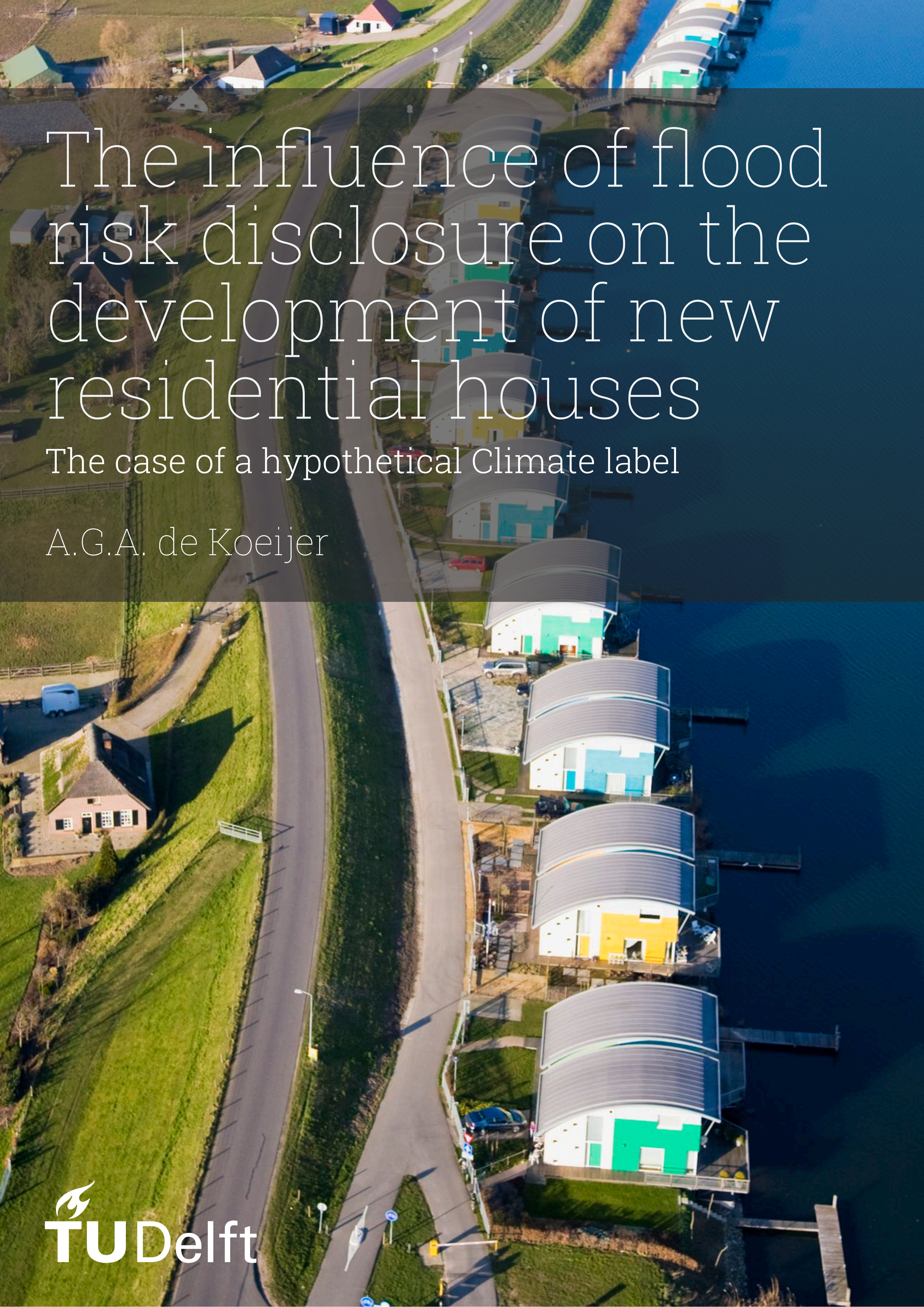
The influence of flood risk disclosure on the development of new residential houses

The case of a hypothetical Climate label

A.G.A. de Koeijer



TU Delft

The influence of flood risk disclosure on the development of new residential houses

The case of a hypothetical Climate label

by

A.G.A. de Koeijer

Student Name	Student Number
A.G.A de Koeijer	4684249

First Supervisor and Chair:	Prof. dr. T. Filatova
Second Supervisor:	Dr. N.Y. Aydin
Advisor:	Dr. Z.J. Taylor
Project Duration:	February, 2024 - July, 2024
Faculty:	Technology Policy and Analysis, Delft

Style: TU Delft Report Style, with modifications by Daan Zwaneveld

TU Delft

Preface

The increasing impacts of climate change are presenting numerous challenges globally, with one of the most pressing being the heightened risk of flooding due to rising sea levels and more intense rainfall patterns. However in many countries, among which the Netherlands, a significant portion of residential properties are at risk of flooding—a risk that is often underappreciated or overlooked by homeowners. The primary focus of this thesis is to explore the potential introduction of a flood risk disclosure policy, referred to as the "Climate Label," and its implications for real estate development practices.

