy option at least in the short and mid-term due to path dependencies and "deep-seated cultural images about life style expectations and related mobility patterns" (Berger et al., 2014, p.315) (not only) in individualized motorized traffic. A wider-reaching transformation could also encompass improving public transportation and connections to the greener urban surroundings in order to *de facto* increase the supply of attractive housing options and hence attenuate price increases (Schwarzbauer et al., 2019). Far reaching societal and infrastructural transformations which might also offer synergistic potential with SDG 13 (climate action) e.g. by reducing CO2 emissions by motorized private transportation, require bottom up societal change and acceptance that seem only feasible in a long-term perspective.
At this point it might be interesting to note, that the results of this study could also be interpreted in that the inter-generational component inherent in the climate debate on a global scale, is also immanent and relevant in the environmental justice debate on a local scale when discussing equitable access to urban green. This is based on my findings showing that the high-income group is composed of a considerably larger share of above 60-year-old dwellers than the low-income group. Delving into this discussion is however outside the scope of this study.
Instead I'd like to come back to possible policy implications of my findings, and discuss a selection of possible measures that might be effective in the mid- and short term. Policymakers could for instance aim at improving low-income HH's access to housing in green neighborhoods by increasing the housing supply, e.g. with social housing. Chorley and Liu (2021), find that social housing and house prices are inversely related in the short run. Using this instrument might however involve a trade-off with economic growth (Chorley and Liu, 2021), as well as a lack of efficiency in targeting relevant low-income households in the long-run (Schwarzbauer et al., 2019). This issue is also relevant with regard to possible discriminatory tendencies towards stigmatized groups (former inmates, homeless people, etc.) within the low-income group, who would still be disadvantaged within the social housing submarket as landlords fear a higher risk of rent loss from these groups (Voigtländer, 2007). Oberhauser (1997) and Voigtländer (2007) thus discuss the option of giving communes the opportunity to acquire "rights of occupancy" for the already existing housing stock. The authors argue that in connection with rent guarantees ensured and single or monthly fees payed by communes, "rights of occupancy" could result in reduced perceived risk rent loss and thus could be a more immediate, flexible and less fiscally intensive instrument. According to the authors of both studies, it could be an effective tool to achieve heterogeneous neighborhood composition and thus achieve multiple socio-environmental policy goals.
In the meantime, policy-makers could further aim at improving existing policy measures, such as

[23] These mechanisms should also be taken into consideration, in case Hamburg policy makers decide to rely on nature based solutions as a means to adapt to potentially increasing flood-risk resulting from sea level rise and changing precipitation patterns in the long-term (Leal Filho, 2017).

housing allowance (Wohngeld), social assistance for individuals capable of working (Arbeitslosengeld II) and the enhanced child allowance (Kinderzuschlag), as for example discussed by Bruckmeier et al. (2018). This is in line with Oberhauser (1997), who stresses the benefits of subsidizing individuals as opposed to funding social housing. Even though, neither social housing policies, "rights of occupancy", nor social benefits address the systemic root causes for income inequality and resulting environmental inequality, they could however present at least partly effective measures to alleviate the income inequality and related environmental inequalities under the current cultural and economic frame conditions, and given the current distribution of UGS and other environmental amenities, in the mid- or even the short-term. Nevertheless, each policy might encompass certain trade-offs with other policy goals such as economic efficiency. The determination of which goals are prioritized is ultimately a political decision, ideally based on functioning democratic mechanisms.

A further instrument, rent-control, which came into force in the form of "The Rent-Cap (Mietpreisbremse)" in 2015, is contested in the literature. Oberhauser (1997) and Deschermeier et al. (2017) as well as Schwarzbauer et al. (2019), reject (a functioning) rent-control as a suitable instrument to reduce inequitable access to amenity-rich housing and find that it could even intensify pressures on low-income HH e.g. by negative supply effects and resulting price increases. In contrast, Mense et al. (2018) find negative effects on rent prices for regulated units and conjecture positive long-run supply effects. They propose that relatively small negative short-run effects on the supply of housing through demolitions are in the long-run outweighed by an incentive to develop new buildings due to the increase in rents for newly constructed housing, since the rent-control does not regulate buildings built after 2014. Based on their results, the rent cap could potentially promote a more equitable access to urban green.

Apart from suitable measures to achieve the SDG 11 sub-goal, relevant indicators to measure policy success or failures should be implemented. I suggest overthinking the choice of the current indicator to measure equitable access to UGS. Currently, the indicators to measure equitable access to safe, inclusive urban green is measured, by the average built-up area in cities accessible to the public, and second, by the share of people who were victims of physical violence differentiated by gender, age, disability status and place (Destatis, 2022). Given my findings and the proposed underlying mechanism, the indicators cannot adequately measure how access to urban green is distributed within a city as it implies that the distribution and resulting access is equitable, which is not necessarily the case as I have discussed above. Heterogeneity in UGS quality is equally not addressed. Thus, I propose per capita access to urban green in the immediate surroundings of housing blocks calculated on housing block level and related to socioeconomic variables as well as environmental quality indices such as biodiversity indicators as just one of many possible options to better account for inner city variations in access to and quality of urban green.

Some might wonder if fully equitable access to UGS is something that is achievable given the current frame conditions. With this in mind, policy-makers could at least focus on a minimum provision of urban green for every city dweller, thereby ideally increasing their life satisfaction. According to Bertram and Rehdanz (2015), an area of 35 ha UGS within a 1 km radius around housing units leads to the largest positive effect on life satisfaction. However, I suggest to also consider the crowdedness of UGS which is not captured in absolute estimates of UGS area.

With relevant indicators, future research could assess how potential reforms of the social welfare services impact neighborhood sorting and resulting access to and endowment with UGS in a long-term assessment.

This study does not include benefits from the ecosystem services of UGS in Hamburg for tourists or people living outside the municipal boundary as well as other city dwellers traveling to UGS further away from their housing unit, nor can the results tell the reader anything about actual UGS use. Since income data is not available, purchasing power was used as a proxy. According to findings of a meta-analysis by Tyllianakis and Skuras (2016), the choice of income or wealth measure is not that crucial when estimating the income elasticity of WTP, I hence deem the use of the income proxy as warranted. As I already mentioned in Section 2.3.2, the use of gridded socioeconomic panel data was merged with spatially overlapping housing offers of the respective year, as individual information on income and socioeconomic status is not available and exact matching was not possible due to data privacy concerns. Nevertheless, I deem this approach valid, as the panel data would at least depict strong changes in housing block composition and theory predicts relatively homogeneous housing block composition. Regardless, the results have to be interpreted with this limitation in mind. Additionally, it is theoretically possible, that different mechanisms, than the theoretical considerations made in this study led to the resulting equilibrium outcomes observed in the present data set. The detailed results are however not contradicting the proposed mechanism in any way. Future research could further delve into the topic e.g. by explicitly simulating the sorting process to further investigate this issue.

Policy-makers pursuing strategies towards reaching SDG 11 are advised to take the various synergies and trade-offs with other policy goals into account. The results of this study indicate that reducing income inequality has the potential to foster diverse synergies related to multiple SDGs. On the other side of the coin, leaving this issue unattended might reinforce existing obstacles in securing sustainable development goals and environmental preservation (Idrees and Majeed, 2022).

3. Revealing preferences for urban biodiversity as an environmental good

Author: Leonie Ratzke

Abstract: Biodiversity is essential for human well-being, but little is known about urban dwellers' preferences and willingness to pay (WTP) for urban biodiversity. Since a large share of the global population concentrates in cities, urban areas are a critical space where humans and nature interact and biodiversity-related preferences are formed. This study investigates urban dwellers' WTP for biodiversity using a revealed-preference approach on a real estate dataset of approximately 140,000 unique entries of rental and sales transactions of apartments. Three biodiversity indicators were used to investigate heterogeneous preferences for biodiversity as an environmental good. The findings indicate that WTP for biodiversity is positive and economically significant. This implies that urban biodiversity conservation and enhancement can result in co-benefits for the local urban population. Moreover, this study identifies a satellite-based biodiversity indicator as a potential alternative to conventional species richness indicators. This finding is significant for benefit transfer studies and primary biodiversity valuation in regions with limited data availability. The results can inform biodiversity conservation and management decisions by highlighting the importance of incorporating urban biodiversity in biodiversity policies.

3.1 Introduction

Biodiversity is crucial to human existence (MEA, 2005; UNEP, 2010; Cardinale et al., 2012). But despite biodiversity's essential role and value for people, alarming rates of ecosystem change, including change due to unprecedented climate change, resulted in considerable biodiversity loss and degradation in the past decades (Dunn et al., 2006; Rega-Brodsky et al., 2022). For a long time, biodiversity conservation efforts mainly focused on safeguarding biodiversity in non-urban landscapes (Mace, 2014; Faeth et al., 2011; Dearborn and Kark, 2010), e.g. in the form of National Parks (Bonn et al., 2020). However, this paradigm has been criticized for its inability to achieve long-term conservation goals and has since evolved towards a paradigm that recognizes the complex and dynamic relationships between human well-being and biodiversity and the need to account for this in research and decision processes (Mace, 2014). During this development, the more complex relationship between urbanization and biodiversity has been highlighted as well: According to Dunn et al. (2006), the expansion of urban areas disturbs nature and results in the loss of a natural environment. In a rapidly urbanizing world with a majority of the population living in cities, urban areas are however a critical space where humans interact with taxonomic, functional, and structural traits impacted by local biodiversity and biodiversity-related preferences are formed. Humans are more likely to develop preferences for conservation when they directly experience nature, especially at an early age, but for some, the experience of urban nature might be the only contact with nature they have.

While urban areas do directly contribute to biodiversity preservation, e.g. by increasing regional habitat heterogeneity or by contributing to species' genetic diversity and pre-adaptation to climate change (Spotswood et al., 2021), many actual encounters of humans with nature in cities are still likely to be with non-native species such as pigeons, rats, and cockroaches that are perceived as pests or nuisances, or have a negative cultural connotation also due to their role in spreading pathogens (Dunn et al., 2006; Lyytimäki et al., 2008; Brock et al., 2017; Broitman et al., 2017; Broitman et al., 2018; Chrobak-Chmiel et al., 2021). Furthermore, even though many species and ecosystems might not be directly preserved and observed in urban areas, it is the people who live in cities, who have a strong influence on their conservation through votes, donations, or future environmental leadership (Dunn et al., 2006). Dunn et al. (2006) labeled this dependence of global conservation on actual interactions with perceivable aspects of urban biodiversity the "pigeon paradox". The paradox summarizes the crucial importance of urban nature and biodiversity both directly, indirectly, locally, and globally, and highlights the importance of empirically investigating whether city dwellers value the aspects of urban biodiversity they can actually perceive and interact with as a good, or as a "bad".

Locally, Biodiversity is essential for supporting ecosystem processes and regulating services that enhance the resilience of urban systems against stressors caused by climate change. This, in turn, results in various benefits for urban residents. However, Farnsworth et al. (2015) argue that lay people often fail to recognize the connection between experienced benefits and biodiversity. Consequently, while people may appreciate biodiversity in an abstract sense in the form of existence and non-use values, their perception of local biodiversity, (i.e. tangible taxonomic, structural, and functional features) and their resulting behavior is what impacts economic outcomes and influences how nature-inclusive current and future urban planning and design is.

Given that real estate development and urbanization are key drivers of land-use change (Bixler et al., 2015; McDonald et al., 2020; Spotswood et al., 2021), the housing market is an apt arena for examining the relationship between local biodiversity, behavior, and economic outcomes. While market prices may only capture a fraction of biodiversity's total economic value and do not account for intrinsic values, they can significantly influence individual and collective actions. Thus, studying how preferences for urban biodiversity translate into economic outcomes in the housing market is an intriguing research goal.

Despite the need to understand how urban dwellers perceive urban biodiversity, Schwarz et al. (2017) find that comparatively little research investigating the relationship of biodiversity proxies and their perceived value and economic consequences has been carried out in an urban context.[1]

In this study, I thus contribute to the urban environmental and biodiversity valuation literature by estimating city dwellers' willingness to pay (WTP) for biodiversity as an environmental good. I use a hedonic property value model (HP)[2], to reveal heterogeneous preferences for the use values of urban biodiversity in the city of Hamburg, Germany. Using this approach can increase the understanding on how the perceived level of local biodiversity impacts outcomes in the housing market which is one important driver of land-use change. For the analysis, I use a real estate dataset comprising around 140,000 unique entries of rental and sales apartment offers. I use an internal instrumental variable method for identification to account for endogeneity stemming from omitted variables, measurement error, or simultaneous causality. Using a convergent validity assessment, I show that using a novel satellite-based biodiversity proxy produces results that are similar to the WTP estimates derived with ground-based species richness. This contribution might be relevant for future benefit transfer studies, as the satellite-based indicator is freely available as a global, uniform dataset. It thus enables researchers to carry out large-scale studies using a comparable biodiversity measure, without encountering high costs to further improve the understanding of the subject.

The mean and interquartile range of WTP estimates derived with three biodiversity proxies are

[1] Among the available studies dealing with the biodiversity and human well-being nexus, mixed findings were reported when investigating preferences for biodiversity. Fuller et al. (2007) found a positive association between two biodiversity indicators and self-reported well-being. These findings are in line with Lindemann-Matthies et al. (2010), who reported a positive association between plant species richness and their aesthetic appreciation in an experiment in an urban context. In accord with these findings, Bronnmann et al. (2020) found a positive median willingness to pay for the naturalness of urban green spaces in 22 major cities in Germany, using a discrete choice experiment including an online survey.

In contrast to these findings, Dallimer et al. (2012) found a negative association between plant richness and self-reported well-being in a similar setting to Lindemann-Matthies et al. (2010). In line with these contrasting results, findings from a hedonic pricing study indicate that people in Singapore mostly preferred managed vegetation with low biodiversity value to vegetation with a high biodiversity value (Belcher and Chisholm, 2018). Additionally, there are mixed findings regarding the question of whether people value the diversity of species itself (e.g. Lindemann-Matthies et al., 2010; Bakhtiari et al., 2014) or are mainly valuing attributes or species (e.g. Christie et al., 2006; Brock et al., 2017). All in all, the mixed findings of this brief glance over the related literature indicate that the conceptual link between (urban) biodiversity and human well-being is more complex than often assumed and still insufficiently understood and defined.

[2] Most economic valuation studies focusing on biodiversity valuation applied stated-preference methods (Bartkowski et al., 2015). Although stated-preference methods have many merits, their results do not always match actual behavior, as modeled in revealed-preference studies. One reason for this might be that they suffer from consequentiality and incentive compatibility (Loomis, 2011; Schläpfer et al., 2004). A further reason specific for biodiversity valuation might be that concrete quantitative measures such as species richness are too abstract for participants of stated preference assessments. According to Farnsworth et al. (2015), these are however the metrics that are most suitable from a biologist's point of view when attempting the valuation of biodiversity. A stated preference framework might hence not always be able to recover the respondents' actual WTP for biodiversity (Bartkowski et al., 2015). Although revealed-preference methods have their own drawbacks, they can be useful to recover WTP for environmental goods based on actual observed behavior.

positive. From this, I conclude that urban dwellers in Hamburg view urban biodiversity as a good. This can be interpreted as an indication that in the current sample, positive encounters with (urban) biodiversity prevail. A welfare analysis shows that an improvement in urban biodiversity would result in significant welfare improvements.
This paper is organized as follows. In the following Section 3.2, I discuss the relevance of HP in estimating biodiversity values. In Section 3.3, I present a theoretical framework for the analysis and derive a hypothesis. This is followed by the methods in Section 3.4, describing the data and identification strategy. The paper concludes with the results and discussion in Sections 3.6 and 3.7.

3.2 Conceptual links between biodiversity and human well-being: Addressing the content validity of biodiversity valuation in a revealed-preference setting

In the following, I focus on the content validity of biodiversity valuation in a revealed-preference setting, using the hedonic property value model (henceforth called HP). Content validity refers to the extent to which the valuation method and procedures employed to implement it are suitable for accurately measuring a conceptual construct (R. C. Bishop and Boyle, 2019). HP can be a useful valuation method, depending on the purpose of valuation. It is based on the idea that variations in housing characteristics and location-specific amenities influence the behavior of agents in the housing market and are ultimately reflected in housing prices (K. C. Bishop et al., 2020). For these variations to be capitalized into housing prices, urban dwellers need to be able to perceive or be informed about changes in environmental amenities or disamenities, which then affect their residential housing choices (Palmquist, 2005a). Although HP is not suitable for recovering the Total Economic Value (TEV) of biodiversity, since it relies on uninformed preferences (Bartkowski, 2017; Farnsworth et al., 2015), it can be useful for reflecting how perceived levels of biodiversity proxies impact local decisions and economic outcomes in the urban housing market. As discussed in the introduction, these outcomes may not only affect local decisions but also influence how biodiversity-related preferences are formed in the long run and have an impact on decisions related to biodiversity conservation. In this study, I refer to biodiversity as an aggregate of three dimensions of diversity, i.e. functional, structural, and taxonomic diversity (Lyashevska and Farnsworth, 2012). From this definition, it becomes apparent that biodiversity is an abstract concept used to address broader theoretical questions and practices, rather than a biological concept in the traditional sense (Meinard and Grill, 2011). According to Meinard and Grill (2011), valuing biodiversity from an anthropocentric perspective requires taking into account that biodiversity is an abstract good. This means that, unlike a single concrete object, an abstract good cannot be identified without observing and analyzing or interpreting related concrete objects representing aspects of the abstract good, such as species richness or structural traits. Figure 3.1 shows how local biodiversity impacts the state of concrete and observable environmental, taxonomic, and structural variables (Please refer to Table B.11 for relevant definitions and references of used terms). These in turn, if perceivable can impact individual utility and resulting housing choice.[3]
To value aspects of biodiversity using HP, suitable proxies must be found that are not only correlated with relevant ecosystem functions, taxonomic diversity, or structural diversity but are also

[3] Please note that the figure does not include several potential feedback loops and interconnections between ETSPs, local biodiversity, and ecosystem processes as it only serves to illustrate the capabilities and limitations of HP in biodiversity valuation.

correlated with what humans perceive. Identifying observable, concrete variables that can be used as proxies is thus an important step in biodiversity valuation using HP, as discussed in subsection 3.4.1.[4] The perceived spatial variation of biodiversity proxies can then impact individual utility and resulting housing location choice and ultimately impact economic outcomes, i.e. housing prices (The theoretical framework connecting individual utility to housing prices as depicted in Figure 3.1, will be discussed in detail in Section 3.3). These in turn can increase or decrease incentives for further real estate development and related surface sealing but also impact if and to what degree biodiversity-related questions and nature-based solutions are considered in urban planning and design (Plieninger et al., 2005; Irwin and Bockstael, 2007; McKinney, 2008).

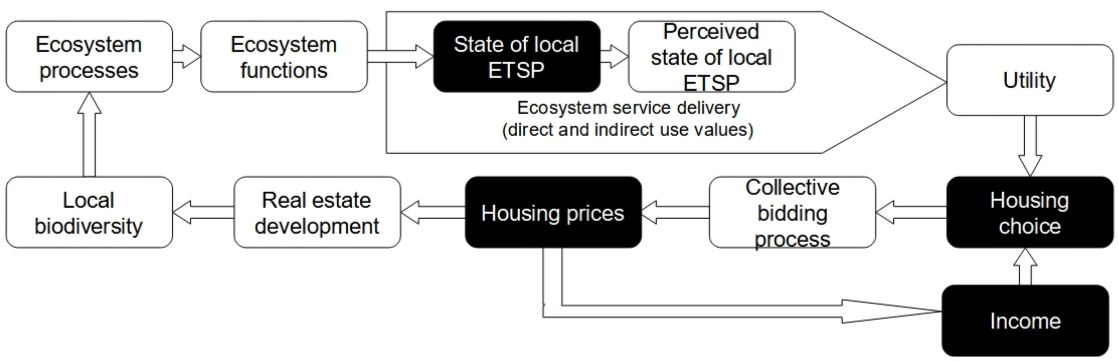

Figure 3.1: Valuing biodiversity in an urban context using the hedonic property model. Own depiction based on Palmquist (2005b), Irwin and Bockstael (2007), Botzat et al. (2016), Pettorelli et al. (2018), Paul et al. (2020), and K. C. Bishop et al. (2020). Black boxes represent which variables are observable or are modeled in this study. Notes: ETSP - local environmental and taxonomic variety or structural proxies.

HP is often used to quantify amenity values of urban ecosystems, i.e. direct non-consumptive use values (Tyrväinen and Miettinen, 2000; Tapsuwan et al., 2009; Sander and Haight, 2012; Czembrowski and Kronenberg, 2016), by assuming implicitly or explicitly that the amenity component of the attribute to be valued is the main driver of perceived benefits and resulting decisions in the housing market (Tapsuwan et al., 2009). However, HP is also able to recover indirect use values, in addition to location-specific direct use values, in an urban context and it has been used for the valuation of changes in air quality, noise, and urban cooling (Johnston et al., 2001; Cavailhès et al., 2009; Brander and Koetse, 2011; Croci et al., 2021). If these environmental variables vary systematically with urban biodiversity, HP could at least theoretically be able to capture also functional aspects of biodiversity-related to perceivable spatial differences in environmental quality. The bundle of values provided or supported by biodiversity that HP can potentially capture thus includes (i) the value urban dwellers attribute to the structural or taxonomic attributes of local biodiversity that they can directly see or hear, and which are related to their local recreational preferences as

[4] Duelli and Obrist (2003), propose to use several biodiversity proxies, which theoretically represent concrete objects of the abstract concept. The results can then be compared to assess if the proxies capture similar or different aspects of the abstract good.

well as the option values associated with perceived future use values[5], and (ii) the indirect effect of ecosystem functions related to local biodiversity, which result in a systematic spatial variation of environmental quality variables that are perceivable by humans (e.g. perceived air quality, noise, and temperature). The estimates derived with HP can thus be interpreted to present a lower bound of use values of urban biodiversity (Lansford Jr and Jones, 1995).

3.3 Revealing preferences and preference heterogeneity for biodiversity

3.3.1 Theoretical framework

Hedonic pricing in the real estate and property market is a cross-sectional method that is applied by regressing housing attributes on property or rent prices to identify households' marginal willingness to pay (MWTP) for each housing characteristic, including surrounding neighborhood and environmental characteristics (Rosen, 1974; Freeman, 1974; Parmeter and Pope, 2009).
The theory relies on the notion that the outcome of a bidding process between a large number of buyers and sellers results in an equilibrium outcome, which can be represented by a hedonic price function for each housing market m (Bajari and Benkard, 2005):

$$p_i = \mathbf{p_m}(\mathbf{x_i}) \tag{3.1}$$

By purchasing or renting a housing unit in a market transaction, households hence reveal their willingness to pay for a bundle of observable housing characteristics. The bundle $\mathbf{x_i}$ is a k-dimensional vector of housing characteristics; $\mathbf{x_i}= (x_{i,1}, ..., x_{i,k)}$, including housing unit and unobservable housing characteristics and the level of perceivable taxonomic, functional and structural biodiversity proxies in the surroundings of a housing unit i. All characteristics k contribute to the overall housing unit price p_i. I assume that households act as rational, utility-maximizing price takers in only one housing market m and have the utility function:

$$U_{j,i} = U_j(\mathbf{x_i}, c_i, \zeta_j), \tag{3.2}$$

Households j are heterogeneous in preferences ζ_j and income y_j, c_j is the numeraire good. Due to budget constraints, households make trade-offs between consumption and local amenities including biodiversity (Banzhaf et al., 2019), and move along the hedonic price schedule until the implicit price of the housing characteristics equals their MWTP. The optimal housing choice for each household can hence be expressed as:

$$\max_{x,c} U_{j,i}(\mathbf{x_i}, \zeta_j, c_j) \;\; s.t. \;\; y_j = \pi * p_i + c_j \tag{3.3}$$

A housing bundle i is the utility-maximizing choice for a household j, if the marginal cost for a continuous housing attribute k of $\mathbf{x_i}$ is equal to the marginal rate of substitution with the numeraire good c_j (Panduro et al., 2018). The product $\pi * p_i$ represents the annual spending for housing unit i.

[5] Generally, option values play an important role in biodiversity valuation as they capture the potential benefits that may arise from preserving biodiversity and the future opportunities it may provide for human well-being, even if they are not currently known or realized. These benefits are particularly important given the uncertainty and spatial interactions in ecosystem service provision (Bartkowski, 2017).

[6] With these assumptions, I estimate the MWTP for biodiversity in a first-stage hedonic regression in six submarkets m differentiated across two dwelling types and three time periods accounting for macroeconomic trends. Since households choose both the amount of the characteristic of interest, i.e. biodiversity, as well as the implicit price for it while maximizing individual utility, there is concern about endogeneity (Freeman et al., 2014).
Using an instrumental variable approach is one of several options to address endogeneity. As finding suitable exogenous instruments is a considerable challenge, I use an identification strategy with internal instrumental variables discussed in Section 3.4.2.
Since it is not possible to recover the households' utility function after only observing one housing choice per household in a cross-sectional setting, Bajari and Benkard (2005) propose to impose structure on the utility function to address this issue. A commonly used utility function is a quasi-linear utility function:

$$U(\mathbf{x_i}, c_j, \zeta_j) = \sum_k \zeta_{j,k} log(x_{i,k}) + c_j \tag{3.5}$$

With this structure imposed on the utility function depending on the preference parameter ζ_j, the numeraire good c_j and $x_{i,k}$, the first-order condition for a maximum can be expressed as

$$\frac{\zeta_{j,k}}{x_{i*,k}} = \frac{\delta \pi p(\mathbf{x_{i*}})}{\delta x_{i,k}} \tag{3.6}$$

$$\zeta_{j,k} = x_{i*,k} \frac{\delta \pi p(\mathbf{x_{i*}})}{\delta x_{i,k}} \tag{3.7}$$

Since the MWTP for characteristic k, multiplied with asset return rate π, $\frac{\delta \pi p(\mathbf{x_{i*}})}{\delta x_{i,k}}$ can be obtained from the first-stage estimation of the hedonic price schedules and the chosen level $x_{i*,k}$ can be observed, I can directly calculate the household specific preference parameter $\zeta_{j,k}$ (Panduro et al., 2018). The ex-ante WTP for the currently chosen level of each housing attribute, is thus $\zeta_{j,k}$ (Panduro et al., 2018). Consequently, heterogeneity in preference parameters or current level of WTP can be decomposed as follows:

$$\zeta_{j,k} = \alpha_k + \sum_d \alpha_{k,d} D_{j,d} + \beta_k Pop_j + \delta_k PP + q_k \tag{3.8}$$

Although not flawless (as for instance, no income elasticity of demand can be estimated due to the quasi-linear functional form of the utility function), the present approach is useful to decompose the preference parameter for biodiversity in relation to a household's sociodemographic characteristics $D_{j,d}$, the overall population density Pop_j and income PP[7]. In this context, α_k represents the mean

[6] To calculate annual spending I differentiate between purchased objects (dummy variable d_{purch}=1) and rental objects (dummy variable d_{rent}=1):

$$\pi = \psi * d_{purch} + 12 * d_{rent} \tag{3.4}$$

In the case of apartments for rent, the discounted implicit prices, representing a monthly value, have to be multiplied by 12 to represent annual expenditures. For apartments for sale, I multiply the sales price with the discount rate ψ. For the latter to represent annual spending, it is necessary to assume that the real estate market works without friction and that p_i can thus be equated to the discounted sum of the stream of annual rents realizable from that property over its expected lifetime in the future, and that the same is the case for the implicit prices for biodiversity in each housing unit's vicinity. With an infinite lifetime and discount rate ψ, implicit prices can be expressed as rents (Day et al., 2007). In this study, I use 3% as a discount rate.

[7] In this study, I use purchasing power, as a proxy for income. It represents the disposable net income after taxes but includes social benefits (RWI and microm, 2019).

WTP for the current level of the characteristic of interest, while the coefficient vectors $\alpha_{k,d}$, β_k and δ_k elicit heterogeneous variation in $\zeta_{j,k}$ and q_k is the remaining idiosyncratic WTP or taste variation. The preference parameter $\zeta_{j,k}$ can be used to calculate welfare effects for non-marginal changes in the level of biodiversity as follows (Bajari and Kahn, 2005; Kuminoff, 2009; Panduro et al., 2018):

$$WTP_{j,k} = \zeta_{j,k}(\log(x^1_{i,k}) - \log(x^0_{i,k})) \tag{3.9}$$

Where $x^0_{i,k}$ is the current level of attribute k and $x^1_{i,k}$ represents the level of the attribute after the change (Bajari and Kahn, 2005).

I carry out the first-stage estimation of the hedonic price function for six distinct *a priori* defined submarkets, and pool the data after. For the definition of submarkets in this study, I assume that demand structures differ systematically between the submarkets *apartments for rent* and *apartments for sale*, as well as over the *a priori* defined time periods accounting for macroeconomic fluctuations and assume that households are only active as bidders in one submarket (Freeman et al., 2014).[8] Additionally, I assume that the respective submarkets are in equilibrium, that a change in biodiversity will not lead the whole price schedule to shift, and that housing is an approximately continuous good. Furthermore, I assume that the supply of housing units does not change considerably within the defined periods.

3.3.2 Hypothesis

As mentioned in the introduction, the values that people place on biodiversity are complex and may differ depending on the context. For example, people may value the existence of certain species and biodiversity in general for its own sake, or they may appreciate its spiritual meaning without necessarily engaging with concrete taxonomic or structural objects related to its use.

In contrast, capitalized use values of biodiversity, such as those that can be observed in the housing market, reflect the perceived benefits that people expect to derive from directly engaging with urban biodiversity. Recent studies investigating use values of biodiversity in an urban context suggest that the relationship between the use values of biodiversity and human well-being is not always positive. Belcher and Chisholm (2018), for instance, have found a negative association between biodiversity and house prices. These findings are consistent with research on ecosystem disservices (Broitman et al., 2018), as well as findings by Qiu et al. (2013) that suggest a negative correlation between biodiversity and recreational preferences.

Recent research in the psychological literature by Meidenbauer et al. (2019) has found evidence that preferences for nature develop over a person's lifetime and may depend on the extent of their interaction with nature. This suggests that city dwellers who have little experience with nature in a less managed environment may be more likely to perceive fauna within the urban environment as a nuisance rather than appreciate their presence.

In a discrete choice experiment, Brock et al. (2017) found that participants had a negative WTP for interactions with woodpigeons compared to a positive WTP for encounters with five other bird species. These results support the idea that people may have negative perceptions of certain aspects of urban biodiversity or specific species supported by local biodiversity, even if they value biodiversity more generally or in other contexts.

[8] Using submarkets is a common practice in similar applications and has for instance been employed by Bourassa et al. (1999) and Liebelt et al. (2018). Bourassa et al. (1999) found that developing several statistical techniques to identify submarkets does not improve the model performance significantly compared to *a priori* defined submarkets.

Furthermore, it has been suggested that in urban environments, it is more likely to find preferences negatively correlated with biodiversity rather than positively correlated, if negatively perceived interactions with nature prevail (Broitman et al., 2018; Faeth et al., 2011; Dunn et al., 2006). This could also be the case if people with low appreciation of nature self-select into urban environments, rather than moving to the countryside.
Based on the framework presented earlier, I can hypothesize that households who perceive urban biodiversity as messy or a nuisance may categorize it as a cultural disservice and ignore or not be informed about the potential benefits that biodiversity can provide in terms of regulating services. Assuming that households have the option to choose between two housing units with similar endowments of urban greenery in terms of absolute area of green spaces, street trees, and unsealed area in the immediate surroundings, but with different levels of biodiversity, it can be speculated that households with larger budgets would prefer the unit with low biodiversity, assuming that perceivable taxonomic or structural components related to urban biodiversity are indeed perceived as a nuisance. As a result, negative WTP estimates for urban biodiversity could emerge in equilibrium (Banzhaf et al., 2019). However, this conjecture rests on the assumption that the "alienation from nature" inherent in the pigeon paradox has sufficiently impacted the preferences of urban dwellers and is reflected in observable behavior in the housing market.
For lack of further revealed-preference studies carried out in the housing market, which could add to the formation of expectations about the outcome of this assessment, I test the following hypothesis:

> ***H*1**: *Mean willingness to pay for urban biodiversity in Hamburg is negative.*

The hypothesis is rejected, if the mean WTP for biodiversity, estimated with three indicators, is positive.

3.4 Method

3.4.1 Available data

Suitable Biodiversity indicators

Biodiversity is an abstract concept, and as Purvis and Hector (2000) state, no biodiversity indicator or proxy[9] can capture every facet of the variety of life. The suitability of a proxy is thus dependent on the context in which it is used.
Concrete objects or structures used to make the abstract concept of biodiversity tangible for empirical research are taxonomic and functional aspects, as well as habitat structure (Ziter, 2016; Schwarz et al., 2017; Pettorelli et al., 2018).
In the present context, taxonomic measures such as faunal species richness, i.e., the number of species observed in a defined spatial unit, intuitively seem useful to capture how city dwellers can observe, or in the case of birds hear, different animal species in the surroundings of their housing unit.
Species richness is a commonly used indicator to describe biodiversity (Noss, 1990; Gotelli and Colwell, 2001; Macdonald et al., 2020), but has also been criticized, e.g., for not being able to adequately capture biodiversity change or that it could overemphasize the importance of rare species

[9] In the following, I use the terms indicator and proxy interchangeably. Even though there is a difference between biodiversity indicators and proxies, this difference becomes more unclear when using a definition of biodiversity that does not only focus on taxonomic aspects but equally considers functional and structural ecosystem components.

and underemphasize the importance of abundant species (Hillebrand et al., 2018). Previous research showed that city dwellers perceive faunal and floral species richness[10] and that it was correlated with cultural ES such as aesthetic appreciation and recreation (Lindemann-Matthies et al., 2010; Dallimer et al., 2012; Qiu et al., 2013; Schwarz et al., 2017; Southon et al., 2018; Tomitaka et al., 2021).

Other taxonomic metrics for biodiversity are also used, but less frequently in an urban context (Schwarz et al., 2017), since detailed ecological data, e.g., on species evenness are often unavailable (Kallimanis et al., 2012). This was also the case in this application.

Hence, I acquired the official faunal species cadastre of Hamburg's authorities (BUE, 2016a) and calculated species richness for each quadrant/pixel of the data.

Unfortunately, even species (richness) data is not always readily available due to time-consuming, expensive data collection, which demands a high level of expertise (Kallimanis et al., 2012), and species richness might not necessarily capture the functional role of biodiversity underpinning regulating ecosystem services (Tilman, 1999).[11] Thus, I use two further proxies that do not rely on the sighting of fauna by experts and test if they initially produce similar results using several convergent validity measures.

First, I acquired satellite-based Dynamic Habitat Indices (DHI) provided by Hobi et al. (2017). With remote sensing products becoming readily available, various authors have used these data to assess biodiversity-related research questions (Rocchini et al., 2007; Costanza et al., 2007; Nagendra et al., 2010; Radeloff et al., 2019). To my knowledge, the data has not been used in the valuation literature. The advantage of satellite products is their temporal and spatial continuity and the absence of monitoring bias. The possible disadvantage is that some of the products are based on complex models deriving measures from satellite sensor data, which might lead to lower precision (Hobi et al., 2017).[12] The DHI summarizes three key measures of vegetative productivity, all related to the species energy hypothesis. Among others, the hypothesis predicts that more species will occur where energy and hence food is consistently available. In this study, I use the annual cumulative productivity as a proxy for biodiversity, which was calculated as the integral of the phenological curve of a year. It relies on the notion that sites with more available energy are generally more biodiverse (Hobi et al., 2017). According to Pettorelli et al. (2018), GPP is a suitable proxy for ecosystem functions such as pollination, supporting habitats, food provision, and barrier effect of vegetation, which all relate to primary production as an underlying ecosystem process. Primary production is also a key ecosystem process related to water and climate regulation. The DHI might hence be a suitable measure to capture specific ecosystem functions and theoretically relates to many ecosystem services relevant in an HP framework. Furthermore, the ecosystem functions food and habitat provision provide a theoretical link to faunal species richness.[13]

[10] For instance, Lindemann-Matthies et al. (2010) showed that urban dwellers perceived differences in floral species richness and that it partly predicted aesthetic appreciation by study participants. Southon et al. (2018) equally found that perceived plant, bird and butterfly richness was a good predictor of actual species richness.

[11] According to Tilman (1999), different species can play various functional roles in ecosystems, and changes in the abundance or composition of specific functional groups can have important effects on ecosystem processes. He suggests that measuring biodiversity should take into account both species richness and functional diversity.

[12] The DHI are composite rasters compiled from 46 MODIS Gross Primary Productivity (GPP) products per year. The DHI is available for the years 2003 to 2015, of which I use the products for the years 2005-2015, as the house transaction data described in the following section only dates back to 2005.

[13] Please refer to Silvis Lab (2020) for further information on data processing, handling of missing values, and references to publications in the environmental science literature using the data for biodiversity assessment. As the data is available in raster format, I merged the point data representing each housing transaction (please refer to the following sub-section) with the raster data by assigning the raster values to spatially overlapping points.

According to Löfvenhaft et al. (2002), different biodiversity indicators may be applicable in an urban context rather than in a more natural environment. In line with this, Feest (2006) proposed to focus on "biotope quality" instead of species richness or functional proxies to assess biodiversity. According to Jalkanen et al. (2020), expert-based assessments of biotope quality can be a useful method to measure biodiversity in urban areas. To calculate a suitable proxy for biodiversity, I acquired data based on detailed assessments of biotope quality carried out by professional nature conservationists (BUE, 2018). The criteria used for assessment were rarity, age, the level of pollution, as well as ecological functions of the respective biotope. In order to have a comparable level of aggregation in the biotope quality and faunal species data, I used the DHI raster resolution to rasterize the biotope quality data using median biotope quality as a measure to summarize the vector data within a pixel.[14] Figure B.3 displays the resulting raster map.

While I cannot directly test if the three biodiversity indicators will initially represent the same abstract concept, I can test if the biodiversity indicators, as well as the resulting WTP estimates, are indeed associated. Figures B.1 and B.2 show that the indicators are associated. Especially the expert-based biotope quality assessment and the satellite-based DHI are correlated, as shown on Figure B.2.

Whereas the link between recreational preferences and species richness has some basis in the literature as discussed above, it is unclear if the variations in regulating services due to a variation in urban biodiversity approximated by the three measures are perceivable to urban dwellers. However, it is possible to test if the selected biodiversity indicators affect proxies of air quality and temperature, and if these match the theoretically expected increase in barrier effect of more biodiverse ecosystems (biodiversity-ecosystem service relationships) (Pettorelli et al., 2018). Please refer to Tables B.1 and B.2 for an exploration of these relationships.

The exploratory results show that all three biodiversity indicators significantly reduce both the urban heat island effect as approximated by maximum annual temperature and particulate matter (PM10) concentration as is theoretically plausible. The coefficient estimates are not identical but have a similar magnitude and can hence be considered robust across indicators. I see these exploratory results as an indication that all three indicators are able to capture relevant functional aspects of urban biodiversity related to air quality and the urban heat island phenomenon.

House price data and housing characteristics

To be able to estimate the hedonic price schedules of the respective submarkets, I used observations on apartment sales and rental offers between the years 2005 and 2018, including the geographical location of housing units as well as offering price and structural housing attributes. To account for the fact that offer prices are typically higher than actual transaction prices, the data provider adjusted the prices with a regularly updated transaction deduction, which is used in this study. The data was extensively checked for plausibility and duplicate entries, including changes in structural characteristics in multiple published offers for the same object, as well as for the plausibility of rental and sales prices. I procured the data set from F+B Forschung und Beratung für Wohnen, Immobilien und Umwelt GmbH in exchange for a procurement fee. Please refer to Ratzke (2022), for a detailed description of adjustment of offer prices, georeferencing with the cadastral map ALKIS

[14] Both raster and vector data are commonly used in Geographic Information Systems (GIS) and spatial analysis. Raster data consists of a grid of cells or pixels, each with a value representing a specific attribute. Raster data is typically used to represent continuous phenomena, whereas vector data consists of points, lines, and polygons that represent discrete features, such as housing units (DeMers, 2015).

of 2018 provided by Landesbetrieb Geoinformation und Vermessung (2019a) as well as handling of missing values.
In this study, I used the data of the submarkets *flats for sale* and *flats for rent* for analysis resulting in sample sizes of 27,970 and 110,626 observations for the estimation of the hedonic price schedules, respectively. I split each of the data into three time periods that represent submarkets to account for macroeconomic developments related to the Euro crisis.[15] I utilized the official urban green spaces cadastre to compute spatial variables that measure the amount of green space in the vicinity of the housing units (BUE, 2016b). I intersected it with spatial buffers with a 1 km radius around the housing units to calculate the absolute area of four green space types within that radius. I equally included the number of street trees within a 100 m radius with a similar procedure using the street tree cadastre BUE (2016c).[16]

Socioeconomic data

For eliciting heterogeneous preferences for urban biodiversity, I additionally include microeconomic data, available as a panel data grid provided by Rheinisch-Westfälisches Institut für Wirtschaftsforschung. The data is available for the years 2005 and 2009–2016 and has a spatial resolution of 1 square km. It includes information on the share of households within different age groups in the respective raster cell, as well as population density, unemployment share, household structure, and purchasing power (RWI and microm, 2019). I merged the data points with the panel grid by spatial and temporal dimensions. Transactions from the years 2006 and 2007 were assigned the socioeconomic variables from the year 2005, while the transactions from the year 2008 were assigned the values from the 2009 RWI grid. Transactions from 2017 and 2018 were merged with the 2016 RWI grid.[17] I use purchasing power as a proxy for income.

3.4.2 Econometric model specification, identification strategy and convergent validity measures

In this application, not all characteristics with an effect on the housing price can be included as explanatory variables due to data constraints or because they cannot be measured. Hence, omitted variable bias poses a problem. Not addressing this issue by appropriate econometric techniques leads to biased results (Kuminoff et al., 2010; Abbott and Klaiber, 2011). Additionally, reverse causality might pose a problem in this application as people moving to a neighborhood might influence the urban planning process which might ultimately change the level of biodiversity in a neighborhood and in turn affect prices. K. C. Bishop et al. (2020) propose several options for identification. One of them is an instrumental variable (IV) approach. In practice, good external instruments which meet the necessary assumptions to achieve identification are however hard to find. In this study, I thus apply a so-called instrument-free or internal IV method using Gaussian copulas by Park and Gupta (2012). An advantage of this method is that it does not need exogenous instruments since

[15] Dividing both the apartments for rent and sale data into three time periods is the result of a trade-off between plausibly assuming that the submarkets are in equilibrium and questions related to the concrete statistical application such as using more comprehensive data and having higher statistical power and greater variability in the variables of interest when pooling data spanning over several years. I thus carried out the analysis for six separate submarkets. The time periods are 2005 to 2009, 2010 to 2014 and 2015 to 2018.
[16] All spatial data was reprojected to the ETRS 89/ UTM zone 32 N (zE-N) projection and preprocessed in QGis. Please refer to Appendix Table B.9 for the full list of included variables.
[17] This is based on the assumption that the composition of housing blocks does not undergo significant changes on average within a two to three-year timeframe.

it directly addresses the correlation between the endogenous variable, in this case, the biodiversity indicator, and the structural error term from the data using Gaussian copulas[18]. Additional to endogeneity caused by omitted variables, the method equally addresses endogeneity resulting from imperfect measurement of variables (since the biodiversity proxies used might not capture perfectly what city dwellers perceive) and simultaneous causality (Zaefarian et al., 2017).
The approach is similar to the control function approach by Petrin and Train (2010). It relies on estimating additional regressors $Z_t* = \phi^{-1}(H(Z_t))$ by estimating the marginal distribution $H(Z)$. Adding the additional regressors (in the following marked by a double asterisk) resolves the correlation between the endogenous biodiversity variables and the error term. The inference is done in two steps. First, the likelihood function is constructed and parameters are estimated using the empirical distribution of the endogenous variable(s). As the standard errors of this procedure are not correct, standard errors and confidence intervals are obtained by bootstrapping (Park and Gupta, 2012). Please refer to Park and Gupta (2012) for a detailed description of the method, to B.3 to test that all necessary model assumptions for identification are met, and to Kostov et al. (2021) for a recent application.
Referring to findings by Ziter (2016), I include variables measuring the overall area of green space in a 1 km radius around the housing unit, the number of street trees as well as spatial fixed effects on the district level in the model specification.I thus carry out the estimation of the hedonic price schedule with each of the three biodiversity indicators using the following specification for six submarkets across dwelling type and time period:

$$ln(P) = \phi + \sum \alpha \boldsymbol{S} + \sum \beta \boldsymbol{G} + Bio(\tau + \sum \gamma \boldsymbol{c}) + \sum \kappa \boldsymbol{c} + \sum \delta \boldsymbol{D} + \eta Bio^{**} + \sum \iota \boldsymbol{G^{**}} + u, \tag{3.10}$$

where P is a vector of observed houseprices, $\boldsymbol{S}$ is a matrix of structural housing characteristics, $\boldsymbol{G}$ is a matrix of the mentioned green space controls and Bio is one of the selected biodiversity indicators (Please refer to Table B.9). $\boldsymbol{D}$ represents spatial fixed effects and $\boldsymbol{c}$ is a matrix of dummy variables indicating the walking distance to the city center.[19] By including interaction terms between the biodiversity indicator and dummy variables $\boldsymbol{c}$, I can account for spatial heterogeneity in implicit prices for biodiversity. All symbols marked with a double asterisk are the additional regressors estimated with Gaussian copulas. ϕ, α, β, τ, γ, κ, δ, η and ι are vectors of regression coefficients, u is a structural error term.[20]

[18] Copulas are functions which link several marginal distributions to a joint multivariate distribution. They are thus useful mathematical objects to model the dependence among random variables. A joint distribution can be decomposed into the copula and marginals. Gaussian copulas are parametric copulas that assume an imperfect dependence between marginal distributions (Jaworski et al., 2010).

[19] Instead of using a continuous variable for walking distance, I use dummy variables, as implicit prices for biodiversity might not vary continuously across space. One reason why implicit prices for biodiversity might not vary continuously across space is because of the way that biodiversity is distributed. Biodiversity tends to be clustered, with some areas having high levels of species richness, while others have relatively low levels. This means that the value that people place on biodiversity may be much higher/lower in areas with high biodiversity, and much lower/higher in areas with low biodiversity, creating discontinuities in the implicit prices as these clusters may not necessarily exhibit a perfect gradient from the city center to the urban fringe. The availability and accessibility of information about biodiversity may also affect implicit prices. If people are more informed about the biodiversity in a particular area, they may be more likely to place a higher value on it, leading to higher implicit prices. Conversely, if people are less informed about biodiversity in an area, they may be less likely to value it highly, leading to lower implicit prices.

[20] The method should account for missing variables, such as environmental variables which relate to perceivable regulating services, such as urban cooling. Adding a variable quantifying a specific regulating service should thus not alter the results significantly. To validate the used approach, I thus include a proxy for the regulating service "cooling" in an auxiliary first-stage estimation and use it for preference elicitation with Equation 3.8 to compare to

$$\hat{\zeta}_{j,Bio} = Bio_{i*} \cdot \pi \cdot \frac{\delta p_{i,m}}{\delta Bio_{i*}} \tag{3.11}$$

In as second stage, I multiply the MWTP recovered with the hedonic price schedules of submarket m, with π and the observed level of each of the biodiversity indicators Bio_{i*} to recover the preference parameter $\hat{\zeta}_{j,Bio}$. With the estimates of WTP calculated using equation 3.11, I can test Hypothesis 1 using the mean and interquartile range of WTP estimates derived with the three biodiversity indicators. Next, I use the WTP estimates derived from the three biodiversity indicators to calculate a number of convergent validity measures and assess how well the WTP estimates using the biodiversity indicators converge with each other. The test statistics used for convergent validity assessment are depicted in Table B.10.

$$\ln \hat{\zeta}_{j,Bio} = \alpha_{Bio} + \kappa_{Bio} + \sum_{d} \alpha_{Bio,d} D_{j,d} + \beta_{Bio} Pop_j + \delta_{Bio} PP_j + \gamma_{Bio} Bio^{**} + \zeta_{Bio} PP^{**} + q_{Bio} \tag{3.12}$$

In the third stage, I regress sociodemographic characteristics $D_{j,d}$, the overall population density Pop_j and purchasing power PP_j[21] on the recovered, preference parameter which indicates the WTP for the current level of biodiversity chosen by households. In this context, α_{Bio} represents the mean WTP for the current level of biodiversity, while the coefficient vectors $\alpha_{Bio,d}$, β_{Bio} and δ_{Bio} elicit heterogenous variation in $\zeta_{j,Bio}$ and q_{Bio} is the error term. Since exact matching of the micro panel data with the apartment offers is not possible, I assume that households who live in close proximity to each other have similar characteristics. This is in line with the data aggregation strategy of the available socioeconomic data (Breidenbach and Eilers, 2018) since the authors aimed at combining similar houses that are also as close as possible in spatial terms. Since socioeconomic variables, preferences and local amenities often correlate (Tiebout, 1956; Hachadoorian, 2016), I deem this assumption warranted.

3.5 Results

In the following subsection, I present the estimates of willingness to pay for preserving the current state of biodiversity in Hamburg estimated using three biodiversity proxies, as well as the results of the convergent validity assessment. The subsequent subsection elicits preference heterogeneity of willingness to pay for biodiversity the current level of biodiversity measured by using all three proxies.

the initial results. Please refer to B.6 for the results of this robustness check. In a separate estimation, I added time fixed effects (TFE) to the first-stage estimation and evaluated the model performance with and without TFE. The model performance measured with the mean square error of predicted vs. actual housing unit prices does not differ between the models. Since the temporal variation of the variable of interest is limited especially in the case of the species richness indicator and the pooling of data only covers relatively short time periods and including time fixed effects does not improve the model's fit at all, including TFE can lead to overfitting the model and potentially biased estimates (Stock and Watson, 2019). I thus use the model without TFE.

[21] In this study, I use purchasing power, as a proxy for income. It represents the net income after taxes but includes social benefits (RWI and microm, 2019).

3.6 Results

In the following subsection I present the estimates of non-marginal willingness to pay for the current state of biodiversity in Hamburg estimated using the benchmark indicator species richness, as well as the results of the convergent validity assessment. The subsequent subsection elicits preference heterogeneity of non-marginal willingness to pay for biodiversity using the benchmark indicator and the Dynamic Habitat Index.

3.6.1 Willingness to pay for urban biodiversity in Hamburg and results of the convergent validity assessment

Table 3.1 displays the descriptive statistics of non-zero WTP estimates derived from the three biodiversity proxies.[22] The WTP estimates indicate a rejection of Hypothesis $H1$ as the mean, as well as the interquartile ranges of WTP estimates for biodiversity, are positive.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(50)	Pctl(75)	Max
Richness	106,567	465.2	735.8	3.1	130.1	230.7	484.6	18,418.1
DHI	81,067	211.2	452.3	−3,440.9	85.5	182.0	314.4	16,717.7
Biotope	117,036	695.0	903.3	−3,898.5	315.2	497.4	809.6	33,775.5

Table 3.1: Descriptive statistics of WTP estimates estimated with the three biodiversity proxies species richness, biotope quality and DHI. The present method can only identify WTP if a non-zero amount of biodiversity is demanded by city dwellers, since the first order condition in equation 3.6 is otherwise not defined. The table only displays non-zero values.

I exclude unidentified preference parameters as only the preferences of dwellers who demanded a non-zero amount of biodiversity can be identified with the present method (Panduro et al., 2018).[23] Figure 3.2 shows the densities of WTP estimated in the second-stage estimation (see equation 3.7). These results represent WTP for preserving the current level of urban biodiversity. The mean WTP for the current level of biodiversity including all non-zero estimates derived with the DHI is 211.2 Euro[2005] per household and annum, while mean WTP derived with the species richness proxy amounts to 465.2 Euro[2005] per household and annum. The densities do not align perfectly but still do seem to have very similar distributions. Please note that the densities displayed in Figure 3.2, are based on a subset of the WTP values. This is the case, as especially the DHI data set contains more zero values (please refer to the descriptive statistics in the Appendix) due to the resolution of the satellite data. At the available resolution, the satellite does not seem to be able to detect small habitats in otherwise extensively built-up areas. Since only preferences for a non-zero level of biodiversity can be recovered, this means that estimation with the satellite-based indicator recovers fewer of the revealed preferences for urban biodiversity (about 81,000 non-zero estimates,

[22] The full first-stage results estimated with equation 3.10 with each of the biodiversity proxies are shown in Tables B.12 to B.23. Please refer to Tables B.3 to B.8 for descriptive statistics of the included variables.

[23] With a biodiversity indicator indicating a non-zero level of biodiversity, resulting WTP can be negative or positive depending on the identified implicit price of biodiversity across the urban space. Please refer to equation 3.7.

please refer to Table B.24 and B.25 for statistics based on subsets using pair-wise, non-zero WTP estimates.) compared to WTP derived with species richness (about 107,000 non-zero estimates) or biotope quality (about 117,000 non-zero estimates).

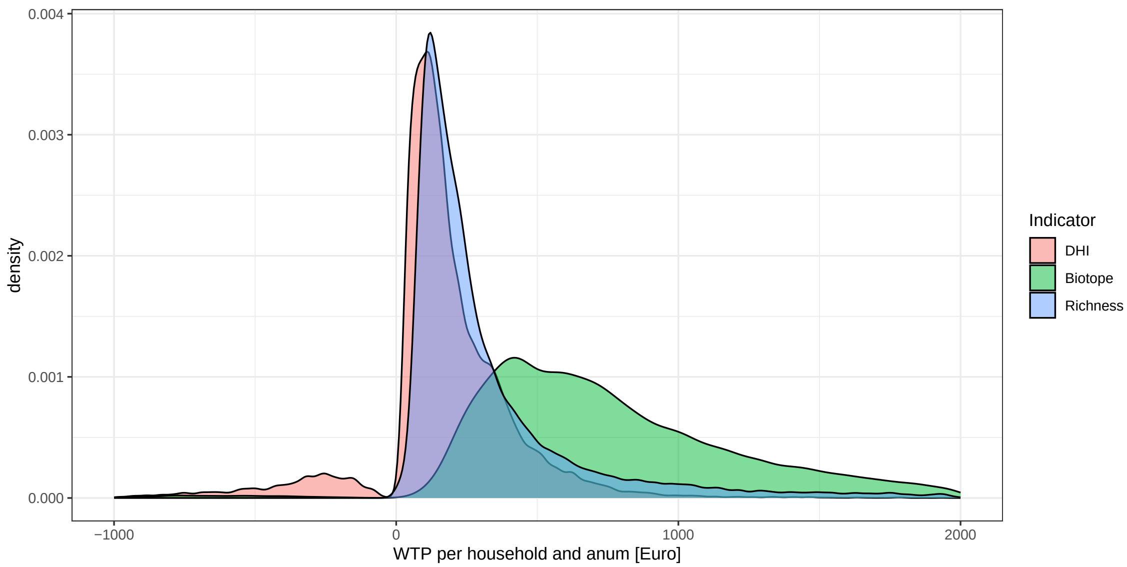

Figure 3.2: Densities of willingness to pay for biodiversity estimated with species richness, the satellite-based Dynamic Habitat Index (DHI) and biotope quality. The visualization excludes extreme outliers, since most estimates are smaller than 2,000 Euro[2005] and larger than -1,000 Euro[2005] per household and annum.

Tables B.24 to B.26 present the statistical results of pairwise comparisons of non-zero WTP estimates from three different subsets of data sources, each varying in their precision in identifying WTP. When using the species richness biodiversity proxy, all WTP estimates are non-negative. However, for the DHI and biotope quality proxies, 4% and 0.9% of the estimates are negative, respectively. Further analysis and robustness checks related to negative WTP estimates can be found in B.6.2.
Table 3.2 displays the results of the convergent validity analysis using WTP estimates derived with three proxies for biodiversity (please refer to Table: B.10 for relevant thresholds of convergent validity measures).
In the case of the WTP estimates derived with the satellite-based proxy, the degree of convergence with the estimates derived with the species richness indicator is not perfect but still relatively high. The results of the first and third convergence measures do not exceed the previously determined threshold of when convergence can be assumed. The mean percentage deviation of WTP estimates is however significantly larger than zero. For the median biotope quality indicator, the results indicate acceptable convergence with the results obtained with the species richness indicator when inspecting the $NRSME$ and r, the mean percentage deviation of WTP estimates is however at 271.31%. The convergence of the WTP estimates derived with the DHI and the biotope quality biodiversity proxies is the lowest. The $NRSME$ exceeds 1, the mean percentage deviation between the estimates is 287.94% and the correlation coefficient r is lower than in the two other cases.

	$NRSME$	λ	r	n
Biotope and Richness	0.84	253.73	0.70	64,958
DHI and Richness	0.63	12.94	0.79	42,009
DHI and Biotope	1.08	287.94	0.61	61,232

Table 3.2: Measures indicating the degree of convergent validity, with Pearson's correlation coefficient r, mean percentage deviation of WTP estimates λ and the root mean square error normalized with the standard deviation of one of the WTP estimates of biodiversity proxies, respectively $NRMSE$, as well as the sample size n excluding all zero values. The calculations are based on pair-wise comparisons where both measures are identified. Negative estimates were handled as described in B.6.2.

3.6.2 Preference heterogeneity of willingness to pay for the current level of biodiversity and welfare analysis

Table 3.3 elicits preference heterogeneity for biodiversity using the identified WTP values estimated with the three biodiversity indicators[24]. The results are relatively robust across indicators and subsamples used. WTP increases by 1.1% to 1.3% when the biodiversity indicator increases by 1%. WTP for biodiversity increases with the share of singles, families, and especially with the share of dwellers between the age of 30 and 60, followed by the share of 60-year-old households as well as with population density and purchasing power. WTP only decreases with the share of unemployed households within a housing block. The latter results could be seen as an indication that low-income households in the housing market may be outbid by high-income households when it comes to access to biodiversity, but could also reflect a systematic variation in preferences between employed and unemployed city dwellers mediated by factors such as education.

Policymakers could be interested in the welfare effects of a non-marginal change in urban biodiversity. I thus present the WTP estimates for a 25% improvement of urban biodiversity as measured by the three indicators. A 25% improvement of the current level of biodiversity in Hamburg would generate annual welfare benefits of between 1214 and 2693 Euro per household depending on the used biodiversity indicator.

[24] I tested several parametric specifications and ranked them based on the root mean square error of predicted values compared to the original WTP estimates, as well as on the Akaike and Bayesian information criterion. A log WTP-log biodiversity indicator specification produced the best model ranking directly followed by a concave quadratic relationship.

	Dependent variable											
	Ln WTP Richness				Ln WTP DHI				Ln WTP Biotope			
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
Intercept	-7.44	0.21	-7.82	-6.96	-10.10	0.33	-10.81	-9.48	-4.47	0.18	-4.86	-4.13
Ln Biodiversity	1.10	0.03	1.05	1.16	1.33	0.02	1.30	1.36	1.22	0.03	1.17	1.28
Between 30 to 60	0.13	2.5e-03	0.12	0.13	0.06	2.6e-03	0.05	0.06	0.07	1.9e-03	0.07	0.08
Above60	0.05	1.7e-03	0.05	0.05	0.01	1.7e-03	0.01	0.01	0.02	1.1e-03	0.02	0.02
Singles	0.01	2.7e-04	0.01	0.01	0.01	3.3e-04	0.01	0.01	0.01	2.2e-04	0.01	0.01
Families	8.7e-04	3.1e-04	2.6e-04	1.5e-03	5.9e-03	3.3e-04	5.2e-03	6.4e-03	1.7e-03	2.1e-04	1.3e-03	2.1e-03
PP	5.2e-05	1.9e-06	4.8e-05	5.6e-05	1.6e-04	5.3e-06	1.5e-04	1.7e-04	6.0e-05	2.0e-06	5.7e-05	6.4e-05
Popden	1.6e-05	6.9e-07	1.4e-05	1.7e-05	1.3e-05	1.3e-06	1.0e-05	1.5e-05	1.5e-05	7.8e-07	1.4e-05	1.7e-05
Unemployed	-0.05	1.1e-03	-0.05	-0.04	-0.03	1.4e-03	-0.04	-0.03	-0.02	8.3e-04	-0.02	-0.02
Ln Biodiversity**	-0.04	0.01	-0.07	-0.02	-0.15	0.01	-0.16	-0.14	-0.04	0.01	-0.06	-0.02
PP**	-0.32	0.01	-0.34	-0.29	-1.09	0.04	-1.15	-1.00	-0.29	0.01	-0.32	-0.26
District fixed effects	TRUE				TRUE				TRUE			
Observations	106,353				69,894				114,652			
Bootstraps	1,000				1,000				1,000			
Indicator	Species richness				DHI				Biotope quality			

Table 3.3: Decomposition of annual willingness to pay (WTP) in Euro[2005] per household and annum for biodiversity calculated with equation 3.8 using the biodiversity indicators species richness, the Dynamic Habitat Index (DHI) and biotope quality. Since the dependent variable is the natural logarithm of WTP values, respectively, the decomposition is based on positive WTP values only. Variables marked with a double asterisk are additional variables estimated with Gaussian copulas. LCI and UCI are the bootstrapped lower and upper confidence intervals. To be able to calculate the logarithm of the normalized biodiversity indicators, I multiplied them by 100. Coefficient estimates can hence be interpreted as percentage change, directly.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
WTP richness	106,567	1,695.5	2,827.1	0.4	424.2	1,763.5	71,289.8
WTP DHI	70,162	1,214.3	1,757.4	21.4	500.9	1,447.5	68,542.4
WTP biotope quality	117,036	2,692.7	3,753.7	−15,073.6	1,158.7	3,102.7	147,965.6

Table 3.4: Welfare analysis assuming a 25% improvement of current biodiversity as measured with three indicators using equation 3.9. The estimates show an annual willingness to pay (WTP) in Euro[2005] per household and annum for this specific improvement.

3.7 Discussion

3.7.1 Discussion and interpretation of the key findings

This study aimed at quantifying city dwellers' willingness to pay for a bundle of direct and indirect use values of biodiversity capitalized in the housing market. The results indicate a positive mean WTP for the current level of biodiversity measured with three indicators. There is considerable heterogeneity in WTP. A positive and economically relevant WTP for urban biodiversity contradicts the notion that city dwellers do not value urban biodiversity, and I reject Hypothesis 1.
The results of the preference decomposition show that given the current distribution of urban biodiversity, WTP increases over-proportionally with species richness, the DHI as well as with biotope quality, and the welfare analysis indicates significant positive welfare effects of a non-marginal improvement of urban biodiversity.
In relation to the pigeon paradox formulated by Dunn et al. (2006), the method of this study is not suited to investigating the underlying mechanisms and the formation of preferences for urban biodiversity in Hamburg and possible connections to preferences for conservation. The results, however, show that the net effect of interactions with urban nature on WTP for urban biodiversity, capitalized in the housing market in Hamburg, is overall positive.

Of course, it might be the case that mechanisms other than the encounter with nature close to the home influence preference formation and revealed WTP for (urban) biodiversity. An important one is education (Dunn et al., 2006). Biénabe and Hearne (2006) show that the level of education significantly affects WTP for biodiversity protection. Since the educational level is generally higher in urban compared to rural contexts (Ulubaşoğlu and Cardak, 2007), this seems to be a very relevant mechanism likely influencing the perception of urban biodiversity in Hamburg.[25]
The results of the convergent validity assessment suggest that the satellite-based Dynamic Habitat Index (DHI) may be a suitable alternative indicator for capturing similar aspects of biodiversity as ground-based species richness in non-market valuation in a revealed-preference context. While the DHI's spatial resolution may limit its ability to capture small habitats in densely built-up areas, its global availability and relatively high temporal resolution make it an attractive option. These findings support Radeloff et al. (2019), who demonstrated that the DHI is correlated with faunal species richness across biomes and is a promising biodiversity indicator for applications in biodiversity science and conservation.

3.7.2 Policy implications

Since the results indicate that urban biodiversity is perceived as a good, policymakers could focus on safeguarding and improving urban biodiversity to keep or to even improve the status quo as envisioned in the biodiversity strategy for Hamburg (BFN, 2022). Improving urban biodiversity could entail restoring habitats to preserve or reinstate native species where it is practical (J. R. Miller, 2005; Dunn et al., 2006). This does not necessarily involve trade-offs with other policy goals, such as flood protection or increasing the supply of housing. Nature-based solutions such as

[25] Unfortunately, I do not have data on educational status available in a sufficient resolution to include in the model specification and verify whether a revealed-preference application would come to similar conclusions.

constructed wetlands and green roofs as alternatives to grey infrastructure can work synergistically in reaching several policy goals. Nature-based solutions work in reducing runoff and thus reduce flood risk, reducing pollutant loads as well as reducing the heat island effect and at the same time improve urban biodiversity by habitat provision (Pankratz et al., 2007; Dearborn and Kark, 2010). Apart from improving biodiversity in existing designated urban green spaces in the city, focusing on improving biodiversity on other patches of green e.g. along roads could be a good option to create co-benefits. Sowing wildflowers to revegetate degraded soil and provide habitat to insects is just one of many examples of how urban biodiversity could be improved at low cost (Bretzel et al., 2016).

In a discrete choice experiment investigating the valuation of direct interaction with everyday wildlife through feeding garden birds, Brock et al. (2017) show that people derive well-being by adopting a warden-like role towards selected bird species they encounter which manifests in a positive WTP for those species. Policy interventions informing and directly involving citizens in local biodiversity enhancement might thus be useful to spark feelings of ownership and relatedness (J. R. Miller, 2005; Dunn et al., 2006). Local communities could, for instance, be involved in the planning, design, and management of green spaces and urban landscapes, and be included in promoting biodiversity by creating and maintaining wildlife habitats, planting native species, and reducing the use of harmful chemicals. Education and awareness campaigns could promote a greater sense of relatedness to nature and a better understanding of the importance of biodiversity. Over time, this might change the degree to which biodiversity capitalizes on the housing market and presents an interesting research question.

Since biodiversity (measured with three indicators, which potentially relate to different aspects of biodiversity to different degrees) capitalizes in the housing market, biodiversity enhancement might involve an increase in rents. This can have adverse effects for low-income households who might not be able to afford the higher rents (Banzhaf et al., 2019). Policymakers should thus take into account the reinforcing mechanism of income inequality and environmental inequality and address them with suitable regulation to reduce or avoid trade-offs between social and environmental policy goals.

3.7.3 Comparison with previous research

The findings of this study contradict those by Belcher and Chisholm (2018), who found a negative effect of vegetation with a high biodiversity value on adjacent housing prices in Singapore. The authors explain their findings by the fact that dangerous animals like deadly snakes or wildlife that are perceived as nuisances, such as long-tailed macaques are more likely to appear in vegetation with a high conservation value than in managed vegetation. In a city such as Hamburg, there is no threat of encountering deadly snakes which could partly explain differing results, but encounters with rats, wild boars, or foxes, which some people will consider dangerous are still possible. A further reason for the differing results could be the different baselines concerning the general "greenness" of the two cities which might also affect city dwellers' perception and preferences for urban biodiversity. While urban green spaces, agricultural land, and forest cover make up around 39 % of Hamburg's land cover (Statistisches Amt für Hamburg und Schleswig-Holstein, 2017), Singapore's vegetation cover amounts to more than 56% of the metropolitan area (Yee et al., 2011). Even though the functional form that best describes the relation between WTP for the current level of biodiversity and the biodiversity indicator was a logarithmic function (please refer to Section 3.6), a quadratic specification came in second when ranking the different transformations according to their Bayesian and Akaike Information Criteria. It might be that WTP for urban biodiversity does not saturate at a specific level, but starts decreasing again once an optimal level from a direct-use perspective is reached. This would be in line with Johansson et al. (2014) who found that an intermediate level of biodiversity in forests was rated highest in preference. These considerations highlight the importance of environmental and cultural context when valuing non-market goods and are broadly in line with Hynes et al. (2013), who stress the importance of adjusting benefit estimates in benefit transfer studies based on cultural factors if study sites do not share institutional and cultural similarities.

A positive WTP for biodiversity is in line with findings of a positive association of biodiversity indicators and self-reported well-being by Fuller et al. (2007), experimental findings by Lindemann-Matthies et al. (2010) and findings of a choice experiment by Bronnmann et al. (2020). The latter study finds a median WTP of 17 Euros per month for an increase in the naturalness of the closest green space by one standard deviation, which is equivalent to 204 Euros per annum. Even though the estimates are not directly comparable as this study quantifies the WTP for the current level of biodiversity around housing units and not exclusively in designated urban green spaces, the median WTP estimates derived with the DHI (182 Euro [2005] per annum and household) and the species richness indicator (231 Euro [2005] per annum and household) are close to this value. The estimate derived with the biotope quality indicator are more than twice as high (497 Euro [2005] per annum and household). Since the values recovered with HP are location-specific values and likely do not capture the whole range of indirect use values, they can be interpreted to present a lower bound of use values of urban biodiversity (Lansford Jr and Jones, 1995).

3.7.4 Strengths and limitations of the study

In this study, I employed species richness, the dynamic habitat index derived from satellite data, and expert-assessed biotope quality to capture both direct and indirect use values of biodiversity. I investigated the correlations between these indicators, as well as their associations with environmental variables that have previously been shown to influence residential housing choice, and compared the distributions and mean values of WTP estimates derived using HP. During this process, it became evident that although HP is an effective method for capturing use values of biodiversity that influence housing market decisions, it poses challenges in distinguishing between captured direct and indirect use values of biodiversity. It is likely that both recreational and aesthetic aspects of biodiversity, as well as functional aspects, drive the capitalization of biodiversity in the housing market. The relative importance of these drivers, however, cannot be assessed in this study. To overcome this challenge, I would recommend employing multiple indicators, including functional, taxonomic, and structural aspects of biodiversity and combining several valuation methods, in future research. Future studies could for example combine the hedonic property model with the production function approach and stated preference methods to investigate this further. Data limitations may restrict the selection of indicators, as was the case in this study.

While previous research found that species richness was correlated with recreational preferences, it is less clear what functional aspects of biodiversity are perceived by households and ultimately affect behavior in the housing market. Since I would expect WTP containing all indirect use values of urban biodiversity to be much higher than found in this assessment (Mace et al., 2012), I believe that the WTP estimates are mainly driven by the amenity value of urban biodiversity.

While the biotope quality indicator might capture what experts perceive, expert judgment introduces another source of inevitable subjectivity in the assessment (Jalkanen et al., 2020) which is not the case for the satellite-based DHI. In this case, this seems to be reflected in the WTP estimates derived with the biotope quality indicator which according to the convergent validity assessment do not seem to capture the same aspects of urban biodiversity, as species richness and the DHI do. Since the biotope quality indicator specifically includes ecological functions as a criterion, one could speculate that the indicator captures more of the indirect-use values related to ecosystem functions. Since all three biodiversity indicators show a similar mean effect on selected environmental quality variables (pm10 concentrations and maximum annual temperature) it does not seem warranted, however, to simply assume this. On the contrary, it is possible that certain evaluation criteria within the biotope quality indicator may drive results that are not necessarily related to biodiversity per se, such as rarity or the level of pollution. Hence, it is recommended to employ several clearly defined biodiversity indicators that have been previously used in similar valuation studies, if feasible. This would enable a more comprehensive and accurate interpretation of the recovered use values of biodiversity while minimizing the potential for measurement biases.

3.7.5 Implications and future directions

Further research is needed to elucidate the complex mechanisms and interrelationships involved in urban biodiversity, human well-being, and conservation efforts. For example, future studies could investigate the impact of specific interactions with urban fauna on willingness to donate for biodiversity conservation in an experimental setting, using a design similar to Brock et al. (2017). It would also be interesting to investigate city dwellers' WTP for urban biodiversity along a gradient of biodiversity and educational status in several urban areas and cultural contexts. To achieve this, the availability of a uniform biodiversity indicator is critical.

All in all, the results show that there is an economically significant positive WTP for urban biodiversity in Hamburg. The estimates of annual WTP per household lie within the range of values found by studies estimating WTP for environmental quality in non-urban settings, which were reviewed by Hökby and Söderqvist (2003).

The findings of this study are relevant for urban planners as they show that biodiversity is an important factor to consider in (future) planning decisions. It might be possible to achieve co-benefits of urban biodiversity conservation and improvement locally, both by directly improving city dwellers' well-being through the amenity value of biodiversity as well as through the role of an underpinning regulator of ecosystem services. As discussed, improving urban biodiversity might also have implications for global biodiversity conservation and related policy goals. Connecting or reconnecting people to nature close to their home seems to be a relevant approach to achieve synergies between broader policy goals such as sustainable development goals 11 ("Sustainable cities and communities"), 14 ("Life below water") and 15 ("Life on land") (J. R. Miller, 2005; Dunn et al., 2006; Rands et al., 2010).

4. Deforestation, Institutions, and Property Rights: Evidence from land titling to indigenous peoples and local communities in Ecuador

Authors: Michael Tanner and Leonie Ratzke

Abstract: Deforestation is a matter of pressing global concern, contributing to declining ecosystem services, biodiversity loss, and ultimately climate change through growing emissions. We evaluate the effect of assigning property rights to indigenous peoples and local communities (IPLCs) in coastal Ecuador on deforestation and the role polycentric institutions play in policy effectiveness. Informed by a theoretical model, we employ causal methods to 1) evaluate changes in forest coverage for the first 12 years of policy adoption, and 2) evaluate the effect of the presence of non-governmental organizations (NGOs) on policy permanence. We find that assigning property rights to IPLCs significantly decreases mangrove deforestation and that the presence of NGOs funded by foreign aid significantly increases the probability of policy adoption and permanence. We assess the positive development implications of the policy concerning local fisheries provisioning and the role of international aid in achieving environmental outcomes. Our work highlights the importance of IPLCs and civil society as actors for sustainable land stewardship in future climate policy.

4.1 Introduction

The problem of the sustainable management of commons is still one of the biggest challenges facing economics. Concerns about water and air quality, pollution and hazardous waste, species extinction, maintenance of stratospheric ozone, and most recently the stability of the global climate have only increased in importance (Stavins, 2011). Amongst these, deforestation is a matter of pressing global concern, contributing to declining ecosystem services, biodiversity loss and growing carbon emissions. In particular the last century has seen an increase of deforestation in previously untouched ecosystems, with the prime example being the amazonian forest. Similarly, mangrove forests, which are inter-tidal forests occurring along tropical, subtropical, and some temperate coasts have been experiencing equal or greater rates of deforestation (Duke et al., 2007b; Richards and Friess, 2016b). Despite this fact, the issue of mangrove degradation and deforestation has received comparatively little attention (Friess et al., 2019).
Mangrove forests overlap with high and increasing densities of human populations. Therefore, mangroves provide key regulating, provisioning and cultural ecosystem services such as coastal protection, pollution control, food provision, and cultural values for hundreds of millions of people (Barbier et al., 2011a). Mangroves' ability to provide relatively larger carbon sequestration when compared to other forests, as well as increased coastal resilience in the face of extreme weather patterns (Del Valle et al., 2020; Hochard et al., 2019), has placed them on the international climate change mitigation and adaptation agenda. Recent global commitments made during COP 26 highlight the critical importance of stopping deforestation. To achieve this, policymakers stressed the central role "[...] and value of knowledge and forest guardianship provided by Indigenous Peoples and local communities, calling for indigenous peoples to be empowered as such" (UNFCCC, 2021).

To curb deforestation numerous policies have been implemented with varying degrees of success. A key contribution of economics to this issue has been the development of market-based approaches to environmental protection of forests (Souza-Rodrigues, 2019). As many forest resources are held as common property or open access, problems pertaining their management have frequently also been addressed by common-property regimes of collective management (Ostrom, 2000). Evidence for the effectiveness of said approaches seems to be available at the local level, but questions remain pertaining their suitability as commons problems have spread beyond communities and even across nations (Stavins, 2011). In that light the promotion of property rights has been proposed as a way to ensure scarcity is well reflected in markets, and large scale land titling interventions have been championed as a policy to reduce deforestation and to achieve development goals, with potential benefits ranging from poverty reduction to food security (Liscow, 2013b; Miller et al., 2021). Moreover, such interventions allow for the testing of the effectiveness and suitability of decentralized or polycentric forms of governance to govern and manage public goods (Ostrom, 2010). Specifically, transferring formal property rights to indigenous peoples and local communities addresses environmental justice and human rights issues concerning violence, expropriation and encroachment (BenYishay et al., 2017b).

Property rights for indigenous and local communities also play a central, albeit, little recognized, role in the fight against climate change. Amazon indigenous territories alone cover nearly one-third of the region's land area across eight countries, and along with protected areas, protect over 52 percent of existing carbon stocks in the entirety of the Amazon forest (Walker et al., 2020). Theoretically, property rights could have ambiguous effects on deforestation depending on institutional and market settings (Busch and Ferretti-Gallon, 2017). Empirical evidence has found that land titling increased deforestation by small landholders in Brazil (Probst et al., 2020), and Nicaragua (Liscow, 2013b), although both studies focus on private land holders. In contrast, recent evidence on communal/indigenous property rights[1] policies, finds mixed evidence on its effect on deforestation (Baragwanath and Bayi, 2020; BenYishay et al., 2017b; Blackman et al., 2017; Buntaine et al., 2015). Rigorous analyses of titling campaigns are rare, with most studies not dealing with the non-random assignment of policy, therefore risking biased estimates of policy impact. Moreover, related theoretical and empirical research suggests that tenureship changes could either stem or spur forest damage impact (Miller et al., 2021; Busch and Ferretti-Gallon, 2017).

We identify several gaps in this broader literature, which mostly focuses on the effectiveness of interventions using panel methods, therefore not dealing with potential time-varying omitted variables that might bias estimates of interest (Blackman et al., 2017; Busch and Ferretti-Gallon, 2017; Miller et al., 2021). Furthermore, this body of work seldom presents empirical evidence of why or how these interventions work, nor do they reconcile observed effects with possible theoretical mechanisms behind said successes or failures (Deaton, 2010b). We address these gaps in our study, and provide, to our knowledge, the first causal evaluation of a property rights based project targeting a previously understudied ecosystem, i.e. mangrove forests. Our aim is to contribute to the research on deforestation in the tropics and relevant climate and development policy, by first empirically examining the effects of formalizing land rights to "ancestral users" and its effectiveness on reducing mangrove deforestation in Ecuador. Secondly, we propose mechanisms that make said policy work, specifically showcasing the wide diversity of institutional arrangements in place, accounting for the role of international aid and NGO involvement in policy enrollment and outcomes. Specifically, we focus on the effect of local institutions by ancestral users, the presence of common-pool resources such as fisheries, and non-governmental organization involvement as the main mechanisms of policy success. To this end, we establish a simple stylized model to guide the empirical strategy and gain insights into conservation outcomes and policy adoption from communities. Our study is centred on the "Acuerdos de uso sustentable y custodia de manglar" (AUSCM) land titling policy, a pioneering land rights program across coastal Ecuador for mangrove conservation launched in the year 2000, and included in Ecuador's national climate policy structure.

Our research contributes to several strands of literature. First we add to the literature on policy evaluation and causal methods in tropical deforestation (Sims, 2010b; Ferraro et al., 2012a; Liscow, 2013b; Souza-Rodrigues, 2019; Assuncao et al., 2022), specifically the effect of property rights granted to indigenous communities on mangrove deforestation, thereby expanding this literature to an important ecosystem, providing a rich data set and identification strategies. Second, this research aims to add to the body of work on common pool resources and institutions, in the framework of decentralized environmental and climate change policy (Ostrom, 2000; Dietz et al., 2003b; Ostrom, 2010), specifically looking to contribute with an empirically rigorous assessment of the existence of a wide variety of institutions for the governance of a large scale commons problem. Finally, we contribute to the literature on the role of transactions costs and property rights in environmental policy making (Libecap and Lueck, 2011; Libecap, 2014; Ayres et al., 2018; Bühler, 2022), and add to the growing body of work studying the impact of the non-profit and non-governmental sector in influencing policy implementation, compliance, and policy relevant outcomes (Usmani et al., 2022;

[1] Communal property rights are usually held in common ownership and may not be transferred or used as collateral (Probst et al., 2020).

L. E. Grant and Grooms, 2017; Fitch-Fleischmann and Kresch, 2021).
The AUSCM policy was formulated in 1999 and implemented in 2000 in response to the rampant deforestation the country experienced during the 20th century which lead to losses of over 40% of all mangrove coverage in Ecuador. This historical process was characterized by systematic encroachment and episodes of violence, leading to not only the loss of the ecosystems, but also to the loss of the traditional means of subsistence of ancestral communities, with adverse effects on development and food security (Beitl, 2014b; Veuthey and Gerber, 2012b). By 2020, 60 communities had property rights assigned, and 94 in total had been historically part of the policy. Communities voluntary join the program, and over 30 percent of all remaining mangrove coverage in the country is covered by the policy.
Given that both policy and NGO presence are not assigned randomly, to achieve our stated goals presented above we develop an identification strategy that deals with the endogeneity of a) policy adoption by communities and b) NGO involvement. First, we evaluate the causal impact of the AUSCM policy on mangrove deforestation by employing an instrumental variable strategy, using the presence of aquatic organisms and relevant soil types as exogenous predictors of policy adoption. Second, by exploiting the variation in NGO involvement across time and communities, we investigate the causal impact of non-profit and non-governmental involvement on policy adoption and permanence. We employ a regression discontinuity design exploiting partisan voting behavior in the United States Congress as exogenous predictor of foreign aid disbursements and thus NGOs presence in policy uptake. We use this approach, since most of the NGOs who were working with ancestral communities in the periods we study were at least partly funded by the United States Agency for International Development (USAID).

Our results confirm that the adoption of communal property rights by ancestral communities reduces mangrove deforestation. This result is robust across different specifications, with the chosen instrumental variable being a strong predictor of policy adoption. This has positive implications for climate policy seeking to reduce emissions from deforestation, and north-south payments compensation mechanisms as part of the global climate mitigation strategies. We estimate that the policy prevented a total of 1.5 million $tCO2$ emissions between 2010 and 2012. Valued at the social cost of carbon[2], this corresponds to almost 60 million $US\$$ of avoided damages.
Additionally, we find that devolution of property rights to ancestral communities provides more protection to mangrove forests against deforestation when compared to state-led protected areas, and that the presence of commercially important fisheries in mangrove forests is a strong predictor of property rights adoption by communities. These results therefore have positive implications for both development and food security benefits of the policy, notwithstanding the environmental justice component of devolution of rights to ancestral communities.
With regards to our second aim of assessing the effect of external actors' involvement on policy uptake, our results show that involvement of the non-profit and non-governmental (NGO) sector has a positive effect on the adoption and permanence of policy by ancestral communities. Our regression discontinuity design (RDD) relies on the partisan vote share margin in the US Congress as an exogenous predictor of foreign aid disbursements and hence the degree of NGO support. Our results suggest that NGO involvement affects policy adoption positively. We deduce that the mechanism for this is the reduction of transaction costs communities would otherwise have to bear to full fill the bureaucratic requirements of the policy. Likewise, our results highlight both the important role NGO involvement plays in environmental policymaking as well as that desired

[2] We used the estimate of 112.86 $US\$/tC$ by Wang et al. (2019).

policy outcomes are at least partly dependent on the availability of international aid.
This paper is organized as follows: in Section 4.2 , we detail the study and policy context. Section 4.3, describes our theoretical model and the mechanisms affecting a communities decision to adopt property rights. In section 4.4 we present the data used in this study. In Section 4.5, we describe our identification strategy. Section 4.6.1 includes findings from the grid-level analysis of the effect of property rights on deforestation, whilst section 4.6.2 includes our results on the presence of NGOs on policy adoption. Section 4.7 continues with a brief discussion of our results.

4.2 Policy description and study context

The AUSCM policy was formulated in 1999 and implemented in 2000 in response to the failure of command-and-control approaches and the deforestation the country experienced during the 20th century. It is estimated that approximately 30% to 40% of all mangrove coverage in Ecuador was lost since 1970 (Friess et al., 2019).

The degradation and deforestation of mangroves has been mainly driven by aquaculture and specifically, shrimp-farming. Onshore aquaculture was the leading cause of mangrove deforestation during the second half of the twentieth century, with its expansion entailing the conversion of standing mangrove forests into aquaculture farms. (Friess et al., 2019) Historically, shrimp-farming started in Ecuador in the late 1960's, promoted both by the state and international development agencies. It boomed during the 20th century benefiting local economic elites, with its expansion encroaching on mangrove ecosystems and the traditional lands of indigenous peoples and local communities (IPLCs)[3] in coastal Ecuador. Ecuador experienced a loss of approximately 30% to 40% of all mangrove coverage, despite the deforestation ban and additional protection status of mangroves provided by protected areas created between 1979 and 1995 (Rodríguez, 2018; Beitl, 2011; Veuthey and Gerber, 2012b). Apart from the overall biodiversity loss caused by deforestation, there were direct impacts on local communities as traditional users of the mangroves' provisioning services, who depend on the respective marine resources as their main source of income. Specifically, two fisheries stand out as the main sources of income of mangrove dependent communities, the red crab and the fishery for mangrove cockles. Both are of artisanal nature, where local fishers collect crabs and cockles in mangrove forests. As communities were not themselves involved in shrimp farming and associated economic benefits, the destruction of mangrove ecosystems resulted in a loss of subsistence for these communities (Rodríguez, 2018; Veuthey and Gerber, 2012b; Beitl, 2014a)[4]. Hence, this historical process was characterized by systematic encroachment and episodes of conflict, leading to not only the loss of ecosystems, but also the traditional means of subsistence, with implications on development and food security (Veuthey and Gerber, 2012b; Beitl, 2014b).

In light of these impacts, the AUSCM institutionalized a "process of devolution of rights to communes, communities, peoples and ancestral nationalities, who may request an AUSCM for their subsistence, use and sustainable exploitation of mangrove based resources" (Bravo, 2013). The explicit aim of the project was to preserve mangrove forests and support the rights and well-being of ancestral communities. The policy is based on the rationale that communities have a self-interest in conserving mangrove ecosystems, which they had managed successfully historically. From the IPLCs perspective, mangrove preservation is a rational behavior, as a functioning mangrove ecosystem provides an ideal breeding and nursery habitat for marine species to prosper (Barbier, 2017). These marine species are highly valued in local markets, and thus increase the resulting benefits for communities (Beitl, 2014a)[5]. AUSCM were and are granted upon request, are non-transferable and are collectively held for 10-year periods subject to renewal. Importantly, communities needed to have a legally established collective entity to apply to the program, be it in the form of an asso-

[3] Please note that in this paper we use the terms IPLCs and ancestral communities interchangeably.

[4] The process of mangrove degradation differs slightly from that of other land forest ecosystems. This is the case, as alternative land-uses such as conventional farming which local communities might otherwise have reverted to are not possible in the mangrove areas as they are regularly flooded by seawater.

[5] According to Beitl (2014a), the people in the communities strongly identify as a fisher men and women and hope to protect the mangroves also to be able to pass traditions on to their children.

ciation, cooperative, or commune. Furthermore, a detailed management plan had to be submitted when applying to the policy. These requirements related to the policy were challenging at least for some communities who already had monetary and time constraints and suddenly had to cope with additional and largely unfamiliar work. Many communities thus received technical assistance by external organizations such as NGOs and universities, to successfully handle bureaucratic tasks and formal complaints to officials when they noticed infringement of the mangrove deforestation ban (Beitl et al., 2019).

If accepted, communities gained exclusive rights over resources within the mangrove forests, also adopting duties of monitoring, and reporting on compliance per semester according to the submitted management plan. We understand both the administrative as well as the monitoring tasks as transaction costs associated with the policy. The communities were and are facing a trade-off of policy related transaction costs and the benefits resulting from harvesting natural resources from the mangrove ecosystem.

The final granting of property rights involved the previously described application process, which was then followed by a demarcation period, entailing the required approval by executive decree by the Environmental Ministry of Ecuador. By 2020, 60 communities located in all coastal provinces of Ecuador where within policy, with over 90 having been historically part of the policy. Figure 4.1 showcases the distribution of all currently remaining mangroves across the Pacific coast of Ecuador. Please refer to Figure A.3, for a depiction of mangroves with and without property rights in the gulf of Guayaquil.

Figure 4.1: Mangrove coverage (marked in black) in Ecuador are our study area. Source: Own depiction.

4.3 Theoretical framework and hypotheses

In the following we present our theoretical model which builds upon work by Usmani et al. (2022) and Souza-Rodrigues (2019). With this model we aim at investigating the theoretical effect of communities' property rights on illegal conversion of mangrove area[6], as well as the effect of NGO involvement on policy uptake and renewal, before addressing the questions empirically in section 4.5.

Each community is treated as a representative agent, assuming that the members of a community have a joint utility function $U(c, E)$. Utility is a function of consumption c and cultural and regulating ecosystem services $E(I, a)$. Ecosystem services $E(I, a)$ are affected by illegal land conversion activities $I(p)$. These are carried out by external actors and are a function of exogenous global shrimp prices p.[7] We assume that cultural and regulating ecosystem services decrease in illegal land conversion activities I:

$$\frac{\partial E}{\partial I} < 0 \tag{4.1}$$

as illegal conversion of mangrove area to shrimp farms entails deforestation of mangroves and thereby reduces mangrove cover and the related ecosystem services such as flood protection and carbon sequestration. Each community decides whether to acquire property rights a by adopting the policy described in section 4.2 and acts as a representative rational utility maximizing agent with a common income and time constraint T. Property rights a are defined as share of land parcels with communal property rights assigned to them.

We assume that cultural and regulating ecosystem services linearly increase in a, as communities are interested in keeping the ecosystem they acquired property rights for intact to increase extractable fishery resources :

$$\frac{\partial E}{\partial a} > 0; \frac{\partial^2 E}{\partial a^2} = 0, \tag{4.2}$$

Each community's utility function is assumed to be twice differentiable, continuous, and concave and increases in consumption, as well as in regulating and cultural ecosystem services:

$$\frac{\partial U}{\partial E} > 0; \tag{4.3}$$

$$\frac{\partial U}{\partial c} > 0 \tag{4.4}$$

A community's available budget consists of extracted environmental goods $F(a, I, e)$, i.e. edible water organisms, such as crustaceans and molluscs with the price p_f

[6] Please note that mangrove deforestation was codified as illegal in Ecuador since 1994, thus total mangrove deforestation is equivalent to illegal deforestation. In the following we use the term 'illegal deforestation'.

[7] Illegal land conversion activities are also affected by other exogenous factors that have an impact on shrimp farm profitability as the sole alternative land use. Among others these factors are monetary sanctions for illegal mangrove deforestation and distance to centers of commerce. Please note at this point that the exogenous environmental variables e affecting the availability of fishing resources $F(a, I, e)$ are not the same as the factors driving shrimp farm profitability. We will come back to this point in section 4.5.1 which illustrates our identification strategy. Please also note that other land-uses such as other agricultural activities are not possible here as the land is regularly flooded by seawater.

The level of fisheries resources $F(a, I, e)$ depends on habitat state and size (Barbier, 2017). As property rights are intended to prevent alternative land-uses and the concurrent destruction of the organisms' hydrological habitat, the level of fisheries is affected by the amount of land for which a community holds property rights a. We assume that F increases linearly in a:

$$\frac{\partial F}{\partial a} > 0; \frac{\partial^2 F}{\partial a^2} = 0, \tag{4.5}$$

Apart from a, the available fisheries resources are impacted by exogenous environmental parameters, such as salinity, temperature and soil type. This is the case as the mentioned organisms can only exist and survive under specific environmental conditions. We define e as the share of soil type with the adequate mineral composition for marine organisms to flourish available within a land parcel. Heterogeneity in e thus represents an exogenous source of variation in fisheries resources $F(a, I, e)$ across land parcels and communities, we will exploit in our identification strategy. We assume

$$\frac{\partial F}{\partial e} > 0; \frac{\partial^2 F}{\partial e^2} < 0 \tag{4.6}$$

Since there are other restrictions to the growth of marine resources such as limited food availability, the resources grow in e at a decreasing rate. Just as with the regulating and cultural services we furthermore assume that provisioning services, i.e. marine resources decrease in illegal land conversion activities:

$$\frac{\partial F}{\partial I} < 0; \tag{4.7}$$

If a community decides to acquire property rights it is entitled to extract the available provisioning services as a source of income. It is however also obliged to comply with legal and administrative requirements associated with the policy as well as an obligation to monitor the mangroves. For these activities the community incurs transactions costs $TAC = w \cdot t(N) \cdot a$ by allocating time $t(N)$ measured in time per land parcel with property rights to administrative tasks and monitoring activities at wage rate $w > 0$.

Involvement of external institutions, such as non-governmental organizations (NGOs) $N(a, f)$ can however support communities with regards to administration time effort. We assume

$$\frac{\partial t(N)}{\partial N} < 0, \frac{\partial^2 t(N)}{\partial N^2} < 0 \tag{4.8}$$

Implying that administration time connected to policy roll-out can be reduced by NGO involvement at a decreasing rate. Apart from a NGO involvement is also affected by the availability of exogenous (international) funding f. We assume that NGO involvement linearly increases with amount of property rights

$$\frac{\partial N}{\partial a} < 0, \frac{\partial^2 N}{\partial a^2} = 0 \tag{4.9}$$

and increases with available exogenous funding f at a decreasing rate:

$$\frac{\partial N}{\partial f} > 0, \frac{\partial^2 N}{\partial f^2} < 0 \tag{4.10}$$

The former relies on the intuition that the administrative effort for communities increases with the amount of land with property rights (e.g. a larger area needs more mapping and surveying effort).

Income is allocated to consumption c and transaction costs of the policy [8] resulting in equation 4.12. In the following we use subscripts to represent partial derivatives.

Thus, the following optimization problem represents the decision each community faces in a specific year when deciding whether to enter or stay in the policy. For ease of reading, community and time-specific subscripts are left out here.

$$\max_{a,c} U = U[c, E(I(p), a)] \tag{4.11}$$

s.t. income constraint

$$F(a, I, e) \cdot p_f = c + w \cdot t(N(a, f)) \cdot a \tag{4.12}$$

and s.t. time constraint

$$T \geq t(N(a, f)) \cdot a \tag{4.13}$$

The Lagrangian for this optimization problem is thus:

$$\begin{aligned} L = U[c, E(I(p), a)] + \\ \pi \cdot (F(a, I, e) \cdot p_f - c - w \cdot t(N(a, f) \cdot a) + \\ \lambda \cdot (T - t(N(a, f)) \cdot a) \end{aligned} \tag{4.14}$$

We use the first order conditions to apply the implicit function theorem using Cramer's rule (please refer to C.3) and get:

$$\frac{\partial I}{\partial e} = \frac{F_e}{F_I} < 0 \tag{4.15}$$

We assume that fishery resources increase with the share of soil type with an adequate mineral composition for marine species to prosper within a land parcel (assumption made in equation 4.6), which renders the enumerator of the previous expression positive. We furthermore assumed that fishery resources decrease in illegal mangrove deforestation activities (see equation 4.7), due to the concurrent destruction of the marine organisms' habitat, rendering the denominator and with it the whole expression negative. The corresponding hypothesis we test with the specifications further described in section 4.5.1 is thus:

> ***H*1**: *Soil type is an exogenous predictor of fishery resources, which in turn results in an increased utility of acquisition of property rights by local communities leading to reduced deforestation of mangroves.*

In order to derive our second hypothesis we apply the implicit function theorem using Cramer's rule again (please refer to C.3) and get:

$$\begin{aligned} \frac{\partial a}{\partial f} = \frac{U_c \cdot w \cdot t_N \cdot N_f}{U_c \cdot w \cdot 2t_N \cdot N_a} = \\ \frac{N_f}{2N_a} > 0 \end{aligned} \tag{4.16}$$

[8] The time spent fishing is not included in the model, as it is not necessary to derive the following hypotheses.

With assumption 4.10 we get a positive enumerator and with assumption 4.9 a positive denominator, resulting in an overall positive expression.
This leads to the second hypothesis, which we test using the identification strategy described in section 4.5.2:

> ***H2***: *Exogenous international aid disbursements as a predictor of NGO involvement increase the probability of property rights acquisition and continuation by local communities*

4.4 Data

In the following we describe how we compiled and processed our data set from various sources. The variable of interest, mangrove forest coverage in a defined spatial unit is available as a $1\ km^2$ resolution grid for the years 2000 – 2012 (Hamilton, 2015). The raster value indicates the mangrove coverage between zero and 955 square meters. We included raster cells that had a mangrove forest coverage larger than zero square meters in one of the mentioned years as observations in our final data set and used the centroid of each cell to extract data from other spatially overlapping data sources [9]:
Please refer to Hamilton and Casey (2016) for detailed information on data pre-processing of the mangrove cover grid. Next, we created a deforestation variable by subtracting the forest cover in of a year t with the mangrove cover in $t-1$ and multiplied the variable with minus one. The larger the value of the new variable is, the stronger the illegal land conversion in a cell.
In order to define whether a cell is treated, i.e. was part of the policy and had property rights assigned to it, we acquired the geographical demarcation of communities with property rights in the AUSCM as vector data and information on the duration of treatment for each community.
Additionally, we extracted covariates describing the communities such as number of members, number of reports issued to the government as well as their size from the management reports communities submitted. We merged the data on communities with the spatial information using the names of communities as unique identifiers. Moreover, we acquired data on the presence and timing of involvement of external actors, as well as on the type of organisation and source of funding supporting each community from the same source.
Furthermore, we included covariates which drive the profitability of shrimp-farming as the sole alternative land-use. We included mean annual temperature, calculated based on I. Harris et al. (2014) down scaled with the procedure by Fick and Hijmans (2017), population density extracted from Center for International Earth Science Information Network - CIESIN - Columbia University (2018), as well as euclidean distance to the closest major city, calculated based on a vector data set by World Bank (2017).
Since several protected areas were created previous to the policy (Rodríguez, 2018), we include the legal protection status of each raster cell as a control variable. We extracted it from a spatial data set providing information on the start date, type and geographical position of legal protection status acquired from the Ministry of the Environment of Ecuador. For our identification strategy described in section 4.5.1 we compiled spatial data on the presence of shellfish, as well as red and blue crabs with maps provided by the Ministry of Environment and from the National Institute of Aquaculture and Fisheries Research in Ecuador and a map of soil types by Dijkshoorn et al.

[9] All available data sets were reprojected to the WSG 84 / UTM zone 17S projection and preprocessed in QGIS and R

(2005).[10] Furthermore we acquired returns for elections to the U.S. House from MIT Election Data and Science Lab (2017) and data on annual foreign aid distributed by USAID (USAID, 2021) for the identification strategy described in section 4.5.2. Please refer to Table C.4 for a list of variables with respective sources.

4.5 Econometric framework and identification strategy

In order to test the hypotheses presented in section 4.3, we need to account for the endogeneity of policy adoption by communities and NGO involvement.
To test hypothesis H1 we exploit the dependence of aquatic organisms on environmental parameters, i.e. selected soil types as exogenous predictors of policy adoption, by carrying out an instrumental variable approach, which is illustrated in Figure 4.2 and further described in subsection 4.5.1. Second, we investigate the causal impact of NGO involvement on policy adoption by testing hypothesis H2 with a regression discontinuity design illustrated in Figure 4.2 and described in more detail in subsection 4.5.2.

[10] Please refer to Figure A.4 for a screenshot of the data showing the spatial distribution of fishery resources in an example community.

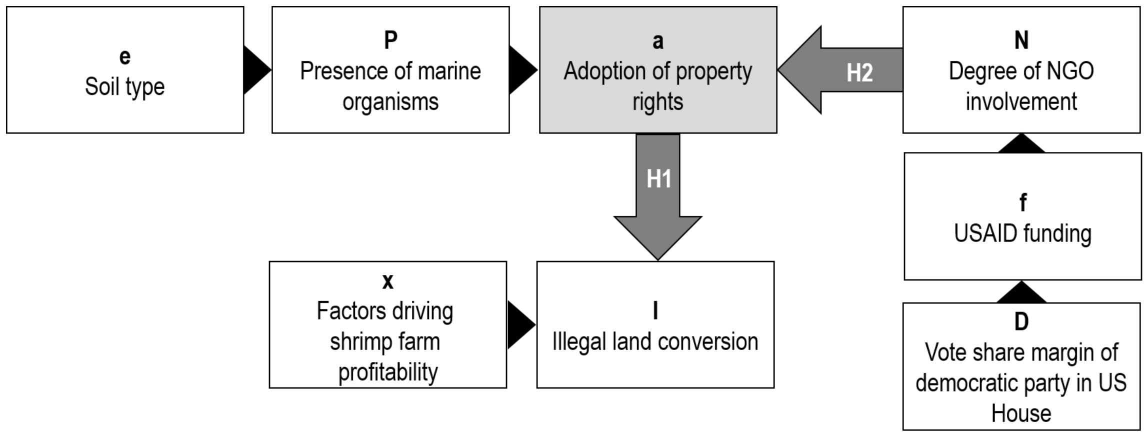

Figure 4.2: Illustration of the identification strategy carried out in sections 4.5.1 and 4.5.2, to test hypotheses H1 and H2 derived in section 4.3 respectively. We use selected soil classes as exogenous environmental parameter e with $cov(e, P) >> 0$ and $cov(a, P) >> 0$. Source: Own depiction.

4.5.1 Effect of Property rights on mangrove deforestation

As stated in section 4.3 local communities rely on harvesting marine organisms to secure their subsistence. The presence of the aquatic species *Ucides Occidentalis* (red mangrove crab), *Cardisoma crassum* (blue mangrove crab) and *Anadara tuberculosa* (black cockle) is thus an important predictor of treatment, as their presence makes it more attractive for communities to protect the mangrove ecosystem. As depicted in Figure 4.2, their presence P is dependent on exogenous environmental parameters, one important environmental parameter being the soil type e. As communities self-select into the program, adoption of property rights is endogenous. In order to identify the effect property rights a have on illegal land conversion activities I, we thus exploit the exogenous variation in soil types as instrumental variable. *Ucides Occidentalis* and *Cardisoma crassum's* habitat is characterized by silty-clayey substrates (Alemán and Ordinola, 2017) while *Anadara tuberculosa* requires a "muddy" substrate with a high water content (Diringer et al., 2019). To verify that the soil types we theoretically expect to be exogenous predictors of the respective species are in fact suitable instruments, we regressed soil type classes extracted from Dijkshoorn et al. (2005) on the presence of each species. In line with the literature, cambisols (CM) and planosoils (PLe) seem to be habitats of shellfish and crabs[11]. Hence, we created a dummy variable indicating the presence of those soil classes as our instrumental variable, hereinafter called soil IV[12]. In the context of forest conservation policy evaluation, instruments are expected not to affect land-cover change except through the probability of treatment. For the instrument to work, it needs to be truly exogenous and sufficiently correlated with the treatment variable (Sovey and Green, 2011; Ferraro and Hanauer, 2014). We argue that the exogeneity assumption is met, as the soil type is exogenous

[11] Cambisols are characterized by sandy or loamy surface horizons with at least 8% clay content, while Planosols have a coarser top horizon which shows signs of water stagnation due to a clayey, slowly permeable sub-horizon (WRB, 2014). Please refer to Table D.2 for the results of the auxiliary regression.

[12] Our work here is most similar to the approach of Sims (2010b), who uses provision of hydrological services and watershed status as an instrument for land conservation policies on development outcomes. We combined all CM and PLe into a single dummy variable and used it as an instrument.

to the decision of shrimp farmers' illegal land conversion activities I. The diagnostics in Table 4.1 show that the soil type used as instrument is sufficiently strong, since a first-stage partial-F test by Staiger and Stock (1997) rejects the Null that the soil IV is weak, i.e. not sufficiently correlated with the treatment at a 0.1% significance level. A Wu-Hausman test reveals that a two- stage least squares estimation is more consistent than ordinary least squares (OLS) estimation. Please refer to Figure A.5, which shows the overlap of the two identified soil types used as combined soil IV with policy adoption.

	df1	df2	statistic	p-value
Weak instruments (F-Test)	1	$13,991,767$	$115,565$	$< 2e-16$
Wu-Hausman	1	$13,991,766$	508.5	$< 2e-16$

Table 4.1: Diagnostics of soil type used as instrument in Models 1 to 3 of Table 4.2 show that the instrument is sufficiently strong. A Wu-Hausman test indicates that the IV approach is more consistent than a simple OLS regression.

With the necessary model assumptions met, we hence carried out an instrumental-variable regression by two-stage least square estimation:

$$I = \alpha + \beta a + \gamma L + \delta \boldsymbol{x} + u \tag{4.17}$$

$$a = \eta + \zeta s + \theta L + \sigma \boldsymbol{x} + k \tag{4.18}$$

With I as illegal deforestation variable, calculated as described in section 4.4, treatment a, legal protection status L, a matrix of variables driving the profitability of the alternative land-use $\boldsymbol{x}$, the soil IV s and error terms u and k. Please note that our chosen IV design identifies a local average treatment effect (LATE) (Ferraro and Hanauer, 2014).

4.5.2 Effect of Non-governmental organization involvement on adoption of property rights

For testing hypothesis H2 we applied a regression discontinuity design within treated units. Regression discontinuity relies on treatment status being fully or partly dependent on a "running" or "forcing" variable crossing a known threshold (Lee and Lemieux, 2010). For the identification of the causal effect of NGO involvement N on policy adoption a, we thus rely on partisan differences over foreign aid allocation in the US Congress. We argue that the NGOs which are fully or partly funded by USAID will adjust their level of support to communities depending on the available funds allocated to Ecuador. The legislative bodies in US government play an defining role in determining the amount of US foreign aid, as they authorize policy and appropriate funds (Lee and Lemieux, 2010). According to Ahmed (2016), the composition of Congress influences foreign aid disbursements[13], with a liberal Congress supporting foreign aid more than a conservative one. We thus defined the vote margin of the Democrats to Republicans in the US House as running

[13] Evidence in the literature shows that the composition of congress also influences environmental policy, with a democratic leaning congress being more supportive of stringent environmental policy (Sussman, 2004; Kim and Urpelainen, 2017; Pacca et al., 2021).

variable D[14]. A positive running variable indicates a relative majority of democrats in the US House. At the cutoff point $c = 0.004$[15], the democrats have a slight relative majority of votes. The running variable is exogenous to the factors that determine whether a community adopts policy or an NGO supports a specific community, as voters who elect the House of Representatives cast their vote based on, or in response to national or regional political and economic conditions in the US (Ahmed, 2016). As the level of NGO involvement is likely not fully determined by the described mechanism, we use a fuzzy regression discontinuity design. The treatment effect β_1 can thus be estimated as follows:

$$\beta_1 = \frac{lim_{\epsilon \downarrow 0.004}\ E[a|D = c + \epsilon] - lim_{\epsilon \uparrow 0.004}\ E[a|D = c + \epsilon]}{lim_{\epsilon \downarrow 0.004}\ E[a|N = c + \epsilon] - lim_{\epsilon \uparrow 0.004}\ E[a|N = c + \epsilon]} \tag{4.19}$$

With involvement of NGOs fully or partly funded by USAID N, running variable D, adoption of property rights a and cutoff c. Please refer to Lee and Lemieux (2010) for detailed information on the regression discontinuity design and to C.7.2 for the results of falsification tests to inspect empirical regularities that are expected to hold in most cases where the identifying assumptions of the regression discontinuity design are met (Cattaneo et al., 2020b).

4.6 Results

4.6.1 Effect of property rights on illegal mangrove deforestation

Table 4.2 shows the results of the estimation strategy described in section 4.5.1. Column (1) shows the significant negative effect of treatment a on illegal mangrove deforestation I. It indicates that adoption of property rights a significantly reduces illegal mangrove deforestation. Hence we do not reject hypothesis H1, which means that the the assignment of communal property rights to ancestral communities has a causal link to reduced mangrove deforestation in Ecuador.

The coefficient of control L, indicating the legal protection status of each cell is negative and significantly different from zero. This suggests that legal protection measures such as the designation of protected areas (PA) seem to work in preventing mangrove deforestation as legal protection status reduces illegal deforestation in our model. The latter results are exploratory, since legal protection status is likely endogenous. Compared to the effect of property rights assignment PA are around 80% less effective in preventing illegal land conversion. The results are robust to the inclusion of spatial fixed effects (Model 2) and further covariates (Model 3).

As expected the coefficients of the covariates population density pop_T and temperature tmp_T are positive and significant, which we propose capture the effects of the profitability of alternative land uses on deforestation. The coefficient of the variable indicating the euclidean distance to relevant business centers has an unexpected negative coefficient. We argue that the chosen distance measure is the reason for this unexpected result, as it cannot account for topography and possibly bad road quality in remote areas, thus not representing driving time or distance to the closest relevant

[14] We used MIT Election Data and Science Lab (2017) to calculate the share of votes each of the party received nationwide in each election. In a second step we took the difference of the democrats and the republican vote share. We use the resulting vote margin in the House as opposed to the Senate as running variable, since all members of the house are subject for re-election in every bi-annual election, introducing more variability, which is not the case in the Senate (Ahmed, 2016).

[15] The value 0.004, i.e. 0.4% is the minimum positive value measured in the data. At 0 no party has the relative majority of votes.

	Dependent variable:		
	I		
	(1)	(2)	(3)
Constant	0.523***	0.652***	−7.499***
	(0.020)	(0.027)	(0.316)
a	−1.767***	−2.016***	−1.765***
	(0.076)	(0.088)	(0.083)
L	−0.168***	−0.385***	−0.335***
	(0.012)	(0.020)	(0.018)
distance			0.00001***
			(0.00000)
pop_T			0.00003***
			(0.00001)
tmp_T			0.309***
			(0.013)
Spatial fixed effects	False	True	False
Observations	13,991,770	13,991,770	13,991,770
Residual Std. Error	9.960 (df = 13991767)	9.964 (df = 13991762)	9.957 (df = 13991764)
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 4.2: Results of effect of treatment a on illegal mangrove deforestation I identified by two-stage least squares estimation with a soil IV which is further described in section 4.5.1.

business center accurately. Please refer to Table F.5 for robustness checks with clustered standard errors to account for spatial auto-correlation.

With our results it is possible to estimate the total amount of CO2 emissions avoided by the policy, which we then value at the social cost of carbon (SCC). We make use of the estimates presented in Table 4.2 to calculate the area of prevented mangrove conversion in each year between 2000 and 2012 [16]. Next we multiply the conserved area in hectare with an average blue carbon emission factor by Alongi (2020) quantifying the annual emissions resulting from conversion of a mangrove ecosystem to aquaculture: 614.4 $tC \cdot ha^{-1} \cdot a^{-1}$ [17]. Based on these calculations, we find that the policy prevented the release of 529,380 tC to the atmosphere between 2000 and 2012 which is equivalent to more than 1.5 million $tCO2$. Valued at the SCC, 112.86 $US\$/tC$ (Wang et al., 2019), this corresponds to 59.7 million US $ in avoided damages due to future climate change impacts.

Aside from benefits of avoided emissions, which are a global public good provided by the policy, we also explore the fisheries benefits of the intervention, which are received by the local communities. We calculate the additional estimated fisheries income provided by the mangroves protected by the policy [18]. We do this for the two main fisheries, which comprise 90% of all existing concessions in our sample, the *Ucides Occidentalis* (red crab) fishery and *Anadara tuberculosa* (black cockle) fishery. In the final year of our period of analysis a total of 4,878 families held communal property rights over mangroves and earned their income from the revenues stemming from both fisheries.

For the red-crab fishery we employ the available catch per unit effort (CPUE) (Alemán-Dyer et al., 2019) associated with this fishery (14±2 units per man-hour), which was calculated based on communities within policy. Data on seasonal closings and effective fishery days per year (240 days) were obtained from Alemán-Dyer et al. (2019). Average prices for a 14 crab bundle are 15 $US\$$, with ex-vessel prices that fisheries receive being 50-60% of the final price (Bravo, 2013). We take into account the average costs per effective fishing day (Bravo, 2013) correcting for annual inflation. [19] Making use of the total number of red-crab fishers within policy, we estimate an average undiscounted net income of more than 134 million $ earned within the first 12 years of policy. Expressed in average benefits of the policy, understood as additional red-crab fishery resources provided by mangrove conservation, we estimate a total added benefit of 281 k $ for the years 2000-2012.

We employ a similar approach for the *Anadara tuberculosa* (black cockle) fishery. The average CPUE of 180 units per fisher per effective day of fishery is calculated for communities within policy. We employ data from the National fisheries institute on both market prices and costs for the fisheries arriving at a daily net benefit of 14 $ per fisherman and day (Cáceres and Gaibor, 2019). There are 23 effective days of fishing a month in the black cockle fishery. Making use of net fishery income per day per fisherman, and the number of fishermen per year, we arrive at an average undiscounted net income of 75.4 million $ earned within the first 12 years of policy. Expressed in average benefits of the policy, understood as additional red-crab fishery resources provided by mangrove conservation, we estimate a total added benefit of 158 k $ for the years 2000-2012.

[16] We do this by multiplying the average policy effect with the total mangrove area with property rights in each year.

[17] 1802.2 $tCO2 \cdot ha^{-1} \cdot a^{-1} \cdot$ 0.34 $tC/tCO2$, with the conversion factor from EPA (2021).

[18] Just as in section 4.3 we assume a linear relationship between mangrove area and population sizes and resulting fishing effort.

[19] We use cost data to avoid over-estimations of fisheries benefits that stem from gross income measures.

4.6.2 NGO presence and policy adoption

Table 4.3 shows the effect of NGO involvement on policy uptake and continuation, estimated within treatment. We find a positive and significant effect of NGO involvement[20] and do not reject hypothesis H2. The second and third column show the results estimated with a first and third order parametric polynomial estimator of a fuzzy regression discontinuity design (RDD) with clustered and heteroskedasticity corrected standard errors, using the Democrat's vote share margin compared to the Republicans in the US House as running variable D. The involvement of NGOs increases the probability of property rights adoption. We believe that apart from external institutions such as NGOs, endogenous institutions and leadership on community level play a role in policy uptake. As we do not have a suitable instrument for strength of endogenous institutions, we cannot formally test this intuition. Arguing that the number of reports issued to the authorities by communities who decided to adopt property rights might be a useful proxy for the strength of endogenous institutions, we compare deforestation rates between communities that issued a number of reports above and below the median number of reports issued by all communities. We find that the communities who issued more than the median number of reports have significantly lower deforestation rates than the comparison group (please refer to figure E.6). We consider these findings to be exploratory results as we do not have a suitable instrument for strength of endogenous institutions.

[20] Please note that we only considered data on the NGOs with full or partial funding from USAID here.

	Dependent variable:		
	a		
	(1)	(2)	(3)
Constant	0.035^{***}	0.035	-0.070^{*}
	(0.001)	(0.091)	(0.041)
N	1.491^{***}	1.491^{***}	1.745^{***}
	(0.004)	(0.144)	(0.265)
D	-0.001^{***}	-0.001	-0.001
	(0.00001)	(0.0004)	(0.001)
Dˆ2			0.0001
			(0.0001)
Dˆ3			0.00000
			(0.00000)
D_right	0.001^{***}	0.001^{**}	0.015^{*}
	(0.00002)	(0.001)	(0.009)
‘Dˆ2_right‘			-0.0004
			(0.0003)
Observations	6,737,471	6,737,471	6,737,471
Order of the polynomial	1	1	3
Clustering on District level	FALSE	TRUE	TRUE
Residual Std. Error	0.534 (df = 6737467)		

Note:
*p<0.1; **p<0.05; ***p<0.01

Table 4.3: Effect of NGO presence on policy uptake and continuation. The results were estimated with a first and third order parametric polynomial estimator of a fuzzy regression discontinuity (RDD) both with clustered and unclustered standard errors using the Democrat’s vote share margin compared to the Republicans in the US house as running variable D

4.7 Discussion

Our work presents a causal analysis of the effect of assigning communal property rights to local and indigenous communities on deforestation, providing the, to our knowledge, first assessment for mangroves ecosystems. We evaluate 12 years of the AUSCM property rights based policy in Ecuador, finding that property rights have a positive impact on reducing deforestation, which had destroyed 30 to 40 percent of all mangrove coverage in the country (Friess et al., 2019). Our results are significant and robust across specifications and when accounting for alternative land-use, using fixed effects and when clustering standard errors to control for spatial auto-correlation.

The existing literature provides mixed evidence, both empirical and theoretical, on the role of property rights on deforestation. On one hand, more secure land tenureship can reduce mangrove deforestation by increasing the present value of standing forests. This in turn discourages land conversion to productive use as a way to reduce expropriation risk, as has been found in Brazil, Haiti, and Malawi (Araujo et al., 2009; Place and Otsuka, 2001; Busch and Ferretti-Gallon, 2017). On the other hand, more secure land tenure might spur an increase in deforestation by encouraging greater investment in productive activities (Busch and Ferretti-Gallon, 2017). Our findings add to this debate, in line with the recent body of literature which has found positive conservation effects of communal property rights in the Peruvian and Brazilian amazonian forest (Blackman et al., 2017; Baragwanath and Bayi, 2020), expanding this literature by providing a novel identification strategy and unique dataset.

This highlights the role local and indigenous communities play for improved land stewardship, which is vital to achieve the climate change goals set forth in the Paris Agreement (Griscom et al., 2017). As mangrove deforestation is not only associated with increased carbon emissions, but also reduced future carbon uptake, our evaluation of property rights to local and indigenous communities supports its application as an effective climate change mitigation strategy. Our estimates show that the policy prevented additional emission of more than 1.55 million $tCO2$ between 2000 and 2012 which is equivalent to almost 60 million $US\$$ of avoided damages resulting from climate change. This has positive implications for climate change related north-south transfers, specifically as this provides strong evidence of additionally avoided emissions. Recent experimental evidence suggest that collective ownership might be well-suited for payments of ecosystem services (Kaczan et al., 2017), which seems to align with our empirical results.

Thus our work provides evidence that nature based solutions to climate change provide much promise, but their implementation must be based on a track record of success, which we believe we asses and provide evidence for through our empirical approach. Moreover, our results are in line with recent evidence on the role of local communities and indigenous peoples in safeguarding forests and their associated carbon stocks. In the Amazon indigenous land tenure and management programs between 2003 to 2016 were more than twice as effective in safeguarding carbon sinks than other approaches (Walker et al., 2020). As the role of mangroves in coastal protection has been well documented, the positive implications of successful conservation interventions can be extended to the nascent policy debate around climate change adaptation (Del Valle et al., 2020; Hochard et al., 2019).

Nevertheless, our result contrasts with similar studies finding little effect of property rights on deforestation (Probst et al., 2020; BenYishay et al., 2017b). Our work differs from this existing literature in that we propose a theoretical model of the mechanisms behind the drivers of policy adoption at the community level, and derive identification strategies from its underlying intuition.

This ensures that we not only asses the effectiveness of granting property rights to local and indigenous communities on deforestation, but also identify the possible causal drivers behind policy failure or success (Deaton, 2010b; Ferraro et al., 2012a; Busch and Ferretti-Gallon, 2017). A potential weakness of our study is that it fails to capture the dynamic nature of the policy, methods such as staggered diff- in diff not possible due to missing pre-policy data necessary to verify parallel trend assumption.

The presence of common-pool resources such as fisheries in mangrove forests, provide clear incentives for ancestral communities to enroll in time consuming and costly property rights based policy. The effects of exclusivity rights over common pool resources, and its potential positive effect on their management is backed by the commons literature (Schlager and Ostrom, 1992; Ostrom, 2000; Ostrom, 2010). We exploit the presence of these, and in particular the exogeneity of soil type as predictor of policy adoption/fisheries presence, to derive our results through an instrumental variable approach. Our findings imply that property rights are associated not only with the conservation of mangroves, but possibly the fisheries associated with them. A significant percentage of mangroves under AUSCM policy have a multitude of fisheries which are of high local market value. This might be suggestive of positive food security, development and poverty impacts of property rights, which would be in line with described causal pathways linking property rights interventions and poverty outcomes (Miller et al., 2021; Ferraro and Hanauer, 2014). Moreover, this provides a potential explanation for our result's divergence from the empirical property rights literature on land forest ecosystems, as mangrove forests offer different provisioning services than other forest ecosystems which are not flooded regularly.

Furthermore, through our theoretical model we propose that high transaction costs of the policy have a negative effect on policy uptake, but that the presence of exogenous institutions such as NGOs plays a role in absorbing said costs. This is in line with recent evidence from both experiments and quasi-experiments looking into the role of NGOs in reducing transaction costs (Usmani et al., 2022) and fostering environmental compliance (L. E. Grant and Langpap, 2019; L. E. Grant and Grooms, 2017). Additionally our results providence evidence on the role of transaction costs in addressing global environmental externalities (Libecap, 2014; Libecap and Lueck, 2011; Ayres et al., 2018). We test the effect of the involvement of NGOs across communities on policy enrollment and renewal, by exploiting data on USAID funding and, specifically partisan preferences for environmental aid from the U.S Congress as source of exogenous variation in NGO involvement to address endogeneity of NGO presence. We find that the presence of NGOs increases the probability of policy enrollment and continuation. This result might also be indicative of preliminary evidence of the effectiveness of international aid, which has been subject to questioning (Bourguignon and Sundberg, 2007; Deaton, 2010b), whilst also adding evidence of partisan preferences in the US for both aid disbursements and environmental policymaking (Pacca et al., 2021; List and Sturm, 2006). To our knowledge our work presents the first evidence on the effect of partisan preferences from a large donor country in environmental policy outcomes in a recipient country.

We propose two mechanisms through which we believe property rights policies can successfully decrease mangrove deforestation 1) increased benefits for indigenous and local communities through exclusive rights over resources and 2) decreased transaction costs by the presence of external institutions like NGOs. Furthermore, we are convinced that endogenous institutions play a central role in the success of management of a valuable resource (Sutter et al., 2009), albeit, we only present exploratory evidence of that role.Moreover, a quick browse over our data of all legal entities that enrolled in the property rights policy shows that 95 percent are associations of fishermen, with existing internal rules and regulations. This is both supportive of our proposed mechanisms of fisheries benefits being a driver of policy success, but can also be interpreted in that endogenous institutions play an important role in the observed conservation outcomes. Finally, we believe that our work showcases the wide diversity of institutional arrangements in place for the management of a common-pool resource, albeit at a large scalef, effectively presenting a polycentric governance system where international donors, NGOs and civil society, indigenous peoples, local and national governments effectively tackle one of the oldest issues concerning economics, the management of the commons. Given the value of the vast swathes of land under indigenous tenureship as some of the last reservoirs of untouched natural capital on Earth, we hope our work contributes to the discussion regarding the two ultimate commons problems of the twenty-first century, global climate change and the species extinction crisis.

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A. Appendix to Chapter 2

A.1 Preprocessing and estimation strategy

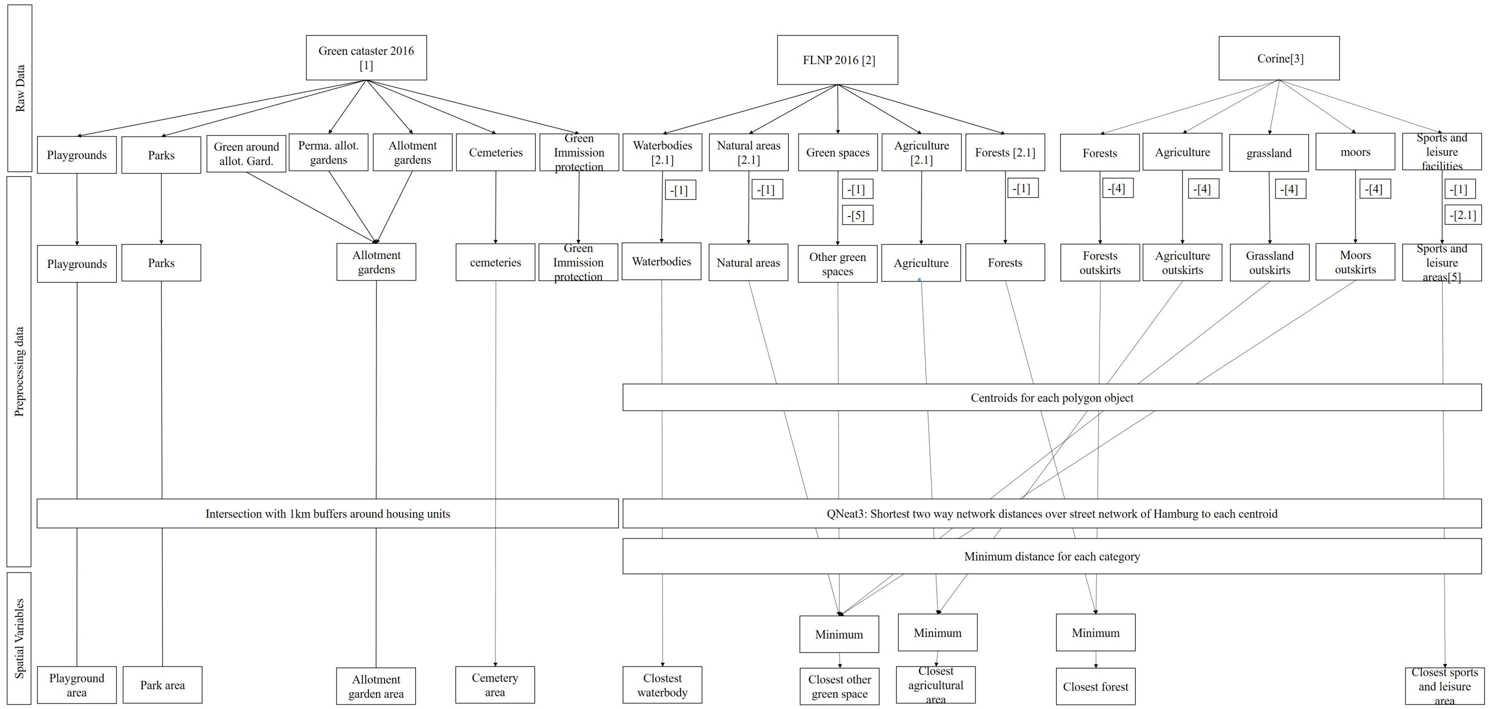

Figure A.1: Process of UGS variable generation with the Land Utilization Plan of 2016 BSW (2016), the Corine Land Cover dataset Copernicus (2012), the cadastres of offical urban greenspaces BUE (2016b) as well as the administrative boundary of Hamburg Landesbetrieb Geoinformation und Vermessung (2019b). [1] Cadastre of urban Green, 10m resolution inside administratory boundary, [2] Land Utilization Plan (1:20.000, 200m) general object size 3 ha, smaller for green open spaces, not specified outside administratory boundary, [3] CORINE Land Cover 10 ha, CLC 2012 [4] Administratory boundary Hamburg. -[..] refers to a spatial difference between the category of the respective shapefile and the whole data set as indicated by the number in brackets.

Variable name	Description
Price	Adjusted offer price in Euro
Park	Park area in a 1 km radius around the housing unit in ha*
Playgound	Playground area in a 1 km radius around the housing unit in ha
Allotment	Allotment garden area in a 1 km radius around the housing unit in ha
Cemetery	Cemetery area in a 1 km radius around the housing unit in ha
CBD	Network distance to the central business district in m
scndring	Dummy variable indicating the second quartile of CBD variable
thrddring	Dummy variable indicating the third quartile of CBD variable
frthring	Dummy variable indicating the fourth quartile of CBD variable
Garden	Size of garden in square meters
BalcTerr	Presence of a balcony or terrace (1 if it is the case, 0 otherwise)
LotSize	Lot size in sqm
Area	Square footage/living area in sqm
Age	Age of housing unit in years
Base	Housing unit is situated on base floor (1 if it is the case, 0 otherwise)
Basement	Presence of a storage compartment (basement) (1 if it is the case, 0 otherwise)
FullBase	Presence of a full basement storage (1 if it is the case, 0 otherwise)
Kitchen	Presence of a built-in kitchen (1 if it is the case, 0 otherwise)
FloorHeat	Presence of a floor heating (1 if it is the case, 0 otherwise)
CentralHeat	Presence of a central heating (1 if it is the case, 0 otherwise)
GasHeat	Presence of a gas heating (1 if it is the case, 0 otherwise)
Garage	Presence of a garage (1 if it is the case, 0 otherwise)
GaragePl	Presence of a parking position (1 if it is the case, 0 otherwise)
HighQual	High quality condition (1 if it is the case, 0 otherwise)
New	Newly built condition (1 if it is the case, 0 otherwise)
Renovated	Renovated condition (1 if it is the case, 0 otherwise)
Badcond	Bad condition (1 if it is the case, 0 otherwise)
Fireplace	Presence of a fireplace (1 if it is the case, 0 otherwise)
Woodenfloor	Hardwood floors (1 if it is the case, 0 otherwise)
Sauna	Presence of a sauna (1 if it is the case, 0 otherwise)
School	Network distance to clostest school in m
Forest	Network distance to clostest forest in m
Other green	Network distance to other type of urban greenspace in m
Water	Network distance to clostest body of water in m
Sport Leisure	Network distance to clostest sport and leisure facility in m
Street trees	Number of streettrees in a 100m radius
Church	Network distance to clostest church in m
PP	Purchasing power in Euro
Poden	Population density in a km^2
Children	Number of children per household
Unemployed	Share of unemployed in 100*%
Above60	Share of inhabitants above the age of 60 in 100*%
Singles	Share of single households 100*%
Families	Share of families 100*%
Couples	Share of couples 100*%

Table A.1: Variable description

Variable name	**Studies previously using this variable**
Area	Tyrväinen and Miettinen (2000), Sirmans et al. (2006), Sue and Wong (2010), Engström and Gren (2017), and Liebelt et al. (2018)
LotSize	Tyrväinen (1997), Sirmans et al. (2006), Engström and Gren (2017), and Plant et al. (2017)
Age	Tyrväinen (1997), Tyrväinen and Miettinen (2000), Sirmans et al. (2006), Sue and Wong (2010), Donovan and Butry (2011), Czembrowski and Kronenberg (2016), Engström and Gren (2017), and Votsis (2017)
Base	Sue and Wong (2010), Czembrowski and Kronenberg (2016), Engström and Gren (2017), Votsis (2017), Liebelt et al. (2018), and Belcher and Chisholm (2018) (floor)
Basement	Palmquist (1992)
FullBase	Palmquist (1992)
Kitchen	Liebelt et al. (2018)
FloorHeat	Liebelt et al. (2018) (heating type)
CentralHeat	Liebelt et al. (2018) (heating type)
GasHeat	Liebelt et al. (2018) (heating type)
Garage	Sirmans et al. (2006), Donovan and Butry (2011), and Plant et al. (2017) (although some studies use number of Garage places)
GaragePl	Sirmans et al. (2006), Donovan and Butry (2011), and Plant et al. (2017) (although some studies use number of Garage places)
Garden	Liebelt et al. (2018) (presence of a garden)
HighQual	Herath et al. (2015), Votsis (2017), and Liebelt et al. (2018) (condition)
New	Herath et al. (2015), Votsis (2017), and Liebelt et al. (2018) (condition)
Renovated	Herath et al. (2015), Votsis (2017), and Liebelt et al. (2018) (condition)
Badcond	Herath et al. (2015), Votsis (2017), and Liebelt et al. (2018) (condition)
Fireplace	Sirmans et al. (2006)
Woodenfloor	Zietz et al. (2008) (type of floor cover)
Sauna	
BalcTerr	Herath et al. (2015) and Liebelt et al. (2018)

Table A.2: Studies that used the included control variables - structural characteristics

Variable name	Studies previously using this variable
School	Tyrväinen (1997), Sue and Wong (2010), and Czembrowski and Kronenberg (2016)
Church	Carroll et al. (1996), Thompson et al. (2012), and Brandt et al. (2014)
CBD	Tyrväinen (1997), Tyrväinen and Miettinen (2000), Donovan and Butry (2011), Engström and Gren (2017), Votsis (2017), Plant et al. (2017), Liebelt et al. (2018), and Belcher and Chisholm (2018)
Forest	Tyrväinen (1997), Tyrväinen and Miettinen (2000), Czembrowski and Kronenberg (2016), and Votsis (2017)
Other green	
Water	Tyrväinen (1997), Engström and Gren (2017), and Liebelt et al. (2018)
Sport Leisure	
Street trees	Donovan and Butry (2011) and Plant et al. (2017)

Table A.3: Studies that used the included control variables - neighborhood characteristics

A.1.1 Testing assumptions for internal instrumental variable approach

When using this method, some assumptions need to be verified. First, the variable of interest should neither have a normal nor a Bernoulli distribution and cannot have a bimodal distribution. In contrast, it is advantageous if the error term is normally distributed or has a different distribution than the endogenous variable of interest for the method to produce valid results (Park and Gupta, 2012; Gui et al., 2018). Referring to Becker et al. (2021), I apply several Anderson Darling tests for the potentially endogenous variables of interest in the different submarkets as well as for sub-samples based on income groups to test if the variables of interest are indeed not normally distributed. Since the structural error term is unobservable (Park and Gupta, 2012), I assume that the distribution of the structural error term differs from the distributions of the endogenous variables. If this assumption is not met, this can lead to confidence intervals that are too wide, which is a result from multicollinearity. To prevent this, it is advisable to use a sufficiently large sample of more than 1,000 or 2,000 observations (Park and Gupta, 2012; Becker et al., 2021). This requirement is met for all analyses in this study. Additionally, I test if the distributions of the residuals of the regression without copulas for the respective endogenous variable and the distribution of the same endogenous variable are significantly different, using Kolmogorov-Smirnov tests. For the first-stage estimations all 63 Anderson Darling (AD) tests[1] are highly significant, indicating that the potentially endogenous variables are not normally distributed. The same holds true for the Kolmogorov-Smirnov (KGS) test, indicating that the regression residuals and the respective variable have significantly different distributions. The same holds true for the 27 AD and KGS tests carried out with the sub-samples of the second and the 36 AD and KGS tests for the third-stage estimations.[2] From these results I conclude that the necessary assumptions for the copula correction method to work are met and continue with the following specifications for the first-stage estimation of the hedonic price schedules.

A.2 Descriptive statistics

A.2.1 Descriptive statistics submarkets hedonic price schedule

[1] I have seven potentially endogenous variables in each of the nine submarkets, which are *a priori* defined based on the time period and housing type as well as sales or rental market.

[2] It is important to test the assumptions again for the sub-samples used in the second and third estimation as the variables are log transformed and the observations are pooled in the second-stage estimation while subsets based on purchasing power percentiles are used in the third-stage estimation.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	29,964	524.0	302.0	68	353	590	5,608
Park	29,964	27.2	24.8	0.0	11.8	33.1	158.0
Playground	29,964	3.1	2.2	0.0	1.5	4.3	13.3
Allotment	29,964	14.6	21.9	0	0.6	18.8	156
Cemetery	29,964	17.4	74.4	0	0	1.8	399
scndring	29,964	0.3	0.4	0	0	1	1
thrddring	29,964	0.3	0.4	0	0	1	1
frthring	29,964	0.3	0.4	0	0	1	1
Garden	29,964	0.2	0.4	0	0	0	1
BalcTerr	29,964	0.5	0.5	0	0	1	1
Lotsize	29,964	4,010.3	7,243.8	0	532.8	4,298.5	72,716
Area	29,964	68.3	25.5	12.0	52.0	80.0	360.0
Age	29,964	52.3	31.9	8	24	66	461
Base	29,964	0.004	0.1	0	0	0	1
Basement	29,964	0.4	0.5	0	0	1	1
FullBase	29,964	0.003	0.1	0	0	0	1
Kitchen	29,964	0.7	0.5	0	0	1	1
FloorHeat	29,964	0.04	0.2	0	0	0	1
CentralHeat	29,964	0.7	0.5	0	0	1	1
GasHeat	29,964	0.01	0.1	0	0	0	1
Garage	29,964	0.3	0.5	0	0	1	1
GaragePl	29,964	0.1	0.2	0	0	0	1
HighQual	29,964	0.1	0.2	0	0	0	1
New	29,964	0.1	0.3	0	0	0	1
Renovated	29,964	0.1	0.3	0	0	0	1
Badcond	29,964	0.01	0.1	0	0	0	1
Fireplace	29,964	0.01	0.1	0	0	0	1
Woodenfloor	29,964	0.1	0.3	0	0	0	1
Sauna	29,964	0.01	0.1	0	0	0	1
School	29,964	1,453.4	288.7	0.0	1,311.1	1,652.4	1,965.1
Forest	29,964	140.1	331.1	0	0	0	1,929
Other green	29,964	1,237.6	374.0	0.0	1,029.7	1,510.4	1,982.4
Water	29,964	688.4	602.0	0.0	0.0	1,245.8	1,971.9
Sport Leisure	29,964	521.6	468.9	0.0	0.0	894.1	1,951.8
Street trees	29,964	28.0	20.2	0	12	40	260
Church	29,964	1,326.2	396.0	0.0	1,128.5	1,610.9	1,985.6

Table A.4: Descriptive statistics of submarket flats for rent in the years 2005 to 2009.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	43,199	680.1	408.3	82.6	419.9	809.9	5,680.8
Park	43,199	28.0	26.4	0.0	11.3	33.0	161.8
Playground	43,199	3.1	2.2	0.0	1.4	4.3	12.6
Allotment	43,199	12.5	19.5	0.0	0.0	17.3	155.4
Cemetery	43,199	14.8	69.1	0	0	0.7	399
scndring	43,199	0.2	0.4	0	0	0	1
thrddring	43,199	0.3	0.4	0	0	1	1
frthring	43,199	0.2	0.4	0	0	0	1
Garden	43,199	0.2	0.4	0	0	0	1
BalcTerr	43,199	0.5	0.5	0	0	1	1
Lotsize	43,199	3,133.0	5,298.1	0	479	3,480	122,241
Area	43,199	75.4	31.0	13.0	56.0	89.0	462.0
Age	43,199	48.0	35.1	4	18	64	369
Base	43,199	0.01	0.1	0	0	0	1
Basement	43,199	0.6	0.5	0	0	1	1
FullBase	43,199	0.003	0.1	0	0	0	1
Kitchen	43,199	0.8	0.4	0	1	1	1
FloorHeat	43,199	0.1	0.3	0	0	0	1
CentralHeat	43,199	0.6	0.5	0	0	1	1
GasHeat	43,199	0.004	0.1	0	0	0	1
Garage	43,199	0.4	0.5	0	0	1	1
GaragePl	43,199	0.1	0.2	0	0	0	1
HighQual	43,199	0.2	0.4	0	0	0	1
New	43,199	0.1	0.3	0	0	0	1
Renovated	43,199	0.1	0.3	0	0	0	1
Badcond	43,199	0.01	0.1	0	0	0	1
Fireplace	43,199	0.02	0.1	0	0	0	1
Woodenfloor	43,199	0.1	0.3	0	0	0	1
Sauna	43,199	0.01	0.1	0	0	0	1
School	43,199	1,447.1	299.4	0.0	1,297.6	1,653.8	1,979.6
Forest	43,199	147.0	340.3	0	0	0	1,946
Other green	43,199	1,248.4	346.8	0.0	1,049.7	1,499.7	1,974.3
Water	43,199	674.4	622.4	0.0	0.0	1,269.4	1,971.9
Sport Leisure	43,199	477.6	463.0	0.0	0.0	832.6	1,946.7
Street trees	43,199	26.1	19.5	0	11	38	163
Church	43,199	1,335.4	370.3	0.0	1,161.0	1,604.1	1,985.6

Table A.5: Descriptive statistics of submarket flats for rent in the years 2010 to 2014.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	41,661	695.5	389.8	58.8	446.3	843.5	5,480.5
Park	41,661	28.1	26.9	0.0	11.0	33.4	161.1
Playground	41,661	3.1	2.2	0.0	1.4	4.4	12.6
Allotment	41,661	13.6	20.6	0.0	0.2	18.5	155.6
Cemetery	41,661	16.0	71.7	0	0	1.5	399
scndring	41,661	0.3	0.4	0	0	1	1
thrddring	41,661	0.3	0.4	0	0	1	1
frthring	41,661	0.2	0.4	0	0	0	1
Garden	41,661	0.2	0.4	0	0	0	1
BalcTerr	41,661	0.5	0.5	0	0	1	1
Lotsize	41,661	2,902.9	4,926.3	0	460	3,129	83,876
Area	41,661	74.0	30.6	12.0	54.0	87.0	370.0
Age	41,661	47.6	35.8	0	15	65	401
Base	41,661	0.02	0.1	0	0	0	1
Basement	41,661	0.5	0.5	0	0	1	1
FullBase	41,661	0.003	0.1	0	0	0	1
Kitchen	41,661	0.8	0.4	0	1	1	1
FloorHeat	41,661	0.2	0.4	0	0	0	1
CentralHeat	41,661	0.6	0.5	0	0	1	1
GasHeat	41,661	0.01	0.1	0	0	0	1
Garage	41,661	0.3	0.5	0	0	1	1
GaragePl	41,661	0.1	0.3	0	0	0	1
HighQual	41,661	0.2	0.4	0	0	0	1
New	41,661	0.1	0.3	0	0	0	1
Renovated	41,661	0.1	0.3	0	0	0	1
Badcond	41,661	0.01	0.1	0	0	0	1
Fireplace	41,661	0.02	0.1	0	0	0	1
Woodenfloor	41,661	0.2	0.4	0	0	0	1
Sauna	41,661	0.01	0.1	0	0	0	1
School	41,661	1,436.4	304.7	0.0	1,286.2	1,647.0	1,974.2
Forest	41,661	134.1	328.0	0	0	0	1,946
Other green	41,661	1,241.4	357.5	0.0	1,022.8	1,507.2	1,982.4
Water	41,661	696.5	622.7	0.0	0.0	1,284.3	1,971.9
Sport Leisure	41,661	467.1	458.5	0.0	0.0	807.8	1,951.8
Street trees	41,661	25.3	19.4	0	9	38	163
Church	41,661	1,342.2	375.1	0.0	1,154.4	1,616.8	1,985.6

Table A.6: Descriptive statistics of submarket flats for rent in the years 2015 to 2018.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	8,097	189,418.4	162,123.1	6,500	90,202.0	233,000	3,097,030
Park	8,097	27.8	26.8	0.0	11.0	32.3	157.2
Playground	8,097	3.4	2.7	0.0	1.2	5.0	12.9
Allotment	8,097	11.7	17.8	0.0	0.0	17.1	155.4
Cemetery	8,097	22.4	84.9	0.0	0.0	2.3	398.9
scndring	8,097	0.2	0.4	0	0	0	1
thrddring	8,097	0.3	0.4	0	0	1	1
frthring	8,097	0.2	0.4	0	0	0	1
Garden	8,097	0.3	0.5	0	0	1	1
BalcTerr	8,097	0.5	0.5	0	0	1	1
Lotsize	8,097	2,335.7	3,434.3	0	436	2,750	44,007
Area	8,097	82.3	38.1	16.0	56.0	100.0	388.0
Age	8,097	49.0	35.5	8	17	63	351
Base	8,097	0.03	0.2	0	0	0	1
Basement	8,097	0.4	0.5	0	0	1	1
FullBase	8,097	0.03	0.2	0	0	0	1
Kitchen	8,097	0.6	0.5	0	0	1	1
FloorHeat	8,097	0.2	0.4	0	0	0	1
CentralHeat	8,097	0.6	0.5	0	0	1	1
GasHeat	8,097	0.01	0.1	0	0	0	1
Garage	8,097	0.5	0.5	0	0	1	1
GaragePl	8,097	0.1	0.3	0	0	0	1
HighQual	8,097	0.2	0.4	0	0	0	1
New	8,097	0.2	0.4	0	0	0	1
Renovated	8,097	0.1	0.3	0	0	0	1
Badcond	8,097	0.05	0.2	0	0	0	1
Fireplace	8,097	0.04	0.2	0	0	0	1
Woodenfloor	8,097	0.1	0.4	0	0	0	1
Sauna	8,097	0.02	0.2	0	0	0	1
School	8,097	1,460.6	297.2	0.0	1,305.1	1,669.8	1,964.3
Forest	8,097	147.8	340.2	0.0	0.0	0.0	1,895.8
Other green	8,097	1,232.0	357.1	0.0	1,028.2	1,481.9	1,974.8
Water	8,097	669.9	615.7	0.0	0.0	1,232.7	1,967.9
Sport Leisure	8,097	446.3	454.6	0.0	0.0	773.3	1,951.8
Street trees	8,097	26.9	20.2	0	11	38	162
Church	8,097	1,327.9	368.3	0.0	1,122.5	1,601.3	1,981.6

Table A.7: Descriptive statistics of submarket flats for sale in the years 2005 to 2009.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	11,100	300,723.6	251,535.1	17,316	143,731.6	367,004.4	3,678,218
Park	11,100	27.3	26.7	0.0	10.5	32.9	157.2
Playground	11,100	3.1	2.5	0.0	1.1	4.7	12.1
Allotment	11,100	11.3	18.7	0.0	0.0	14.8	155.4
Cemetery	11,100	21.3	83.8	0	0	2.3	399
scndring	11,100	0.3	0.4	0	0	1	1
thrddring	11,100	0.3	0.4	0	0	1	1
frthring	11,100	0.2	0.4	0	0	0	1
Garden	11,100	0.3	0.5	0	0	1	1
BalcTerr	11,100	0.4	0.5	0	0	1	1
Lotsize	11,100	2,087.0	3,328.0	0	457	2,229	44,007
Area	11,100	96.4	46.5	19.0	65.0	117.0	678.0
Age	11,100	34.8	36.3	3	6	54	249
Base	11,100	0.02	0.1	0	0	0	1
Basement	11,100	0.6	0.5	0	0	1	1
FullBase	11,100	0.01	0.1	0	0	0	1
Kitchen	11,100	0.5	0.5	0	0	1	1
FloorHeat	11,100	0.3	0.5	0	0	1	1
CentralHeat	11,100	0.5	0.5	0	0	1	1
GasHeat	11,100	0.01	0.1	0	0	0	1
Garage	11,100	0.6	0.5	0	0	1	1
GaragePl	11,100	0.1	0.3	0	0	0	1
HighQual	11,100	0.3	0.4	0	0	1	1
New	11,100	0.3	0.4	0	0	1	1
Renovated	11,100	0.1	0.3	0	0	0	1
Badcond	11,100	0.03	0.2	0	0	0	1
Fireplace	11,100	0.03	0.2	0	0	0	1
Woodenfloor	11,100	0.2	0.4	0	0	0	1
Sauna	11,100	0.01	0.1	0	0	0	1
School	11,100	1,419.4	309.4	0.0	1,248.4	1,635.7	1,984.4
Forest	11,100	132.8	332.4	0	0	0	1,947
Other green	11,100	1,238.5	359.6	0.0	1,021.3	1,504.7	1,969.7
Water	11,100	649.9	638.4	0.0	0.0	1,282.6	1,968.0
Sport Leisure	11,100	428.0	465.0	0.0	0.0	791.0	1,927.6
Street trees	11,100	25.3	18.7	0	11	35	164
Church	11,100	1,305.4	378.1	0.0	1,086.6	1,596.1	1,973.8

Table A.8: Descriptive statistics of submarket flats for sale in the years 2010 to 2014.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	8,773	355,810.8	267,621.3	34,145.2	202,432.3	414,864.4	3,024,290.0
Park	8,773	26.3	24.2	0.0	11.0	32.9	157.1
Playground	8,773	3.0	2.3	0.0	1.3	4.0	12.9
Allotment	8,773	12.4	15.8	0	0	20.0	154
Cemetery	8,773	18.2	76.9	0	0	1.9	399
scndring	8,773	0.2	0.4	0	0	0	1
thrddring	8,773	0.3	0.4	0	0	1	1
frthring	8,773	0.3	0.5	0	0	1	1
Garden	8,773	0.3	0.5	0	0	1	1
BalcTerr	8,773	0.3	0.5	0	0	1	1
Lotsize	8,773	2,027.6	2,799.0	0	460	2,266	44,018
Area	8,773	93.3	41.5	15.0	65.0	111.0	453.0
Age	8,773	28.4	36.4	0	3	49	353
Base	8,773	0.04	0.2	0	0	0	1
Basement	8,773	0.5	0.5	0	0	1	1
FullBase	8,773	0.01	0.1	0	0	0	1
Kitchen	8,773	0.4	0.5	0	0	1	1
FloorHeat	8,773	0.5	0.5	0	0	1	1
CentralHeat	8,773	0.5	0.5	0	0	1	1
GasHeat	8,773	0.01	0.1	0	0	0	1
Garage	8,773	0.6	0.5	0	0	1	1
GaragePl	8,773	0.1	0.3	0	0	0	1
HighQual	8,773	0.4	0.5	0	0	1	1
New	8,773	0.4	0.5	0	0	1	1
Renovated	8,773	0.1	0.3	0	0	0	1
Badcond	8,773	0.03	0.2	0	0	0	1
Fireplace	8,773	0.04	0.2	0	0	0	1
Woodenfloor	8,773	0.2	0.4	0	0	0	1
Sauna	8,773	0.02	0.1	0	0	0	1
School	8,773	1,383.9	371.7	0.0	1,220.2	1,652.4	1,973.4
Forest	8,773	254.5	497.9	0	0	131.3	1,937
Other green	8,773	1,185.3	393.5	0.0	970.8	1,479.4	1,973.5
Water	8,773	626.2	624.8	0.0	0.0	1,230.7	1,936.5
Sport Leisure	8,773	464.3	478.9	0	0	808.4	1,768
Street trees	8,773	20.6	17.8	0	5	33	163
Church	8,773	1,289.9	360.6	0.0	1,094.6	1,551.2	1,963.3

Table A.9: Descriptive statistics of submarket flats for sale in the years 2015 to 2018.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	3,254	271,420.7	130,261.6	27,564	196,787.7	318,811.9	1,266,139
Park	3,254	21.1	22.1	0.0	5.9	29.8	162.5
Playground	3,254	1.8	1.7	0	0.6	2.6	12
Allotment	3,254	11.7	14.7	0	0	19.1	105
Cemetery	3,254	16.9	68.8	0	0	2.4	399
scndring	3,254	0.1	0.3	0	0	0	1
thrddring	3,254	0.4	0.5	0	0	1	1
frthring	3,254	0.5	0.5	0	0	1	1
Garden	3,254	0.4	0.5	0	0	1	1
BalcTerr	3,254	0.4	0.5	0	0	1	1
Lotsize	3,254	1,709.3	17,622.4	0	391	1,106	993,861
Area	3,254	126.3	43.5	31.0	102.0	140.0	584.0
Age	3,254	38.8	29.7	9	12	59	169
Base	3,254	0.1	0.2	0	0	0	1
Basement	3,254	0.4	0.5	0	0	1	1
FullBase	3,254	0.2	0.4	0	0	0	1
Kitchen	3,254	0.4	0.5	0	0	1	1
FloorHeat	3,254	0.2	0.4	0	0	0	1
CentralHeat	3,254	0.6	0.5	0	0	1	1
GasHeat	3,254	0.05	0.2	0	0	0	1
Garage	3,254	0.6	0.5	0	0	1	1
GaragePl	3,254	0.1	0.3	0	0	0	1
HighQual	3,254	0.2	0.4	0	0	0	1
New	3,254	0.2	0.4	0	0	0	1
Renovated	3,254	0.05	0.2	0	0	0	1
Badcond	3,254	0.1	0.3	0	0	0	1
Fireplace	3,254	0.2	0.4	0	0	0	1
Woodenfloor	3,254	0.1	0.3	0	0	0	1
Sauna	3,254	0.05	0.2	0	0	0	1
School	3,254	1,222.9	416.7	0.0	1,037.8	1,511.6	1,940.2
Forest	3,254	385.5	495.9	0.0	0.0	734.1	1,927.4
Other green	3,254	1,108.5	393.4	0.0	876.1	1,380.6	1,947.9
Water	3,254	379.6	510.4	0	0	759.3	1,946
Sport Leisure	3,254	413.0	463.3	0	0	718.6	1,961
Street trees	3,254	16.0	16.0	0	3	24	111
Church	3,254	1,043.5	477.9	0.0	745.7	1,399.4	1,955.1

Table A.10: Descriptive statistics of submarket houses for sale in the years 2005 to 2009.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	2,961	359,451.1	322,553.5	40,405.1	218,019.8	394,187.0	3,155,635.0
Park	2,961	23.1	27.0	0.0	5.4	31.4	161.5
Playground	2,961	1.7	1.5	0.0	0.5	2.6	11.3
Allotment	2,961	11.0	17.3	0.0	0.0	16.4	140.4
Cemetery	2,961	17.7	68.8	0.0	0.0	2.7	398.9
scndring	2,961	0.1	0.3	0	0	0	1
thrddring	2,961	0.4	0.5	0	0	1	1
frthring	2,961	0.5	0.5	0	0	1	1
Garden	2,961	0.4	0.5	0	0	1	1
BalcTerr	2,961	0.3	0.5	0	0	1	1
Lotsize	2,961	1,577.1	4,044.8	0	385	1,059	89,126
Area	2,961	138.8	59.8	45.0	106.0	154.0	518.0
Age	2,961	36.1	32.8	3	8	58	371
Base	2,961	0.05	0.2	0	0	0	1
Basement	2,961	0.5	0.5	0	0	1	1
FullBase	2,961	0.1	0.4	0	0	0	1
Kitchen	2,961	0.3	0.5	0	0	1	1
FloorHeat	2,961	0.2	0.4	0	0	0	1
CentralHeat	2,961	0.5	0.5	0	0	1	1
GasHeat	2,961	0.05	0.2	0	0	0	1
Garage	2,961	0.7	0.5	0	0	1	1
GaragePl	2,961	0.1	0.3	0	0	0	1
HighQual	2,961	0.2	0.4	0	0	0	1
New	2,961	0.2	0.4	0	0	0	1
Renovated	2,961	0.1	0.2	0	0	0	1
Badcond	2,961	0.1	0.3	0	0	0	1
Fireplace	2,961	0.2	0.4	0	0	0	1
Woodenfloor	2,961	0.1	0.3	0	0	0	1
Sauna	2,961	0.04	0.2	0	0	0	1
School	2,961	1,202.3	410.3	0.0	989.6	1,478.7	1,958.6
Forest	2,961	358.4	509.1	0	0	681.4	1,954
Other green	2,961	1,124.0	416.5	0.0	857.9	1,413.0	1,969.7
Water	2,961	359.1	504.4	0	0	722.0	1,897
Sport Leisure	2,961	406.4	473.2	0	0	738.8	1,848
Street trees	2,961	16.4	16.2	0	3	25	112
Church	2,961	1,027.4	471.2	0.0	735.0	1,354.4	1,956.5

Table A.11: Descriptive statistics of submarket houses for sale in the years 2010 to 2014.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Price	1,685	434,697.7	249,980.1	73,153.1	285,827.3	491,460.4	2,638,614.0
Park	1,685	25.5	29.2	0.0	6.2	33.2	157.2
Playground	1,685	2.0	1.9	0.0	0.6	3.0	11.1
Allotment	1,685	12.2	16.9	0.0	0.0	17.8	140.4
Cemetery	1,685	15.9	65.9	0	0	2.7	399
scndring	1,685	0.1	0.3	0	0	0	1
thrddring	1,685	0.4	0.5	0	0	1	1
frthring	1,685	0.5	0.5	0	0	1	1
Garden	1,685	0.5	0.5	0	0	1	1
BalcTerr	1,685	0.4	0.5	0	0	1	1
Lotsize	1,685	1,551.6	2,748.4	0	456	1,475	44,015
Area	1,685	135.0	47.4	51.0	108.0	155.0	498.0
Age	1,685	26.4	31.8	0	3	50	255
Base	1,685	0.1	0.2	0	0	0	1
Basement	1,685	0.4	0.5	0	0	1	1
FullBase	1,685	0.1	0.3	0	0	0	1
Kitchen	1,685	0.3	0.5	0	0	1	1
FloorHeat	1,685	0.4	0.5	0	0	1	1
CentralHeat	1,685	0.4	0.5	0	0	1	1
GasHeat	1,685	0.05	0.2	0	0	0	1
Garage	1,685	0.5	0.5	0	0	1	1
GaragePl	1,685	0.2	0.4	0	0	0	1
HighQual	1,685	0.4	0.5	0	0	1	1
New	1,685	0.3	0.5	0	0	1	1
Renovated	1,685	0.1	0.3	0	0	0	1
Badcond	1,685	0.1	0.3	0	0	0	1
Fireplace	1,685	0.2	0.4	0	0	0	1
Woodenfloor	1,685	0.2	0.4	0	0	0	1
Sauna	1,685	0.04	0.2	0	0	0	1
School	1,685	1,224.4	404.3	0.0	995.1	1,532.3	1,955.1
Forest	1,685	331.1	493.0	0	0	651.6	1,923
Other green	1,685	1,101.0	401.1	0.0	865.5	1,384.0	1,924.8
Water	1,685	440.4	560.5	0.0	0.0	889.7	1,896.7
Sport Leisure	1,685	497.9	509.3	0.0	0.0	856.5	1,895.8
Street trees	1,685	16.3	16.3	0	2	24	112
Church	1,685	1,099.9	465.7	0.0	819.3	1,420.5	1,958.0

Table A.12: Descriptive statistics of submarket houses for sale in the years 2015 to 2018.

A.2.2 Descriptive statistics Socioeconomic characteristics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Above60	141,875	23.9	5.5	8.7	19.5	28.0	39.4
Singles	141,875	60.5	21.1	0.0	45.9	78.7	100.0
Families	141,875	16.7	15.7	0.0	3.9	25.3	100.0
Children	141,875	0.2	0.04	0.1	0.2	0.2	0.7
Unemployed	141,875	7.3	4.2	0.0	4.2	9.8	23.3
Poden	141,875	6,662.2	4,339.1	19	3,573	9,429	24,961
Purchasing Power (PP)	141,875	42,264.6	7,957.3	20,229.7	36,184.4	47,026.3	84,230.7

Table A.13: Descriptive statistics of socioeconomic variables - full sample

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Above60	47,154	20.0	4.0	8.7	17.9	23.0	31.1
Singles	47,154	73.8	14.2	0.8	66.4	84.1	99.6
Families	47,154	12.2	14.2	0.0	1.8	18.7	95.2
Children	47,154	0.2	0.03	0.1	0.2	0.2	0.4
Unemployed	47,154	10.9	3.4	0.7	8.5	12.7	23.3
Poden	47,154	9,174.0	4,453.8	36	5,958	11,814	24,961
Purchasing Power (PP)	47,154	34,197.9	2,609.7	20,229.7	32,814.8	36,184.4	37,847.7

Table A.14: Descriptive statistics of socioeconomic variables - low-income group

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Above60	47,141	23.8	4.7	9.1	20.9	26.9	38.3
Singles	47,141	63.0	17.2	0.0	53.4	76.8	100.0
Families	47,141	17.3	15.7	0.0	4.7	26.1	94.4
Children	47,141	0.2	0.03	0.1	0.2	0.2	0.6
Unemployed	47,141	7.3	2.7	0.0	5.3	8.9	18.5
Poden	47,141	6,806.2	4,065.1	35	3,906	9,098	20,231
Purchasing Power (PP)	47,141	41,330.4	2,104.3	37,847.8	39,477.8	43,151.2	44,945.8

Table A.15: Descriptive statistics of socioeconomic variables - mid income group

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Above60	47,206	27.9	4.6	9.8	25.4	31.5	39.4
Singles	47,206	44.7	20.2	0.0	31.2	59.9	98.3
Families	47,206	20.7	16.0	0.0	8.0	28.6	100.0
Children	47,206	0.2	0.05	0.1	0.2	0.3	0.7
Unemployed	47,206	3.7	2.8	0.0	1.5	5.0	17.7
Poden	47,206	4,009.4	2,600.0	19	2,557	4,754	15,695
Purchasing Power (PP)	47,206	51,254.5	5,643.3	44,945.8	47,025.3	54,332.4	84,230.7

Table A.16: Descriptive statistics of socioeconomic variables - high-income group

Table A.17: Summary descriptive statistics table by high and low-income group displaying differences in means of sociodemopgraphic variables as well as differences in the size of each of the closest UGS types and number of UGS in a 1 km radius.

	high N=47206	low N=47154	p.overall
Above60	27.9 (4.56)	20.0 (3.95)	0.000
Singles	44.7 (20.2)	73.8 (14.2)	0.000
Families	20.7 (16.0)	12.2 (14.2)	0.000
Children	0.24 (0.05)	0.22 (0.03)	0.000
Unemployed	3.66 (2.82)	10.9 (3.36)	0.000
Poden	4009 (2600)	9174 (4454)	0.000
park count	15.7 (10.2)	21.9 (9.43)	0.000
play count	4.55 (4.26)	13.4 (7.92)	0.000
cem count	0.34 (0.67)	0.46 (0.83)	<0.001
Size park	2.12 (4.16)	1.02 (2.14)	0.000
Size playground	0.43 (0.62)	0.34 (0.31)	<0.001
Size cemetery	11.4 (55.7)	2.30 (18.0)	<0.001

A.2.3 Spatial distribution of urban green spaces

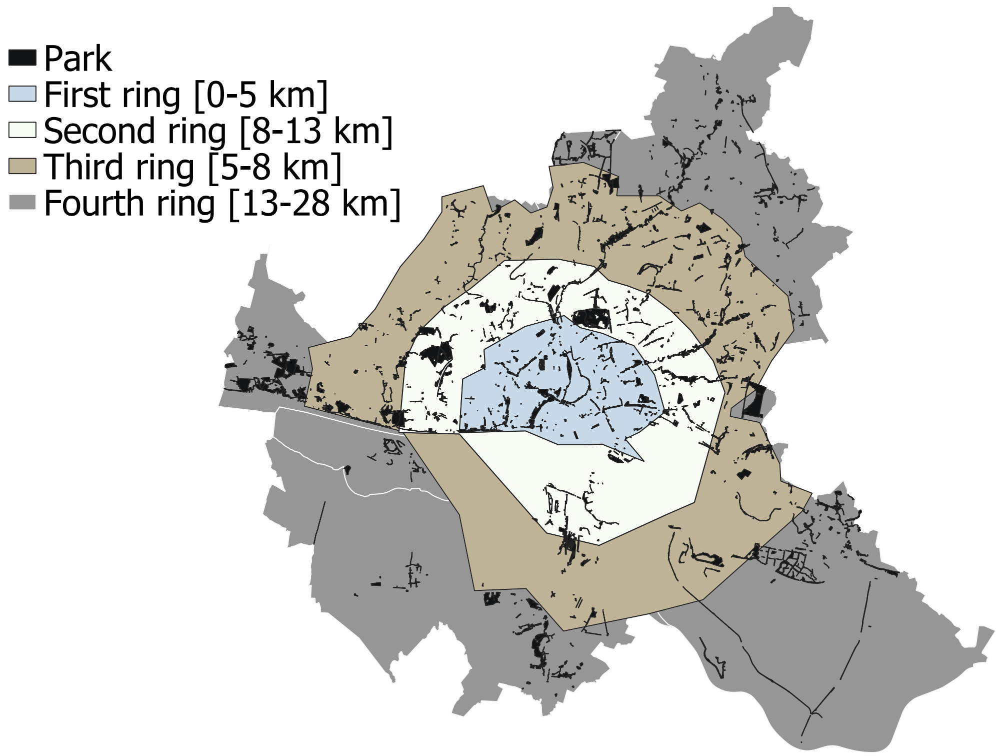

Figure A.2: Spatial distribution of parks (BUE, 2016c) across the urban space as well as rings indicating the walking distance from the city center over the street map.

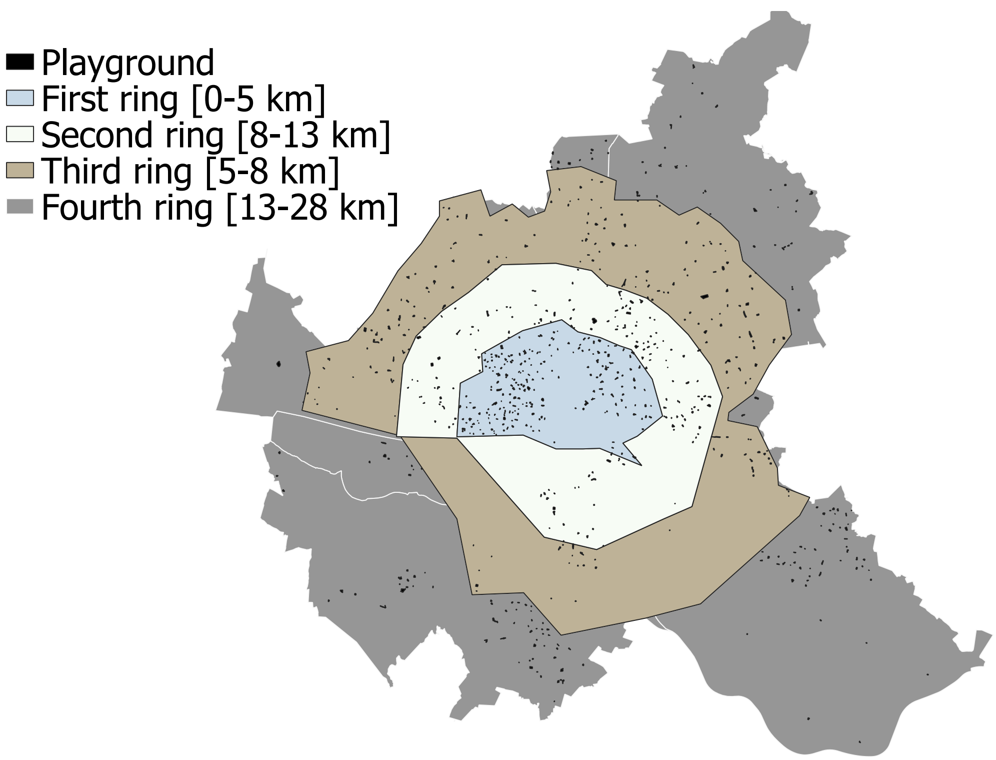

Figure A.3: Spatial distribution of playgrounds (BUE, 2016c) across the urban space as well as rings indicating the walking distance from the city center over the street map.

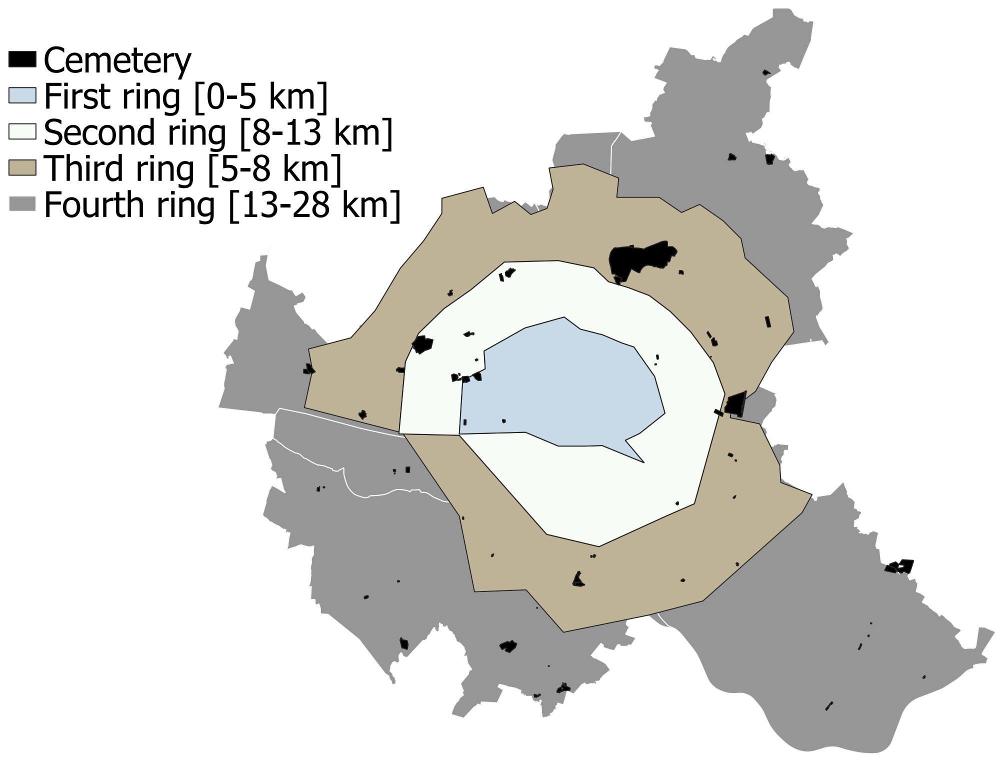

Figure A.4: Spatial distribution of cemeteries (BUE, 2016c) across the urban space as well as rings indicating the walking distance from the city center over the street map.

A.3 First-stage results: Hedonic price schedule and marginal willingness to pay

	Dependent variable:											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	5.480	0.020	5.441	5.520	5.790	0.019	5.752	5.827	5.764	0.018	5.730	5.803
Park	-0.001	2.4E-04	-0.001	0.000	-0.001	1.9E-04	-0.002	-0.001	-0.001	1.9E-04	-0.001	0.000
Playgound	-0.003	0.004	-0.009	0.005	-0.002	0.004	-0.010	0.004	-0.010	0.004	-0.017	-0.003
Allotment	-0.001	2.7E-04	-0.002	-0.001	-0.001	2.8E-04	-0.002	-0.001	-1.7E-04	2.8E-04	-0.001	0.000
Cemetery	0.001	0.001	-1.4E-04	0.003	-0.003	0.001	-0.004	-0.002	-0.001	0.001	-0.003	0.001
scndring	-0.236	0.012	-0.259	-0.214	-0.227	0.010	-0.245	-0.209	-0.165	0.012	-0.189	-0.142
thrddring	-0.231	0.012	-0.253	-0.208	-0.380	0.009	-0.398	-0.363	-0.285	0.010	-0.305	-0.264
frthring	-0.274	0.013	-0.299	-0.248	-0.442	0.010	-0.461	-0.423	-0.325	0.011	-0.348	-0.302
Garden	0.052	0.007	0.040	0.066	0.016	0.006	0.006	0.028	-0.005	0.006	-0.018	0.008
BalcTerr	0.003	0.005	-0.010	0.011	-0.007	0.004	-0.015	0.003	-0.011	0.005	-0.024	-0.003
LotSize	1.1E-06	3.4E-07	3.9E-07	1.7E-06	-3.8E-06	4.5E-07	-4.7E-06	-2.9E-06	-4.3E-06	6.2E-07	-5.7E-06	-3.1E-06
Area	0.013	1.0E-04	0.013	0.013	0.012	8.5E-05	0.011	0.012	0.011	6.6E-05	0.011	0.011
Age	-3.4E-04	5.2E-05	-4.4E-04	-2.4E-04	-0.001	4.1E-05	-0.001	-0.001	-0.001	4.5E-05	-0.001	0.000
Base	0.041	0.015	0.012	0.069	-0.010	0.013	-0.037	0.016	0.100	0.009	0.081	0.116
Basement	0.000	0.002	-0.004	0.004	-0.008	0.002	-0.012	-0.004	-0.004	0.002	-0.008	0.001
FullBase	0.038	0.017	0.006	0.071	0.014	0.018	-0.022	0.048	0.037	0.017	0.003	0.071
Kitchen	0.107	0.002	0.102	0.111	0.083	0.002	0.078	0.087	0.066	0.003	0.061	0.072
FloorHeat	0.112	0.006	0.101	0.123	0.082	0.003	0.075	0.089	0.080	0.004	0.072	0.088
CentralHeat	-0.012	0.002	-0.016	-0.007	-0.039	0.002	-0.043	-0.035	-0.035	0.002	-0.040	-0.030
GasHeat	0.005	0.013	-0.021	0.031	0.029	0.013	0.003	0.055	0.019	0.012	-0.005	0.042
Garage	0.062	0.003	0.057	0.068	0.055	0.002	0.050	0.059	0.061	0.003	0.055	0.066
GaragePl	0.044	0.005	0.035	0.053	0.032	0.004	0.024	0.039	0.027	0.004	0.019	0.035
HighQual	0.096	0.006	0.085	0.107	0.056	0.003	0.050	0.061	0.080	0.003	0.073	0.086
New	-0.009	0.004	-0.017	-0.003	0.073	0.004	0.066	0.080	0.070	0.004	0.061	0.078
Renovated	0.023	0.004	0.015	0.032	0.069	0.003	0.062	0.076	0.067	0.003	0.060	0.074
Badcond	-0.058	0.009	-0.075	-0.041	-0.098	0.012	-0.122	-0.073	-0.093	0.013	-0.121	-0.069
Fireplace	-0.017	0.015	-0.048	0.012	-0.044	0.011	-0.066	-0.025	-0.058	0.011	-0.081	-0.037
Woodenfloor	0.061	0.004	0.053	0.069	0.046	0.003	0.041	0.052	0.030	0.003	0.024	0.036
Sauna	0.018	0.024	-0.026	0.066	-0.008	0.021	-0.052	0.030	0.020	0.014	-0.006	0.048
School	-1.7E-06	4.3E-06	-1.0E-05	6.7E-06	-9.9E-06	3.9E-06	-1.8E-05	-2.5E-06	4.6E-06	4.2E-06	-3.4E-06	1.3E-05
Forest	-1.7E-05	4.4E-06	-2.5E-05	-8.3E-06	-2.3E-05	3.7E-06	-3.0E-05	-1.6E-05	-1.6E-05	4.1E-06	-2.4E-05	-7.9E-06
Other green	-7.2E-06	3.4E-06	-1.4E-05	-4.7E-07	-2.5E-06	3.2E-06	-8.8E-06	3.5E-06	-1.2E-05	3.7E-06	-1.9E-05	-4.7E-06
Water	1.6E-05	2.9E-06	1.1E-05	2.2E-05	1.0E-05	2.6E-06	5.3E-06	1.6E-05	1.4E-05	3.0E-06	8.2E-06	2.0E-05
Sport Leisure	-1.8E-06	1.4E-06	-4.2E-06	1.0E-06	-5.4E-06	1.3E-06	-8.2E-06	-3.0E-06	-8.5E-07	1.2E-06	-3.2E-06	1.6E-06
Street trees	-3.8E-04	5.6E-05	-4.9E-04	-2.7E-04	-4.9E-04	5.7E-05	-6.0E-04	-3.8E-04	-3.5E-04	6.4E-05	-4.7E-04	-2.2E-04
Church	9.5E-07	3.1E-06	-5.0E-06	6.9E-06	-4.7E-06	3.1E-06	-1.1E-05	1.5E-06	6.8E-06	3.6E-06	6.7E-09	1.4E-05
submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	29,964				43,199				41,661			
Bootstraps	1,000				1,000				1,000			

Table A.18: Hedonic price schedules for three market equilibria in the submarket flats for rent estimated with an internal instrumental variable method (first half of results). The Ln Price is the dependent variable.

	Dependent variable:											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
Park*scndring	0.001	1.6E-04	0.001	0.001	0.001	1.3E-04	0.001	0.001	0.001	1.4E-04	3.0E-04	0.001
Park*thrddring	-2.9E-04	2.1E-04	-0.001	1.1E-04	0.002	1.8E-04	0.001	0.002	0.001	1.7E-04	0.001	0.001
Park*frthring	-6.7E-05	2.0E-04	-4.3E-04	3.2E-04	0.001	1.7E-04	0.001	0.001	3.3E-06	1.7E-04	-3.4E-04	3.3E-04
Park*Garden	-4.1E-04	1.1E-04	-0.001	-1.7E-04	9.3E-05	9.9E-05	-1.1E-04	2.9E-04	2.0E-04	1.1E-04	-1.3E-05	4.1E-04
Park*BalcTerr	6.3E-05	8.7E-05	-1.1E-04	2.4E-04	3.2E-04	7.2E-05	1.7E-04	4.6E-04	1.6E-04	8.1E-05	2.0E-05	3.3E-04
Park*LotSize	-4.9E-09	1.1E-08	-2.7E-08	1.7E-08	7.2E-08	1.1E-08	5.0E-08	9.2E-08	9.4E-08	1.1E-08	7.2E-08	1.2E-07
Park*Playground	-1.5E-05	2.7E-05	-6.8E-05	3.8E-05	1.3E-04	2.3E-05	8.2E-05	1.7E-04	9.4E-05	2.7E-05	3.9E-05	1.4E-04
Park*Cemetery	-2.6E-07	8.6E-07	-1.9E-06	1.5E-06	-2.6E-06	6.1E-07	-3.7E-06	-1.5E-06	-2.7E-06	6.4E-07	-4.1E-06	-1.5E-06
Playground*scndring	0.013	0.002	0.009	0.017	0.015	0.002	0.012	0.019	0.007	0.002	0.002	0.011
Playground*thrddring	0.002	0.003	-0.003	0.008	-0.002	0.002	-0.006	0.002	-0.011	0.002	-0.015	-0.006
Playground*frthring	0.024	0.003	0.018	0.030	0.035	0.003	0.030	0.041	0.014	0.003	0.007	0.020
Playground*Garden	-0.002	0.001	-0.004	0.001	-0.003	0.001	-0.005	-0.001	0.003	0.001	-2.0E-04	0.006
Playground*BalcTerr	0.002	0.001	-3.6E-04	0.004	0.002	0.001	0.000	0.003	0.002	0.001	3.7E-04	0.004
Playground*LotSize	-7.1E-09	1.1E-07	-2.1E-07	2.3E-07	1.7E-07	1.3E-07	-9.1E-08	4.2E-07	2.0E-07	1.6E-07	-1.2E-07	4.9E-07
Playground*Cemetery	-2.6E-05	1.2E-05	-4.8E-05	-3.6E-06	3.6E-05	9.6E-06	1.7E-05	5.4E-05	5.0E-05	9.5E-06	3.1E-05	6.9E-05
Allotment*scndring	0.001	1.4E-04	0.001	0.001	0.001	1.4E-04	0.001	0.001	4.2E-04	1.4E-04	1.4E-04	0.001
Allotment*thrddring	0.002	2.1E-04	0.001	0.002	0.004	2.1E-04	0.004	0.004	0.002	2.3E-04	0.002	0.003
Allotment*frthring	4.3E-04	3.4E-04	-2.2E-04	0.001	0.001	3.0E-04	0.001	0.002	0.002	3.7E-04	0.001	0.003
Allotment*Garden	0.001	1.5E-04	3.2E-04	0.001	0.001	1.5E-04	0.001	0.001	4.8E-04	1.9E-04	7.2E-05	0.001
Allotment*BalcTerr	1.1E-04	8.7E-05	-5.1E-05	2.8E-04	-2.7E-04	9.7E-05	-4.6E-04	-8.2E-05	-2.1E-04	1.1E-04	-4.2E-04	2.8E-06
Allotment*LotSize	-1.4E-08	1.1E-08	-3.5E-08	7.1E-09	2.3E-08	1.4E-08	-3.6E-09	4.9E-08	1.1E-07	2.0E-08	7.7E-08	1.5E-07
Park*Allotment	-7.8E-06	4.5E-06	-1.6E-05	7.6E-07	-1.1E-05	4.0E-06	-1.9E-05	-3.2E-06	-1.0E-05	4.4E-06	-1.9E-05	-1.7E-06
Playground*Allotment	3.4E-04	4.2E-05	2.6E-04	4.3E-04	3.8E-04	4.3E-05	2.9E-04	4.7E-04	2.4E-04	4.7E-05	1.5E-04	3.3E-04
Allotment*Cemetery	-9.4E-06	1.7E-06	-1.3E-05	-6.4E-06	-1.1E-05	2.1E-06	-1.5E-05	-7.3E-06	-1.3E-05	1.9E-06	-1.6E-05	-8.8E-06
Cemetery*scndring	-0.001	0.001	-0.003	4.2E-04	0.003	0.001	0.002	0.004	0.001	0.001	-4.4E-04	0.003
Cemetery*thrddring	-0.001	0.001	-0.003	3.4E-04	0.003	0.001	0.002	0.005	0.001	0.001	-2.5E-04	0.003
Cemetery*frthring	0.001	0.001	-0.001	0.002	0.005	0.001	0.004	0.007	0.003	0.001	0.001	0.005
Cemetery*Garden	-6.7E-05	3.5E-05	-1.3E-04	-5.6E-07	-2.3E-06	3.1E-05	-6.6E-05	6.6E-05	-5.2E-07	3.9E-05	-8.3E-05	7.0E-05
Cemetery*BalcTerr	-3.7E-06	2.4E-05	-4.8E-05	4.4E-05	7.2E-06	2.2E-05	-3.4E-05	5.3E-05	-4.2E-05	2.6E-05	-9.3E-05	6.7E-06
Cemetery*LotSize	-4.9E-09	3.2E-09	-1.1E-08	1.5E-09	5.7E-09	2.4E-09	7.0E-10	1.0E-08	-4.5E-09	3.0E-09	-1.1E-08	4.6E-10
Allotment**	-0.001	2.7E-04	-0.002	-0.001	-0.001	2.8E-04	-0.002	-0.001	-1.7E-04	2.8E-04	-0.001	3.7E-04
Park**	-0.001	2.4E-04	-0.001	0.000	-0.001	1.9E-04	-0.002	-0.001	-0.001	1.9E-04	-0.001	-1.3E-04
Playgound**	-0.003	0.004	-0.009	0.005	-0.002	0.004	-0.010	0.004	-0.010	0.004	-0.017	-0.003
Cemetery**	0.001	0.001	0.000	0.003	-0.003	0.001	-0.004	-0.002	-0.001	0.001	-0.003	0.001
LotSize**	1.1E-06	3.4E-07	3.9E-07	1.7E-06	-3.8E-06	4.5E-07	-4.7E-06	-2.9E-06	-4.3E-06	6.2E-07	-5.7E-06	-3.1E-06
BalcTerr**	0.003	0.005	-0.010	0.011	-0.007	0.004	-0.015	0.003	-0.011	0.005	-0.024	-0.003
Garden**	0.052	0.007	0.040	0.066	0.016	0.006	0.006	0.028	-0.005	0.006	-0.018	0.008
submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	29,964				43,199				41,661			
Bootstraps	1,000				1,000				1,000			

Table A.19: Hedonic price schedules for three market equilibria in the submarket flats for rent estimated with an internal instrumental variable method (continued). The Ln Price is the dependent variable.

	Dependent variable:											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	11.078	0.058	10.958	11.194	12.008	0.066	11.893	12.151	12.079	0.050	11.979	12.177
Park	-0.002	0.001	-0.003	-0.001	-0.002	0.001	-0.003	0.000	0.000	0.001	-0.001	0.001
Playgound	0.001	0.008	-0.016	0.017	-0.046	0.008	-0.064	-0.033	-0.028	0.008	-0.044	-0.015
Allotment	-0.004	0.001	-0.006	-0.002	0.004	0.001	0.002	0.006	0.000	0.001	-0.002	0.002
Cemetery	-0.006	0.003	-0.012	-0.001	-0.003	0.003	-0.008	0.002	-0.010	0.002	-0.014	-0.007
scndring	-0.356	0.035	-0.421	-0.287	-0.311	0.036	-0.385	-0.243	-0.253	0.033	-0.310	-0.183
thrddring	-0.425	0.031	-0.484	-0.363	-0.510	0.033	-0.573	-0.445	-0.354	0.031	-0.411	-0.288
frthring	-0.409	0.036	-0.476	-0.339	-0.314	0.034	-0.374	-0.246	-0.340	0.034	-0.401	-0.272
Garden	0.006	0.017	-0.031	0.034	0.004	0.015	-0.025	0.032	-0.006	0.014	-0.029	0.027
BalcTerr	-0.002	0.016	-0.023	0.041	0.007	0.014	-0.030	0.023	-0.046	0.014	-0.070	-0.014
LotSize	1.3E-05	2.9E-06	6.8E-06	1.8E-05	-7.9E-06	2.8E-06	-1.4E-05	-2.9E-06	-2.4E-06	3.4E-06	-9.8E-06	3.6E-06
Area	0.013	2.2E-04	0.012	0.013	0.010	3.7E-04	0.009	0.011	0.010	1.7E-04	0.010	0.011
Age	-0.002	1.5E-04	-0.002	-0.002	-0.003	1.4E-04	-0.003	-0.002	-0.001	1.3E-04	-0.002	-0.001
Base	0.022	0.018	-0.015	0.054	0.025	0.020	-0.016	0.062	-0.024	0.014	-0.055	0.002
Basement	-0.003	0.007	-0.017	0.011	-0.005	0.008	-0.020	0.010	0.002	0.006	-0.009	0.014
FullBase	-0.035	0.019	-0.073	0.002	-0.123	0.035	-0.192	-0.054	-0.044	0.026	-0.094	0.007
Kitchen	0.012	0.007	-0.002	0.027	-0.015	0.007	-0.029	-0.002	-0.020	0.007	-0.034	-0.006
FloorHeat	0.100	0.010	0.081	0.119	0.096	0.007	0.083	0.109	0.077	0.007	0.064	0.090
CentralHeat	-0.010	0.007	-0.023	0.004	-0.054	0.007	-0.068	-0.041	-0.060	0.006	-0.071	-0.048
GasHeat	-0.019	0.028	-0.071	0.036	-0.026	0.049	-0.127	0.070	-0.031	0.026	-0.078	0.022
Garage	0.087	0.009	0.070	0.105	0.081	0.011	0.060	0.103	0.048	0.007	0.033	0.062
GaragePl	0.017	0.014	-0.009	0.044	0.049	0.014	0.024	0.078	-0.019	0.010	-0.039	-1.6E-05
HighQual	0.127	0.008	0.110	0.143	0.113	0.008	0.098	0.129	0.071	0.006	0.058	0.082
New	0.147	0.011	0.126	0.168	0.129	0.007	0.115	0.142	0.081	0.006	0.069	0.092
Renovated	0.052	0.011	0.030	0.073	0.064	0.014	0.037	0.090	0.031	0.011	0.009	0.052
Badcond	-0.145	0.017	-0.180	-0.113	-0.111	0.021	-0.153	-0.069	-0.102	0.022	-0.149	-0.059
Fireplace	0.011	0.020	-0.030	0.048	0.031	0.026	-0.021	0.083	-0.008	0.019	-0.044	0.030
Woodenfloor	0.044	0.009	0.027	0.063	0.033	0.007	0.019	0.046	0.041	0.006	0.029	0.053
Sauna	0.007	0.022	-0.037	0.049	-0.013	0.034	-0.079	0.055	0.039	0.029	-0.015	0.096
School	5.4E-06	1.4E-05	-2.1E-05	3.3E-05	-6.8E-05	1.2E-05	-9.0E-05	-4.4E-05	-6.9E-05	1.2E-05	-9.2E-05	-4.7E-05
Forest	3.6E-05	1.5E-05	7.8E-06	6.5E-05	-4.8E-05	1.0E-05	-6.8E-05	-2.7E-05	3.5E-05	1.0E-05	1.4E-05	5.4E-05
Other green	1.4E-05	1.1E-05	-8.4E-06	3.6E-05	1.1E-05	1.1E-05	-1.0E-05	3.2E-05	2.0E-06	9.2E-06	-1.6E-05	2.2E-05
Water	3.8E-05	9.8E-06	2.0E-05	5.8E-05	3.5E-05	9.2E-06	1.7E-05	5.3E-05	7.1E-05	7.7E-06	5.6E-05	8.7E-05
Sport Leisure	8.8E-06	3.9E-06	1.8E-06	1.7E-05	-6.2E-06	3.7E-06	-1.3E-05	1.1E-06	2.3E-06	1.4E-06	-4.4E-07	5.1E-06
Street trees	4.6E-04	1.9E-04	1.1E-04	8.2E-04	7.6E-04	2.0E-04	3.8E-04	1.2E-03	5.4E-04	2.0E-04	1.7E-04	9.3E-04
Church	2.8E-05	1.2E-05	4.3E-06	5.0E-05	-1.2E-05	1.1E-05	-3.5E-05	7.1E-06	2.3E-05	9.9E-06	5.2E-06	4.2E-05
submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table A.20: Hedonic price schedules for three market equilibria in the submarket flats for sale, estimated with an internal instrumental variable method (first half of results). The Ln Price is the dependent variable.

	Dependent variable:											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
Park*scndring	0.002	4.1E-04	0.001	0.003	0.002	4.2E-04	0.001	0.002	0.001	4.3E-04	0.000	0.002
Park*thrddring	0.002	0.001	0.001	0.003	0.004	0.001	0.003	0.005	0.000	0.001	-0.001	0.002
Park*frthring	-0.001	0.001	-0.002	0.000	-0.001	0.001	-0.002	0.000	-0.001	0.001	-0.002	0.000
Park*Garden	0.001	2.8E-04	0.001	0.002	8.7E-05	2.2E-04	0.000	0.001	1.7E-04	2.5E-04	0.000	0.001
Park*BalcTerr	0.001	2.5E-04	1.7E-04	0.001	6.4E-05	2.2E-04	-3.5E-04	5.0E-04	3.1E-04	2.2E-04	-1.0E-04	0.001
Park*LotSize	-4.5E-08	4.7E-08	-1.3E-07	5.1E-08	5.3E-08	3.1E-08	-8.2E-09	1.1E-07	4.9E-08	7.8E-08	-1.0E-07	2.1E-07
Park*Playground	-1.4E-04	7.6E-05	-2.9E-04	2.6E-06	5.4E-05	6.7E-05	-7.9E-05	1.8E-04	-2.1E-04	8.1E-05	-3.7E-04	-5.4E-05
Park*Cemetery	-5.4E-06	2.4E-06	-1.0E-05	-7.8E-07	-6.4E-06	3.1E-06	-1.3E-05	-8.0E-07	-1.1E-05	3.6E-06	-1.9E-05	-4.6E-06
Playground*scndring	0.022	0.006	0.011	0.033	0.023	0.006	0.011	0.035	0.022	0.005	0.011	0.032
Playground*thrddring	0.007	0.007	-0.007	0.021	-0.020	0.013	-0.046	0.000	-0.004	0.007	-0.018	0.010
Playground*frthring	0.047	0.012	0.023	0.070	0.005	0.011	-0.017	0.025	0.008	0.009	-0.012	0.025
Playground*Garden	-0.002	0.003	-0.007	0.003	-0.002	0.002	-0.007	0.003	-0.015	0.003	-0.020	-0.009
Playground*BalcTerr	0.006	0.003	0.001	0.011	0.007	0.002	0.001	0.011	0.005	0.003	0.000	0.010
Playground*LotSize	-2.3E-06	4.5E-07	-3.1E-06	-1.4E-06	-1.6E-06	4.4E-07	-2.5E-06	-7.0E-07	-1.1E-06	5.7E-07	-2.2E-06	1.9E-08
Playground*Cemetery	5.7E-05	3.4E-05	-9.6E-06	1.2E-04	-5.8E-05	4.2E-05	-1.3E-04	3.0E-05	1.5E-04	4.7E-05	6.7E-05	2.5E-04
Allotment*scndring	0.001	0.001	3.4E-04	0.002	-0.002	4.0E-04	-0.003	-0.001	1.3E-04	0.001	-0.001	0.001
Allotment*thrddring	0.004	0.001	0.003	0.005	0.002	0.001	0.001	0.003	0.001	0.001	-4.4E-04	0.002
Allotment*frthring	0.006	0.002	0.003	0.009	0.002	0.001	3.2E-04	0.004	0.005	0.001	0.003	0.007
Allotment*Garden	4.5E-04	3.7E-04	0.000	0.001	4.6E-04	3.6E-04	-2.4E-04	0.001	0.003	4.2E-04	0.002	0.003
Allotment*BalcTerr	-0.001	3.2E-04	-0.001	9.6E-05	2.6E-05	3.0E-04	-0.001	0.001	-3.8E-04	4.0E-04	-0.001	3.8E-04
Allotment*LotSize	3.5E-09	7.4E-08	-1.4E-07	1.5E-07	2.9E-08	8.2E-08	-1.3E-07	1.9E-07	7.8E-08	9.3E-08	-9.7E-08	2.6E-07
Park*Allotment	-3.4E-05	1.3E-05	-6.0E-05	-1.0E-05	-1.0E-04	1.4E-05	-1.3E-04	-7.3E-05	-5.5E-05	1.7E-05	-8.6E-05	-2.3E-05
Playground*Allotment	0.001	1.2E-04	0.001	0.001	0.001	1.7E-04	2.2E-04	0.001	0.001	1.4E-04	0.001	0.001
Allotment*Cemetery	-1.1E-05	6.6E-06	-2.4E-05	1.9E-06	1.0E-06	7.5E-06	-1.3E-05	1.5E-05	-4.3E-06	7.9E-06	-2.0E-05	1.1E-05
Cemetery*scndring	0.007	0.003	0.002	0.012	0.005	0.002	-0.001	0.009	0.010	0.002	0.007	0.013
Cemetery*thrddring	0.007	0.003	0.002	0.013	0.004	0.002	-0.001	0.009	0.011	0.002	0.007	0.014
Cemetery*frthring	0.012	0.003	0.006	0.017	0.008	0.003	0.003	0.013	0.013	0.002	0.009	0.016
Cemetery*Garden	6.4E-05	7.2E-05	-7.9E-05	2.0E-04	2.0E-04	7.2E-05	4.7E-05	3.4E-04	-2.2E-05	6.4E-05	-1.5E-04	1.1E-04
Cemetery*BalcTerr	-2.1E-04	6.3E-05	-3.4E-04	-9.0E-05	6.9E-05	6.5E-05	-5.9E-05	1.8E-04	1.8E-04	8.2E-05	1.7E-05	3.3E-04
Cemetery*LotSize	-1.3E-08	8.1E-09	-2.9E-08	2.8E-09	2.3E-08	6.9E-09	9.8E-09	3.7E-08	-3.2E-08	1.6E-08	-6.5E-08	-5.9E-09
Allotment**	-0.004	0.001	-0.006	-0.002	0.004	0.001	0.002	0.006	-3.8E-04	0.001	-0.002	0.002
Park**	-0.002	0.001	-0.003	-0.001	-0.002	0.001	-0.003	0.000	0.000	0.001	-0.001	0.001
Playgound**	0.001	0.008	-0.016	0.017	-0.046	0.008	-0.064	-0.033	-0.028	0.008	-0.044	-0.015
Cemetery**	-0.006	0.003	-0.012	-0.001	-0.003	0.003	-0.008	0.002	-0.010	0.002	-0.014	-0.007
LotSize**	1.3E-05	2.9E-06	6.8E-06	1.8E-05	-7.9E-06	2.8E-06	-1.4E-05	-2.9E-06	-2.4E-06	3.4E-06	-9.8E-06	3.6E-06
BalcTerr**	-0.002	0.016	-0.023	0.041	0.007	0.014	-0.030	0.023	-0.046	0.014	-0.070	-0.014
Garden**	0.006	0.017	-0.031	0.034	0.004	0.015	-0.025	0.032	-0.006	0.014	-0.029	0.027
submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table A.21: Hedonic price schedules for three market equilibria in the submarket flats for sale, estimated with an internal instrumental variable method (continued). The Ln Price is the dependent variable.

	Dependent variable:											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	12.121	0.153	11.868	12.475	11.571	0.169	11.267	11.927	12.134	0.172	11.771	12.451
Park	-3.4E-04	0.001	-0.003	0.003	0.007	0.003	0.001	0.011	0.002	0.003	-0.002	0.009
Playgound	-0.004	0.023	-0.055	0.036	0.043	0.026	-0.002	0.099	0.003	0.028	-0.045	0.064
Allotment	0.001	0.007	-0.012	0.014	0.002	0.002	-0.002	0.006	0.004	0.002	-4.5E-04	0.009
Cemetery	-0.027	0.032	-0.109	0.045	-0.016	0.025	-0.065	0.035	-0.147	0.115	-0.280	0.190
scndring	-0.395	0.144	-0.687	-0.114	0.349	0.165	0.007	0.666	-0.200	0.163	-0.482	0.157
thrddring	-0.545	0.134	-0.823	-0.305	0.173	0.155	-0.135	0.459	-0.228	0.142	-0.503	0.048
frthring	-0.582	0.135	-0.858	-0.343	0.154	0.160	-0.185	0.452	-0.283	0.143	-0.550	0.012
Garden	0.028	0.021	-0.024	0.058	0.021	0.022	-0.044	0.043	0.048	0.030	0.000	0.118
BalcTerr	-0.055	0.022	-0.100	-0.017	-0.013	0.023	-0.058	0.031	0.017	0.029	-0.049	0.060
LotSize	1.7E-07	1.1E-05	-2.8E-05	3.0E-07	-1.6E-05	5.1E-06	-3.1E-05	-1.2E-05	-1.4E-05	8.9E-06	-3.9E-05	-5.5E-06
Area	0.006	2.9E-04	0.006	0.007	0.006	1.5E-04	0.006	0.006	0.006	2.3E-04	0.006	0.006
Age	-0.002	2.7E-04	-0.002	-0.001	-0.002	2.9E-04	-0.002	-0.001	-0.002	4.0E-04	-0.003	-0.001
Base	0.053	0.019	0.018	0.092	-0.009	0.021	-0.049	0.033	0.048	0.031	-0.021	0.104
Basement	0.001	0.010	-0.018	0.021	0.043	0.011	0.021	0.066	0.067	0.016	0.037	0.099
FullBase	0.030	0.009	0.014	0.050	0.024	0.013	-0.003	0.049	-0.067	0.021	-0.107	-0.025
Kitchen	0.009	0.010	-0.011	0.029	-0.021	0.012	-0.043	0.002	0.043	0.016	0.011	0.075
FloorHeat	0.016	0.012	-0.008	0.041	0.053	0.013	0.030	0.078	0.026	0.016	-0.006	0.058
CentralHeat	0.019	0.010	0.001	0.040	0.012	0.011	-0.008	0.033	0.017	0.014	-0.011	0.044
GasHeat	0.011	0.022	-0.036	0.053	-0.040	0.027	-0.092	0.016	-0.074	0.033	-0.138	-0.010
Garage	0.123	0.011	0.100	0.144	0.040	0.013	0.012	0.063	0.053	0.014	0.023	0.080
GaragePl	0.062	0.015	0.032	0.090	0.042	0.019	0.003	0.078	-0.028	0.019	-0.067	0.006
HighQual	0.081	0.011	0.058	0.101	0.103	0.014	0.077	0.128	0.084	0.016	0.052	0.114
New	0.079	0.012	0.054	0.099	0.059	0.014	0.031	0.084	0.092	0.016	0.056	0.118
Renovated	0.003	0.025	-0.044	0.051	0.041	0.028	-0.015	0.095	0.006	0.028	-0.043	0.064
Badcond	-0.107	0.019	-0.147	-0.070	-0.115	0.021	-0.157	-0.076	-0.131	0.032	-0.192	-0.065
Fireplace	0.050	0.014	0.020	0.074	0.040	0.017	0.008	0.072	0.057	0.020	0.016	0.098
Woodenfloor	0.053	0.017	0.020	0.086	0.099	0.016	0.070	0.132	0.098	0.020	0.060	0.142
Sauna	0.004	0.024	-0.047	0.048	0.019	0.027	-0.035	0.069	0.019	0.042	-0.069	0.104
School	4.2E-05	1.5E-05	1.5E-05	7.3E-05	5.1E-05	1.7E-05	2.0E-05	8.3E-05	3.8E-05	2.3E-05	-3.7E-06	8.8E-05
Forest	-1.0E-07	1.1E-05	-2.0E-05	2.1E-05	1.5E-05	1.4E-05	-1.1E-05	4.2E-05	-5.1E-05	1.8E-05	-8.5E-05	-1.4E-05
Other green	4.4E-06	1.3E-05	-1.8E-05	3.2E-05	5.1E-05	1.4E-05	2.4E-05	7.8E-05	6.7E-05	2.0E-05	2.4E-05	1.0E-04
Water	2.1E-06	1.2E-05	-2.5E-05	2.5E-05	-4.9E-07	1.4E-05	-2.9E-05	2.5E-05	3.6E-06	2.0E-05	-3.5E-05	4.3E-05
Sport Leisure	-4.5E-06	7.6E-06	-2.4E-05	4.4E-06	-5.8E-06	5.4E-06	-1.8E-05	2.7E-06	1.2E-06	6.8E-06	-7.2E-06	2.3E-05
Street trees	-0.001	3.2E-04	-0.001	-1.2E-04	-0.001	3.6E-04	-0.001	1.3E-04	-2.7E-04	4.2E-04	-0.001	0.001
Church	-5.4E-05	1.3E-05	-8.3E-05	-3.1E-05	-8.0E-06	1.5E-05	-4.0E-05	2.0E-05	-1.5E-05	1.9E-05	-5.1E-05	2.4E-05
submarket	Houses for sale				Houses for sale				Houses for sale			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	3,254				2,961				1,685			
Bootstraps	1,000				1,000				1,000			

Table A.22: Hedonic price schedules for three market equilibria in the submarket houses for sale, estimated with an internal instrumental variable method (first half of results). The Ln Price is the dependent variable.

	Dependent variable:											
					Ln Price							
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
Park*scndring	-0.001	0.002	-0.005	0.002	-0.004	0.003	-0.008	0.001	0.001	0.002	-0.005	0.005
Park*thrddring	-2.8E-04	0.001	-0.003	0.002	-0.007	0.002	-0.011	-0.001	-0.001	0.003	-0.007	0.003
Park*frthring	-3.0E-04	0.001	-0.003	0.002	-0.007	0.002	-0.011	-0.001	-0.002	0.003	-0.008	0.001
Park*Garden	0.001	4.6E-04	8.5E-06	0.002	-2.6E-04	3.9E-04	-0.001	4.9E-04	-0.002	4.9E-04	-0.003	-0.001
Park*BalcTerr	4.6E-04	4.6E-04	-4.4E-04	0.001	2.9E-04	3.9E-04	-4.3E-04	0.001	-1.8E-04	0.001	-0.001	0.001
Park*LotSize	6.4E-08	1.1E-07	-9.4E-08	3.0E-07	2.0E-07	6.6E-08	4.2E-08	3.1E-07	7.2E-08	1.2E-07	-1.5E-07	3.3E-07
Park*Playground	-4.4E-05	1.8E-04	-3.7E-04	2.9E-04	-3.2E-04	1.5E-04	-0.001	-1.4E-05	-3.4E-04	2.2E-04	-0.001	9.7E-05
Park*Cemetery	1.4E-05	7.0E-06	-1.5E-06	2.6E-05	3.1E-06	7.9E-06	-1.3E-05	1.7E-05	-9.3E-06	1.0E-05	-3.1E-05	9.6E-06
Playground*scndring	0.027	0.027	-0.026	0.079	-0.054	0.026	-0.103	0.000	0.020	0.028	-0.034	0.078
Playground*thrddring	0.021	0.019	-0.016	0.059	-0.118	0.023	-0.162	-0.076	-0.037	0.021	-0.075	0.004
Playground*frthring	0.057	0.020	0.017	0.094	-0.075	0.025	-0.124	-0.027	-0.005	0.025	-0.047	0.050
Playground*Garden	0.007	0.006	-0.006	0.019	0.002	0.007	-0.013	0.016	0.001	0.007	-0.013	0.014
Playground*BalcTerr	-0.010	0.007	-0.023	0.003	0.000	0.007	-0.013	0.015	-0.010	0.008	-0.026	0.006
Playground*LotSize	-5.5E-06	2.9E-06	-1.1E-05	4.0E-07	-6.4E-07	2.1E-06	-3.8E-06	4.6E-06	-1.1E-06	2.3E-06	-3.2E-06	5.6E-06
Playground*Cemetery	1.5E-04	7.6E-05	3.9E-06	2.9E-04	3.8E-04	8.1E-05	2.2E-04	5.5E-04	1.9E-04	1.2E-04	-8.8E-05	4.1E-04
Allotment*scndring	0.001	0.006	-0.012	0.013	-0.005	0.001	-0.008	-0.002	1.6E-04	0.002	-0.003	0.003
Allotment*thrddring	1.8E-04	0.006	-0.012	0.012	0.001	0.001	-0.001	0.003	2.5E-04	0.001	-0.002	0.003
Allotment*frthring	0.001	0.006	-0.011	0.013	-0.001	0.002	-0.004	0.002	0.006	0.002	0.002	0.009
Allotment*Garden	-0.003	0.001	-0.004	-0.001	5.0E-04	0.001	-0.001	0.002	0.001	0.001	-4.5E-04	0.003
Allotment*BalcTerr	0.001	0.001	-0.001	0.002	-5.3E-05	0.001	-0.002	0.002	0.001	0.001	-0.001	0.003
Allotment*LotSize	-1.7E-07	1.6E-07	-4.0E-07	2.2E-07	-4.1E-07	1.6E-07	-7.1E-07	-8.6E-08	-3.4E-07	2.1E-07	-6.7E-07	1.5E-07
Park*Allotment	-2.2E-05	2.3E-05	-6.4E-05	2.5E-05	8.2E-06	2.8E-05	-4.6E-05	6.5E-05	1.5E-05	2.8E-05	-4.4E-05	6.6E-05
Playground*Allotment	0.001	2.4E-04	2.6E-04	0.001	4.9E-04	3.4E-04	-2.9E-04	0.001	1.6E-04	3.7E-04	-0.001	0.001
Allotment*Cemetery	1.4E-06	1.6E-05	-3.5E-05	2.7E-05	-2.2E-05	1.8E-05	-5.7E-05	1.6E-05	-8.1E-07	2.9E-05	-6.6E-05	5.0E-05
Cemetery*scndring	0.012	0.033	-0.063	0.091	0.014	0.025	-0.038	0.062	0.146	0.115	-0.190	0.278
Cemetery*thrddring	0.027	0.032	-0.046	0.109	0.015	0.025	-0.036	0.065	0.147	0.115	-0.190	0.281
Cemetery*frthring	0.029	0.032	-0.044	0.111	0.015	0.025	-0.036	0.064	0.149	0.115	-0.191	0.282
Cemetery*Garden	1.1E-04	2.0E-04	-3.0E-04	5.2E-04	2.0E-04	2.2E-04	-2.2E-04	6.3E-04	2.2E-04	2.9E-04	-4.5E-04	6.8E-04
Cemetery*BalcTerr	-1.3E-04	1.7E-04	-4.5E-04	2.3E-04	1.8E-04	2.5E-04	-2.9E-04	6.8E-04	1.3E-04	2.9E-04	-4.1E-04	7.1E-04
Cemetery*LotSize	-1.5E-08	2.9E-08	-7.0E-08	4.4E-08	-4.7E-09	3.2E-08	-5.3E-08	6.3E-08	3.4E-08	5.1E-08	-8.3E-08	8.3E-08
Allotment**	0.001	0.007	-0.012	0.014	0.002	0.002	-0.002	0.006	0.004	0.002	0.000	0.009
Park**	-3.4E-04	0.001	-0.003	0.003	0.007	0.003	0.001	0.011	0.002	0.003	-0.002	0.009
Playgound**	-0.004	0.023	-0.055	0.036	0.043	0.026	-0.002	0.099	0.003	0.028	-0.045	0.064
Cemetery**	-0.027	0.032	-0.109	0.045	-0.016	0.025	-0.065	0.035	-0.147	0.115	-0.280	0.190
LotSize**	1.7E-07	1.1E-05	-2.8E-05	3.0E-07	-1.6E-05	5.1E-06	-3.1E-05	-1.2E-05	-1.4E-05	8.9E-06	-3.9E-05	-5.5E-06
BalcTerr**	-0.055	0.022	-0.100	-0.017	-0.013	0.023	-0.058	0.031	0.017	0.029	-0.049	0.060
Garden**	0.028	0.021	-0.024	0.058	0.021	0.022	-0.044	0.043	0.048	0.030	0.000	0.118
submarket	Houses for sale				Houses for sale				Houses for sale			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	3,254				2,961				1,685			
Bootstraps	1,000				1,000				1,000			

Table A.23: Hedonic price schedules for three market equilibria in the submarket houses for sale, estimated with an internal instrumental variable method (continued). The Ln Price is the dependent variable.

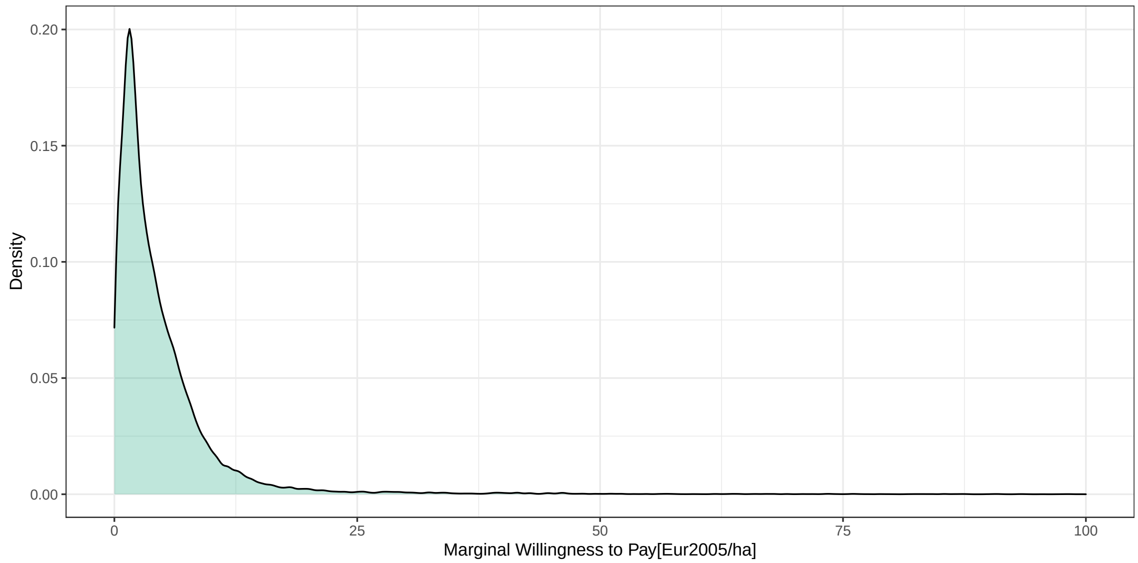

Figure A.5: Density of non-zero estimates of marginal willingness to pay for park area in a 1 km^2 radius around a housing unit.

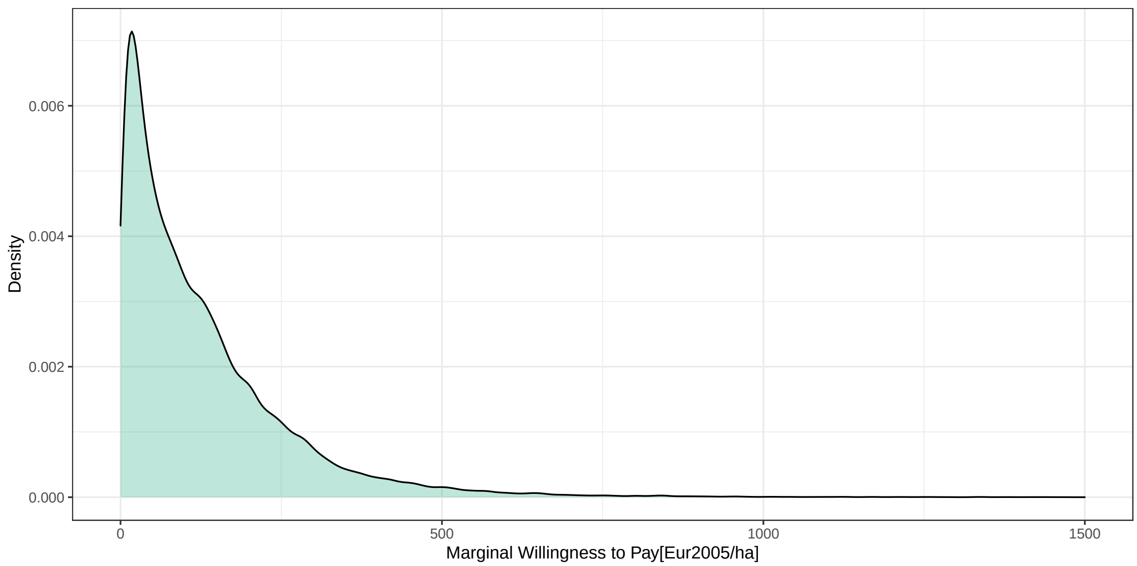

Figure A.6: Density of non-zero estimates of marginal willingness to pay for playground area in a 1 km^2 radius around a housing unit.

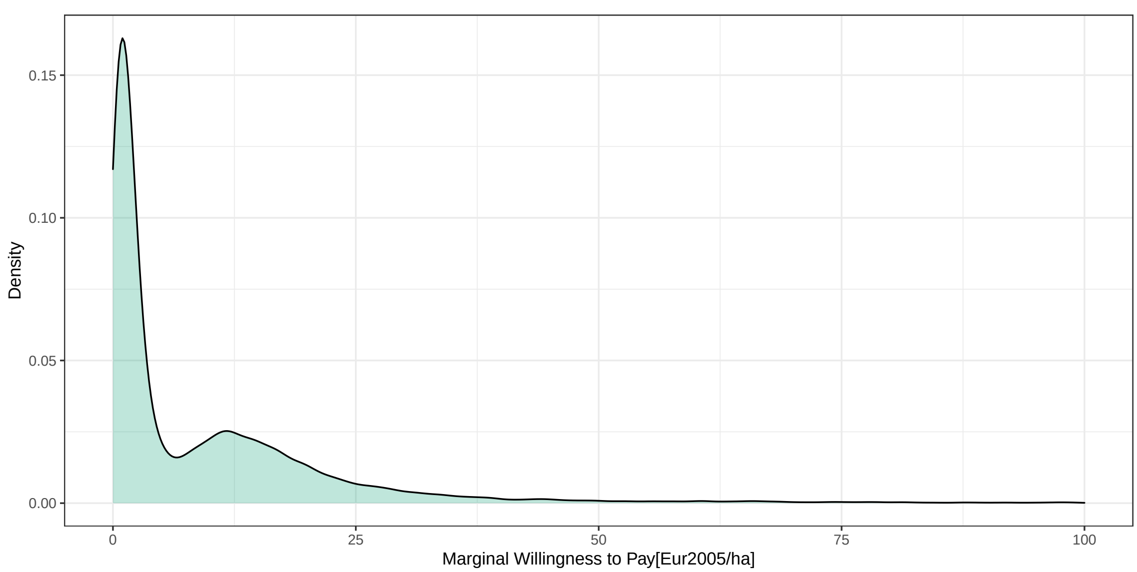

Figure A.7: Density of non-zero estimates of marginal willingness to pay for cemetery area in a 1 km^2 radius around a housing unit.

A.4 Second-stage results: Regression results, non-marginal willingness to pay (WTP) density plots and estimated mean WTP for parks, playgrounds and cemeteries across income groups, robustness checks

A.4.1 2nd stage regression results estimated with rearranged Equation 2.7

	Dependent variable:							
	$\frac{\delta \pi p_m(x_{i*})}{\delta x_{i,Park}} \frac{x_{i,Park}}{c_j}$							
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	-3.7E-03	3.8E-03	-1.1E-02	3.8E-03	-3.9E-03	3.7E-03	-1.2E-02	2.4E-03
Ln Above60	-2.1E-04	6.2E-05	-3.3E-04	-8.5E-05				
Ln Unemployed	2.9E-04	2.9E-05	2.3E-04	3.4E-04	3.0E-04	2.8E-05	2.5E-04	3.5E-04
Ln Children	2.7E-03	5.9E-04	1.5E-03	3.8E-03	2.7E-03	5.8E-04	1.6E-03	3.8E-03
Ln Families	-3.2E-04	1.7E-05	-3.5E-04	-2.9E-04	-3.2E-04	1.8E-05	-3.6E-04	-2.9E-04
Ln Singles	1.4E-04	4.1E-05	6.4E-05	2.3E-04	1.1E-04	3.6E-05	4.0E-05	1.8E-04
Ln Couples	-4.7E-04	2.3E-05	-5.2E-04	-4.2E-04	-4.8E-04	2.3E-05	-5.3E-04	-4.3E-04
Ln Area	-9.2E-04	7.2E-04	-2.3E-03	4.6E-04	-9.4E-04	7.1E-04	-2.2E-03	4.5E-04
Ln CBD	2.5E-03	9.0E-05	2.3E-03	2.7E-03	2.5E-03	9.2E-05	2.3E-03	2.6E-03
Ln Popden	-6.6E-04	2.2E-05	-7.0E-04	-6.2E-04	-6.5E-04	2.3E-05	-7.0E-04	-6.0E-04
Ln Park	-1.3E-03	5.9E-05	-1.4E-03	-1.1E-03	-1.3E-03	5.9E-05	-1.4E-03	-1.2E-03
Ln Playground	-3.4E-03	1.2E-04	-3.6E-03	-3.1E-03	-3.4E-03	1.2E-04	-3.6E-03	-3.1E-03
Ln Cemetery	5.2E-05	1.2E-05	2.8E-05	7.5E-05	5.2E-05	1.2E-05	3.0E-05	7.6E-05
Ln Allotment	6.1E-04	2.6E-05	5.6E-04	6.6E-04	6.2E-04	2.7E-05	5.6E-04	6.6E-04
BalcTerr	5.8E-04	3.8E-05	4.7E-04	6.2E-04	5.0E-04	3.7E-05	4.7E-04	6.1E-04
Ln GardenSize	-1.7E-04	9.5E-06	-1.9E-04	-1.5E-04	-1.7E-04	9.9E-06	-1.9E-04	-1.5E-04
Ln Cemetery**	5.2E-05	1.2E-05	2.8E-05	7.5E-05	5.2E-05	1.2E-05	3.0E-05	7.6E-05
Ln Allotment**	6.1E-04	2.6E-05	5.6E-04	6.6E-04	6.2E-04	2.7E-05	5.6E-04	6.6E-04
Ln Playground**	-3.4E-03	1.2E-04	-3.6E-03	-3.1E-03	-3.4E-03	1.2E-04	-3.6E-03	-3.1E-03
Ln Area**	-9.2E-04	7.2E-04	-2.3E-03	4.6E-04	-9.4E-04	7.1E-04	-2.2E-03	4.5E-04
Ln CBD**	2.5E-03	9.0E-05	2.3E-03	2.7E-03	2.5E-03	9.2E-05	2.3E-03	2.6E-03
Ln Park**	-1.3E-03	5.9E-05	-1.4E-03	-1.1E-03	-1.3E-03	5.9E-05	-1.4E-03	-1.2E-03
Ln GardenSize**	-1.7E-04	9.5E-06	-1.9E-04	-1.5E-04	-1.7E-04	9.9E-06	-1.9E-04	-1.5E-04
BalcTerr **	5.8E-04	3.8E-05	4.7E-04	6.2E-04	5.0E-04	3.7E-05	4.7E-04	6.1E-04
Model	A				B			
District fixed effects	TRUE				TRUE			
Observations	141,875				141,875			
Bootstraps	1,000				1,000			

Table A.24: Estimation of non-marginal Willingness to pay for park area in a 1km radius around housing units, estimated with rearranged Equation 2.7. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:							
	$\frac{\delta \pi p_m(x_{i*})}{\delta x_{i,Playground}} \frac{x_{i,Playground}}{c_j}$							
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	1.4E-01	7.0E-03	1.3E-01	1.6E-01	1.4E-01	6.9E-03	1.2E-01	1.5E-01
Ln Above60	-5.4E-03	1.6E-04	-5.7E-03	-5.1E-03				
Ln Unemployed	6.0E-04	5.3E-05	5.0E-04	7.0E-04	1.0E-03	4.9E-05	9.4E-04	1.1E-03
Ln Children	-7.9E-03	1.7E-03	-1.1E-02	-4.6E-03	-8.0E-03	1.6E-03	-1.1E-02	-4.9E-03
Ln Families	-6.0E-04	3.7E-05	-6.7E-04	-5.3E-04	-7.6E-04	3.7E-05	-8.4E-04	-6.9E-04
Ln Singles	6.8E-05	1.0E-04	-1.4E-04	2.7E-04	-7.7E-04	9.8E-05	-9.6E-04	-5.8E-04
Ln Couples	1.4E-04	6.2E-05	2.1E-05	2.6E-04	-1.6E-04	5.5E-05	-2.7E-04	-5.9E-05
Ln Area	-1.4E-02	1.3E-03	-1.6E-02	-1.1E-02	-1.4E-02	1.3E-03	-1.7E-02	-1.2E-02
Ln CBD	-5.2E-03	2.1E-04	-5.6E-03	-4.8E-03	-6.1E-03	2.2E-04	-6.6E-03	-5.7E-03
Ln Popden	3.5E-04	6.3E-05	2.2E-04	4.6E-04	5.5E-04	5.9E-05	4.4E-04	6.7E-04
Ln Park	-5.6E-04	1.2E-04	-8.0E-04	-3.3E-04	-9.4E-04	1.2E-04	-1.2E-03	-7.1E-04
Ln Playground	1.4E-03	2.6E-04	8.7E-04	1.9E-03	7.7E-04	2.7E-04	2.7E-04	1.3E-03
Ln Cemetery	-8.9E-04	3.9E-05	-9.6E-04	-8.0E-04	-8.9E-04	3.9E-05	-9.7E-04	-8.2E-04
Ln Allotment	-8.2E-04	6.2E-05	-9.3E-04	-6.9E-04	-6.9E-04	6.2E-05	-8.1E-04	-5.7E-04
BalcTerr	8.2E-04	8.8E-05	6.9E-04	1.0E-03	8.7E-04	9.0E-05	6.8E-04	1.0E-03
Ln GardenSize	-2.6E-04	1.8E-05	-3.0E-04	-2.2E-04	-2.7E-04	1.8E-05	-3.1E-04	-2.4E-04
Ln Cemetery**	-8.9E-04	3.9E-05	-9.6E-04	-8.0E-04	-8.9E-04	3.9E-05	-9.7E-04	-8.2E-04
Ln Allotment**	-8.2E-04	6.2E-05	-9.3E-04	-6.9E-04	-6.9E-04	6.2E-05	-8.1E-04	-5.7E-04
Ln Playground**	1.4E-03	2.6E-04	8.7E-04	1.9E-03	7.7E-04	2.7E-04	2.7E-04	1.3E-03
Ln Area**	-1.4E-02	1.3E-03	-1.6E-02	-1.1E-02	-1.4E-02	1.3E-03	-1.7E-02	-1.2E-02
Ln CBD**	-5.2E-03	2.1E-04	-5.6E-03	-4.8E-03	-6.1E-03	2.2E-04	-6.6E-03	-5.7E-03
Ln Park**	-5.6E-04	1.2E-04	-8.0E-04	-3.3E-04	-9.4E-04	1.2E-04	-1.2E-03	-7.1E-04
Ln GardenSize**	-2.6E-04	1.8E-05	-3.0E-04	-2.2E-04	-2.7E-04	1.8E-05	-3.1E-04	-2.4E-04
BalcTerr **	8.2E-04	8.8E-05	6.9E-04	1.0E-03	8.7E-04	9.0E-05	6.8E-04	1.0E-03
Model	A				B			
District fixed effects	TRUE				TRUE			
Observations	141,875				141,875			
Bootstraps	1,000				1,000			

Table A.25: Estimation of non-marginal Willingness to pay for playground area in a 1km radius around housing units, estimated with rearranged Equation 2.7. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:							
	$\frac{\delta \pi p_m(x_{i*})}{\delta x_{i,Cemetery}} \frac{x_{i,Cemetery}}{c_j}$							
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	5.3E-03	1.1E-03	3.2E-03	7.4E-03	5.8E-03	1.1E-03	3.7E-03	8.0E-03
Ln Above60	5.5E-04	2.3E-05	5.0E-04	5.9E-04				
Ln Unemployed	-2.4E-04	1.2E-05	-2.6E-04	-2.2E-04	-2.9E-04	1.2E-05	-3.1E-04	-2.6E-04
Ln Children	-6.3E-04	1.6E-04	-9.4E-04	-3.2E-04	-6.2E-04	1.5E-04	-9.1E-04	-3.2E-04
Ln Families	-1.6E-05	6.1E-06	-2.8E-05	-3.3E-06	5.8E-07	6.2E-06	-1.2E-05	1.3E-05
Ln Singles	1.1E-04	1.8E-05	7.8E-05	1.5E-04	2.0E-04	1.8E-05	1.6E-04	2.3E-04
Ln Couples	9.0E-05	9.0E-06	7.4E-05	1.1E-04	1.2E-04	8.4E-06	1.0E-04	1.4E-04
Ln Area	-1.1E-03	2.0E-04	-1.6E-03	-7.3E-04	-1.1E-03	2.0E-04	-1.5E-03	-6.9E-04
Ln CBD	-5.0E-05	4.3E-05	-1.3E-04	4.3E-05	4.1E-05	4.6E-05	-4.9E-05	1.3E-04
Ln Popden	5.4E-05	9.8E-06	3.4E-05	7.2E-05	3.3E-05	1.0E-05	1.4E-05	5.4E-05
Ln Park	-1.4E-04	3.5E-05	-2.0E-04	-7.2E-05	-9.8E-05	3.4E-05	-1.7E-04	-3.5E-05
Ln Playground	-7.0E-04	4.4E-05	-7.9E-04	-6.1E-04	-6.4E-04	4.5E-05	-7.3E-04	-5.5E-04
Ln Cemetery	5.8E-04	1.6E-05	5.5E-04	6.1E-04	5.8E-04	1.5E-05	5.5E-04	6.1E-04
Ln Allotment	3.9E-05	8.3E-06	2.3E-05	5.5E-05	2.6E-05	8.3E-06	9.4E-06	4.2E-05
BalcTerr	-2.9E-05	1.5E-05	-6.8E-05	-8.5E-06	-2.7E-05	1.6E-05	-6.9E-05	-6.7E-06
Ln GardenSize	1.3E-05	3.0E-06	7.0E-06	1.9E-05	1.4E-05	3.0E-06	8.4E-06	2.0E-05
Ln Cemetery**	5.8E-04	1.6E-05	5.5E-04	6.1E-04	5.8E-04	1.5E-05	5.5E-04	6.1E-04
Ln Allotment**	3.9E-05	8.3E-06	2.3E-05	5.5E-05	2.6E-05	8.3E-06	9.4E-06	4.2E-05
Ln Playground**	-7.0E-04	4.4E-05	-7.9E-04	-6.1E-04	-6.4E-04	4.5E-05	-7.3E-04	-5.5E-04
Ln Area**	-1.1E-03	2.0E-04	-1.6E-03	-7.3E-04	-1.1E-03	2.0E-04	-1.5E-03	-6.9E-04
Ln CBD**	-5.0E-05	4.3E-05	-1.3E-04	4.3E-05	4.1E-05	4.6E-05	-4.9E-05	1.3E-04
Ln Park**	-1.4E-04	3.5E-05	-2.0E-04	-7.2E-05	-9.8E-05	3.4E-05	-1.7E-04	-3.5E-05
Ln GardenSize**	1.3E-05	3.0E-06	7.0E-06	1.9E-05	1.4E-05	3.0E-06	8.4E-06	2.0E-05
BalcTerr **	-2.9E-05	1.5E-05	-6.8E-05	-8.5E-06	-2.7E-05	1.6E-05	-6.9E-05	-6.7E-06
Model	A				B			
District fixed effects	TRUE				TRUE			
Observations	141,875				141,875			
Bootstraps	1,000				1,000			

Table A.26: Estimation of non-marginal Willingness to pay for cemetery area in a 1km radius around housing units, estimated with rearranged Equation 2.7. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

A.4.2 WTP density plots and mean WTP across income groups

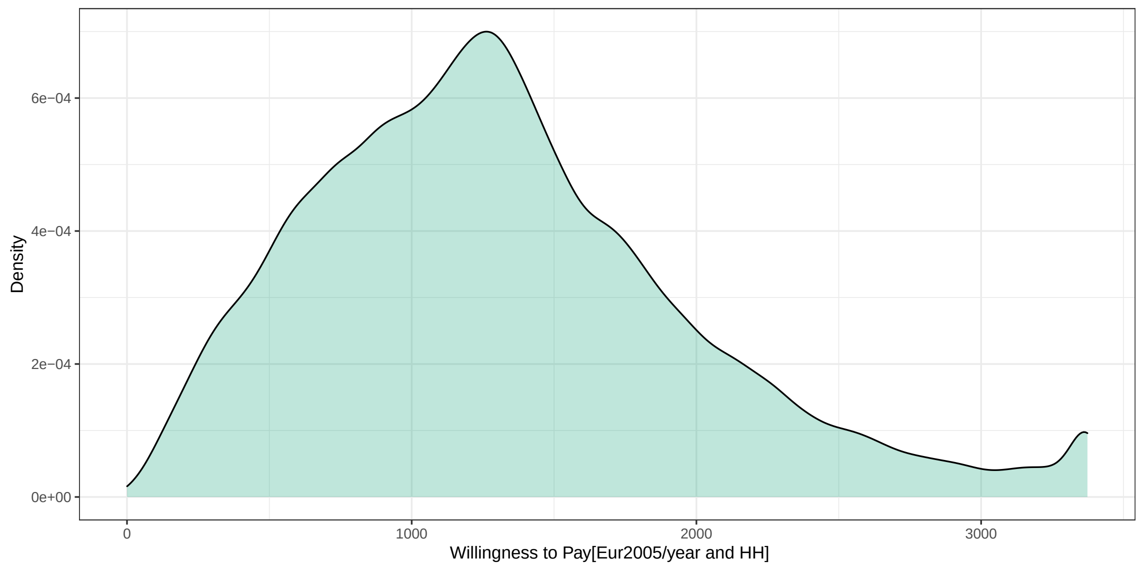

Figure A.8: Density of non-marginal willingness to pay (WTP) for park area in a 1 km radius. Extreme outliers above the 99% percentile of were replaced by the 99% percentile

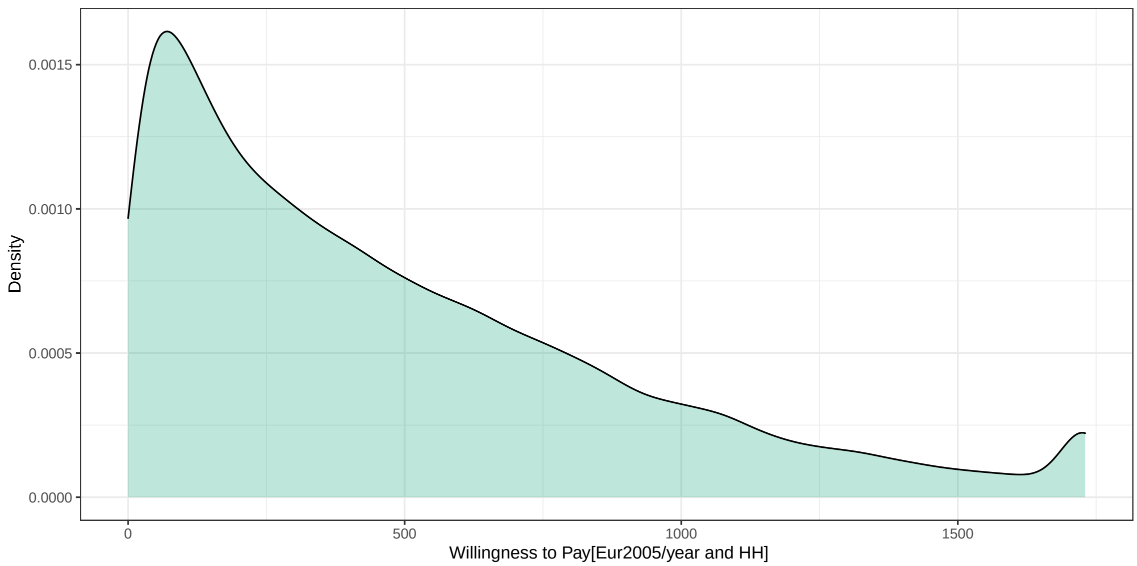

Figure A.9: Density of non-marginal willingness to pay (WTP) for playground area in a 1 km radius. Extreme outliers above the 99% percentile of were replaced by the 99% percentile

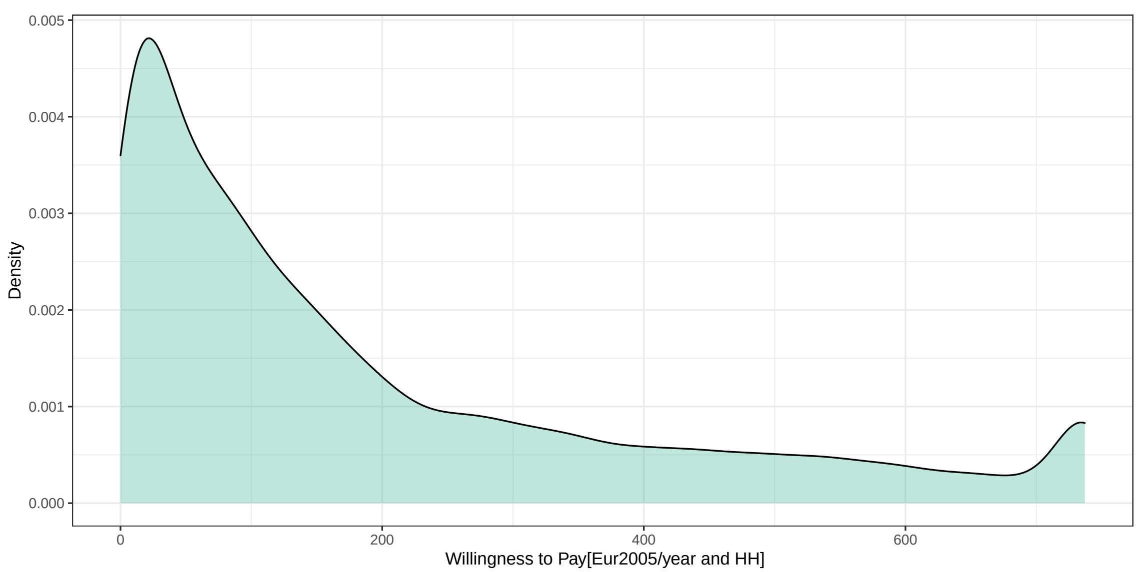

Figure A.10: Density of non-marginal willingness to pay (WTP) for cemetery area in a 1 km radius. Extreme outliers above the 99% percentile of were replaced by the 99% percentile

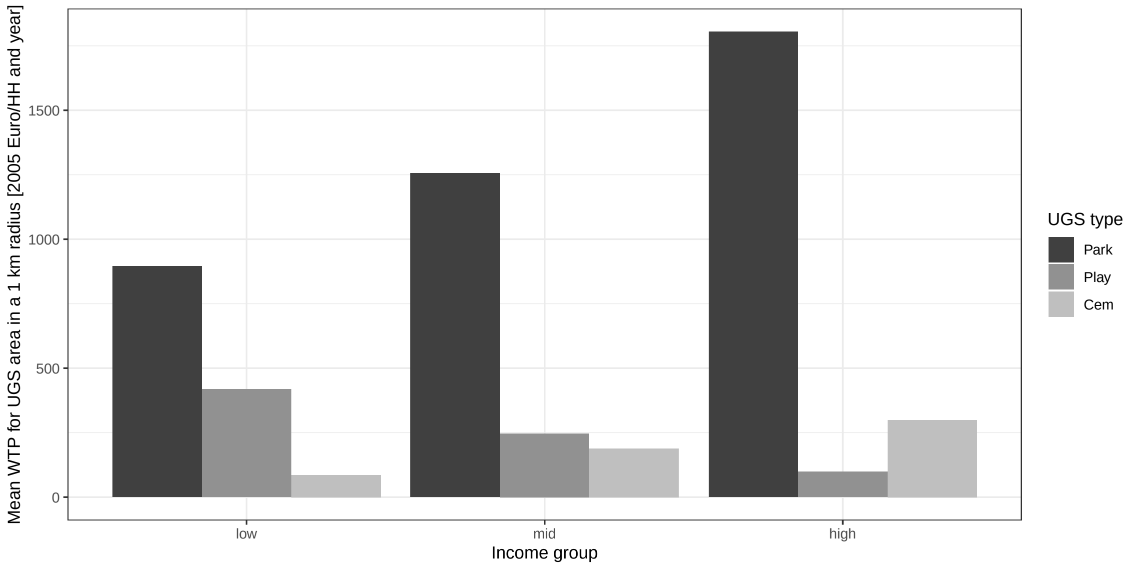

Figure A.11: Mean non-marginal willingness to pay (WTP) for urban green space (UGS) area in a 1 km radius across income groups and green space types. WTP indicates how benefits are distributed across income groups. WTP is only recovered for HH who bought the good.

A.4.3 Robustness check: Comparison of WTP estimates of 2nd stage models A and B

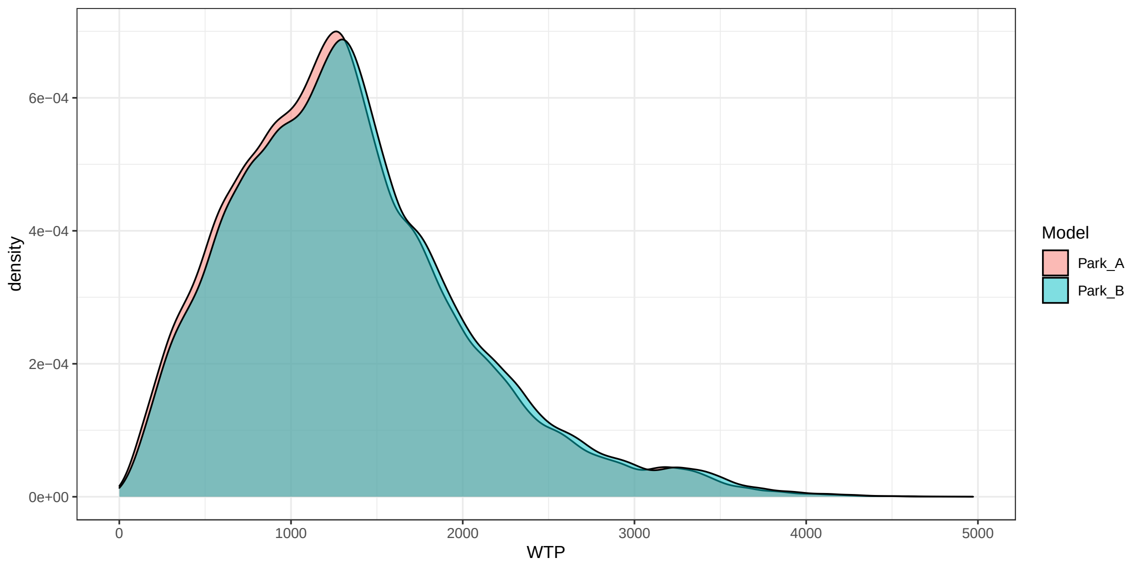

Figure A.12: Comparison of densities of non-marginal willingness to pay (WTP) for park area in a 1 km radius estimated with the results of 2nd stage model A and B

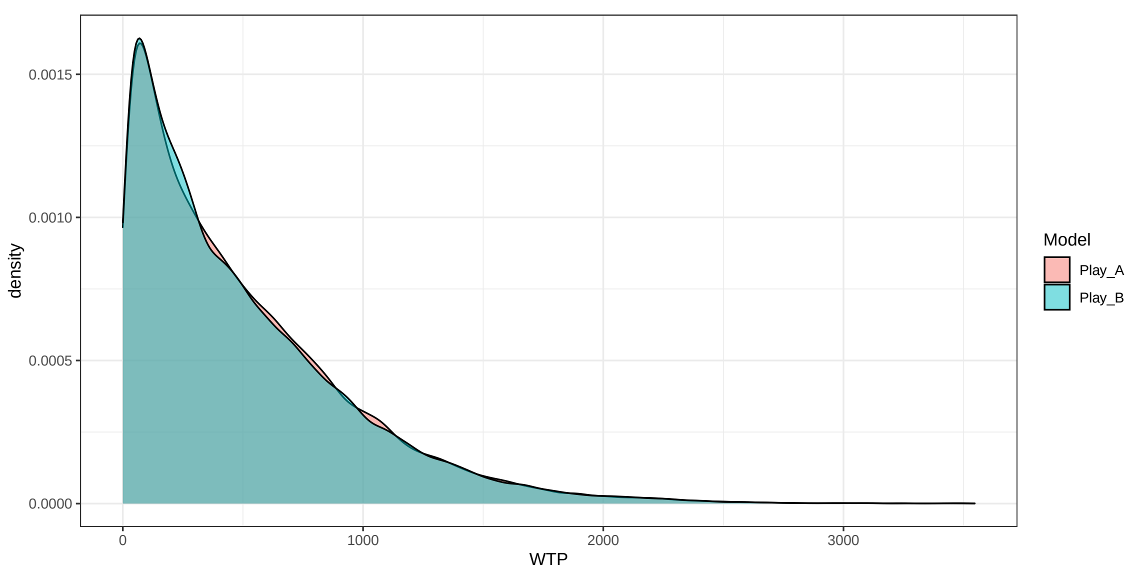

Figure A.13: Comparison of densities of non-marginal willingness to pay (WTP) for playground area in a 1 km radius estimated with the results of 2nd stage model A and B

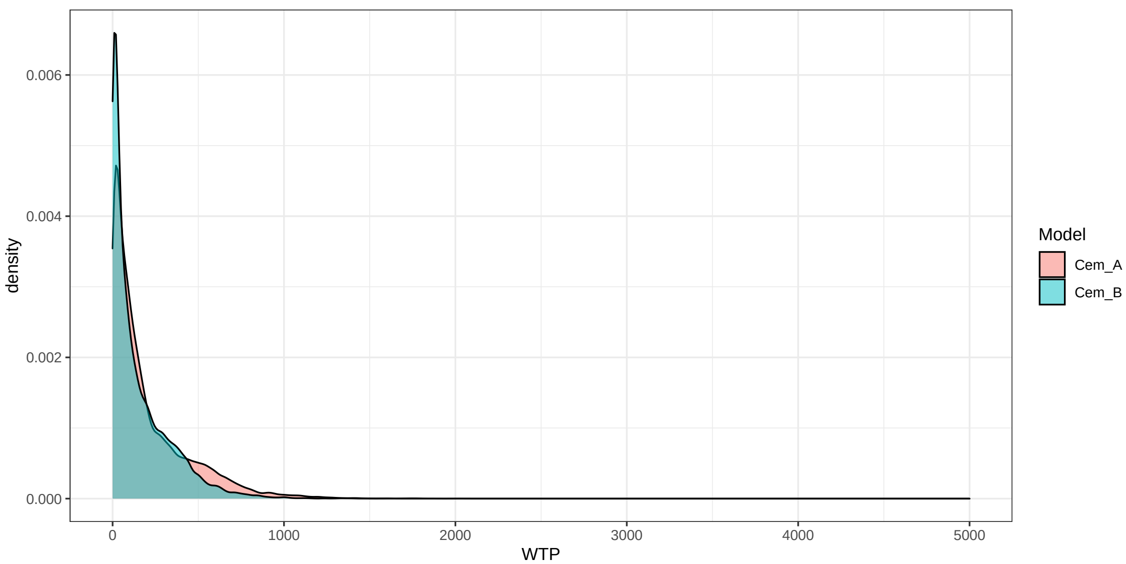

Figure A.14: Comparison of densities of non-marginal willingness to pay (WTP) for cemetery area in a 1 km radius estimated with the results of 2nd stage model A and B

A.5 Demand for selected public and private goods across income groups

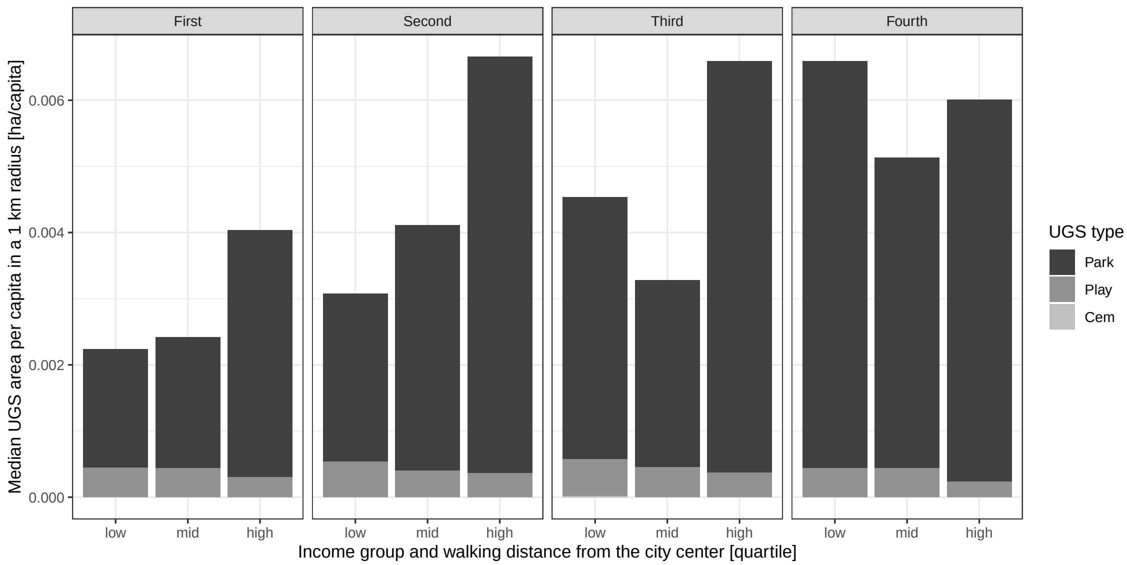

Figure A.15: Median per capita urban green space (UGS) area in a 1 km radius around the housing units across UGS types, income groups and walking distance from the city center. Walking distance from the city center is grouped in quartiles, with the first quartile being closest to the city center.

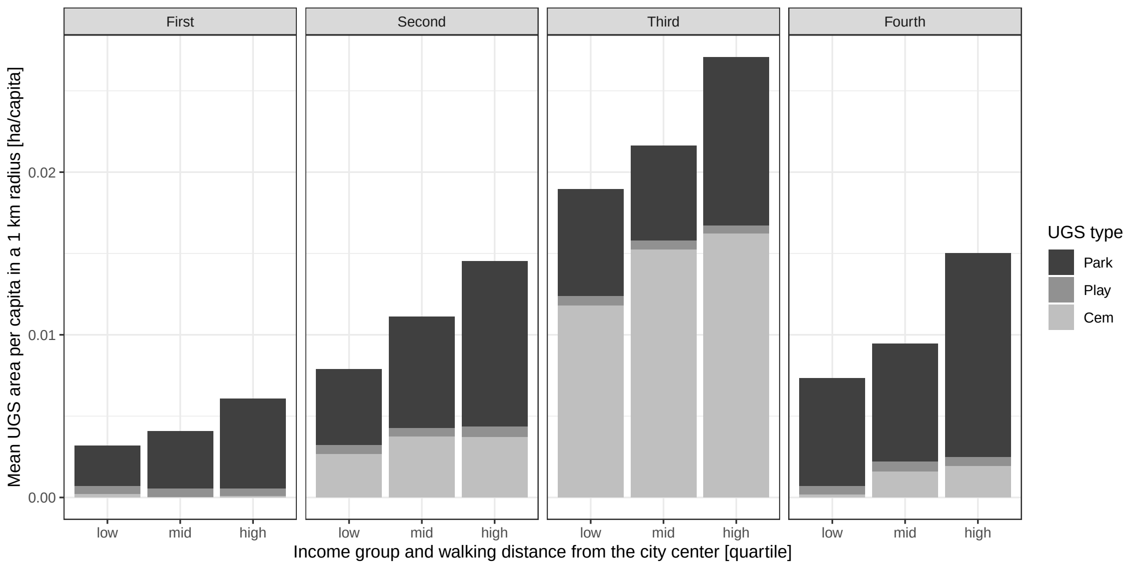

Figure A.16: Mean per capita urban green space (UGS) area in a 1 km radius around the housing units across UGS types, income groups and walking distance from the city center. Walking distance from the city center is grouped in quartiles, with the first quartile being closest to the city center.

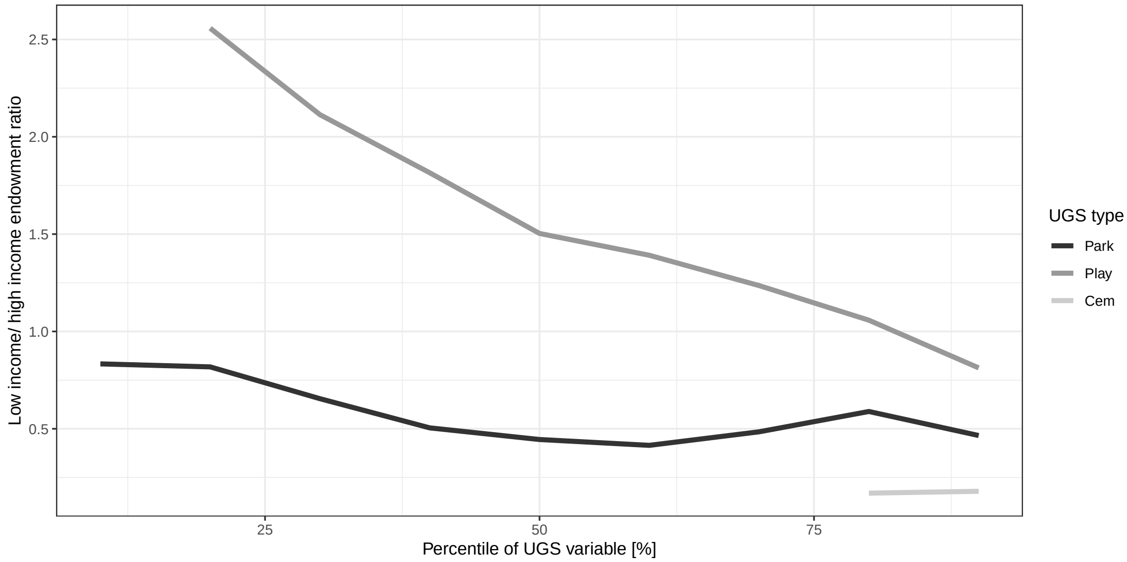

Figure A.17: Between group endowment ratios across the distribution of park, playground and cemetery area in a 1 km^2 radius around housing units. At a ratio of 1 the UGS area is equally distributed. For values larger than 1, the endowment is larger in the low-income group, for values smaller than 1, the endowment is larger in the high-income group. Coef = Coefficient estimate, SE= Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

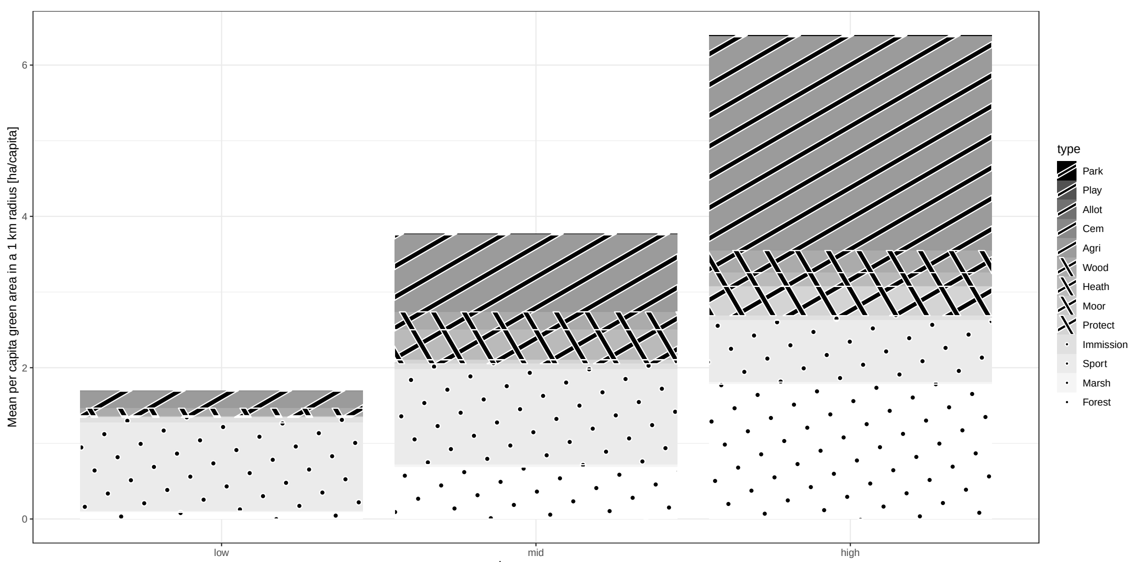

Figure A.18: Mean endowment with all green areas in hectare per capita.

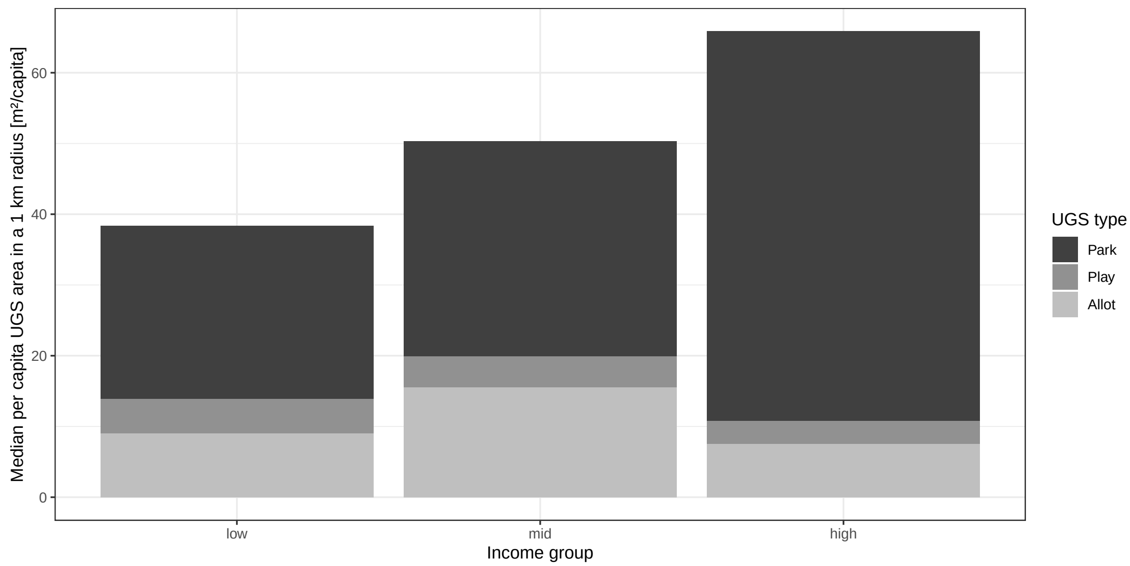

Figure A.19: Median endowment with all green areas in square meters per capita. Since only very few city dwellers, the median endowment with all other green areas is zero except for parks, playgrounds and allotment gardens (see Figure A.18 for mean endowment with green area)

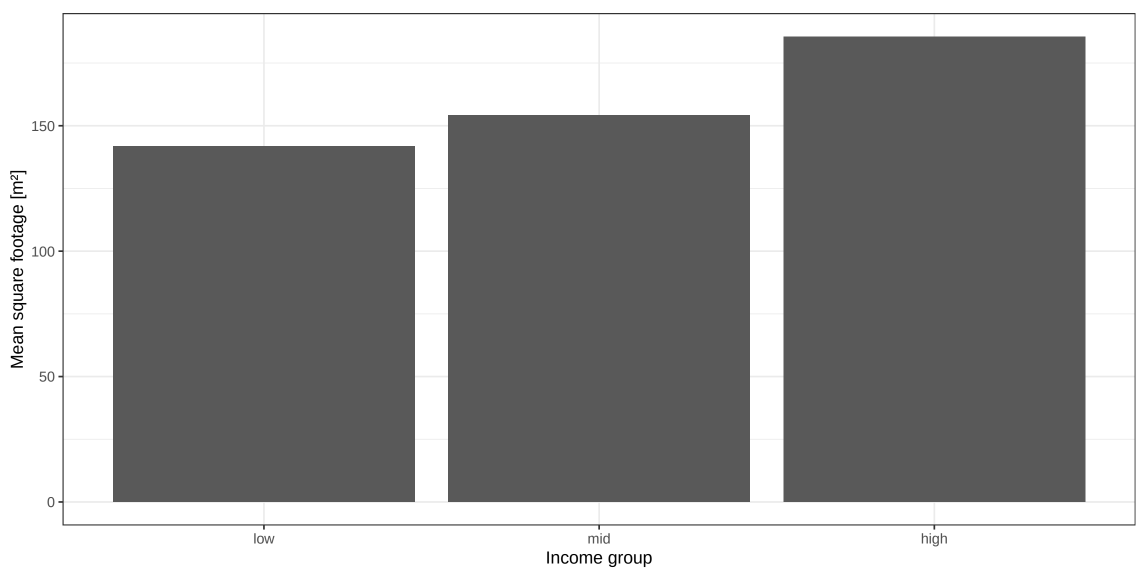

Figure A.20: Mean square footage [sqm] available to households across income groups.

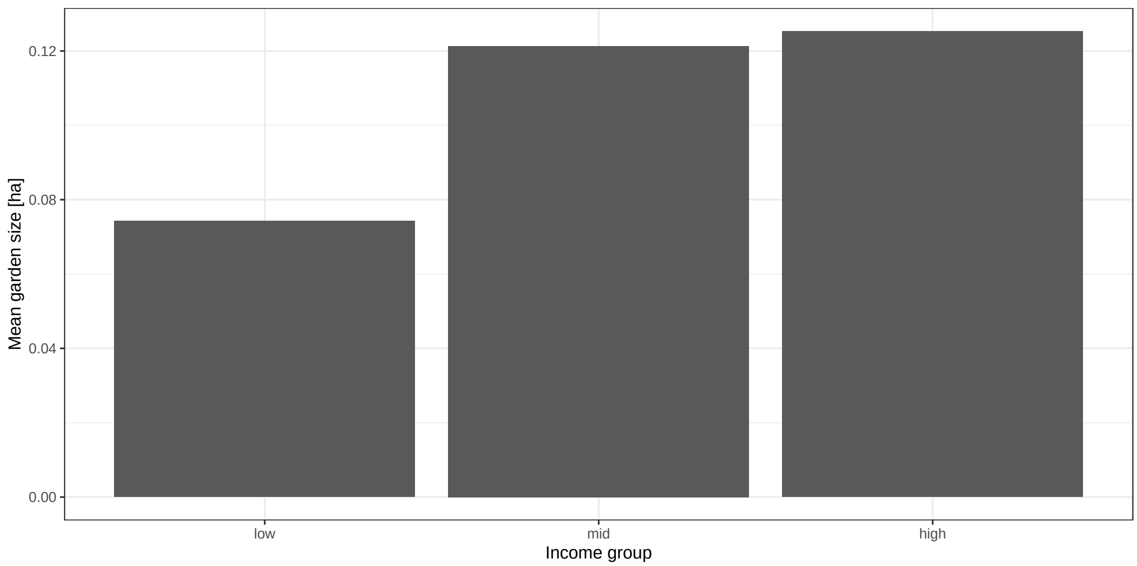

Figure A.21: Mean garden size [ha] available to households across income groups.

A.6 Third-stage regression results including robustness checks

A.6.1 Park

	Dependent variable:											
	Ln WTP Park											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	44.57	20.29	3.99	83.10	52.77	20.84	11.50	93.20	42.00	19.64	3.08	78.98
Ln Area	-0.37	0.13	-0.65	-0.15	-0.35	0.13	-0.63	-0.13	-0.38	0.13	-0.66	-0.16
Ln GardenSize	-0.03	0.001	-0.03	-0.02	-0.03	0.001	-0.03	-0.02	-0.02	0.001	-0.03	-0.02
BalcTerr	0.10	0.004	0.09	0.11	0.10	0.004	0.09	0.11	0.09	0.003	0.08	0.09
Ln PP	1.25	0.04	1.17	1.33	1.23	0.04	1.14	1.31	1.23	0.04	1.16	1.31
Ln Popden	-0.07	0.003	-0.07	-0.06	-0.07	0.003	-0.07	-0.06	-0.06	0.003	-0.07	-0.06
Ln CBD	0.80	0.02	0.75	0.84	0.80	0.02	0.75	0.84	0.74	0.02	0.70	0.78
Ln Park	0.57	0.01	0.55	0.59	0.57	0.01	0.55	0.59	0.57	0.01	0.54	0.58
Ln Playground	0.43	0.03	0.37	0.49	0.43	0.03	0.37	0.49	0.39	0.03	0.34	0.45
Ln Allotment	0.10	0.003	0.09	0.10	0.09	0.003	0.09	0.10	0.09	0.002	0.09	0.10
Ln Cemetery	-0.001	0.001	-0.004	0.002	-0.002	0.001	-0.005	0.001	-0.001	0.001	-0.003	0.002
Above60	0.10	0.05	0.00	0.18	0.09	0.04	-0.003	0.18	0.26	0.04	0.17	0.34
Children	-0.30	0.06	-0.42	-0.19	-0.67	0.07	-0.81	-0.54	-0.31	0.06	-0.42	-0.20
Unemployed	0.01	0.00	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.001	0.01	0.01
Singles	-59.48	20.31	-97.49	-18.74	-67.37	20.85	-107.11	-25.94	-56.06	19.65	-93.00	-16.77
Families	-59.73	20.31	-97.73	-18.98	-67.61	20.85	-107.34	-26.15	-56.26	19.65	-93.21	-16.94
Couples	-0.60	0.20	-0.98	-0.19	-0.68	0.21	-1.07	-0.26	-0.56	0.20	-0.93	-0.17
Ln Area**	-0.37	0.13	-0.65	-0.15	-0.35	0.13	-0.63	-0.13	-0.38	0.13	-0.66	-0.16
Ln GardenSize**	-0.03	0.001	-0.03	-0.02	-0.03	0.001	-0.03	-0.02	-0.02	0.001	-0.03	-0.02
Ln CBD**	0.80	0.02	0.75	0.84	0.80	0.02	0.75	0.84	0.74	0.02	0.70	0.78
BalcTerr **	0.10	0.004	0.09	0.11	0.10	0.004	0.09	0.11	0.09	0.003	0.08	0.09
Ln PP**	1.25	0.04	1.17	1.33	1.23	0.04	1.14	1.31	1.23	0.04	1.16	1.31
Ln Park**	0.57	0.01	0.55	0.59	0.57	0.01	0.55	0.59	0.57	0.01	0.54	0.58
Ln Playground**	0.43	0.03	0.37	0.49	0.43	0.03	0.37	0.49	0.39	0.03	0.34	0.45
Ln Allotment**	0.10	0.003	0.09	0.10	0.09	0.003	0.09	0.10	0.09	0.002	0.09	0.10
Ln Cemetery**	-0.001	0.001	-0.004	0.002	-0.002	0.001	-0.005	0.001	-0.001	0.001	-0.003	0.002
Income group	Low				Low				Low			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	46,820				46,820				46,820			
Bootstraps	1,000				1,000				1,000			

Table A.27: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for park area in a 1 km radius around housing units in the low-income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Park											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	-117.61	21.59	-160.18	-73.88	-121.76	21.67	-164.92	-78.59	-114.37	21.05	-156.74	-73.33
Ln Area	-0.06	0.10	-0.27	0.10	-0.06	0.10	-0.27	0.09	-0.06	0.10	-0.28	0.10
Ln GardenSize	-0.02	0.001	-0.02	-0.01	-0.02	0.001	-0.02	-0.01	-0.01	0.001	-0.02	-0.01
BalcTerr	0.08	0.003	0.08	0.09	0.08	0.003	0.08	0.09	0.07	0.003	0.07	0.08
Ln PP	0.95	0.07	0.81	1.09	1.02	0.08	0.87	1.16	0.97	0.07	0.82	1.10
Ln Popden	-0.08	0.002	-0.09	-0.08	-0.09	0.002	-0.09	-0.08	-0.08	0.002	-0.09	-0.08
Ln CBD	0.78	0.03	0.72	0.84	0.79	0.03	0.73	0.86	0.73	0.03	0.68	0.79
Ln Park	0.79	0.02	0.76	0.82	0.79	0.02	0.76	0.82	0.79	0.02	0.76	0.82
Ln Playground	0.47	0.03	0.41	0.53	0.48	0.03	0.42	0.54	0.44	0.03	0.37	0.49
Ln Allotment	0.07	0.003	0.06	0.07	0.07	0.003	0.06	0.07	0.07	0.003	0.06	0.07
Ln Cemetery	0.01	0.001	0.004	0.01	0.01	0.001	0.005	0.01	0.01	0.001	0.004	0.01
Above60	-0.13	0.05	-0.22	-0.03	-0.26	0.06	-0.38	-0.15	-0.004	0.05	-0.10	0.08
Children	0.11	0.05	0.02	0.21	0.11	0.05	0.02	0.21	0.11	0.05	0.02	0.20
Unemployed	0.01	0.001	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.001	0.01	0.01
Singles	104.41	21.51	60.96	147.43	107.73	21.59	64.50	150.72	101.47	21.00	60.59	144.03
Families	104.23	21.51	60.77	147.22	107.51	21.58	64.27	150.49	101.31	21.00	60.44	143.86
Couples	1.04	0.22	0.61	1.47	1.07	0.22	0.64	1.50	1.01	0.21	0.60	1.44
Ln Area**	-0.06	0.10	-0.27	0.10	-0.06	0.10	-0.27	0.09	-0.06	0.10	-0.28	0.10
Ln GardenSize**	-0.02	0.001	-0.02	-0.01	-0.02	0.001	-0.02	-0.01	-0.01	0.001	-0.02	-0.01
Ln CBD**	0.78	0.03	0.72	0.84	0.79	0.03	0.73	0.86	0.73	0.03	0.68	0.79
BalcTerr **	0.08	0.003	0.08	0.09	0.08	0.003	0.08	0.09	0.07	0.003	0.07	0.08
Ln PP**	0.95	0.07	0.81	1.09	1.02	0.08	0.87	1.16	0.97	0.07	0.82	1.10
Ln Park**	0.79	0.02	0.76	0.82	0.79	0.02	0.76	0.82	0.79	0.02	0.76	0.82
Ln Playground**	0.47	0.03	0.41	0.53	0.48	0.03	0.42	0.54	0.44	0.03	0.37	0.49
Ln Allotment**	0.07	0.003	0.06	0.07	0.07	0.003	0.06	0.07	0.07	0.003	0.06	0.07
Ln Cemetery**	0.01	0.001	0.004	0.01	0.01	0.001	0.005	0.01	0.01	0.001	0.004	0.01
Income group	Mid				Mid				Mid			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	46,823				46,823				46,823			
Bootstraps	1,000				1,000				1,000			

Table A.28: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for park area in a 1 km radius around housing units in the mid income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Park											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	-137.27	20.32	-177.37	-99.20	-131.82	20.36	-172.44	-93.30	-124.53	19.69	-164.31	-87.15
Ln Area	0.28	0.12	0.0001	0.49	0.28	0.12	0.004	0.49	0.30	0.12	0.02	0.50
Ln GardenSize	-0.01	0.001	-0.01	-0.01	-0.01	0.001	-0.01	-0.01	-0.01	0.001	-0.01	-0.01
BalcTerr	0.06	0.004	0.05	0.07	0.06	0.004	0.05	0.07	0.05	0.004	0.05	0.06
Ln PP	0.93	0.05	0.84	1.04	1.01	0.06	0.90	1.14	0.87	0.05	0.78	0.96
Ln Popden	-0.03	0.003	-0.04	-0.03	-0.04	0.00	-0.04	-0.03	-0.03	0.003	-0.04	-0.02
Ln CBD	0.63	0.03	0.57	0.69	0.65	0.04	0.59	0.72	0.56	0.03	0.51	0.61
Ln Park	0.64	0.01	0.62	0.67	0.64	0.01	0.61	0.67	0.63	0.01	0.60	0.66
Ln Playground	-0.04	0.03	-0.10	0.02	-0.04	0.03	-0.10	0.02	-0.04	0.03	-0.09	0.02
Ln Allotment	0.05	0.002	0.05	0.05	0.05	0.002	0.05	0.05	0.05	0.002	0.05	0.05
Ln Cemetery	-0.002	0.001	-0.004	0.000	-0.001	0.001	-0.004	0.001	-0.002	0.001	-0.004	0.000
Above60	-0.82	0.11	-1.04	-0.60	-0.96	0.13	-1.23	-0.71	-0.56	0.09	-0.75	-0.39
Children	0.20	0.06	0.09	0.31	0.20	0.06	0.08	0.32	0.17	0.05	0.06	0.27
Unemployed	0.001	0.001	-0.001	0.003	0.001	0.001	-0.001	0.003	0.002	0.001	0.000	0.004
Singles	125.12	20.23	87.35	165.03	118.64	20.24	79.96	158.33	113.70	19.67	76.89	152.74
Families	124.91	20.22	87.12	164.78	118.34	20.23	79.64	157.99	113.54	19.67	76.71	152.55
Couples	1.25	0.20	0.87	1.65	1.18	0.20	0.79	1.58	1.13	0.20	0.77	1.52
Ln Area**	0.28	0.12	0.00	0.49	0.28	0.12	0.004	0.49	0.30	0.12	0.02	0.50
Ln GardenSize**	-0.01	0.001	-0.01	-0.01	-0.01	0.001	-0.01	-0.01	-0.01	0.001	-0.01	-0.01
Ln CBD**	0.63	0.03	0.57	0.69	0.65	0.04	0.59	0.72	0.56	0.03	0.51	0.61
BalcTerr **	0.06	0.004	0.05	0.07	0.06	0.004	0.05	0.07	0.05	0.004	0.05	0.06
Ln PP**	0.93	0.05	0.84	1.04	1.01	0.06	0.90	1.14	0.87	0.05	0.78	0.96
Ln Park**	0.64	0.01	0.62	0.67	0.64	0.01	0.61	0.67	0.63	0.01	0.60	0.66
Ln Playground**	-0.04	0.03	-0.10	0.02	-0.04	0.03	-0.10	0.02	-0.04	0.03	-0.09	0.02
Ln Allotment**	0.05	0.002	0.05	0.05	0.05	0.002	0.05	0.05	0.05	0.002	0.05	0.05
Ln Cemetery**	-0.002	0.001	-0.004	0.0004	-0.001	0.001	-0.004	0.001	-0.002	0.001	-0.004	0.0002
Income group	High				High				High			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	45,945				45,945				45,945			
Bootstraps	1,000				1,000				1,000			

Table A.29: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for park area in a 1 km radius around housing units in the high-income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

A.6.2 Playground

	Dependent variable:											
	Ln WTP Play											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	379.52	119.52	156.19	611.03	463.77	119.41	230.93	692.84	526.19	119.74	289.38	766.49
Ln Area	-2.15	0.64	-3.46	-0.90	-2.14	0.64	-3.46	-0.91	-3.65	0.72	-5.16	-2.30
Ln GardenSize	-0.06	0.004	-0.07	-0.05	-0.06	0.004	-0.07	-0.05	-0.06	0.005	-0.07	-0.05
BalcTerr	0.35	0.02	0.31	0.40	0.34	0.02	0.31	0.40	0.34	0.02	0.31	0.40
Ln PP	1.12	0.29	0.56	1.71	0.56	0.30	0.00	1.16	1.73	0.28	1.19	2.27
Ln Popden	0.34	0.02	0.30	0.37	0.35	0.02	0.32	0.39	0.36	0.02	0.33	0.39
Ln CBD	-0.42	0.09	-0.60	-0.25	-0.52	0.09	-0.69	-0.35	-1.35	0.09	-1.52	-1.19
Ln Park	-0.66	0.04	-0.74	-0.57	-0.66	0.04	-0.74	-0.57	-0.75	0.04	-0.83	-0.66
Ln Playground	1.46	0.07	1.31	1.60	1.46	0.07	1.31	1.60	1.28	0.08	1.13	1.43
Ln Allotment	-0.09	0.02	-0.13	-0.06	-0.10	0.02	-0.14	-0.07	-0.08	0.02	-0.11	-0.05
Ln Cemetery	-0.29	0.01	-0.31	-0.27	-0.29	0.01	-0.31	-0.27	-0.32	0.01	-0.34	-0.30
Above60	-13.27	0.26	-13.80	-12.77	-12.54	0.28	-13.13	-12.03	-3.89	0.26	-4.39	-3.41
Children	-2.13	0.37	-2.84	-1.40	-2.66	0.44	-3.47	-1.75	-1.62	0.37	-2.36	-0.92
Unemployed	0.06	0.004	0.05	0.07	0.07	0.004	0.06	0.07	0.07	0.004	0.07	0.08
Singles	-372.98	119.64	-607.05	-151.23	-450.81	119.53	-678.47	-213.67	-512.16	119.74	-749.45	-279.40
Families	-376.05	119.64	-610.15	-154.23	-453.61	119.53	-681.25	-216.54	-515.24	119.74	-752.51	-282.46
Couples	-3.73	1.20	-6.07	-1.51	-4.50	1.20	-6.77	-2.12	-5.12	1.20	-7.50	-2.79
Ln Area**	-2.15	0.64	-3.46	-0.90	-2.14	0.64	-3.46	-0.91	-3.65	0.72	-5.16	-2.30
Ln GardenSize**	-0.06	0.004	-0.07	-0.05	-0.06	0.00	-0.07	-0.05	-0.06	0.005	-0.07	-0.05
Ln CBD**	-0.42	0.09	-0.60	-0.25	-0.52	0.09	-0.69	-0.35	-1.35	0.09	-1.52	-1.19
BalcTerr **	0.35	0.02	0.31	0.40	0.34	0.02	0.31	0.40	0.34	0.02	0.31	0.40
Ln PP**	1.12	0.29	0.56	1.71	0.56	0.30	0.00	1.16	1.73	0.28	1.19	2.27
Ln Park**	-0.66	0.04	-0.74	-0.57	-0.66	0.04	-0.74	-0.57	-0.75	0.04	-0.83	-0.66
Ln Playground**	1.46	0.07	1.31	1.60	1.46	0.07	1.31	1.60	1.28	0.08	1.13	1.43
Ln Allotment**	-0.09	0.02	-0.13	-0.06	-0.10	0.02	-0.14	-0.07	-0.08	0.02	-0.11	-0.05
Ln Cemetery**	-0.29	0.01	-0.31	-0.27	-0.29	0.01	-0.31	-0.27	-0.32	0.01	-0.34	-0.30
Income group	Low				Low				Low			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	47,006				47,006				47,006			
Bootstraps	1,000				1,000				1,000			

Table A.30: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for playground area in a 1 km radius around housing units in the low-income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Play											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	22.15	153.94	-282.71	297.51	84.89	154.20	-218.36	365.51	-237.40	151.90	-533.75	36.55
Ln Area	9.14	0.75	7.79	10.67	9.13	0.75	7.76	10.66	13.28	0.83	11.70	15.01
Ln GardenSize	-0.03	0.004	-0.04	-0.03	-0.04	0.004	-0.04	-0.03	-0.06	0.004	-0.07	-0.05
BalcTerr	0.30	0.02	0.26	0.35	0.30	0.02	0.26	0.35	0.39	0.02	0.34	0.43
Ln PP	1.55	0.53	0.44	2.58	1.53	0.53	0.43	2.57	2.26	0.52	1.19	3.24
Ln Popden	0.26	0.02	0.23	0.30	0.27	0.02	0.23	0.30	0.30	0.02	0.27	0.33
Ln CBD	-1.20	0.10	-1.40	-1.00	-1.24	0.11	-1.45	-1.04	-1.48	0.10	-1.68	-1.29
Ln Park	-0.50	0.05	-0.60	-0.41	-0.49	0.05	-0.59	-0.39	-0.52	0.05	-0.62	-0.43
Ln Playground	-1.31	0.18	-1.62	-0.92	-1.33	0.18	-1.63	-0.93	-0.21	0.18	-0.53	0.16
Ln Allotment	-0.36	0.01	-0.39	-0.33	-0.35	0.01	-0.38	-0.32	-0.29	0.01	-0.32	-0.26
Ln Cemetery	-0.29	0.01	-0.31	-0.27	-0.29	0.01	-0.30	-0.27	-0.34	0.01	-0.35	-0.32
Above60	-8.69	0.24	-9.18	-8.19	-8.58	0.27	-9.10	-8.04	-1.85	0.24	-2.29	-1.37
Children	-2.04	0.35	-2.69	-1.35	-1.02	0.38	-1.71	-0.25	-2.41	0.35	-3.05	-1.74
Unemployed	0.07	0.004	0.06	0.07	0.06	0.004	0.06	0.07	0.08	0.004	0.07	0.09
Singles	-64.10	153.65	-340.37	242.29	-126.51	153.92	-406.12	174.73	166.26	151.51	-103.86	467.20
Families	-65.68	153.65	-341.95	240.70	-128.20	153.92	-408.01	172.97	164.62	151.51	-105.51	465.53
Couples	-0.63	1.54	-3.39	2.43	-1.26	1.54	-4.05	1.76	1.67	1.52	-1.04	4.67
Ln Area**	9.14	0.75	7.79	10.67	9.13	0.75	7.76	10.66	13.28	0.83	11.70	15.01
Ln GardenSize**	-0.03	0.004	-0.04	-0.03	-0.04	0.004	-0.04	-0.03	-0.06	0.004	-0.07	-0.05
Ln CBD**	-1.20	0.10	-1.40	-1.00	-1.24	0.11	-1.45	-1.04	-1.48	0.10	-1.68	-1.29
BalcTerr **	0.30	0.02	0.26	0.35	0.30	0.02	0.26	0.35	0.39	0.02	0.34	0.43
Ln PP**	1.55	0.53	0.44	2.58	1.53	0.53	0.43	2.57	2.26	0.52	1.19	3.24
Ln Park**	-0.50	0.05	-0.60	-0.41	-0.49	0.05	-0.59	-0.39	-0.52	0.05	-0.62	-0.43
Ln Playground**	-1.31	0.18	-1.62	-0.92	-1.33	0.18	-1.63	-0.93	-0.21	0.18	-0.53	0.16
Ln Allotment**	-0.36	0.01	-0.39	-0.33	-0.35	0.01	-0.38	-0.32	-0.29	0.01	-0.32	-0.26
Ln Cemetery**	-0.29	0.01	-0.31	-0.27	-0.29	0.01	-0.30	-0.27	-0.34	0.01	-0.35	-0.32
Income group	Mid				Mid				Mid			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	46,481				46,481				46,481			
Bootstraps	1,000				1,000				1,000			

Table A.31: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for playground area in a 1 km radius around housing units in the mid income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Play											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	-740.87	157.61	-1044.23	-432.63	-739.91	157.35	-1039.43	-426.58	-947.52	158.90	-1245.14	-633.16
Ln Area	-3.12	2.36	-7.87	1.71	-3.03	2.34	-7.74	1.79	-3.13	2.39	-7.94	1.75
Ln GardenSize	-0.01	0.003	-0.01	0.0004	-0.01	0.003	-0.01	0.00	-0.01	0.003	-0.02	-0.004
BalcTerr	0.06	0.02	0.02	0.12	0.06	0.02	0.02	0.12	0.05	0.03	0.02	0.12
Ln PP	1.80	0.26	1.28	2.26	2.13	0.26	1.62	2.59	2.27	0.26	1.75	2.74
Ln Popden	0.20	0.01	0.17	0.23	0.19	0.01	0.17	0.22	0.23	0.01	0.20	0.25
Ln CBD	-2.08	0.05	-2.18	-1.97	-2.03	0.05	-2.14	-1.93	-2.28	0.05	-2.38	-2.19
Ln Park	0.08	0.03	0.01	0.14	0.08	0.03	0.01	0.14	-0.12	0.03	-0.19	-0.06
Ln Playground	1.27	0.09	1.10	1.43	1.22	0.09	1.05	1.39	1.43	0.09	1.25	1.59
Ln Allotment	-0.07	0.01	-0.10	-0.05	-0.07	0.01	-0.10	-0.04	-0.11	0.01	-0.14	-0.08
Ln Cemetery	-0.12	0.01	-0.14	-0.10	-0.12	0.01	-0.14	-0.10	-0.17	0.01	-0.19	-0.15
Above60	-7.10	0.30	-7.69	-6.52	-7.91	0.31	-8.54	-7.32	-9.46	0.29	-10.05	-8.87
Children	-0.79	0.24	-1.24	-0.29	-0.90	0.24	-1.36	-0.41	-0.67	0.25	-1.13	-0.18
Unemployed	0.00	0.01	-0.01	0.01	0.01	0.01	0.00	0.02	0.01	0.01	0.002	0.02
Singles	757.60	156.28	451.61	1057.50	752.24	155.98	449.94	1043.61	961.47	157.68	658.65	1255.05
Families	756.22	156.28	450.14	1055.95	750.60	155.98	448.29	1041.86	959.94	157.68	657.26	1253.48
Couples	7.58	1.56	4.52	10.58	7.53	1.56	4.50	10.44	9.62	1.58	6.59	12.56
Ln Area**	-3.12	2.36	-7.87	1.71	-3.03	2.34	-7.74	1.79	-3.13	2.39	-7.94	1.75
Ln GardenSize**	-0.01	0.003	-0.01	0.0004	-0.01	0.003	-0.01	0.00	-0.01	0.003	-0.02	-0.004
Ln CBD**	-2.08	0.05	-2.18	-1.97	-2.03	0.05	-2.14	-1.93	-2.28	0.05	-2.38	-2.19
BalcTerr **	0.06	0.02	0.02	0.12	0.06	0.02	0.02	0.12	0.05	0.03	0.02	0.12
Ln PP**	1.80	0.26	1.28	2.26	2.13	0.26	1.62	2.59	2.27	0.26	1.75	2.74
Ln Park**	0.08	0.03	0.01	0.14	0.08	0.03	0.01	0.14	-0.12	0.03	-0.19	-0.06
Ln Playground**	1.27	0.09	1.10	1.43	1.22	0.09	1.05	1.39	1.43	0.09	1.25	1.59
Ln Allotment**	-0.07	0.01	-0.10	-0.05	-0.07	0.01	-0.10	-0.04	-0.11	0.01	-0.14	-0.08
Ln Cemetery**	-0.12	0.01	-0.14	-0.10	-0.12	0.01	-0.14	-0.10	-0.17	0.01	-0.19	-0.15
Income group	High				High				High			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	41,743				41,743				41,743			
Bootstraps	1,000				1,000				1,000			

Table A.32: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for playground area in a 1 km radius around housing units in the high-income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

A.6.3 Cemetery

	Dependent variable:											
	Ln WTP Cem											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	- 331.55	141.63	- 631.96	- 50.44	- 287.62	145.40	- 594.55	2.09	644.40	158.92	346.18	975.81
Ln Area	- 0.53	0.40	- 1.35	0.26	- 0.50	0.40	- 1.31	0.29	2.32	0.41	1.49	3.05
Ln GardenSize	0.05	0.01	0.04	0.06	0.06	0.01	0.04	0.06	0.05	0.005	0.04	0.06
BalcTerr	- 0.02	0.02	- 0.08	0.01	- 0.02	0.02	- 0.08	0.01	- 0.04	0.03	- 0.09	0.02
Ln PP	1.55	0.37	0.83	2.30	1.27	0.38	0.52	2.05	- 1.64	0.43	- 2.44	- 0.69
Ln Popden	- 0.01	0.02	- 0.05	0.02	0.00	0.02	- 0.03	0.04	- 0.06	0.02	- 0.10	- 0.02
Ln CBD	- 1.39	0.10	- 1.58	- 1.18	- 1.42	0.10	- 1.62	- 1.21	- 0.57	0.10	- 0.76	- 0.37
Ln Park	- 0.46	0.04	- 0.52	- 0.38	- 0.48	0.04	- 0.54	- 0.40	- 0.35	0.05	- 0.44	- 0.26
Ln Playground	- 1.25	0.09	- 1.44	- 1.07	- 1.23	0.09	- 1.41	- 1.06	- 2.55	0.10	- 2.73	- 2.34
Ln Allotment	0.43	0.01	0.40	0.46	0.43	0.01	0.40	0.45	- 0.12	0.02	- 0.15	- 0.09
Ln Cemetery	0.63	0.01	0.61	0.65	0.63	0.01	0.61	0.65	0.95	0.01	0.93	0.97
Above60	1.93	0.37	1.26	2.65	2.60	0.40	1.84	3.42	1.91	0.38	1.14	2.64
Children	- 4.01	0.43	- 4.90	- 3.18	- 5.31	0.55	- 6.41	- 4.22	- 0.28	0.49	- 1.23	0.66
Unemployed	0.00	0.01	- 0.01	0.01	0.00	0.01	- 0.01	0.01	- 0.06	0.01	- 0.07	- 0.04
Singles	335.71	142.18	55.01	635.91	295.07	145.97	6.73	605.04	- 625.31	159.15	- 952.46	- 327.63
Families	336.04	142.18	55.41	636.40	295.73	145.98	7.25	605.64	- 626.50	159.16	- 953.68	- 328.84
Couples	3.37	1.42	0.56	6.38	2.97	1.46	0.08	6.07	- 6.24	1.59	- 9.52	- 3.27
Ln Area**	- 0.53	0.40	- 1.35	0.26	- 0.50	0.40	- 1.31	0.29	2.32	0.41	1.49	3.05
Ln GardenSize**	0.05	0.01	0.04	0.06	0.06	0.01	0.04	0.06	0.05	0.005	0.04	0.06
Ln CBD**	- 1.39	0.10	- 1.58	- 1.18	- 1.42	0.10	- 1.62	- 1.21	- 0.57	0.10	- 0.76	- 0.37
BalcTerr **	- 0.02	0.02	- 0.08	0.01	- 0.02	0.02	- 0.08	0.01	- 0.04	0.03	- 0.09	0.02
Ln PP**	1.55	0.37	0.83	2.30	1.27	0.38	0.52	2.05	- 1.64	0.43	- 2.44	- 0.69
Ln Park**	- 0.46	0.04	- 0.52	- 0.38	- 0.48	0.04	- 0.54	- 0.40	- 0.35	0.05	- 0.44	- 0.26
Ln Playground**	- 1.25	0.09	- 1.44	- 1.07	- 1.23	0.09	- 1.41	- 1.06	- 2.55	0.10	- 2.73	- 2.34
Ln Allotment**	0.43	0.01	0.40	0.46	0.43	0.01	0.40	0.45	- 0.12	0.02	- 0.15	- 0.09
Ln Cemetery**	0.63	0.01	0.61	0.65	0.63	0.01	0.61	0.65	0.95	0.01	0.93	0.97
Income group	Low				Low				Low			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	14,357				14,357				14,357			
Bootstraps	1,000				1,000				1,000			

Table A.33: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for cemetery area in a 1 km radius around housing units in the low-income group. Coef = Coefficient estimate, SE= Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Cem											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	247.79	133.74	3.27	523.45	341.08	134.28	96.05	613.29	- 105.53	130.10	- 351.78	152.67
Ln Area	- 2.74	0.46	- 3.57	- 1.86	- 2.71	0.46	- 3.52	- 1.83	0.94	0.41	- 0.04	1.51
Ln GardenSize	0.04	0.004	0.03	0.04	0.04	0.004	0.03	0.04	0.03	0.003	0.02	0.04
BalcTerr	- 0.05	0.02	- 0.07	0.00	- 0.05	0.02	- 0.06	0.01	- 0.00	0.02	- 0.06	0.02
Ln PP	- 0.97	0.28	- 1.53	- 0.44	- 1.32	0.31	- 1.93	- 0.71	0.63	0.26	0.15	1.17
Ln Popden	- 0.07	0.02	- 0.10	- 0.04	- 0.07	0.02	- 0.11	- 0.04	0.11	0.01	0.08	0.14
Ln CBD	- 0.03	0.12	- 0.26	0.22	- 0.03	0.12	- 0.26	0.23	3.03	0.21	2.61	3.45
Ln Park	0.06	0.04	- 0.02	0.13	0.08	0.04	- 0.00	0.14	- 0.11	0.02	- 0.14	- 0.08
Ln Playground	0.92	0.07	0.78	1.06	0.89	0.07	0.75	1.04	0.58	0.07	0.43	0.72
Ln Allotment	0.10	0.01	0.08	0.12	0.10	0.01	0.08	0.12	- 0.07	0.02	- 0.10	- 0.04
Ln Cemetery	0.61	0.01	0.60	0.63	0.61	0.01	0.60	0.63	0.46	0.01	0.43	0.48
Above60	4.16	0.24	3.66	4.59	4.57	0.30	3.97	5.10	1.99	0.43	1.15	2.81
Children	- 0.84	0.36	- 1.55	- 0.16	- 1.13	0.38	- 1.87	- 0.41	- 6.20	0.21	- 6.64	- 5.78
Unemployed	- 0.02	0.004	- 0.03	- 0.01	- 0.02	0.004	- 0.03	- 0.01	- 0.04	0.01	- 0.05	- 0.03
Singles	- 221.60	133.57	- 494.86	23.63	- 311.16	134.12	- 584.17	- 69.06	66.93	129.63	- 189.69	314.04
Families	- 221.46	133.57	- 494.74	23.80	- 310.82	134.13	- 583.79	- 68.73	68.26	129.63	- 188.38	315.46
Couples	- 2.20	1.34	- 4.94	0.25	- 3.10	1.34	- 5.83	- 0.68	0.68	1.30	- 1.88	3.15
Ln Area**	- 2.74	0.46	- 3.57	- 1.86	- 2.71	0.46	- 3.52	- 1.83	0.94	0.41	- 0.04	1.51
Ln GardenSize**	0.04	0.00	0.03	0.04	0.04	0.00	0.03	0.04	0.03	0.00	0.02	0.04
Ln CBD**	- 0.03	0.12	- 0.26	0.22	- 0.03	0.12	- 0.26	0.23	3.03	0.21	2.61	3.45
BalcTerr **	- 0.05	0.02	- 0.07	0.00	- 0.05	0.02	- 0.06	0.01	- 0.00	0.02	- 0.06	0.02
Ln PP**	- 0.97	0.28	- 1.53	- 0.44	- 1.32	0.31	- 1.93	- 0.71	0.63	0.26	0.15	1.17
Ln Park**	0.06	0.04	- 0.02	0.13	0.08	0.04	- 0.00	0.14	- 0.11	0.02	- 0.14	- 0.08
Ln Playground**	0.92	0.07	0.78	1.06	0.89	0.07	0.75	1.04	0.58	0.07	0.43	0.72
Ln Allotment**	0.10	0.01	0.08	0.12	0.10	0.01	0.08	0.12	- 0.07	0.02	- 0.10	- 0.04
Ln Cemetery**	0.61	0.01	0.60	0.63	0.61	0.01	0.60	0.63	0.46	0.01	0.43	0.48
Income group	Mid				Mid				Mid			
WTP estimates	A				A				B			
District fixed effects	TRUE				TRUE				TRUE			
Time fixed effects	FALSE				TRUE				FALSE			
Observations	15,155				15,155				15,155			
Bootstraps	1,000				1,000				1,000			

Table A.34: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for cemetery area in a 1 km radius around housing units in the mid income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

	Dependent variable:											
	Ln WTP Cem											
Variable	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**	**Coef**	**SE**	**LCI**	**HCI**
(Intercept)	- 130.40	128.33	- 361.18	135.44	- 105.53	130.10	- 351.78	152.67	- 163.59	219.70	- 585.78	272.00
Ln Area	0.94	0.41	- 0.05	1.52	0.94	0.41	- 0.04	1.51	- 0.03	0.56	- 1.22	1.00
Ln GardenSize	0.03	0.00	0.03	0.04	0.03	0.00	0.02	0.04	0.03	0.00	0.03	0.04
BalcTerr	- 0.01	0.02	- 0.07	0.01	- 0.00	0.02	- 0.06	0.02	- 0.01	0.03	- 0.06	0.07
Ln PP	0.53	0.25	0.04	1.06	0.63	0.26	0.15	1.17	0.94	0.43	0.11	1.77
Ln Popden	0.11	0.01	0.08	0.13	0.11	0.01	0.08	0.14	0.36	0.02	0.32	0.40
Ln CBD	3.23	0.21	2.80	3.66	3.03	0.21	2.61	3.45	2.52	0.23	2.02	2.93
Ln Park	- 0.10	0.02	- 0.13	- 0.07	- 0.11	0.02	- 0.14	- 0.08	- 0.05	0.03	- 0.11	0.01
Ln Playground	0.59	0.08	0.43	0.73	0.58	0.07	0.43	0.72	- 0.81	0.07	- 0.93	- 0.68
Ln Allotment	- 0.07	0.02	- 0.10	- 0.04	- 0.07	0.02	- 0.10	- 0.04	- 0.14	0.02	- 0.18	- 0.09
Ln Cemetery	0.47	0.01	0.45	0.50	0.46	0.01	0.43	0.48	0.84	0.02	0.79	0.88
Above60	1.52	0.36	0.82	2.21	1.99	0.43	1.15	2.81	- 3.63	0.47	- 4.56	- 2.70
Children	- 6.06	0.21	- 6.45	- 5.64	- 6.20	0.21	- 6.64	- 5.78	2.67	0.28	2.15	3.22
Unemployed	- 0.04	0.01	- 0.05	- 0.03	- 0.04	0.01	- 0.05	- 0.03	- 0.20	0.01	- 0.21	- 0.18
Singles	91.33	127.79	- 171.10	321.69	66.93	129.63	- 189.69	314.04	129.46	219.60	- 307.71	551.41
Families	92.39	127.79	- 169.95	322.72	68.26	129.63	- 188.38	315.46	127.82	219.60	- 309.44	549.75
Couples	0.92	1.28	- 1.70	3.22	0.68	1.30	- 1.88	3.15	1.30	2.20	- 3.07	5.52
Ln Area**	0.94	0.41	- 0.05	1.52	0.94	0.41	- 0.04	1.51	- 0.03	0.56	- 1.22	1.00
Ln GardenSize**	0.03	0.003	0.03	0.04	0.03	0.003	0.02	0.04	0.03	0.005	0.03	0.04
Ln CBD**	3.23	0.21	2.80	3.66	3.03	0.21	2.61	3.45	2.52	0.23	2.02	2.93
BalcTerr **	- 0.01	0.02	- 0.07	0.01	- 0.00	0.02	- 0.06	0.02	- 0.01	0.03	- 0.06	0.07
Ln PP**	0.53	0.25	0.04	1.06	0.63	0.26	0.15	1.17	0.94	0.43	0.11	1.77
Ln Park**	- 0.10	0.02	- 0.13	- 0.07	- 0.11	0.02	- 0.14	- 0.08	- 0.05	0.03	- 0.11	0.01
Ln Playground**	0.59	0.08	0.43	0.73	0.58	0.07	0.43	0.72	- 0.81	0.07	- 0.93	- 0.68
Ln Allotment**	- 0.07	0.02	- 0.10	- 0.04	- 0.07	0.02	- 0.10	- 0.04	- 0.14	0.02	- 0.18	- 0.09
Ln Cemetery**	0.47	0.01	0.45	0.50	0.46	0.01	0.43	0.48	0.84	0.02	0.79	0.88
Income group		High				High				High		
WTP estimates		A				A				B		
District fixed effects		TRUE				TRUE				TRUE		
Time fixed effects		FALSE				TRUE				FALSE		
Observations		11,692				11,692				11,692		
Bootstraps		1,000				1,000				1,000		

Table A.35: Third-stage estimation and robustness checks of substitution effects and income elasticity of willingness to pay (WTP) for hypothesis testing. The dependent variable is Ln non-marginal WTP for cemetery area in a 1 km radius around housing units in the high-income group. Coef = Coefficient estimate, SE = Standard Error, LCI = lower bound of the confidence interval, HCI = upper bound of the confidence interval.

B. Appendix to Chapter 3

B.1 Indicator correlation

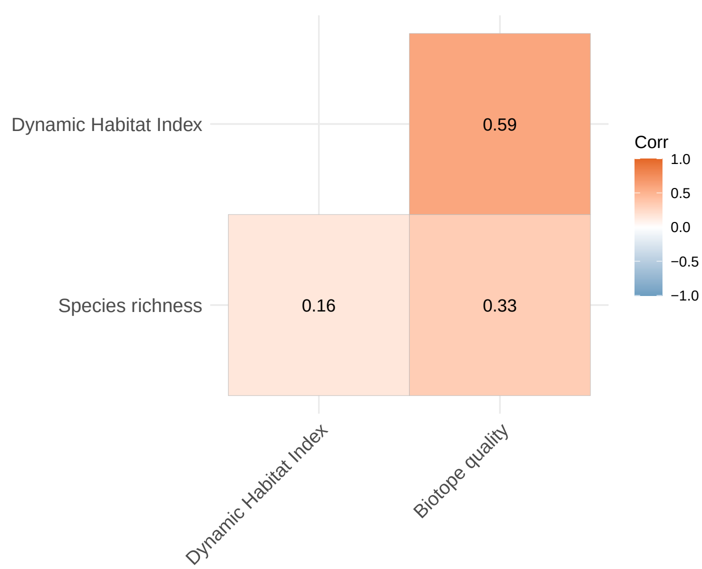

Figure B.1: Correlation plot showing positive Pearson's correlation coefficient of the three biodiversity indicators *Species richness* calculated from the species cadastre BUE (2016a), median *biotope quality* calculated from the official biotope cadastre BUE (2018) and the satellite-based *Dynamic Habitat index* (Hobi et al., 2017). No point in the center of each square indicates a significant correlation coefficient

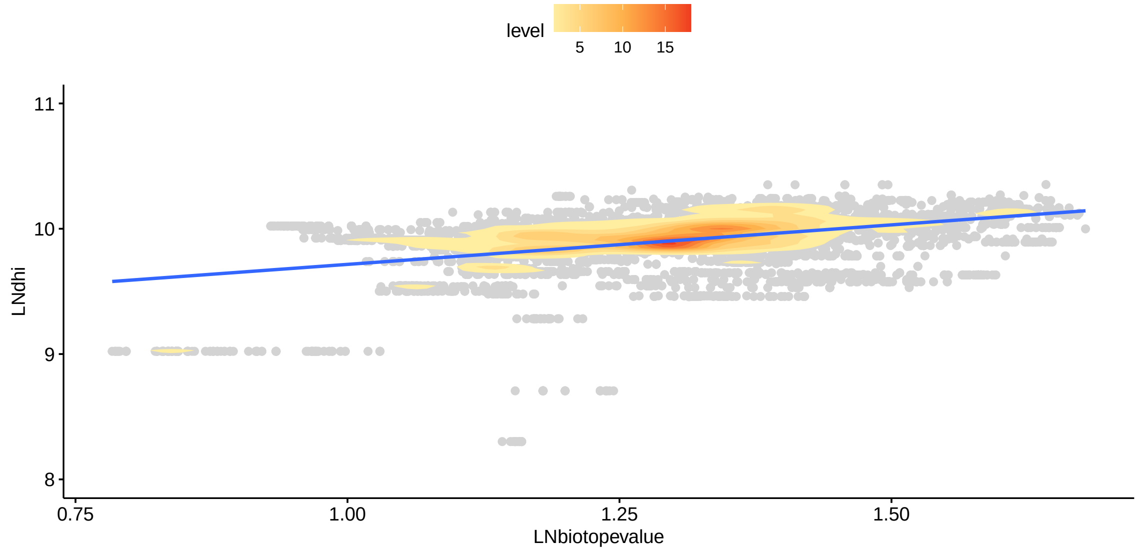

Figure B.2: Correlation plot showing significant positive linear correlation of the natural logarithm of the biodiversity indicators median *biotope quality* calculated from the official biotope cadastre BUE (2018) and the satellite based *Dynamic Habitat index* (Hobi et al., 2017). Density of the observations is indicated by the level variable. Only observations for the years 2017 and 2018 were included to make the two data sources comparable.

B.2]

Descriptive statistics, variable description and hypothesized effects of the first-stage estimation

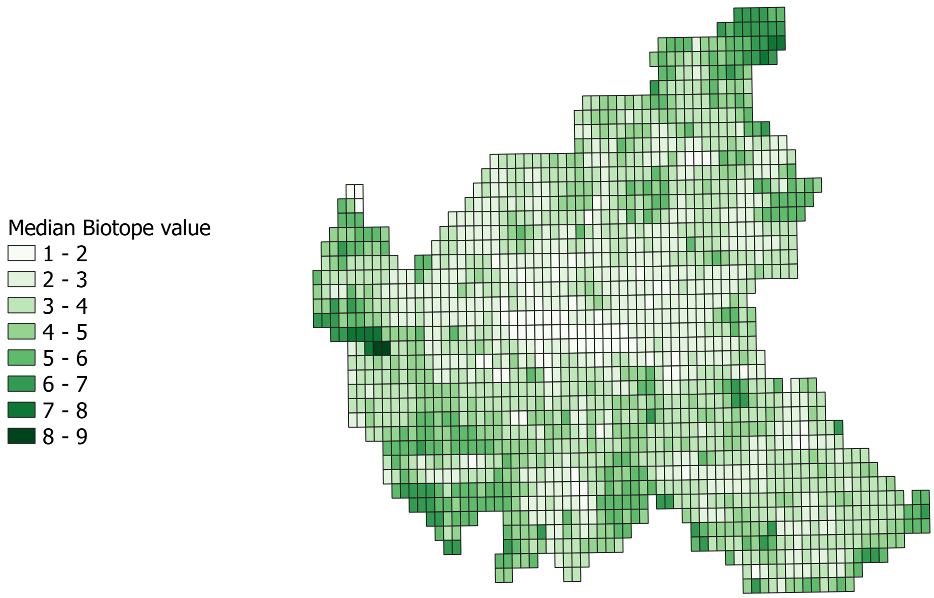

Figure B.3: Rasterized median biotope quality calculated from BUE (2018). The original data are based on expert assessment classifying biotope quality on a scale from 0 to 10, with 10 indicating highest biotope quality.

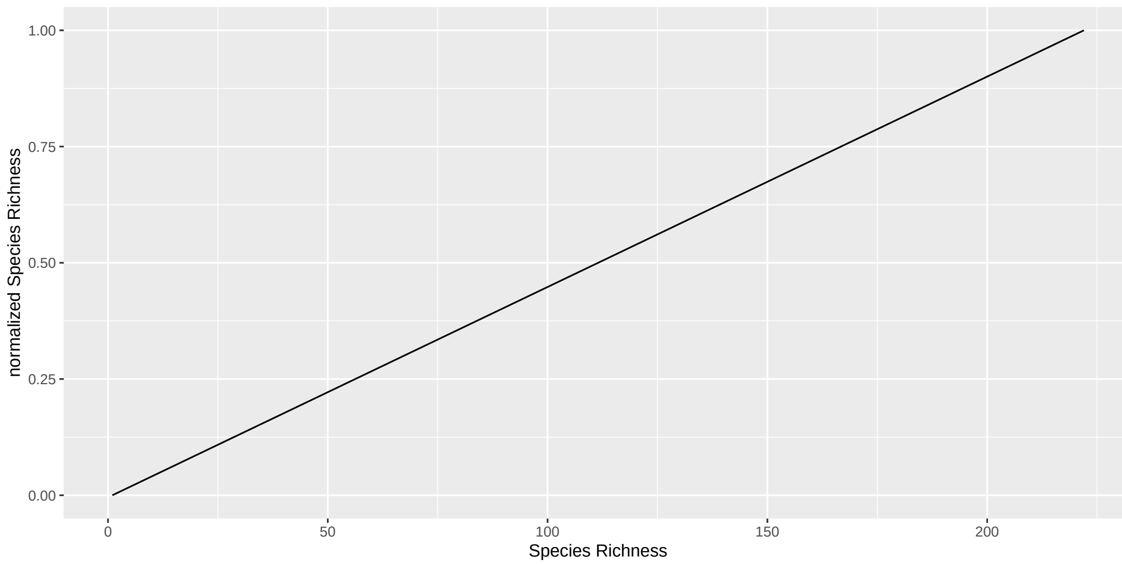

Figure B.4: Plot of normalized and non-normalized species richness indicator

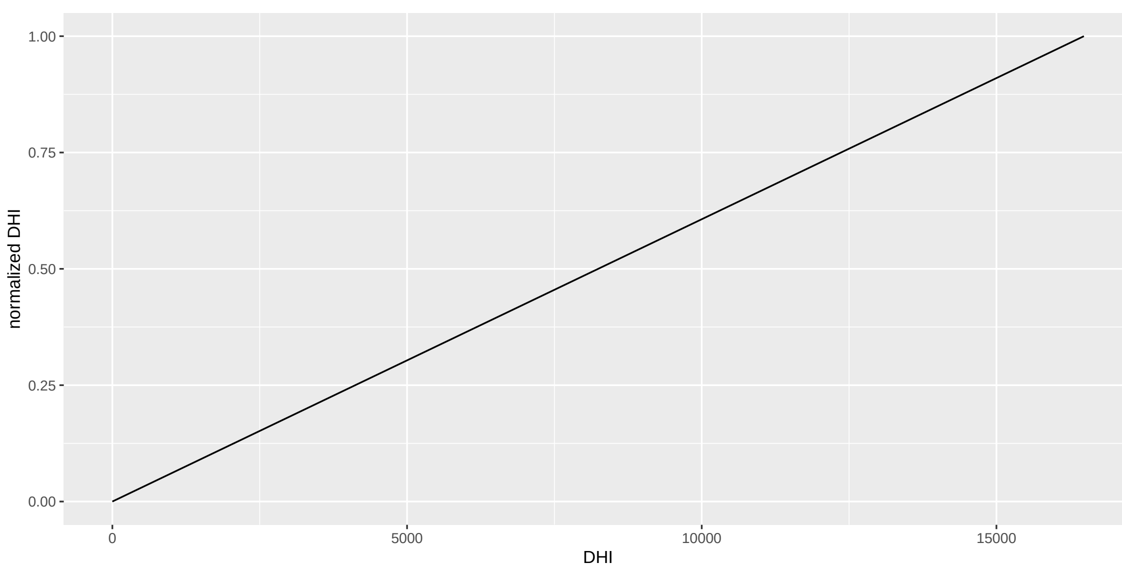

Figure B.5: Plot of normalized and non-normalized Dynamic Habitat Index

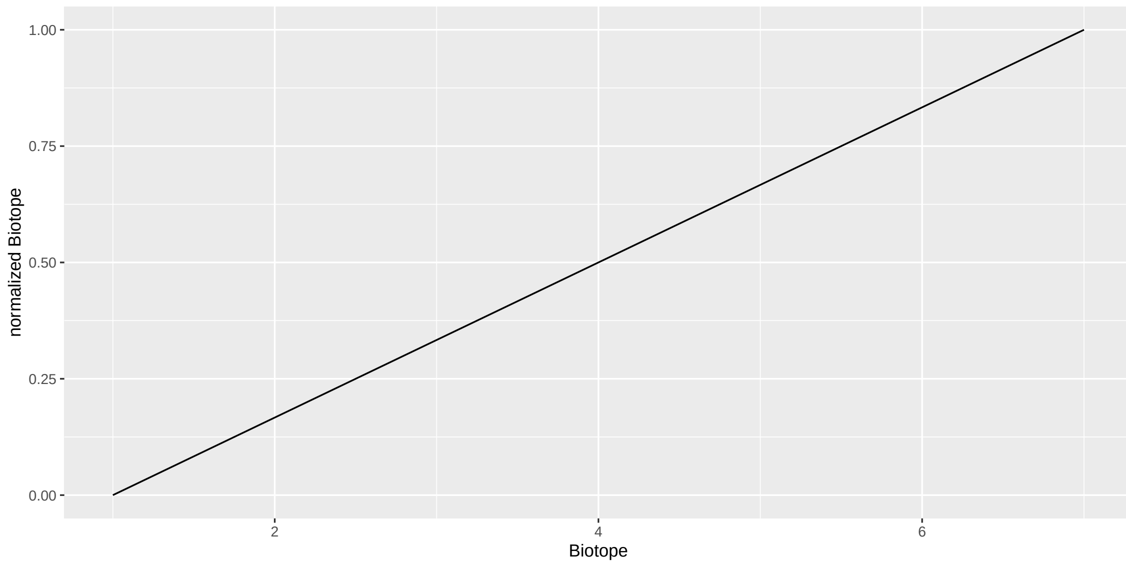

Figure B.6: Plot of normalized and non-normalized biotope quality indicator

	Dependent variable											
	Maximum annual temperature [Kelvin]											
	Coef	SE	LCI	UCI	Coef	SE	LCI	UCI	Coef	SE	LCI	UCI
(Intercept)	3.0e+02	5.5e-01	3.0e+02	3.0e+02	3.0e+02	4.8e-01	3.0e+02	3.0e+02	3.0e+02	4.9e-01	3.0e+02	3.0e+02
Bio	-2.2	5.4e-01	-3.2	-1.3	-1.4	8.6e-02	-1.6	-1.3	-1.7	3.5e-01	-2.4	-1.0
Min_dist_industry	-3.8e-04	1.5e-05	-4.1e-04	-3.5e-04	-2.7e-04	1.5e-05	-3.0e-04	-2.4e-04	-3.6e-04	1.5e-05	-3.9e-04	-3.3e-04
CBD	-1.3e-04	1.2e-05	-1.5e-04	-1.1e-04	-1.5e-04	1.2e-05	-1.7e-04	-1.2e-04	-1.0e-04	1.2e-05	-1.2e-04	-8.2e-05
Min_dist_rail	-1.6e-04	2.1e-05	-1.9e-04	-1.1e-04	-8.3e-05	2.0e-05	-1.2e-04	-4.3e-05	-1.3e-04	2.1e-05	-1.6e-04	-8.5e-05
Min_dist_forest	-7.5e-05	1.3e-05	-1.0e-04	-5.3e-05	-1.2e-04	1.2e-05	-1.4e-04	-9.7e-05	-7.3e-05	1.3e-05	-9.8e-05	-4.9e-05
Min_dist_watbod	1.8e-05	1.1e-05	-9.7e-07	3.5e-05	6.7e-05	1.1e-05	4.4e-05	8.4e-05	2.3e-05	1.1e-05	5.0e-06	3.8e-05
Min_dist_sportleisure	2.3e-01	3.7e-02	1.6e-01	2.9e-01	1.1e-01	3.5e-02	4.5e-02	1.7e-01	2.3e-01	3.6e-02	1.6e-01	2.9e-01
Size Allotment garden	-1.6e-06	4.0e-07	-2.4e-06	-8.9e-07	-2.7e-06	3.7e-07	-3.5e-06	-2.0e-06	-2.2e-06	3.8e-07	-2.9e-06	-1.5e-06
Size Cemetery	-6.2e-08	1.8e-08	-9.7e-08	-2.7e-08	-5.2e-08	1.8e-08	-8.7e-08	-1.8e-08	-4.6e-08	1.8e-08	-8.1e-08	-1.4e-08
Size Playground	7.3e-05	4.6e-06	6.5e-05	8.1e-05	7.2e-05	4.4e-06	6.3e-05	8.1e-05	7.7e-05	4.5e-06	6.8e-05	8.5e-05
Size Park	-4.0e-02	1.0e-02	-5.9e-02	-2.4e-02	-2.8e-02	1.0e-02	-4.8e-02	-8.8e-03	-2.7e-02	1.0e-02	-4.5e-02	-9.7e-03
share_ugs	7.1e-01	2.3e-01	2.2e-01	1.1	1.2	2.3e-01	6.4e-01	1.6	1.1	2.4e-01	5.1e-01	1.5
nrugs	3.9e-02	6.0e-03	2.9e-02	5.0e-02	2.4e-02	6.0e-03	1.3e-02	3.6e-02	4.4e-02	6.1e-03	3.4e-02	5.7e-02
scndring	3.6e-01	4.9e-02	2.8e-01	4.5e-01	5.3e-01	4.8e-02	4.5e-01	6.1e-01	3.4e-01	4.8e-02	2.6e-01	4.3e-01
thrddring	5.7e-01	7.6e-02	4.3e-01	7.0e-01	9.7e-01	7.6e-02	8.3e-01	1.1	5.1e-01	7.4e-02	3.9e-01	6.6e-01
frthring	1.7	1.2e-01	1.5	1.9	1.9	1.2e-01	1.7	2.1	1.4	1.1e-01	1.2	1.6
Street trees6	2.1e-02	6.7e-03	8.5e-03	3.4e-02	2.4e-02	6.8e-03	1.1e-02	3.9e-02	2.6e-02	6.9e-03	1.2e-02	3.9e-02
PStar.Street trees6	-4.9e-01	1.4e-01	-7.3e-01	-2.3e-01	-5.5e-01	1.4e-01	-8.3e-01	-3.1e-01	-5.9e-01	1.4e-01	-8.7e-01	-3.4e-01
Bio**	1.4e-01	6.9e-02	1.7e-02	2.9e-01	-3.2e-01	4.5e-02	-4.0e-01	-2.4e-01	-5.6e-02	5.1e-02	-1.6e-01	2.8e-02
District fixed effects	TRUE				TRUE				TRUE			
Observations	12,966				12,966				12,966			
Bootstraps	1,000				1,000				1,000			
Indicator	Species richness				DHI				Biotope quality			

Table B.1: Exploring the effect of three biodiversity indicators on the maximum annnual temperature [Kelvin] calculated from 8-day per-pixel Land Surface Temperature and Emissivity products with a 1 kilometer spatial resolution from NASA (2020) in 2017.

	Dependent variable											
	pm 10 concentration											
	Coef	SE	LCI	UCI	Coef	SE	LCI	UCI	Coef	SE	LCI	UCI
(Intercept)	2.0e+01	8.3e-02	2.0e+01	2.0e+01	2.0e+01	7.9e-02	2.0e+01	2.0e+01	2.0e+01	7.5e-02	2.0e+01	2.0e+01
Bio	-4.1e-01	7.2e-02	-5.4e-01	-2.8e-01	-3.2e-02	1.2e-02	-5.4e-02	-1.1e-02	-1.6e-01	4.9e-02	-2.6e-01	-7.2e-02
Min_dist_industry	-2.5e-05	2.1e-06	-2.9e-05	-2.1e-05	-2.4e-05	2.3e-06	-2.9e-05	-2.0e-05	-2.4e-05	2.1e-06	-2.8e-05	-2.0e-05
CBD	-1.7e-05	1.9e-06	-2.0e-05	-1.4e-05	-1.7e-05	1.9e-06	-2.1e-05	-1.4e-05	-1.5e-05	1.9e-06	-1.8e-05	-1.2e-05
Min_dist_rail	3.1e-06	2.3e-06	-8.3e-07	7.2e-06	3.4e-06	2.4e-06	-8.9e-07	7.9e-06	5.1e-06	2.4e-06	1.1e-06	9.6e-06
Min_dist_forest	4.6e-06	1.7e-06	1.0e-06	7.3e-06	5.7e-06	1.7e-06	1.7e-06	8.4e-06	5.7e-06	1.7e-06	1.8e-06	8.5e-06
Min_dist_watbod	4.2e-06	1.1e-06	2.2e-06	6.2e-06	4.1e-06	1.1e-06	2.0e-06	6.3e-06	3.8e-06	1.1e-06	1.9e-06	5.9e-06
Min_dist_sportleisure	-1.1e-02	3.9e-03	-1.9e-02	-2.8e-03	-1.5e-02	4.1e-03	-2.3e-02	-7.0e-03	-1.1e-02	4.0e-03	-1.8e-02	-3.0e-03
Size Allotment garden	6.4e-07	8.0e-08	4.9e-07	7.8e-07	6.1e-07	8.0e-08	4.7e-07	7.5e-07	6.1e-07	7.9e-08	4.7e-07	7.6e-07
Size Cemetery	-6.3e-09	1.6e-09	-9.1e-09	-3.7e-09	-6.6e-09	1.6e-09	-9.4e-09	-4.0e-09	-5.0e-09	1.6e-09	-8.1e-09	-2.0e-09
Size Playground	2.3e-06	4.4e-07	1.6e-06	3.2e-06	2.2e-06	4.6e-07	1.4e-06	3.1e-06	2.5e-06	4.4e-07	1.7e-06	3.4e-06
Size Park	-1.7e-03	1.1e-03	-3.7e-03	5.4e-04	-1.6e-03	1.1e-03	-3.7e-03	5.4e-04	-9.4e-04	1.0e-03	-3.0e-03	1.1e-03
share_ugs	-6.3e-02	3.0e-02	-1.2e-01	-1.2e-02	-5.4e-02	3.0e-02	-1.1e-01	-4.4e-04	-1.9e-02	3.0e-02	-7.9e-02	3.7e-02
nrugs	5.1e-03	6.8e-04	3.8e-03	6.4e-03	4.7e-03	6.9e-04	3.4e-03	6.0e-03	4.8e-03	6.8e-04	3.5e-03	6.1e-03
scndring	3.2e-02	5.1e-03	2.3e-02	4.1e-02	3.4e-02	5.0e-03	2.4e-02	4.3e-02	2.9e-02	5.0e-03	2.0e-02	3.8e-02
thrddring	-1.8e-02	9.3e-03	-3.5e-02	1.1e-03	-8.8e-03	9.3e-03	-2.5e-02	9.3e-03	-1.8e-02	9.2e-03	-3.4e-02	4.6e-05
frthring	1.7e-02	1.4e-02	-9.4e-03	4.4e-02	1.8e-02	1.5e-02	-9.3e-03	4.5e-02	1.8e-03	1.5e-02	-2.8e-02	3.2e-02
Street trees6	-5.3e-03	7.6e-04	-6.8e-03	-3.8e-03	-5.3e-03	7.4e-04	-6.6e-03	-3.8e-03	-5.1e-03	7.3e-04	-6.4e-03	-3.7e-03
Street trees6 **	1.1e-01	1.5e-02	8.5e-02	1.4e-01	1.1e-01	1.4e-02	8.5e-02	1.4e-01	1.1e-01	1.4e-02	8.0e-02	1.3e-01
Bio**	5.7e-02	9.1e-03	4.1e-02	7.6e-02	1.6e-02	6.1e-03	4.3e-03	2.7e-02	3.6e-03	6.4e-03	-7.0e-03	1.4e-02
District fixed effects	TRUE				TRUE				TRUE			
Observations	12,966				12,966				12,966			
Bootstraps	1,000				1,000				1,000			
Indicator	Species richness				DHI				Biotope quality			

Table B.2: Exploring the effect of three biodiversity indicators on the particulate matter concentration (pm10) in 2017, extracted European Air Quality maps with a 1 kilometer spatial resolution (European Topic Centre on Air Pollution et al., 2019).

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	30,581	0.3	0.1	0.0	0.2	0.4	1.0
DHI	30,581	0.3	0.3	0	0	0.7	1
Biotope	30,581	0.4	0.1	0.0	0.3	0.3	1.0
Park	30,581	27.1	24.7	0.0	11.8	33.1	158.0
Playground	30,581	3.2	2.2	0.0	1.5	4.3	13.3
Allotment	30,581	14.6	21.8	0	0.6	18.8	156
Cemetery	30,581	17.5	74.5	0	0	1.8	399
fstring	30,581	0.2	0.4	0	0	0	1
scndring	30,581	0.3	0.4	0	0	1	1
thrddring	30,581	0.3	0.4	0	0	1	1
Garden	30,581	0.2	0.4	0	0	0	1
BalcTerr	30,581	0.5	0.5	0	0	1	1
Area	30,581	67.8	26.2	12	52	79	760
Age	30,581	52.4	31.8	8	24	66	461
Base	30,581	0.004	0.1	0	0	0	1
Basement	30,581	0.4	0.5	0	0	1	1
FullBase	30,581	0.003	0.1	0	0	0	1
Kitchen	30,581	0.7	0.5	0	0	1	1
FloorHeat	30,581	0.04	0.2	0	0	0	1
CentralHeat	30,581	0.7	0.5	0	0	1	1
GasHeat	30,581	0.01	0.1	0	0	0	1
Garage	30,581	0.3	0.5	0	0	1	1
GaragePl	30,581	0.1	0.2	0	0	0	1
garden.1	30,581	0.2	0.4	0	0	0	1
HighQual	30,581	0.1	0.2	0	0	0	1
New	30,581	0.1	0.3	0	0	0	1
Renovated	30,581	0.1	0.3	0	0	0	1
Badcond	30,581	0.01	0.1	0	0	0	1
Fireplace	30,581	0.01	0.1	0	0	0	1
Woodenfloor	30,581	0.1	0.3	0	0	0	1
Sauna	30,581	0.01	0.1	0	0	0	1
Street trees	30,581	28.0	20.2	0	12	40	260

Table B.3: Descriptive statistics of submarket flats for rent in the years 2005 to 2009.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	44,072	0.3	0.1	0.0	0.2	0.4	1.0
DHI	44,072	0.3	0.3	0	0	0.6	1
Biotope	44,072	0.3	0.1	0.0	0.3	0.3	1.0
Park	44,072	28.0	26.5	0.0	11.4	33.0	161.8
Playground	44,072	3.1	2.2	0.0	1.4	4.3	12.6
Allotment	44,072	12.5	19.5	0.0	0.0	17.3	155.4
Cemetery	44,072	14.8	69.1	0	0	0.7	399
fstring	44,072	0.3	0.4	0	0	1	1
scndring	44,072	0.2	0.4	0	0	0	1
thrddring	44,072	0.3	0.4	0	0	1	1
Garden	44,072	0.2	0.4	0	0	0	1
BalcTerr	44,072	0.5	0.5	0	0	1	1
Area	44,072	74.8	31.5	13	55	88	570
Age	44,072	48.1	35.0	4	18	64	369
Base	44,072	0.01	0.1	0	0	0	1
Basement	44,072	0.6	0.5	0	0	1	1
FullBase	44,072	0.003	0.1	0	0	0	1
Kitchen	44,072	0.8	0.4	0	1	1	1
FloorHeat	44,072	0.1	0.3	0	0	0	1
CentralHeat	44,072	0.6	0.5	0	0	1	1
GasHeat	44,072	0.005	0.1	0	0	0	1
Garage	44,072	0.4	0.5	0	0	1	1
GaragePl	44,072	0.1	0.2	0	0	0	1
HighQual	44,072	0.2	0.4	0	0	0	1
New	44,072	0.1	0.3	0	0	0	1
Renovated	44,072	0.1	0.3	0	0	0	1
Badcond	44,072	0.01	0.1	0	0	0	1
Fireplace	44,072	0.02	0.1	0	0	0	1
Woodenfloor	44,072	0.1	0.3	0	0	0	1
Sauna	44,072	0.01	0.1	0	0	0	1
Street trees	44,072	26.0	19.5	0	11	38	163

Table B.4: Descriptive statistics of submarket flats for rent in the years 2010 to 2014.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	35,973	0.3	0.1	0.0	0.2	0.4	1.0
DHI	35,973	0.3	0.3	0	0	0.6	1
Biotope	35,973	0.3	0.1	0.0	0.3	0.3	1.0
Park	35,973	27.9	26.7	0.0	11.0	33.2	161.1
Playground	35,973	3.1	2.2	0.0	1.5	4.4	12.6
Allotment	35,973	13.7	20.9	0.0	0.3	18.3	155.4
Cemetery	35,973	15.8	70.9	0	0	1.7	399
fstring	35,973	0.3	0.4	0	0	1	1
scndring	35,973	0.3	0.4	0	0	1	1
thrddring	35,973	0.3	0.4	0	0	1	1
Garden	35,973	0.2	0.4	0	0	0	1
BalcTerr	35,973	0.5	0.5	0	0	1	1
Area	35,973	73.3	30.4	12	54	86	400
Age	35,973	48.6	35.4	2	18	65	369
Base	35,973	0.01	0.1	0	0	0	1
Basement	35,973	0.5	0.5	0	0	1	1
FullBase	35,973	0.003	0.1	0	0	0	1
Kitchen	35,973	0.7	0.4	0	0	1	1
FloorHeat	35,973	0.1	0.3	0	0	0	1
CentralHeat	35,973	0.6	0.5	0	0	1	1
GasHeat	35,973	0.01	0.1	0	0	0	1
Garage	35,973	0.3	0.5	0	0	1	1
GaragePl	35,973	0.1	0.3	0	0	0	1
HighQual	35,973	0.2	0.4	0	0	0	1
New	35,973	0.1	0.3	0	0	0	1
Renovated	35,973	0.1	0.3	0	0	0	1
Badcond	35,973	0.01	0.1	0	0	0	1
Fireplace	35,973	0.02	0.1	0	0	0	1
Woodenfloor	35,973	0.2	0.4	0	0	0	1
Sauna	35,973	0.01	0.1	0	0	0	1
Street trees	35,973	25.5	19.4	0	9	38	163

Table B.5: Descriptive statistics of submarket flats for rent in the years 2015 to 2018.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	8,299	0.3	0.1	0.0	0.2	0.4	1.0
DHI	8,299	0.3	0.4	0.0	0.0	0.7	1.0
Biotope	8,299	0.4	0.1	0.0	0.3	0.3	1.0
Park	8,299	27.9	26.9	0.0	11.0	32.3	157.2
Playground	8,299	3.4	2.7	0.0	1.2	5.0	12.9
Allotment	8,299	11.7	17.7	0.0	0.0	16.9	155.4
Cemetery	8,299	22.3	84.5	0.0	0.0	2.3	398.9
fstring	8,299	0.3	0.5	0	0	1	1
scndring	8,299	0.2	0.4	0	0	0	1
thrddring	8,299	0.3	0.4	0	0	1	1
Garden	8,299	0.3	0.5	0	0	1	1
BalcTerr	8,299	0.5	0.5	0	0	1	1
Area	8,299	81.7	38.5	16	55	100	400
Age	8,299	49.1	35.4	8	17	63	351
Base	8,299	0.03	0.2	0	0	0	1
Basement	8,299	0.4	0.5	0	0	1	1
FullBase	8,299	0.03	0.2	0	0	0	1
Kitchen	8,299	0.6	0.5	0	0	1	1
FloorHeat	8,299	0.2	0.4	0	0	0	1
CentralHeat	8,299	0.6	0.5	0	0	1	1
GasHeat	8,299	0.01	0.1	0	0	0	1
Garage	8,299	0.5	0.5	0	0	1	1
GaragePl	8,299	0.1	0.3	0	0	0	1
HighQual	8,299	0.2	0.4	0	0	0	1
New	8,299	0.1	0.4	0	0	0	1
Renovated	8,299	0.1	0.3	0	0	0	1
Badcond	8,299	0.1	0.2	0	0	0	1
Fireplace	8,299	0.04	0.2	0	0	0	1
Woodenfloor	8,299	0.1	0.4	0	0	0	1
Sauna	8,299	0.02	0.2	0	0	0	1
Street trees	8,299	26.8	20.1	0	11	38	162

Table B.6: Descriptive statistics of submarket flats for sale in the years 2005 to 2009.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	11,253	0.4	0.2	0.0	0.2	0.5	1.0
DHI	11,253	0.3	0.3	0.0	0.0	0.7	1.0
Biotope	11,253	0.4	0.1	0.0	0.3	0.4	1.0
Park	11,253	27.3	26.6	0.0	10.5	32.9	157.2
Playground	11,253	3.1	2.5	0.0	1.1	4.7	12.1
Allotment	11,253	11.3	18.6	0.0	0.0	14.8	155.4
Cemetery	11,253	21.4	84.0	0	0	2.3	399
fstring	11,253	0.3	0.4	0	0	1	1
scndring	11,253	0.3	0.4	0	0	1	1
thrddring	11,253	0.3	0.4	0	0	1	1
Garden	11,253	0.3	0.5	0	0	1	1
BalcTerr	11,253	0.4	0.5	0	0	1	1
Area	11,253	96.3	47.9	19	65	117	765
Age	11,253	35.0	36.3	3	6	54	249
Base	11,253	0.02	0.1	0	0	0	1
Basement	11,253	0.6	0.5	0	0	1	1
FullBase	11,253	0.01	0.1	0	0	0	1
Kitchen	11,253	0.5	0.5	0	0	1	1
FloorHeat	11,253	0.3	0.4	0	0	1	1
CentralHeat	11,253	0.5	0.5	0	0	1	1
GasHeat	11,253	0.01	0.1	0	0	0	1
Garage	11,253	0.6	0.5	0	0	1	1
GaragePl	11,253	0.1	0.3	0	0	0	1
HighQual	11,253	0.3	0.4	0	0	1	1
New	11,253	0.3	0.4	0	0	1	1
Renovated	11,253	0.1	0.3	0	0	0	1
Badcond	11,253	0.03	0.2	0	0	0	1
Fireplace	11,253	0.03	0.2	0	0	0	1
Woodenfloor	11,253	0.2	0.4	0	0	0	1
Sauna	11,253	0.01	0.1	0	0	0	1
Street trees	11,253	25.2	18.7	0	11	35	164

Table B.7: Descriptive statistics of submarket flats for sale in the years 2010 to 2014.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
richness	9,328	0.4	0.2	0.0	0.3	0.5	1.0
DHI	9,328	0.4	0.3	0.0	0.0	0.7	1.0
Biotope	9,328	0.4	0.2	0.0	0.3	0.5	1.0
Park	9,328	26.3	24.3	0.0	11.0	32.7	157.1
Playground	9,328	3.0	2.3	0.0	1.3	4.0	12.9
Allotment	9,328	12.5	16.0	0	0	20.0	154
Cemetery	9,328	18.1	77.0	0	0	1.9	399
fstring	9,328	0.2	0.4	0	0	0	1
scndring	9,328	0.2	0.4	0	0	0	1
thrddring	9,328	0.3	0.4	0	0	1	1
Garden	9,328	0.3	0.5	0	0	1	1
BalcTerr	9,328	0.3	0.5	0	0	1	1
Area	9,328	93.5	44.3	15	65	111	712
Age	9,328	28.6	36.4	0	3	49	353
Base	9,328	0.03	0.2	0	0	0	1
Basement	9,328	0.5	0.5	0	0	1	1
FullBase	9,328	0.01	0.1	0	0	0	1
Kitchen	9,328	0.4	0.5	0	0	1	1
FloorHeat	9,328	0.5	0.5	0	0	1	1
CentralHeat	9,328	0.5	0.5	0	0	1	1
GasHeat	9,328	0.01	0.1	0	0	0	1
Garage	9,328	0.6	0.5	0	0	1	1
GaragePl	9,328	0.1	0.3	0	0	0	1
HighQual	9,328	0.4	0.5	0	0	1	1
New	9,328	0.4	0.5	0	0	1	1
Renovated	9,328	0.1	0.3	0	0	0	1
Badcond	9,328	0.03	0.2	0	0	0	1
Fireplace	9,328	0.04	0.2	0	0	0	1
Woodenfloor	9,328	0.2	0.4	0	0	0	1
Sauna	9,328	0.02	0.1	0	0	0	1
Street trees	9,328	20.6	17.7	0	5	33	163

Table B.8: Descriptive statistics of submarket flats for sale in the years 2015 to 2018.

Variable name	Description	Hypothesized sign of coefficient
Price	Transaction price in 2005 Euro	NA
Biotope	Normallized biodiversity indicator based on ground based ecological assessment	-
DHI	Normalized biodiversity indicator based on Modis data	-
Richness	Normalized biodiversity indicator, species richness from species cadastre	-
	Structural characteristics and green space variables	
Area	Living area in sqm	+
Age	Age of housing unit in years	-
Base	Housing unit is situated on base floor (1 if it is the case, 0 otherwise)	+
Basement	Presence of a storagecompartment in the basement (1 if it is the case, 0 otherwise)	+
FullBase	Presence of a full basement storage (1 if it is the case, 0 otherwise)	+
Kitchen	Presence of a built-in kitchen (1 if it is the case, 0 otherwise)	+
FloorHeat	Presence of a floor heating (1 if it is the case, 0 otherwise)	+
CentralHeat	Presence of a central heating (1 if it is the case, 0 otherwise)	+
GasHeat	Presence of a gas heating (1 if it is the case, 0 otherwise)	-
Garage	Presence of a garage (1 if it is the case, 0 otherwise)	+
GaragePl	Presence of a parking position (1 if it is the case, 0 otherwise)	+
Garden	Presence of a garden (1 if it is the case, 0 otherwise)	+
HighQual	High quality condition (1 if it is the case, 0 otherwise)	+
New	Newly built condition (1 if it is the case, 0 otherwise)	+
Renovated	Renovated condition (1 if it is the case, 0 otherwise)	+
Badcond	Bad condition (1 if it is the case, 0 otherwise)	-
Fireplace	Presence of a fireplace (1 if it is the case, 0 otherwise)	+
Woodenfloor	Hardwood floors (1 if it is the case, 0 otherwise)	+
Sauna	Presence of a sauna (1 if it is the case, 0 otherwise)	+
BalcTerr	Presence of a balcony or terrace (1 if it is the case, 0 otherwise)	+
Playground	Playground area in a 1 km radius around the housing unit in ha	+
Park	Park area in a 1 km radius around the housing unit in ha	+
Allotment	Allotment garden area in a 1 km radius around the housing unit in ha	+
Cemetery	Cemetery area in a 1 km radius around the housing unit in ha	+
Street trees	Number of streettrees in a 100m radius	-
CBD	Network distance to the central business district in m	-
scndring	Dummy variable indicating the second quartile of CBD variable	-
thrddring	Dummy variable indicating the third quartile of CBD variable	-
frthring	Dummy variable indicating the fourth quartile of CBD variable	-
PP	Purchasing power in Euro	NA
Poden	Population density in a km^2	NA
Unemployed	Share of unemployed in 100*%	NA
Above60	Share of inhabitants above the age of 60 in 100*%	NA
Singles	Share of single households 100*%	NA
Families	Share of families 100*%	NA

Table B.9: Variable description and hypothesized effects

B.3 Model assumptions and measures to assess convergent validity and definitions

For the method to work, it is necessary that several assumptions are met. The method assumes that (i) the endogenous variable is not normally distributed and does not have a bimodal distribution, (ii) if the endogenous variable is discrete, it must not have a Bernoulli distribution, and additionally that (iii) it is an advantage if the structural error term is normally distributed. If the last assumption does not hold, the method still performs well, given that the error and the endogenous variable have different distributions (Park and Gupta, 2012; Gui et al., 2018). I use Anderson Darling tests (AD) to test that assumption (i) is met here for all endogenous variables and estimations with different sub-samples. All AD reject the hypothesis of an underlying normal distribution. Assumption (ii) is not relevant in this case as the biodiversity indicators and green space variables are continuous variables. If assumption (iii) is violated, i.e. the structural error and the endogenous variable do not have sufficiently different distributions, this can lead to multicollinearity and confidence intervals for the auxiliary variables that are wider than would be the case if the assumption were met. Park and Gupta (2012) propose to use a large dataset to avert this efficiency problem, which is the case here, as the dataset used in this study contains more than 8,000 observations in all submarkets.

Measure	Relevant threshold	Statistic
r	$r > 0.7$, (Carlson and Herdman, 2012)	Pearsons correlation coefficient
λ	values close to 0, (Shrestha, 2003)	Mean percentage deviation
NRMSE	$NRMSE < 1$, (Otto et al., 2018; Otto, 2019)	Root Mean Square Error standardized with standard deviation of benchmark indicator

Table B.10: Measures to assess convergent validity. When Pearson's correlation coefficient r is equal to 1, it indicates perfect convergent validity. A normalized root mean square error (NRSME) as well as a mean percentage deviation of WTP equal to zero show perfect convergent validity. In the case of the $NRSME < 1$ the RSME has less noise than is naturally occurring in the estimates used for comparison. Relevant thresholds indicate when a high degree but not a perfect convergent validity is achieved.

Concept	Definition	Reference
Ecological processes	Activities that result from interactions among organisms and between organisms and their environment	Gaston (1996)
Ecosystem processes	Transfer of energy, material, or organisms among pools in an ecosystem	Lovett et al. (2005)
Ecosystem functions	Attributes related to the performance of an ecosystem that is the consequence of one or of multiple ecosystem processes	Lovett et al. (2005)
Ecosystem services	The benefits human populations derive, directly or indirectly, from ecosystem functions. All ecosystem services are related to ecosystem functions, but not all processes are related to a service.	Costanza et al. (1997) and Paul et al. (2020)

Table B.11: Definitions used in this study, partly based on Table 1 in Pettinotti et al. (2018).

B.4 Full first-stage results

B.4.1 Apartments for sale

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	10.825	0.073	10.682	10.970	11.563	0.066	11.438	11.697	11.989	0.054	11.875	12.089
Richness	0.476	0.184	0.144	0.843	0.510	0.133	0.254	0.774	-0.107	0.107	-0.305	0.114
Richness*scndring	0.322	0.091	0.142	0.499	0.070	0.067	-0.056	0.205	0.191	0.070	0.054	0.330
Richness*thrddring	-0.162	0.083	-0.324	0.001	0.212	0.069	0.080	0.351	0.063	0.072	-0.072	0.211
Richness*frthring	-0.207	0.095	-0.388	-0.014	-0.112	0.066	-0.242	0.021	0.115	0.064	-0.001	0.239
Street trees	0.001	1.9E-04	2.4E-04	0.001	0.001	2.0E-04	4.7E-04	0.001	0.000	2.1E-04	-1.3E-04	0.001
Park	-0.001	2.8E-04	-0.002	-0.001	-9.1E-05	2.8E-04	-0.001	4.5E-04	-0.001	2.8E-04	-0.002	-0.001
Playgound	0.024	0.007	0.010	0.039	-0.004	0.006	-0.018	0.007	0.001	0.006	-0.011	0.012
Allotment	0.001	0.001	-4.8E-04	0.002	0.003	0.001	0.002	0.004	0.001	0.001	-4.7E-06	0.002
Cemetery	3.5E-04	6.4E-05	2.3E-04	4.8E-04	0.001	7.2E-05	0.001	0.001	1.8E-04	5.4E-05	8.1E-05	2.9E-04
scndring	-0.312	0.029	-0.368	-0.258	-0.230	0.026	-0.285	-0.182	-0.231	0.027	-0.284	-0.181
thrddring	-0.272	0.029	-0.328	-0.216	-0.521	0.031	-0.586	-0.461	-0.403	0.030	-0.460	-0.342
frthring	-0.258	0.037	-0.328	-0.190	-0.351	0.031	-0.412	-0.287	-0.409	0.033	-0.474	-0.345
Garden	0.037	0.007	0.023	0.051	0.015	0.007	0.001	0.030	0.012	0.006	-0.001	0.023
BalcTerr	0.039	0.007	0.026	0.053	0.022	0.007	0.009	0.035	-0.020	0.007	-0.034	-0.008
Area	0.013	2.2E-04	0.013	0.013	0.010	3.8E-04	0.009	0.010	0.009	3.4E-04	0.009	0.010
Age	-0.002	1.5E-04	-0.002	-0.001	-0.003	1.5E-04	-0.003	-0.002	-0.001	1.4E-04	-0.001	-0.001
Base	0.042	0.018	0.008	0.077	0.018	0.020	-0.023	0.057	-0.031	0.014	-0.060	-0.002
Storage	-0.006	0.016	-0.037	0.026	0.071	0.020	0.032	0.109	0.057	0.018	0.024	0.092
Basement	-0.008	0.007	-0.022	0.006	-0.005	0.008	-0.020	0.010	-0.012	0.006	-0.024	0.001
FullBase	-0.045	0.021	-0.089	-0.004	-0.112	0.034	-0.175	-0.042	-0.055	0.035	-0.127	0.010
Kitchen	0.010	0.008	-0.005	0.024	-0.026	0.007	-0.041	-0.012	-0.030	0.008	-0.045	-0.014
FloorHeat	0.114	0.010	0.095	0.133	0.101	0.007	0.086	0.115	0.110	0.008	0.094	0.126
CentralHeat	-0.018	0.008	-0.034	-0.003	-0.077	0.007	-0.090	-0.063	-0.064	0.007	-0.078	-0.051
GasHeat	-0.016	0.028	-0.071	0.039	-0.106	0.094	-0.292	0.054	-0.043	0.025	-0.092	0.006
Garage	0.081	0.009	0.064	0.100	0.078	0.011	0.054	0.098	0.047	0.008	0.031	0.064
GaragePl	-0.004	0.014	-0.032	0.024	0.015	0.017	-0.020	0.047	-0.030	0.012	-0.052	-0.006
HighQual	0.156	0.009	0.139	0.173	0.134	0.008	0.117	0.149	0.104	0.007	0.089	0.118
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.12: First-stage results of the hedonic regressions of the submarket apartments for sale, estimated with species richness as benchmark biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

Dependent variable

	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	0.164	0.011	0.143	0.186	0.145	0.008	0.129	0.159	0.089	0.007	0.076	0.102
Renovated	0.068	0.011	0.046	0.091	0.080	0.015	0.050	0.109	0.042	0.012	0.019	0.065
Badcond	-0.158	0.017	-0.191	-0.122	-0.117	0.021	-0.159	-0.077	-0.121	0.028	-0.178	-0.072
Fireplace	0.012	0.023	-0.032	0.056	0.060	0.028	0.003	0.115	0.085	0.024	0.036	0.131
Woodenfloor	0.041	0.010	0.021	0.060	0.040	0.007	0.025	0.054	0.043	0.006	0.031	0.055
Sauna	0.005	0.021	-0.038	0.045	-0.031	0.031	-0.090	0.029	0.056	0.027	-0.002	0.108
Richness**	0.476	0.184	0.144	0.843	0.510	0.133	0.254	0.774	-0.107	0.107	-0.305	0.114
Park**	-0.001	2.8E-04	-0.002	-0.001	-9.1E-05	2.8E-04	-0.001	4.5E-04	-0.001	2.8E-04	-0.002	-0.001
Playgound**	0.024	0.007	0.010	0.039	-0.004	0.006	-0.018	0.007	0.001	0.006	-0.011	0.012
Allotment**	0.001	0.001	-4.8E-04	0.002	0.003	0.001	0.002	0.004	0.001	0.001	-4.7E-06	0.002
Cemetery**	3.5E-04	6.4E-05	2.3E-04	4.8E-04	0.001	7.2E-05	0.001	0.001	1.8E-04	5.4E-05	8.1E-05	2.9E-04
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.13: Continued first-stage results of the hedonic regressions of the submarket apartments for sale, estimated with species richness as benchmark biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

	Dependent variable											
					Ln Price							
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	11.001	0.039	10.924	11.076	11.686	0.051	11.591	11.787	11.976	0.037	11.900	12.050
DHI	0.092	0.046	0.003	0.179	0.302	0.043	0.218	0.384	0.155	0.052	0.050	0.253
DHI*scndring	-0.019	0.050	-0.112	0.081	-0.311	0.045	-0.399	-0.221	-0.218	0.054	-0.326	-0.108
DHI*thrddring	-0.073	0.051	-0.173	0.028	-0.427	0.052	-0.522	-0.323	-0.268	0.056	-0.375	-0.154
DHI*frthring	-0.005	0.055	-0.110	0.106	-0.320	0.053	-0.423	-0.217	-0.163	0.056	-0.272	-0.057
Street trees	0.001	1.9E-04	2.2E-04	0.001	0.001	2.0E-04	0.001	0.001	2.6E-04	2.1E-04	-1.6E-04	0.001
Park	-0.001	2.9E-04	-0.002	-0.001	-3.8E-04	2.7E-04	-0.001	1.6E-04	-0.001	2.8E-04	-0.002	-0.001
Playgound	0.017	0.007	0.004	0.031	0.004	0.007	-0.010	0.016	-0.002	0.006	-0.014	0.009
Allotment	0.001	0.001	-3.8E-04	0.002	0.003	0.001	0.002	0.004	0.001	0.001	-3.6E-04	0.002
Cemetery	3.5E-04	6.5E-05	2.3E-04	4.8E-04	0.001	7.4E-05	0.001	0.001	1.8E-04	5.5E-05	7.9E-05	2.9E-04
scndring	-0.238	0.014	-0.264	-0.212	-0.177	0.014	-0.206	-0.151	-0.152	0.013	-0.178	-0.126
thrddring	-0.312	0.019	-0.349	-0.276	-0.346	0.018	-0.383	-0.311	-0.326	0.020	-0.365	-0.286
frthring	-0.360	0.029	-0.414	-0.302	-0.343	0.023	-0.387	-0.298	-0.372	0.025	-0.420	-0.321
Garden	0.036	0.007	0.022	0.051	0.011	0.007	-0.003	0.026	0.011	0.006	-0.002	0.023
BalcTerr	0.039	0.007	0.025	0.053	0.023	0.007	0.010	0.036	-0.019	0.007	-0.032	-0.007
Area	0.013	2.2E-04	0.013	0.013	0.010	3.8E-04	0.009	0.010	0.009	3.5E-04	0.008	0.010
Age	-0.002	1.5E-04	-0.002	-0.001	-0.002	1.5E-04	-0.003	-0.002	-0.001	1.4E-04	-0.001	-0.001
Base	0.040	0.018	0.005	0.075	0.023	0.020	-0.017	0.061	-0.030	0.014	-0.058	-0.001
Storage	-0.003	0.016	-0.035	0.029	0.070	0.020	0.030	0.106	0.064	0.018	0.031	0.098
Basement	-0.010	0.007	-0.023	0.004	-0.009	0.008	-0.023	0.007	-0.007	0.006	-0.019	0.006
FullBase	-0.048	0.021	-0.092	-0.008	-0.109	0.034	-0.171	-0.038	-0.069	0.035	-0.140	-0.005
Kitchen	0.009	0.008	-0.006	0.023	-0.029	0.007	-0.043	-0.014	-0.035	0.008	-0.051	-0.020
FloorHeat	0.113	0.010	0.094	0.132	0.102	0.007	0.087	0.116	0.110	0.008	0.094	0.126
CentralHeat	-0.019	0.008	-0.035	-0.004	-0.074	0.007	-0.087	-0.060	-0.066	0.007	-0.079	-0.053
GasHeat	-0.024	0.028	-0.079	0.031	-0.106	0.093	-0.292	0.053	-0.037	0.025	-0.087	0.013
Garage	0.081	0.009	0.063	0.099	0.080	0.011	0.056	0.100	0.049	0.008	0.032	0.066
GaragePl	-0.003	0.015	-0.031	0.025	0.019	0.017	-0.015	0.052	-0.028	0.012	-0.050	-0.005
HighQual	0.156	0.009	0.139	0.173	0.134	0.008	0.117	0.150	0.108	0.007	0.093	0.122
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.14: First-stage results of the hedonic regressions of the submarket apartments for sale, estimated with the Dynamic Habitat Index (DHI) as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	0.166	0.011	0.144	0.188	0.151	0.008	0.135	0.166	0.087	0.007	0.074	0.100
Renovated	0.068	0.011	0.046	0.092	0.075	0.015	0.044	0.103	0.043	0.011	0.019	0.065
Badcond	-0.155	0.017	-0.188	-0.120	-0.122	0.021	-0.163	-0.083	-0.122	0.028	-0.178	-0.072
Fireplace	0.013	0.023	-0.029	0.056	0.049	0.028	-0.006	0.103	0.073	0.023	0.025	0.116
Woodenfloor	0.043	0.010	0.023	0.062	0.037	0.008	0.022	0.051	0.045	0.006	0.032	0.058
Sauna	0.002	0.022	-0.043	0.043	-0.027	0.032	-0.086	0.034	0.056	0.027	0.001	0.105
DHI**	0.092	0.046	0.003	0.179	0.302	0.043	0.218	0.384	0.155	0.052	0.050	0.253
Park**	-0.001	2.9E-04	-0.002	-0.001	-3.8E-04	2.7E-04	-0.001	1.6E-04	-0.001	2.8E-04	-0.002	-0.001
Playgound**	0.017	0.007	0.004	0.031	0.004	0.007	-0.010	0.016	-0.002	0.006	-0.014	0.009
Allotment**	0.001	0.001	-3.8E-04	0.002	0.003	0.001	0.002	0.004	0.001	0.001	-3.6E-04	0.002
Cemetery**	3.5E-04	6.5E-05	2.3E-04	4.8E-04	0.001	7.4E-05	0.001	0.001	1.8E-04	5.5E-05	7.9E-05	2.9E-04
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.15: Continued first-stage results of the hedonic regressions of the submarket apartments for sale, estimated with the Dynamic Habitat Index (DHI) as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	10.798	0.082	10.673	10.993	11.659	0.096	11.522	11.886	11.659	0.096	11.522	11.886
Biotope	0.876	0.244	0.251	1.233	0.465	0.273	-0.168	0.797	0.465	0.273	-0.168	0.797
Biotope*scndring	-0.435	0.106	-0.646	-0.211	-0.131	0.094	-0.291	0.070	-0.131	0.094	-0.291	0.070
Biotope*thrddring	0.161	0.161	-0.075	0.576	0.727	0.145	0.494	1.057	0.727	0.145	0.494	1.057
Biotope*frthring	-0.151	0.143	-0.378	0.202	0.077	0.110	-0.111	0.317	0.077	0.110	-0.111	0.317
Street trees	0.001	1.9E-04	1.7E-04	0.001	0.001	2.1E-04	0.001	0.001	0.001	2.1E-04	0.001	0.001
Park	-0.001	2.9E-04	-0.002	-4.8E-04	-2.8E-05	2.7E-04	-0.001	4.8E-04	-2.8E-05	2.7E-04	-0.001	4.8E-04
Playgound	0.013	0.007	-0.002	0.025	-0.014	0.007	-0.029	-0.002	-0.014	0.007	-0.029	-0.002
Allotment	2.3E-04	0.001	-0.001	0.001	0.003	0.001	0.002	0.004	0.003	0.001	0.002	0.004
Cemetery	3.5E-04	6.2E-05	2.3E-04	4.8E-04	0.001	6.8E-05	4.8E-04	0.001	0.001	6.8E-05	4.8E-04	0.001
scndring	-0.102	0.033	-0.170	-0.040	-0.161	0.030	-0.225	-0.111	-0.161	0.030	-0.225	-0.111
thrddring	-0.385	0.059	-0.532	-0.298	-0.715	0.061	-0.851	-0.622	-0.715	0.061	-0.851	-0.622
frthring	-0.242	0.055	-0.376	-0.149	-0.383	0.042	-0.474	-0.313	-0.383	0.042	-0.474	-0.313
Garden	0.039	0.007	0.026	0.053	0.013	0.007	-0.002	0.027	0.013	0.007	-0.002	0.027
BalcTerr	0.039	0.007	0.025	0.052	0.022	0.007	0.009	0.034	0.022	0.007	0.009	0.034
Area	0.013	2.2E-04	0.013	0.013	0.010	3.8E-04	0.009	0.010	0.010	3.8E-04	0.009	0.010
Age	-0.002	1.5E-04	-0.002	-0.001	-0.003	1.5E-04	-0.003	-0.002	-0.003	1.5E-04	-0.003	-0.002
Base	0.041	0.018	0.008	0.078	0.024	0.020	-0.017	0.061	0.024	0.020	-0.017	0.061
Storage	0.003	0.016	-0.028	0.037	0.075	0.020	0.035	0.112	0.075	0.020	0.035	0.112
Basement	-0.009	0.007	-0.024	0.004	-0.004	0.008	-0.019	0.011	-0.004	0.008	-0.019	0.011
FullBase	-0.050	0.021	-0.095	-0.009	-0.111	0.034	-0.174	-0.040	-0.111	0.034	-0.174	-0.040
Kitchen	0.012	0.007	-0.002	0.027	-0.021	0.007	-0.035	-0.007	-0.021	0.007	-0.035	-0.007
FloorHeat	0.114	0.010	0.094	0.133	0.104	0.007	0.090	0.118	0.104	0.007	0.090	0.118
CentralHeat	-0.011	0.008	-0.027	0.003	-0.073	0.007	-0.086	-0.059	-0.073	0.007	-0.086	-0.059
GasHeat	-0.018	0.029	-0.074	0.036	-0.113	0.093	-0.298	0.055	-0.113	0.093	-0.298	0.055
Garage	0.081	0.009	0.064	0.099	0.070	0.011	0.047	0.091	0.070	0.011	0.047	0.091
GaragePl	0.000	0.015	-0.028	0.028	0.017	0.017	-0.018	0.049	0.017	0.017	-0.018	0.049
HighQual	0.148	0.009	0.131	0.164	0.129	0.008	0.113	0.144	0.129	0.008	0.113	0.144
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.16: First-stage results of the hedonic regressions of the submarket apartments for sale, estimated with the median biotope quality assessed by experts as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

Dependent variable

	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	0.172	0.011	0.151	0.194	0.147	0.008	0.133	0.162	0.147	0.008	0.133	0.162
Renovated	0.067	0.011	0.045	0.089	0.067	0.015	0.037	0.096	0.067	0.015	0.037	0.096
Badcond	-0.152	0.017	-0.184	-0.116	-0.114	0.021	-0.155	-0.075	-0.114	0.021	-0.155	-0.075
Fireplace	0.014	0.022	-0.029	0.058	0.059	0.028	0.004	0.113	0.059	0.028	0.004	0.113
Woodenfloor	0.038	0.010	0.018	0.056	0.041	0.007	0.026	0.054	0.041	0.007	0.026	0.054
Sauna	0.015	0.022	-0.030	0.056	-0.019	0.032	-0.080	0.044	-0.019	0.032	-0.080	0.044
Biotope**	0.876	0.244	0.251	1.233	0.465	0.273	-0.168	0.797	0.465	0.273	-0.168	0.797
Park**	-0.001	2.9E-04	-0.002	-4.8E-04	-2.8E-05	2.7E-04	-0.001	4.8E-04	-2.8E-05	2.7E-04	-0.001	4.8E-04
Playgound**	0.013	0.007	-0.002	0.025	-0.014	0.007	-0.029	-0.002	-0.014	0.007	-0.029	-0.002
Allotment**	0.000	0.001	-0.001	0.001	0.003	0.001	0.002	0.004	0.003	0.001	0.002	0.004
Cemetery**	0.000	6.2E-05	2.3E-04	0.000	0.001	6.8E-05	4.8E-04	0.001	0.001	6.8E-05	4.8E-04	0.001
Submarket	Flats for sale				Flats for sale				Flats for sale			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	8,097				11,100				8,773			
Bootstraps	1,000				1,000				1,000			

Table B.17: Continued first-stage results of the hedonic regressions of the submarket apartments for sale, estimated with the median biotope quality assessed by experts as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

B.4.2 Apartments for rent

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	5.355	0.025	5.305	5.404	5.578	0.022	5.537	5.622	5.631	0.022	5.585	5.670
Richness	0.031	0.059	-0.077	0.147	0.171	0.050	0.067	0.263	0.074	0.056	-0.031	0.182
Richness*scndring	0.100	0.036	0.027	0.169	-0.060	0.029	-0.110	0.000	-0.014	0.032	-0.077	0.048
Richness*thrddring	-0.037	0.037	-0.109	0.031	-0.071	0.027	-0.120	-0.014	-0.012	0.031	-0.073	0.044
Richness*frthring	0.024	0.034	-0.046	0.088	-0.060	0.027	-0.109	-0.007	0.016	0.029	-0.039	0.071
Street trees	-1.9E-04	5.5E-05	-3.0E-04	-8.5E-05	-3.6E-04	6.1E-05	-4.8E-04	-2.5E-04	-1.5E-04	6.2E-05	-2.7E-04	-2.9E-05
Park	5.3E-06	1.1E-04	-2.2E-04	2.2E-04	6.0E-04	9.0E-05	4.3E-04	7.9E-04	8.2E-04	9.3E-05	6.4E-04	9.9E-04
Playgound	-0.002	0.003	-0.008	0.003	0.008	0.003	0.002	0.014	-0.002	0.003	-0.008	0.004
Allotment	0.001	1.1E-04	0.001	0.001	2.5E-05	1.2E-04	-2.2E-04	2.6E-04	0.001	1.3E-04	2.8E-04	0.001
Cemetery	-6.9E-05	2.4E-05	-1.2E-04	-2.3E-05	1.0E-04	2.2E-05	6.1E-05	1.5E-04	1.2E-04	2.7E-05	6.5E-05	1.7E-04
scndring	-0.157	0.010	-0.177	-0.137	-0.127	0.009	-0.146	-0.112	-0.128	0.010	-0.147	-0.108
thrddring	-0.205	0.011	-0.226	-0.183	-0.281	0.009	-0.300	-0.265	-0.264	0.010	-0.284	-0.243
frthring	-0.250	0.011	-0.271	-0.229	-0.358	0.010	-0.378	-0.341	-0.325	0.011	-0.346	-0.304
Garden	0.044	0.003	0.038	0.050	0.023	0.003	0.017	0.028	0.009	0.003	0.002	0.015
BalcTerr	0.012	0.003	0.007	0.018	0.003	0.002	-0.001	0.007	-0.002	0.002	-0.006	0.003
Area	0.012	2.7E-04	0.012	0.013	0.012	1.2E-04	0.011	0.012	0.012	8.0E-05	0.011	0.012
Age	-3.9E-05	5.5E-05	-1.4E-04	6.9E-05	-0.001	4.1E-05	-0.001	-4.5E-04	-3.7E-04	4.6E-05	-4.6E-04	-2.8E-04
Base	0.044	0.014	0.016	0.073	0.008	0.014	-0.020	0.034	0.118	0.009	0.099	0.138
Storage	0.014	0.006	0.003	0.026	-0.027	0.005	-0.036	-0.017	0.016	0.005	0.006	0.026
Basement	-0.004	0.002	-0.009	2.2E-04	-0.006	0.002	-0.010	-0.002	-0.018	0.002	-0.022	-0.014
FullBase	0.058	0.017	0.023	0.091	0.029	0.018	-0.007	0.062	0.044	0.021	0.002	0.083
Kitchen	0.113	0.003	0.108	0.118	0.094	0.003	0.089	0.099	0.085	0.003	0.079	0.091
FloorHeat	0.133	0.007	0.120	0.146	0.094	0.004	0.087	0.102	0.093	0.004	0.084	0.102
CentralHeat	-0.008	0.003	-0.013	-0.003	-0.039	0.002	-0.044	-0.035	-0.031	0.003	-0.036	-0.026
GasHeat	0.002	0.014	-0.026	0.028	0.023	0.014	-0.005	0.049	0.022	0.012	-0.003	0.045
Garage	0.060	0.004	0.053	0.067	0.055	0.002	0.050	0.060	0.051	0.003	0.046	0.057
GaragePl	0.040	0.005	0.031	0.049	0.029	0.004	0.022	0.037	0.019	0.004	0.011	0.028
HighQual	0.104	0.007	0.092	0.117	0.063	0.003	0.057	0.069	0.083	0.004	0.076	0.091
Submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District Fixed effects	TRUE				TRUE				TRUE			
Observations	30,581				44,072				35,973			
Bootstraps	1,000				1,000				1,000			

Table B.18: First-stage results of the hedonic regressions of the submarket apartments for rent, estimated with species richness as benchmark biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

Dependent variable

	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	-0.007	0.005	-0.016	0.002	0.083	0.004	0.076	0.091	0.087	0.004	0.079	0.095
Renovated	0.027	0.004	0.018	0.035	0.070	0.003	0.063	0.076	0.076	0.004	0.069	0.083
Badcond	-0.056	0.009	-0.073	-0.038	-0.098	0.012	-0.122	-0.075	-0.106	0.023	-0.154	-0.063
Fireplace	-0.002	0.018	-0.036	0.035	-0.040	0.011	-0.062	-0.020	-0.046	0.013	-0.071	-0.021
Woodenfloor	0.063	0.005	0.055	0.072	0.048	0.003	0.043	0.055	0.029	0.003	0.023	0.035
Sauna	0.010	0.023	-0.033	0.058	0.000	0.021	-0.043	0.039	-0.036	0.016	-0.070	-0.005
Richness**	0.031	0.059	-0.077	0.147	0.171	0.050	0.067	0.263	0.074	0.056	-0.031	0.182
Park**	5.3E-06	1.1E-04	-2.2E-04	0.000	0.001	9.0E-05	4.3E-04	0.001	0.001	9.3E-05	0.001	0.001
Playgound**	-0.002	0.003	-0.008	0.003	0.008	0.003	0.002	0.014	-0.002	0.003	-0.008	0.004
Allotment**	0.001	1.1E-04	0.001	0.001	2.5E-05	1.2E-04	-2.2E-04	2.6E-04	0.001	1.3E-04	2.8E-04	0.001
Cemetery**	-6.9E-05	2.4E-05	-1.2E-04	-2.3E-05	1.0E-04	2.2E-05	6.1E-05	1.5E-04	1.2E-04	2.7E-05	6.5E-05	1.7E-04
Submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	30,581				44,072				35,973			
Bootstraps	1,000				1,000				1,000			

Table B.19: Continued first-stage results of the hedonic regressions of the submarket apartments for rent, estimated with species richness as benchmark biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	5.349	0.018	5.316	5.384	5.623	0.015	5.595	5.652	5.642	0.013	5.616	5.668
DHI	0.088	0.021	0.047	0.128	0.092	0.017	0.057	0.124	0.012	0.016	-0.018	0.044
DHI*scndring	0.004	0.021	-0.039	0.047	-0.048	0.018	-0.081	-0.012	0.007	0.017	-0.026	0.040
DHI*thrddring	0.004	0.022	-0.039	0.047	-0.022	0.017	-0.055	0.012	0.069	0.018	0.034	0.103
DHI*frthring	-0.055	0.022	-0.096	-0.015	-0.061	0.018	-0.094	-0.027	-0.033	0.018	-0.069	0.003
Street trees	-1.9E-04	5.6E-05	-3.0E-04	-8.8E-05	-3.8E-04	6.1E-05	-5.0E-04	-2.6E-04	-1.9E-04	6.3E-05	-3.1E-04	-7.1E-05
Park	-2.4E-05	1.1E-04	-2.5E-04	1.8E-04	6.3E-04	8.7E-05	4.6E-04	8.1E-04	8.6E-04	9.2E-05	6.8E-04	1.0E-03
Playgound	0.001	0.003	-0.004	0.007	0.010	0.003	0.004	0.016	0.002	0.003	-0.004	0.008
Allotment	1.2E-03	1.1E-04	9.6E-04	1.4E-03	7.3E-05	1.2E-04	-1.7E-04	3.0E-04	5.4E-04	1.3E-04	3.0E-04	8.0E-04
Cemetery	-1.1E-04	2.4E-05	-1.6E-04	-6.3E-05	1.1E-04	2.2E-05	6.6E-05	1.5E-04	8.0E-05	2.8E-05	2.8E-05	1.4E-04
scndring	-0.137	0.004	-0.146	-0.129	-0.144	0.004	-0.152	-0.136	-0.134	0.004	-0.143	-0.126
thrddring	-0.235	0.006	-0.248	-0.224	-0.307	0.005	-0.317	-0.298	-0.297	0.006	-0.309	-0.285
frthring	-0.231	0.007	-0.243	-0.217	-0.355	0.006	-0.367	-0.342	-0.287	0.007	-0.301	-0.272
Garden	0.044	0.003	0.038	0.050	0.023	0.003	0.018	0.029	0.009	0.003	0.003	0.016
BalcTerr	0.013	0.003	0.007	0.018	0.003	0.002	-0.001	0.007	-0.002	0.002	-0.006	0.002
Area	0.012	2.7E-04	0.012	0.013	0.012	1.2E-04	0.011	0.012	0.012	8.0E-05	0.011	0.012
Age	-1.0E-05	5.5E-05	-1.1E-04	9.8E-05	-5.3E-04	4.1E-05	-6.1E-04	-4.5E-04	-3.7E-04	4.6E-05	-4.6E-04	-2.8E-04
Base	0.046	0.014	0.018	0.074	0.010	0.014	-0.018	0.036	0.122	0.010	0.103	0.143
Storage	0.016	0.006	0.005	0.028	-0.027	0.005	-0.037	-0.018	0.019	0.005	0.009	0.029
Basement	-0.003	0.002	-0.008	0.001	-0.008	0.002	-0.012	-0.003	-0.019	0.002	-0.023	-0.014
FullBase	0.059	0.017	0.023	0.093	0.028	0.018	-0.009	0.063	0.041	0.021	-0.002	0.079
Kitchen	0.114	0.003	0.109	0.119	0.094	0.003	0.089	0.099	0.084	0.003	0.078	0.090
FloorHeat	0.132	0.007	0.119	0.145	0.093	0.004	0.085	0.100	0.092	0.004	0.083	0.101
CentralHeat	-0.007	0.003	-0.013	-0.003	-0.039	0.002	-0.043	-0.035	-0.031	0.003	-0.036	-0.026
GasHeat	0.002	0.014	-0.026	0.028	0.023	0.014	-0.003	0.049	0.020	0.012	-0.005	0.042
Garage	0.059	0.003	0.053	0.066	0.055	0.002	0.050	0.060	0.051	0.003	0.045	0.057
GaragePl	0.040	0.005	0.031	0.049	0.030	0.004	0.023	0.037	0.020	0.004	0.012	0.029
HighQual	0.104	0.007	0.092	0.117	0.061	0.003	0.055	0.067	0.084	0.004	0.076	0.091
Submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	30,581				44,072				35,973			
Bootstraps	1,000				1,000				1,000			

Table B.20: First-stage results of the hedonic regressions of the submarket apartments for rent, estimated with the Dynamic Habitat Index (DHI) as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

					Dependent variable							
					Ln Price							
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	-0.005	0.005	-0.014	0.004	0.083	0.004	0.076	0.091	0.087	0.004	0.079	0.095
Renovated	0.027	0.004	0.018	0.034	0.068	0.003	0.062	0.075	0.076	0.004	0.069	0.083
Badcond	-0.054	0.009	-0.071	-0.036	-0.098	0.012	-0.121	-0.075	-0.108	0.023	-0.156	-0.065
Fireplace	0.000	0.018	-0.035	0.036	-0.040	0.011	-0.063	-0.020	-0.046	0.013	-0.072	-0.022
Woodenfloor	0.064	0.005	0.055	0.073	0.048	0.003	0.043	0.055	0.028	0.003	0.022	0.034
Sauna	0.009	0.023	-0.034	0.058	0.002	0.021	-0.040	0.042	-0.038	0.016	-0.071	-0.006
DHI**	0.088	0.021	0.047	0.128	0.092	0.017	0.057	0.124	0.012	0.016	-0.018	0.044
Park**	-2.4E-05	1.1E-04	-2.5E-04	1.8E-04	6.3E-04	8.7E-05	4.6E-04	8.1E-04	8.6E-04	9.2E-05	6.8E-04	1.0E-03
Playgound**	0.001	0.003	-0.004	0.007	0.010	0.003	0.004	0.016	0.002	0.003	-0.004	0.008
Allotment**	0.001	1.1E-04	0.001	0.001	7.3E-05	1.2E-04	-1.7E-04	3.0E-04	0.001	1.3E-04	3.0E-04	0.001
Cemetery**	-1.1E-04	2.4E-05	-1.6E-04	-6.3E-05	1.1E-04	2.2E-05	6.6E-05	1.5E-04	8.0E-05	2.8E-05	2.8E-05	1.4E-04
Submarket		Flats for rent				Flats for rent				Flats for rent		
Years		2005-2009				2010-2014				2015-2018		
District FE		TRUE				TRUE				TRUE		
Observations		30,581				44,072				35,973		
Bootstraps		1,000				1,000				1,000		

Table B.21: Continued first-stage results of the hedonic regressions of the submarket apartments for rent, estimated with the Dynamic Habitat Index (DHI) as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

	Dependent variable											
	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	5.385	0.023	5.347	5.432	5.697	0.021	5.658	5.738	5.680	0.023	5.635	5.725
Biotope	-0.002	0.064	-0.135	0.120	-0.047	0.056	-0.167	0.054	0.001	0.064	-0.116	0.126
Biotope*scndring	0.071	0.040	-0.008	0.154	0.261	0.033	0.197	0.327	0.180	0.034	0.117	0.253
Biotope*thrddring	0.128	0.045	0.045	0.221	0.361	0.035	0.295	0.429	0.266	0.040	0.188	0.342
Biotope*frthring	0.224	0.041	0.143	0.303	0.176	0.030	0.119	0.237	0.059	0.035	-0.010	0.126
Street trees	-1.9E-04	5.4E-05	-2.9E-04	-8.2E-05	-3.8E-04	6.0E-05	-5.0E-04	-2.6E-04	-1.6E-04	6.1E-05	-2.8E-04	-3.7E-05
Park	2.1E-04	1.1E-04	-8.7E-06	4.1E-04	5.3E-04	8.5E-05	3.7E-04	7.1E-04	8.0E-04	9.0E-05	6.3E-04	9.7E-04
Playgound	-0.005	0.003	-0.011	0.000	-0.004	0.003	-0.010	0.001	-0.008	0.003	-0.013	-0.002
Allotment	1.3E-03	1.1E-04	1.1E-03	1.5E-03	4.2E-04	1.2E-04	1.7E-04	6.5E-04	8.9E-04	1.3E-04	6.5E-04	1.2E-03
Cemetery	-7.5E-05	2.3E-05	-1.2E-04	-2.9E-05	6.4E-05	2.3E-05	2.3E-05	1.1E-04	8.3E-05	2.7E-05	3.0E-05	1.4E-04
scndring	-0.151	0.013	-0.178	-0.127	-0.220	0.011	-0.241	-0.199	-0.185	0.011	-0.208	-0.165
thrddring	-0.241	0.016	-0.274	-0.211	-0.404	0.013	-0.429	-0.380	-0.346	0.014	-0.374	-0.318
frthring	-0.306	0.015	-0.334	-0.278	-0.396	0.011	-0.419	-0.375	-0.308	0.013	-0.333	-0.281
Garden	0.047	0.003	0.041	0.053	0.025	0.003	0.019	0.031	0.011	0.003	0.004	0.017
BalcTerr	0.013	0.003	0.007	0.018	0.004	0.002	0.000	0.008	-0.001	0.002	-0.005	0.003
Area	0.012	2.7E-04	0.012	0.013	0.012	1.2E-04	0.011	0.012	0.012	8.0E-05	0.011	0.012
Age	-3.6E-05	5.5E-05	-1.4E-04	7.2E-05	-5.0E-04	4.1E-05	-5.7E-04	-4.2E-04	-3.6E-04	4.6E-05	-4.5E-04	-2.8E-04
Base	0.047	0.014	0.019	0.077	0.010	0.014	-0.017	0.036	0.120	0.010	0.101	0.140
Storage	0.014	0.006	0.002	0.025	-0.025	0.005	-0.034	-0.015	0.019	0.005	0.009	0.029
Basement	-0.005	0.002	-0.009	-6.3E-05	-0.007	0.002	-0.012	-0.003	-0.018	0.002	-0.022	-0.013
FullBase	0.058	0.017	0.022	0.091	0.027	0.018	-0.008	0.061	0.037	0.021	-0.007	0.076
Kitchen	0.113	0.003	0.108	0.118	0.094	0.003	0.089	0.099	0.085	0.003	0.079	0.090
FloorHeat	0.127	0.007	0.115	0.140	0.091	0.004	0.083	0.098	0.087	0.004	0.078	0.096
CentralHeat	-0.006	0.003	-0.011	-0.001	-0.036	0.002	-0.040	-0.032	-0.030	0.003	-0.035	-0.025
GasHeat	0.004	0.014	-0.024	0.031	0.021	0.014	-0.006	0.047	0.023	0.012	-0.002	0.046
Garage	0.059	0.004	0.053	0.066	0.053	0.002	0.048	0.057	0.049	0.003	0.044	0.055
GaragePl	0.038	0.005	0.029	0.047	0.030	0.004	0.023	0.038	0.022	0.004	0.014	0.031
HighQual	0.105	0.007	0.093	0.118	0.062	0.003	0.056	0.068	0.081	0.004	0.074	0.089
Submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	30,581				44,072				35,973			
Bootstraps	1,000				1,000				1,000			

Table B.22: First-stage results of the hedonic regressions of the submarket apartments for rent, estimated with the median biotope quality assessed by experts as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

Dependent variable

	Ln Price											
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
New	-0.006	0.005	-0.015	0.003	0.082	0.004	0.075	0.090	0.086	0.004	0.078	0.094
Renovated	0.026	0.004	0.017	0.034	0.068	0.003	0.062	0.075	0.077	0.004	0.070	0.083
Badcond	-0.057	0.009	-0.074	-0.040	-0.098	0.012	-0.121	-0.075	-0.105	0.023	-0.154	-0.062
Fireplace	0.004	0.018	-0.030	0.040	-0.026	0.011	-0.048	-0.005	-0.041	0.013	-0.066	-0.017
Woodenfloor	0.064	0.005	0.055	0.073	0.047	0.003	0.041	0.053	0.026	0.003	0.019	0.032
Sauna	0.015	0.023	-0.028	0.063	8.9E-05	0.020	-0.042	0.038	-0.030	0.017	-0.063	0.002
Biotope**	-0.002	0.064	-0.135	0.120	-0.047	0.056	-0.167	0.054	0.001	0.064	-0.116	0.126
Park**	2.1E-04	1.1E-04	-8.7E-06	4.1E-04	0.001	8.5E-05	3.7E-04	0.001	0.001	9.0E-05	0.001	0.001
Playgound**	-0.005	0.003	-0.011	7.2E-05	-0.004	0.003	-0.010	0.001	-0.008	0.003	-0.013	-0.002
Allotment**	0.001	1.1E-04	0.001	0.002	4.2E-04	1.2E-04	1.7E-04	0.001	0.001	1.3E-04	0.001	0.001
Cemetery**	-7.5E-05	2.3E-05	-1.2E-04	-2.9E-05	6.4E-05	2.3E-05	2.3E-05	1.1E-04	8.3E-05	2.7E-05	3.0E-05	1.4E-04
Submarket	Flats for rent				Flats for rent				Flats for rent			
Years	2005-2009				2010-2014				2015-2018			
District FE	TRUE				TRUE				TRUE			
Observations	30,581				44,072				35,973			
Bootstraps	1,000				1,000				1,000			

Table B.23: Continued First-stage results of the hedonic regressions of the submarket apartments for rent, estimated with the median biotope quality assessed by experts as biodiversity indicator and with equation 3.10. Dependent variable is the natural logarithm of the offer price. LCI and UCI are the bootstrapped lower and upper confidence interval.

B.5 Descriptive statistics of non-marginal willingness to pay estimates

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Richness	42,009	366.2	639.4	3.1	128.7	367.2	16,440.2
DHI	42,009	278.9	466.5	6.2	107.4	328.7	16,717.7

Table B.24: Descriptive statistics of WTP estimates estimated with species richness and the Dynamic Habitat Index (DHI) derived from satellite data. Based on further analyses of negative WTP estimates (please refer to B.6.2) negative WTP estimates derived with the DHI are set to zero. The statistics are based on a subset of pair-wise, non-zero estimates.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
DHI	61,232	241.8	189.6	6.2	114.2	317.6	5,781.8
Biotope	61,232	765.1	843.4	32.1	366.4	902.8	33,775.5

Table B.25: Descriptive statistics of WTP estimates estimated with biotope quality and the Dynamic Habitat Index (DHI) derived from satellite data. Based on further analyses of negative WTP estimates (please refer to B.6.2) negative WTP estimates derived with the DHI are set to zero. The statistics are based on a subset of pair-wise, non-zero estimates.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Richness	64,958	375.2	605.9	3.1	124.1	368.5	16,440.2
Biotope	64,958	844.6	1,144.3	−3,898.5	368.4	990.5	33,775.5

Table B.26: Descriptive statistics of WTP estimates estimated with species richness and median Biotope quality assessed by an expert group. The statistics are based on a subset of pair-wise, non-zero estimates

B.6 Robustness check

B.6.1 Adding additional variables to the first-stage estimation

In order to test if the identification strategy applied in this study works as expected, I include a proxy quantifying the regulating service ”cooling” in an additional run of the first-stage estimation of the hedonic price schedules. This is an omitted variable correlated with the biodiversity proxies. The copula correction should account for this endogeneity, and if it works correctly results should be robust. For this I acquired data on the land surface temperature (LST) for the years 2005 to 2018 from Modis satellite data. I downloaded 8-day per-pixel Land Surface Temperature and Emissivity products with a 1 kilometer spatial resolution from NASA (2020). Based on the spatial data, I calculated annual maximum temperature grids and merged the raster data with the respective spatial point data representing housing offers in space and time. I used the difference of the overall maximum LST measured allover Hamburg in a each year and the maximum LST value detected by the satellite in a each spatially defined position and respective year as a proxy for "cooling". The results of the first stage regressions are available on request. Table B.27 shows the results of the preference elicitation with Equation 3.8, using both the WTP estimates derived with or without the additional cooling proxy in the first stage estimation. The results are robust.

	Dependent variable							
	Ln WTP Richness				Ln WTP Richness			
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
(Intercept)	-7.26	0.20	-7.67	-6.88	-5.79	0.19	-6.16	-5.44
Ln Biodiversity	1.10	0.03	1.04	1.16	1.08	0.03	1.03	1.13
Between 30 to 60	0.13	2.5E-03	0.12	0.13	0.11	2.2E-03	0.11	0.11
Above60	0.05	1.7E-03	0.05	0.05	0.04	1.5E-03	0.04	0.04
Singles	0.01	2.6E-04	0.01	0.01	0.01	2.5E-04	0.01	0.01
Families	1.0E-03	3.0E-04	4.5E-04	1.6E-03	8.6E-04	2.7E-04	3.3E-04	1.4E-03
PP	5.5E-05	1.9E-06	5.2E-05	5.9E-05	5.6E-05	1.8E-06	5.3E-05	6.0E-05
Popden	1.6E-05	7.0E-07	1.4E-05	1.7E-05	1.2E-05	6.5E-07	1.0E-05	1.3E-05
Unemployed	-0.05	1.2E-03	-0.05	-0.04	-0.04	9.9E-04	-0.05	-0.04
Ln Biodiversity**	1.10	0.03	1.04	1.16	1.08	0.03	1.03	1.13
PP**	5.5E-05	1.9E-06	5.2E-05	5.9E-05	5.6E-05	1.8E-06	5.3E-05	6.0E-05
District fixed effects	TRUE				TRUE			
Observations	106,353				106,353			
Bootstraps	1,000				1,000			
Cooling variable 1st stage	False				TRUE			
Indicator	Species richness				Species richness			

Table B.27: Results of the preference decomposition with Equation 3.8, using both the WTP estimates derived without (left column) or with (right column) an additional proxy for the regulating service ”cooling” in the first stage estimation. The cooling proxy was calculated based on 8-day Land Surface Temperature Modis products acquired from NASA (2020).

B.6.2 Analysis of negative WTP estimates derived with the DHI and related robusness checks of convergent validity measures

Table B.28 shows the descriptive statistics of negative willingness to pay (WTP) estimates derived with the implicit prices calculated using the DHI. It compares the estimates of WTP calculated using the point estimates of the of the main and spatial interaction effect of the model presented in equation 3.10 with the estimates derived with the lower and upper bound of the confidence intervals, as well as the WTP calculated with the point estimates of a model without the spatial interaction effect (DHI_{no}). Since the DHI_{no} values are all equal to zero and WTP is strictly positive when using the upper bound of the confidence interval for the main and spatial interaction effect (DHI_{UCI}), I conclude that the negative values are likely modeling errors and exclude the values from the convergent validity analysis.

Statistic	N	Mean	St. Dev.	Min	Max
DHI_{LCI}	9,879	−1,331.1	976.0	−9,523.1	−74.3
DHI_{Point}	9,879	−284.1	340.2	−3,440.9	−3.6
DHI_{UCI}	9,879	750.9	696.6	17.7	7,379.2
DHI_{no}	9,879	0.0	0.0	0	0

Table B.28: Descriptive statistics of negative willingness to pay (WTP) estimates derived with the DHI and comparison of estimates of WTP calculated using the lower (DHI_{LCI}) and upper (DHI_{UCI}) bound as well as the point estimate (DHI_{Point}) of the confidence intervals of the main and spatial interaction effect of the model presented in equation 3.10, as well as the WTP calculated with the point estimates of a model without the spatial interaction effect DHI_{no}.

In case of the WTP estimates derived with the biotope quality indicator only 0.9% of non-zero WTP estimates are negative. Since the values are negative regardless of if the lower or upper bound of the confidence intervals of the main and spatial effects are used, I do not exclude these values from the convergent validity analysis.

Statistic	N	Mean	St. Dev.	Min	Max
$Biotope_{LCI}$	1,874	−1,363.8	1,001.6	−6,908.5	−118.1
$Biotope_{Point}$	1,874	−769.6	565.2	−3,898.5	−66.6
$Biotope_{UCI}$	1,874	−201.2	147.7	−1,019.0	−17.4
$Biotope_{no}$	1,874	0.0	0.0	0	0

Table B.29: Descriptive statistics of negative willingness to pay (WTP) estimates derived with the biotope quality proxy and comparison of estimates of WTP calculated using the lower ($Biotope_{LCI}$) and upper ($Biotope_{UCI}$) bound as well as the point estimate ($Biotope_{Point}$) of the confidence intervals of the main and spatial interaction effect of the model presented in equation 3.10, as well as the WTP calculated with the point estimates of a model without the spatial interaction effect $Biotope_{no}$.

The first-stage model including spatial interaction terms performed slightly better in terms of the root mean squared error of predicted and actual adjusted price offers. Nevertheless, I include a convergent validity analysis of the WTP estimates derived by a model without spatial interaction effects in Table B.30 as a robustness check. The conclusions drawn from the analysis stay qualitatively the same, even though the ´convergence of the biotope quality proxy and the species richness proxy increases while the convergence of the estimates derived with the DHI and the species richness proxies decreases.

	NRSME	lambda	r	n
Biotope vs. Richness	0.68	165.96	0.85	120,439
DHI vs. Richness	0.93	7.93	0.50	53,104
DHI vs. Biotope	1.12	318.55	0.50	52,999

Table B.30: Robustness check: Convergent validity analysis based on non-zero WTP estimates and on a first-stage model excluding spatial interaction terms.

	Dependent variable							
	Ln WTP Richness				Ln WTP DHI			
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
Intercept	-1.3e+01	4.5e-01	-1.4e+01	-1.2e+01	-1.3e+01	5.1e-01	-1.4e+01	-1.2e+01
Ln Biodiversity	1.0	2.4e-02	9.9e-01	1.1	1.3	2.2e-02	1.3	1.3
Between 30 to 60	1.3e-01	3.9e-03	1.2e-01	1.4e-01	8.3e-02	3.9e-03	7.6e-02	9.0e-02
Above60	5.6e-02	2.5e-03	5.1e-02	6.1e-02	2.7e-02	2.6e-03	2.1e-02	3.1e-02
Singles	9.8e-03	3.7e-04	9.1e-03	1.1e-02	1.2e-02	3.9e-04	1.2e-02	1.3e-02
Families	6.4e-03	3.5e-04	5.7e-03	7.1e-03	8.7e-03	4.0e-04	7.9e-03	9.5e-03
PP	1.8e-04	7.9e-06	1.6e-04	1.9e-04	1.9e-04	8.1e-06	1.8e-04	2.1e-04
Popden	1.4e-05	1.5e-06	1.1e-05	1.7e-05	1.2e-05	1.6e-06	8.4e-06	1.5e-05
Unemployed	-5.2e-02	1.9e-03	-5.6e-02	-4.9e-02	-3.4e-02	1.9e-03	-3.8e-02	-3.1e-02
Alt	-4.1e-02	2.3e-02	-6.2e-02	4.1e-02	-3.2e-01	2.1e-01	-6.0e-01	3.2e-01
Berg	-6.7e-02	4.7e-02	-9.1e-02	5.1e-02	-8.9e-01	4.6e-01	-9.2e-01	3.3e-01
Mitte	-2.1e-02	3.6e-02	-7.4e-02	5.2e-02	-3.8e-01	2.5e-01	-4.0e-01	3.3e-01
Nord	-9.6e-02	4.2e-02	-1.7e-01	-3.0e-02	-3.0e-01	3.0e-01	-7.8e-01	4.7e-02
Harburg	-1.9e-01	6.4e-02	-2.1e-01	4.0e-02	-1.1	4.4e-01	-1.1	3.2e-01
Wandsbek	-1.1e-01	5.6e-02	-1.2e-01	5.6e-02	-4.0e-01	2.7e-01	-4.1e-01	3.4e-01
Ln Biodiversity**	-1.7e-02	1.1e-02	-3.6e-02	3.3e-03	-1.6e-01	9.4e-03	-1.7e-01	-1.4e-01
PP**	-1.2	5.5e-02	-1.4	-1.1	-1.3	5.6e-02	-1.4	-1.2
District fixed effects	TRUE				TRUE			
Observations	106,353				106,353			
Bootstraps	1,000				1,000			
Indicator	Species richness				DHI			

Table B.31: Decomposition of annual willingness to pay (WTP) in Euro[2005] per household and annum for biodiversity calculated with equation 3.8 using the for a sub sample based on a pairwise comparison of WTP estimates where both the WTP derived with species richness and DHI are non-zero. Variables marked with a double asterisk are additional variables estimated with Gaussian copulas. LCI and UCI are the bootstrapped lower and upper confidence interval. To be able to calculate the logarithm of the normalized biodiversiy indicators, I multiplied them with 100. Coefficient estimates can hence be interpreted as percentage change, directly.

	Dependent variable							
	Ln WTP Richness				Ln WTP Biotope quality			
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
Intercept	-8.1	2.6e-01	-8.7	-7.6	-5.2	2.7e-01	-5.7	-4.7
Ln Biodiversity	1.0	2.4e-02	9.5e-01	1.0	1.2	4.3e-02	1.1	1.3
Between 30 to 60	1.3e-01	3.1e-03	1.3e-01	1.4e-01	9.4e-02	2.7e-03	8.9e-02	9.9e-02
Above60	7.1e-02	1.9e-03	6.8e-02	7.5e-02	4.8e-02	1.7e-03	4.5e-02	5.2e-02
Singles	-1.7e-03	3.3e-04	-2.3e-03	-1.0e-03	2.5e-03	3.0e-04	1.9e-03	3.1e-03
Families	-9.5e-05	3.3e-04	-7.6e-04	5.6e-04	3.7e-03	2.8e-04	3.2e-03	4.3e-03
PP	6.4e-05	3.2e-06	5.8e-05	7.1e-05	4.8e-05	2.8e-06	4.3e-05	5.4e-05
Popden	3.4e-05	1.0e-06	3.2e-05	3.6e-05	1.9e-05	9.8e-07	1.7e-05	2.1e-05
Unemployed	-4.5e-03	1.5e-03	-7.3e-03	-1.6e-03	-1.3e-02	1.3e-03	-1.6e-02	-1.1e-02
Ln Biodiversity**	1.8e-02	1.1e-02	-5.9e-03	3.8e-02	-4.2e-02	1.5e-02	-7.0e-02	-1.0e-02
PP**	-4.9e-01	2.3e-02	-5.4e-01	-4.5e-01	-3.5e-01	2.1e-02	-3.9e-01	-3.1e-01
District fixed effects	TRUE				TRUE			
Observations	62,635				62,635			
Bootstraps	1,000				1,000			
Indicator	Species richness				Biotope quality			

Table B.32: Decomposition of annual willingness to pay (WTP) in Euro[2005] per household and annum for biodiversity calculated with equation 3.8 using the for a sub sample based on a pairwise comparison of WTP estimates where both the WTP derived with species richness and the biotope quality indicator are non-zero. Variables marked with a double asterisk are additional variables estimated with Gaussian copulas. LCI and UCI are the bootstrapped lower and upper confidence interval. To be able to calculate the logarithm of the normalized biodiversiy indicators, I multiplied them with 100. Coefficient estimates can hence be interpreted as percentage change, directly.

	Dependent variable							
	Ln WTP Biotope quality				Ln WTP DHI			
Variable	**Coef**	**SE**	**LCI**	**UCI**	**Coef**	**SE**	**LCI**	**UCI**
Intercept	-1.1	2.9e-01	-1.7	-5.9e-01	-4.1	3.0e-01	-4.8	-3.7
Ln Biodiversity	1.1	4.6e-02	9.9e-01	1.2	1.3	1.7e-02	1.3	1.3
Between 30 to 60	6.8e-03	2.8e-03	1.6e-03	1.2e-02	-1.0e-02	2.7e-03	-1.5e-02	-5.4e-03
Above60	-2.2e-02	1.7e-03	-2.6e-02	-1.9e-02	-1.4e-02	1.7e-03	-1.8e-02	-1.1e-02
Singles	8.9e-03	2.9e-04	8.3e-03	9.4e-03	2.5e-03	3.0e-04	1.9e-03	3.0e-03
Families	1.8e-03	2.8e-04	1.2e-03	2.3e-03	3.4e-03	3.0e-04	2.7e-03	3.9e-03
PP	8.1e-05	3.6e-06	7.3e-05	8.7e-05	1.2e-04	4.4e-06	1.1e-04	1.3e-04
Popden	1.2e-05	1.5e-06	9.0e-06	1.5e-05	1.0e-05	1.4e-06	7.4e-06	1.3e-05
Unemployed	-2.9e-02	1.5e-03	-3.1e-02	-2.6e-02	-1.4e-02	1.4e-03	-1.7e-02	-1.1e-02
Ln Biodiversity**	2.1e-04	1.6e-02	-2.9e-02	3.2e-02	-1.2e-01	6.3e-03	-1.3e-01	-1.1e-01
PP**	-3.5e-01	2.6e-02	-3.9e-01	-2.9e-01	-7.7e-01	3.2e-02	-8.2e-01	-7.0e-01
District fixed effects	TRUE				TRUE			
Observations	60,964				60,964			
Bootstraps	1,000				1,000			
Indicator	Biotope quality				DHI			

Table B.33: Decomposition of annual willingness to pay (WTP) in Euro[2005] per household and annum for biodiversity calculated with equation 3.8 using the for a sub sample based on a pairwise comparison of WTP estimates where both the WTP derived with the biotope quality indicator and DHI are non-zero. Variables marked with a double asterisk are additional variables estimated with Gaussian copulas. LCI and UCI are the bootstrapped lower and upper confidence interval. To be able to calculate the logarithm of the normalized biodiversiy indicators, I multiplied them with 100. Coefficient estimates can hence be interpreted as percentage change, directly.

B.6.3 Sensitivity to different discount rates

The discount rate used to calculate annual housing expenditures was set to 3% . The following Figures B.7 to B.7, tests the sensitivity of the results to the chosen discount rate. Since most of the observations stem from the submarket for apartments for rent which are not impacted by the chosen discount rate, overall densities of WTP do not change significantly.

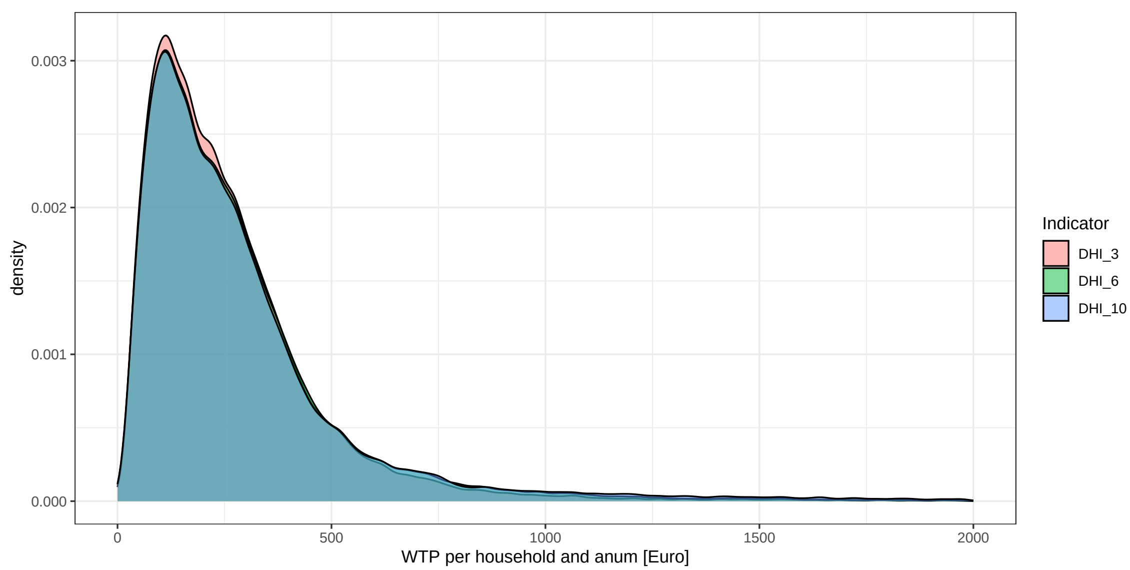

Figure B.7: Sensitivity of Willingness to pay estimates to different discount rates, 3%, 6% and 10 %, using DHI as biodiversity proxy. I only display values above zero here.

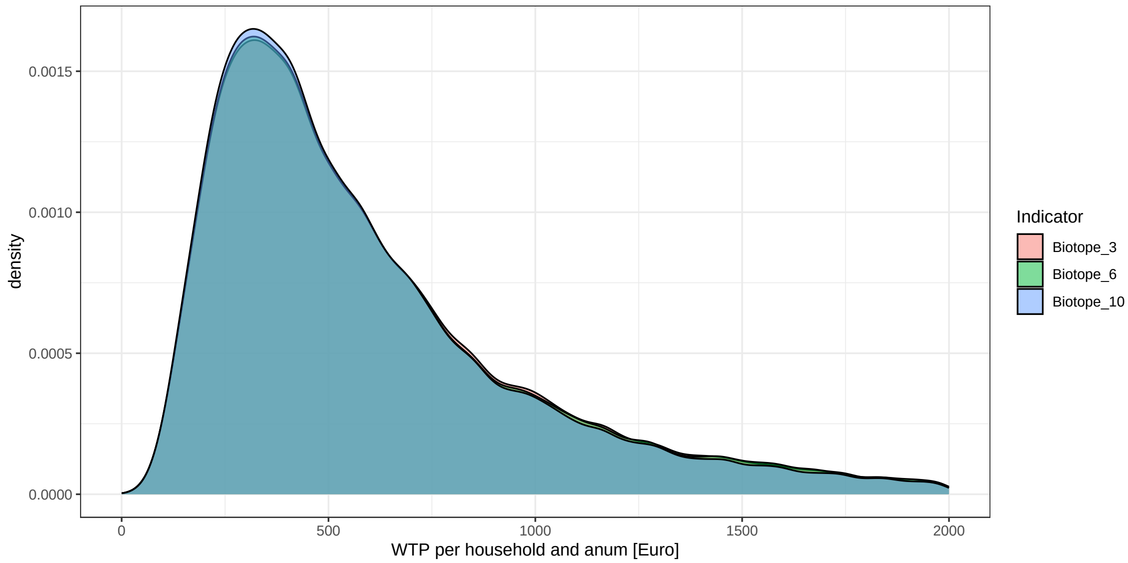

Figure B.8: Sensitivity of Willingness to pay estimates to different discount rates, 3%, 6% and 10 %, using Biotope quality as biodiversity proxy. I only display values above zero here.

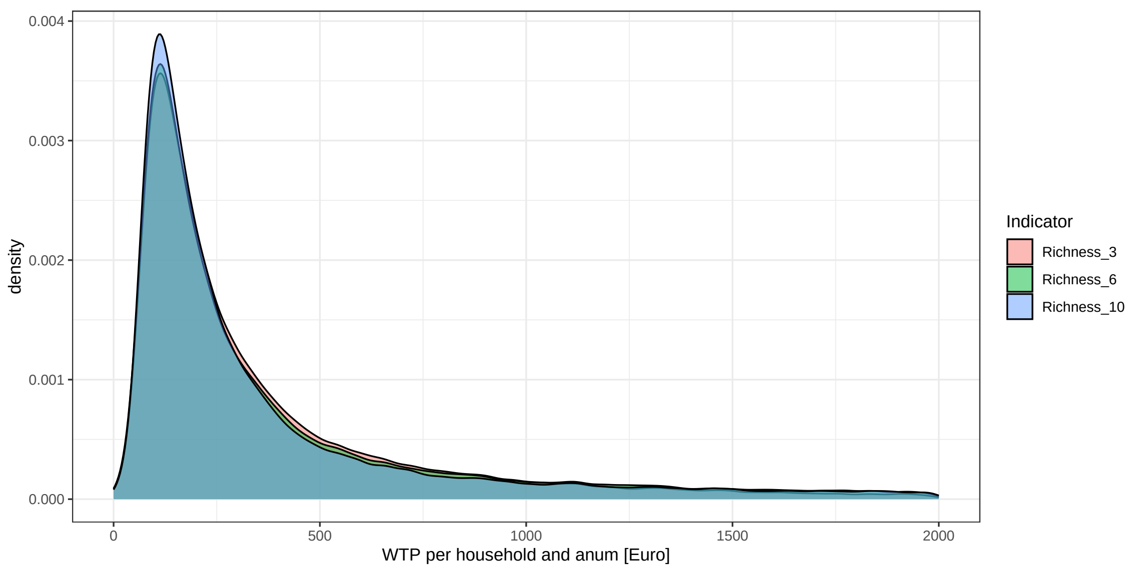

Figure B.9: Sensitivity of Willingness to pay estimates to different discount rates, 3%, 6% and 10 %, using faunal species richness as biodiversity proxy. I only display values above zero here.

C. Appendix to Chapter 4

C.1 Spatial distribution of treated and non-treated mangroves in the largest estuary in Ecuador

Figure C.1: Treated (orange) versus non-treated (green) mangroves in the gulf of Guayaquil. Own depiction based on data acquired from the Ministry of Environment of Ecuador and Ecuador Coastal Resources Management Project.

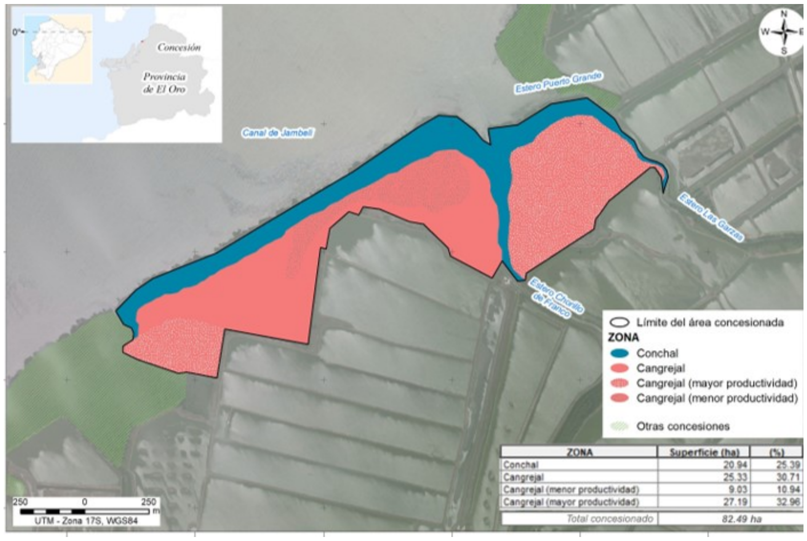

Figure C.2: Spatial distribution of fishery resources in an example community. Blue represents the presence of shellfish, while the red polygons indicate the presence of crabs. Source: Ministry of Environment and the National Institute of Aquaculture and Fisheries Research in Ecuador.

C.2 Spatial distribution of treated and non-treated mangroves in the largest estuary in Ecuador

Figure A.3: Treated (orange) versus non-treated (green) mangroves in the gulf of Guayaquil. Own depiction based on data acquired from the Ministry of Environment of Ecuador and Ecuador Coastal Resources Management Project.

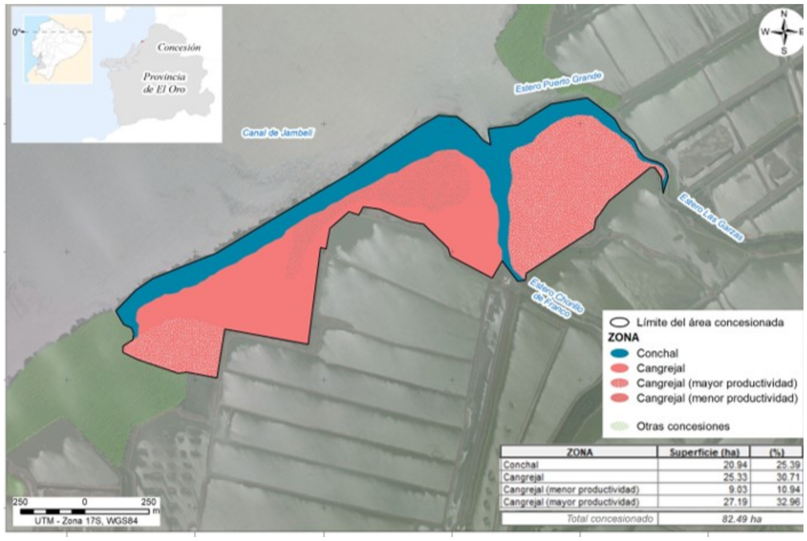

Figure A.4: Spatial distribution of fishery resources in an example community. Blue represents the presence of shellfish, while the red polygons indicate the presence of crabs. Source: Ministry of Environment and the National Institute of Aquaculture and Fisheries Research in Ecuador.

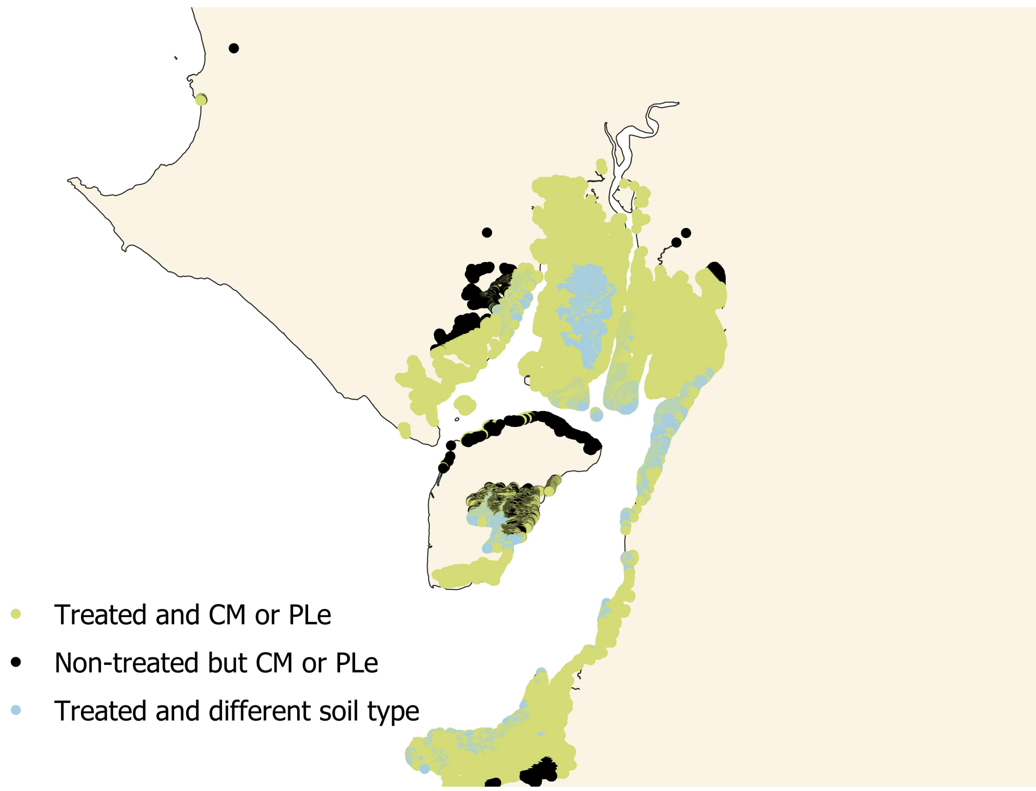

Figure A.5: Overlap of treatment with soil types CM and PLe used as combined instrumental variable in the Gulf of Guayaquil. This figure is supposed to give the reader an intuition of the spatial distribution of relevant soil types and policy adoption in a example estuary.

C.3 A community's optimization problem

$$\max_{a,c} U = U[c, E(I(p), a)] \tag{B.1}$$

s.t. income constraint

$$F(a, I, e) \cdot p_f = c + w \cdot t(N(a, f)) \cdot a \tag{B.2}$$

and s.t. time constraint

$$T \geq t(N(a, f)) \cdot a \tag{B.3}$$

The Lagrangian for this optimization problem is thus:

$$\begin{aligned} L = & U[c, E(I(p), a)] + \\ & \pi \cdot (F(a, I, e) \cdot p_f - c - w \cdot t(N(a, f)) \cdot a) + \\ & \qquad \lambda \cdot (T - t(N(a, f)) \cdot a) \end{aligned} \tag{B.4}$$

The corresponding first order conditions for the Lagrangian shown in equation B.4 are as follows:

$$L_a = U_E \cdot E_a + \pi \cdot (F_a \cdot p_f - w \cdot (t(N(a, f)) + t_N \cdot N_a \cdot a)) - \lambda \cdot (t_N \cdot N_a \cdot a + t(N(a, f))) = 0 \tag{B.5}$$

$$L_c = U_c - \pi = 0 \tag{B.6}$$

$$L_\pi = F(a, I, e) \cdot p_f - c - w \cdot t(N(a, f)) \cdot a = 0 \tag{B.7}$$

$$L_\lambda = T - t(N(a, f)) \cdot a \geq 0; \lambda \cdot (T - t(N(a, f) \cdot a) = 0 \tag{B.8}$$

Assuming that the members of a community spend some non-zero hours T with other activities such as fishing and leisure, λ has to be equal to zero to full fill the constraint.
With $\lambda = 0$ and by substituting $\pi = U_c$ from B.6 in B.5, we get the following system of equations:

$$f_1 = U_E \cdot E_a + U_c \cdot (F_a \cdot p_f - w \cdot (t(N(a, f)) + t_N \cdot N_a \cdot a) = 0 \tag{B.9}$$

$$f_2 = F(a, I, e) \cdot p_f - c - w \cdot t(N(a, f)) \cdot a = 0 \tag{B.10}$$

The Jacobinian of the two equations w.r.t. I and a is thus defined as

$$J_A = \begin{bmatrix} \frac{\partial f1}{\partial I} & \frac{\partial f1}{\partial a} \\ \frac{\partial f2}{\partial I} & \frac{\partial f2}{\partial a} \end{bmatrix} = \begin{bmatrix} 0 & U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a) \\ F_I \cdot p_f & F_a \cdot p_f - w \cdot (t_N \cdot N_a \cdot a + t(N(a, f))) \end{bmatrix} \tag{B.11}$$

with the determinant

$$\left|J_A\right| = -(U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a)) \cdot F_I \cdot p_f \neq 0 \tag{B.12}$$

The Jacobinian w.r.t. e and f is defined as

$$J_B = \begin{bmatrix} \frac{\partial f1}{\partial e} & \frac{\partial f1}{\partial f} \\ \frac{\partial f2}{\partial e} & \frac{\partial f2}{\partial f} \end{bmatrix} = \begin{bmatrix} 0 & -U_c \cdot w \cdot t_N \cdot N_f \\ F_e \cdot p_f & -w \cdot t_N \cdot N_f \cdot a \end{bmatrix} \tag{B.13}$$

we apply the implicit function theorem using Cramer's rule:

$$\frac{\partial I}{\partial e} = \frac{\begin{vmatrix} 0 & U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a) \\ F_e \cdot p_f & F_a \cdot p_f - w \cdot (t_N \cdot N_a \cdot a + t(N(a,f))) \end{vmatrix}}{|J_A|}$$
$$= \frac{-(U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a)) \cdot F_e \cdot p_f}{-(U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a)) \cdot F_I \cdot p_f} \tag{B.14}$$
$$= \frac{F_e}{F_I}$$

In order to derive our second hypothesis we apply the implicit function theorem using Cramer's rule again:

$$\frac{\partial a}{\partial f} = \frac{\begin{vmatrix} 0 & -U_c \cdot w \cdot t_N \cdot N_f \\ F_I \cdot p_f & -w \cdot t_N \cdot N_f \cdot a \end{vmatrix}}{|J_A|}$$
$$= \frac{F_I \cdot p_f \cdot U_c \cdot w \cdot t_N \cdot N_f}{-(U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a)) \cdot F_I \cdot p_f} \tag{B.15}$$
$$= \frac{U_c \cdot w \cdot t_N \cdot N_f}{-(U_E \cdot E_{aa} + U_c \cdot F_{aa} \cdot p_f - U_c \cdot w \cdot (t_N N_{aa} \cdot a + 2t_N \cdot N_a))}$$

With assumptions 4.2, 4.5 and 4.9 this expression is reduced to:

$$\frac{\partial a}{\partial f} = \frac{U_c \cdot w \cdot t_N \cdot N_f}{U_c \cdot w \cdot 2t_N \cdot N_a} = \frac{N_f}{2N_a} \tag{B.16}$$

C.4 Data sources

Notation	Variable	Unit	Temporal resolution	Source
M	Mangrove coverage	m^2	2000-2012	Hamilton (2015)
L	Legal protection status	-	2000-2012	A
a	Treatment, i.e. demarcation of communities with property rights	-	cross-section	A
	Duration of treatment for each community	-	2000-2012	A
-	Size of communities	m^2	cross-section	B
-	Number of members of a community		cross-section	B
r	Total number of reports issued by each community	-	cross-section	B
N_all	Presence of external institution supporting communities		2000-2012	B
N	Presence of NGO funded by USAID supporting communities	-	2000-2012	B
mussle_rep	Presence of Mussles	-	cross-section	C
redcrab_re	Presence of red crabs	-	cross-section	C
-	Presence of blue crabs	-	cross-section	C
soiliv	Soil type	-	-	Dijkshoorn et al. (2005)
D	Vote shares of Democrats' in the U.S. House	%	2000-2012	Vote shares calculated based on MIT Election Data and Science Lab (2017)
N_aid	Annual foreign aid distributed to Ecuador by USAID	Mio US $	2000-2012	Calculated with USAID (2021)
pop_T	Population density in 2005	-	cross section	Center for International Earth Science Information Network - CIESIN - Columbia University (2018)
tmp_T	Mean annual temperature	°C	2000-2012	Calculated based on I. Harris et al. (2014) downscaled with Fick and Hijmans (2017)
distance	Distance to business centers	km	-	Calculated based on World Bank (2017)

Table C.1: Variable description and sources. Notation, description and sources of variables. A: Ministry of Environment of Ecuador; Ecuador Coastal Resources Management Project (PMRC), B: Management reports submitted to Ministry of Environment of Ecuador, C: Ministry of Environment of Ecuador; National Institute of Aquaculture and Fisheries Research in Ecuador.

C.5 Auxiliary regression testing theoretical assumptions about soil type used as instrumental variable

	Dependent variable:	
	mussle_rep	redcrab_re
	(1)	(2)
factor(DOMSOIL_UN)ARh	-0.155^{***}	-0.127^{***}
	(0.020)	(0.018)
factor(DOMSOIL_UN)CMd	-0.094^{***}	-0.127^{***}
	(0.007)	(0.006)
factor(DOMSOIL_UN)CMe	0.311^{***}	0.250^{***}
	(0.002)	(0.001)
factor(DOMSOIL_UN)CMo	0.532^{***}	-0.127^{*}
	(0.081)	(0.075)
factor(DOMSOIL_UN)FLe	-0.155^{*}	-0.127
	(0.093)	(0.086)
factor(DOMSOIL_UN)FLt	-0.052^{***}	-0.041^{***}
	(0.001)	(0.001)
factor(DOMSOIL_UN)LVf	-0.136^{***}	-0.126^{***}
	(0.003)	(0.003)
factor(DOMSOIL_UN)LVh	-0.145^{***}	-0.127^{***}
	(0.003)	(0.003)
factor(DOMSOIL_UN)PHl	-0.155	-0.127
	(0.228)	(0.211)
factor(DOMSOIL_UN)PLe	0.067^{***}	0.076^{***}
	(0.005)	(0.004)
factor(DOMSOIL_UN)VRe	-0.112^{***}	-0.084^{***}
	(0.009)	(0.008)
Constant	0.155^{***}	0.127^{***}
	(0.001)	(0.001)
Observations	1,090,700	1,090,700
Residual Std. Error (df = 1090688)	0.323	0.299
F Statistic (df = 11; 1090688)	$6,438.786^{***}$	$4,952.813^{***}$
Note:	*p<0.1; **p<0.05; ***p<0.01	

Table D.2: Auxiliary regression with the variables indicating presence of mussels and red mangrove crabs ad dependent variables respectively and soil classes as predictors of their presence. As expected the cambisoils (CM) and planosoils (PLe) are positive predictors of the presence of mussels and red mangrove crabs, confirming soil class as suitable instrumental variable.

C.6 Descriptive statistics

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
M	13,991,770	758.29	235.82	0	754	859	955
I	13,991,770	0.11	9.94	0	0	0	955
a	13,991,770	0.19	0.39	0	0	0	1
L	13,991,770	0.48	0.50	0	0	1	1
distance	13,991,770	45,237.00	23,159.60	87.46	30,681.83	53,015.39	110,417.70
tmp_T	13,991,770	25.04	0.40	22.76	24.76	25.27	26.18
pop_T	13,991,770	498.85	495.12	0.00	11.83	1,024.20	2,384.71
redcrab	13,991,770	0.10	0.30	0	0	0	1
mussle	13,991,770	0.13	0.33	0	0	0	1
soiliv	13,991,770	0.05	0.23	0	0	0	1

Table E.3: Descriptive statistics of sample for estimation strategy described in section 4.5.1. With mangrove cover within a cell M and illegal mangrove deforestation I in square meters, treatment status a, legal protection status L, euclidian distance to the closest business center [m], (water) temperature tmp_T [Celsius] and population density pop_T, as well as the instrumental variable indicating a suitable soil type (cambisols and planosoils) and thus habitat for marine species relevant for communities' subsistence.

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
a	6,737,471	0.39	0.49	0	0	1	1
N_{all}	6,737,471	0.37	0.48	0	0	1	1
N	6,737,471	0.22	0.41	0	0	0	1
r	6,737,471	5.72	4.70	0	1	10	13
diff_house	6,737,471	−0.002	0.06	−0.07	−0.06	0.07	0.09
N_aid	6,737,471	13.10	26.12	0	0	0	89

Table E.4: Descriptive statistics of sample for estimation strategy within treatment described in section 4.6.2.With treatment a, presence of external organizations N_{all}, presence of non-governmental organizations with access to USAID funding N, voteshare margin in the US House $diff_house$ and variable indicating NGO access to overall funding distributed to Ecuador N_aid [million US$]. The mean of a is smaller than 1, as some communities dropped out of the policy or joined the policy later than other communities.

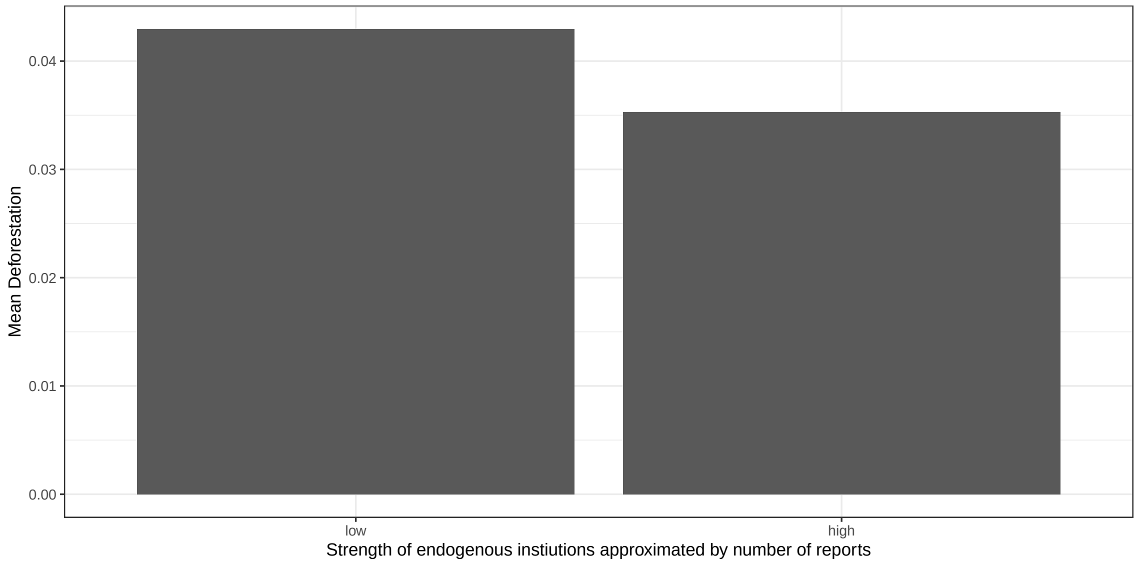

Figure E.6: The mean levels of deforestation for communities issuing more (high) or less (low) than the median number of reports, i.e. 6, issued by all communities to the authorities. A t-test reveals that the difference between the mean levels of deforestation is significant at a 0.01% significance level.

C.7 Robustness checks and falsification tests

C.7.1 Accounting for spatial auto-correlation for Instrumental variable estimation strategy

As a robustness check we include specifications accounting for spatial auto-correlation by clustering standard errors in Table F.5 Unfortunately, choosing the correct level of clustering is not trivial, as it requires in-depth knowledge of the underlying spatial interaction processes. According to Colin Cameron and D. L. Miller (2015) fewer and larger clusters have more variability than smaller clusters but result in less bias. We argue that clustering at the smallest, the community level is not appropriate in case of the specification testing for the effect of treatment on illegal deforestation (Table F.5) for two reasons: First of all, there might be (spatial) correlation between communities, for example, when two communities are geographically close and support each other in their monitoring efforts. Second, if we were to cluster at the community level, each community would represent a separate cluster and all non treated observations would belong to one big remaining cluster. Clustering at the community level would thus not represent the possible spatial interaction of non-treated cells belonging to one large cluster with proximate treated mangrove cells within a treated community. Due to these considerations, and the general consensus to avoid bias by using bigger more aggregate clusters further described in Colin Cameron and D. L. Miller (2015), we cluster at the province level. Additionally we ran a k-means clustering algorithm to determine clusters from the data with unsupervised learning methods. The algorithm creates a random split of the data into a predefined number of k groups to then incrementally adjust clusters based on an

Euclidean dissimilarity criterion. The algorithm converges when within-cluster variation is minimized (Please refer to Hastie et al. (2009, p. 460) for a detailed summary on the clustering method). The results remain significant regardless of the chosen level of clustering.

	Dependent variable:						
	I						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.523***	0.523***	0.523***	0.523***	0.523***	0.523***	0.523**
	(0.020)	(0.133)	(0.037)	(0.037)	(0.035)	(0.036)	(0.209)
a	−1.767***	−1.767***	−1.767***	−1.767***	−1.767***	−1.767***	−1.767**
	(0.076)	(0.491)	(0.091)	(0.134)	(0.122)	(0.138)	(0.719)
L	−0.168***	−0.168	−0.168***	−0.168***	−0.168***	−0.168***	−0.168
	(0.012)	(0.151)	(0.022)	(0.021)	(0.020)	(0.020)	(0.114)
Cluster	None	Province	k-means, k=5	k-means, k7	k-means, k=10	k-means, k=12	Year
Observations	13,991,770						
R^2	−0.004						
Adjusted R^2	−0.004						
Residual Std. Error	9.960 (df = 13991767)						
Note:							*p<0.1; **p<0.05; ***p<0.01

Table F.5: Robustness checks with clustered standard errors at province level and at cluster level determined by a k-means clustering algorithm which identifies clusters from the data with an unsupervised learning method.

C.7.2 Falsification tests and robustness checks of Regression Discontinuity Design

In the following, we present the results of three falsification test showing that empirical regularities that should hold if the assumptions necessary to identify a causal effect are not breached. Table F.6 shows falsification tests on the available predetermined covariates i.e. relevant variables that might be correlated with USAID funded NGO involvement N, here the treatment, before treatment is actually assigned. Since covariates are measured before treatment occurs, the effect of treatment on the predetermined covariates should be zero (Cattaneo et al., 2020b). Table F.6 shows that this is the case for both available predetermined covariates. We conclude that relevant covariates are balanced around the cutoff and continue with analyzing the density of the running variable around the cutoff.

	Dependent variable:	
	Cov	
	(1)	(2)
Constant	537.783***	750.391***
	(0.831)	(0.435)
N	0.000	0.000
	(3.441)	(1.802)
D	−0.000	−0.000
	(9.186)	(4.823)
D_right	0.000	0.000
	(14.329)	(7.523)
Observations	6,712,303	6,737,471
Cov	Population of 2000	Mangrove coverage in 2000
Residual Std. Error	455.641 (df = 6712299)	239.683 (df = 6737467)

Note:
*p<0.1; **p<0.05; ***p<0.01

Table F.6: Falsification tests of predetermined covariates. The tests show no significant effects of treatment N on predetermined covariates. There were some missing values in the variable measuring the population of 2000.

Even though we deem it very unlikely that USAID funded NGOs based in Ecuador would be able to manipulate or influence US House election outcomes, we employ the robust density estimator by Cattaneo et al. (2020a), to test the null hypothesis that the density of the vote share margin used as running variable is continuous at the chosen cutoff. The test results presented in Table F.7 show that the null hypothesis continuous running variable is not rejected.

Number of obs =	6737471	
Model =	unrestricted	
Kernel =	triangular	
BW method =	estimated	
VCE method =	jackknife	
c = 0.004295	Left of c	Right of c
Number of obs	4146136	2591335
Eff. Number of obs	4146136	2591335
Order est. (p)	2	2
Order bias (q)	3	3
BW est. (h)	0.088047	0.088047
Method	T	P > |T|
Robust	-0.006	0.9952

Table F.7: Results of the robust density estimator by Cattaneo et al. (2020a), showing that the null hypothesis of a continuous running variable is not rejected.

Next, we carry out placebo tests using alternative cutoff values on all treated observations. By construction no treatment effect should be detectable at the placebo cutoff values, since there is no variation in treatment status (Cattaneo et al., 2020b). Table F.8 shows the results of the placebo tests. No significant treatment effects were found using artificial cutoff values.

Even though we do not control for endogeneity of NGO presence in Table F.9, the results confirm that in presence of both policy and NGOs there are significant effects on reductions of deforestation. This, is in line with both our results, where NGO presence affects the adoption of the policy, and the policy itself significantly reduces deforestation. Moreover, we believe this is tentative evidence in support for presence of polycentric governance system, given the wide diversity of institutional arrangements that humans craft to govern, provide, and manage public goods and common-pool resources Ostrom (2010)

Erklärung

Hiermit erkläre ich, Leonie Josefine Ratzke, dass ich keine kommerzielle Promotionsberatung in Anspruch genommen habe. Die Arbeit wurde nicht schon einmal in einem früheren Promotionsverfahren angenommen oder als ungenügend beurteilt.

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Konzeption / Planung:: Formulierung des grundlegenden wissenschaftlichen Problems, basierend auf bisher unbeantworteten theoretischen Fragestellungen inklusive der Zusammenfassung der generellen Fragen, die anhand von Analysen oder Experimenten/Untersuchungen beantwortbar sind. Planung der Experimente/ Analysen und Formulierung der methodischen Vorgehensweise, inklusive Wahl der Methode und unabhängige methodologische Entwicklung.

Durchführung: Grad der Einbindung in die konkreten Untersuchungen bzw. Analysen.

Manuskripterstellung: Präsentation, Interpretation und Diskussion der erzielten Ergebnisse in Form eines wissenschaftlichen Artikels.

Die Einschätzung des geleisteten Anteils erfolgt mittels Punkteinschätzung von 1 – 100 %

Für den in Kapitel 2 vorgelegten Artikel liegt die Eigenleistung bei 100 %.

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die Durchführung bei	100%
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	Dependent variable:			
	a			
	(1)	(2)	(3)	(4)
Constant	1.000***	1.000***	1.000***	1.000***
	(0.000)	(0.000)	(0.000)	(0.000)
N	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
D	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
D_right	0.000	0.000	0.000	
	(0.000)	(0.000)	(0.000)	
Observations	2,655,757	2,655,757	2,655,757	2,655,757
Alternative cutoff	0.05	0.06	0.07	0.08
Residual Std. Error	0.000 (df = 2655753)	0.000 (df = 2655753)	0.000 (df = 2655753)	0.000 (df = 2655754)
Note:				*p<0.1; **p<0.05; ***p<0.01

Table F.8: Placebo falsifications tests revealing that no treatment effect can be found at artificial cutoff values.

	Dependent variable:
	I
Constant	0.077***
	(0.010)
a	−0.388***
	(0.074)
N	1.083***
	(0.096)
a*N	−0.843***
	(0.128)
Observations	5,836,935
Residual Std. Error	5.272 (df = 5836931)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table F.9: Additional robustness check to test hypothesis using a two-stage least squares regression with the soil IV.

Hinweis / Reference

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