The Climate Label is proposed as a tool to provide transparency about the flood risk associated with individual properties. By making this information readily available, the policy aims to influence market values and guide investment decisions, potentially encouraging more resilient housing developments. The central question of this study examines how such a policy might affect the decision-making processes of real estate developers and, consequently, the distribution of flood risks across new residential constructions. This research employs an Agent-Based Modeling (ABM) approach to simulate the interactions within the housing market, developer decision-making, and assess the potential outcomes of implementing the Climate Label.

Conducting this research has been a challenging yet rewarding journey. I am grateful for the guidance and support I have received from my supervisors of the TU Delft, whose expertise and encouragement have been very valuable. Their insights have shaped the direction and quality of this thesis. I would like to extend my thanks to my first supervisor and chair Prof. dr. Tatiana Filatova and my second supervisor Dr. Nazli Aydin for their continuous mentorship and feedback, which have been significant in refining my research quality. I am equally indebted to my advisor Dr. Zac Taylor of the Faculty of Management in the Built Environment, whose expertise in housing policy and urban planning helped me achieve a deeper understanding of the housing market system and provided me with valuable feedback on how to approach the interviews with real-estate developers.
Furthermore, I would like to express my gratitude to Asli Mutli, whose interest and support in my research have helped me work out the difficult details and improve the quality of my thesis. Lastly, I would like to thank Dr. Nick Magliocca for helping me give shape and structure to my ABM model and how to properly compose a real-estate developer agent.

Moreover, I wish to acknowledge the real estate developers and the soil and water system expert who participated in the interviews, offering their valuable perspectives and experiences. Their willingness to engage with my research and share their insights has enriched the empirical foundation of this thesis.

Lastly, I would like to say I am grateful to my family and friends for their unwavering support and encouragement throughout this process. Their patience and understanding have been a source of strength, enabling me to persevere through the challenges of this research journey.

In presenting this thesis, I hope to contribute to the ongoing discourse on climate resilience and housing policy. It is my aspiration that the findings of this research will inform and inspire more effective and equitable climate adaptation strategies, fostering a housing market that not only acknowledges but actively mitigates flood risks.

A.G.A (Anne) de Koeijer
Delft, July 2024

Excecutive Summary

Climate change presents multifaceted challenges, one of the most significant being increased flood risks due to rising sea levels and intensified rainfall patterns. This phenomenon poses a direct threat to properties, leading to structural damages and associated costs. In the Netherlands, approximately 51% of homes are currently vulnerable to flooding, a risk often underestimated or unrecognized by homeowners. This thesis explores the potential of introducing the flood risk disclosure policy 'Climate Label' to enhance flood risk awareness and consequently capitalise on flood risks in housing value. The Climate Label aims to provide transparency regarding an individual property's vulnerability to climate risks, particularly flooding, thereby influencing market values and investment decisions.
However, the question remains whether such a policy would also stimulate the supply of new resilient housing by either building less in flood-prone areas or by constructing houses with adaptation measures. The body of literature examining the impact of flood risks and policies on the supply of new housing, and the extent to which relevant actors incorporate flood resilience into their decision-making processes is notably limited. Studies examining the perspectives and responses of developers to climate change within the context of urban planning are scarce. This is notable because real estate developers play a key role in supplying new residential housing, and their investment behaviour is significant in fostering a more flood-resilient housing stock. The behaviour of private developers, in particular, is of interest due to their 'build-to-sell' approach, which is primarily profit-oriented. Policies that potentially influence the revenue and profit of housing projects could, therefore, significantly impact developers' decision-making processes.

The central research question guiding this study is: *"How would a flood risk information disclosure policy influence the decision-making dynamics of real-estate developers and, consequently, the distribution of flood risks across new residential houses?"*
This study is conducted in the context of utilizing a Climate Label as a 'flood information disclosure policy and single-family owner-occupied houses as residential houses. This broad inquiry is broken down into specific sub-questions:

1. "Which information will the Flood label disclose and in what degree of granularity?"
2. "What are relevant project decision-making dynamics of developers?"
3. "What are the current perspectives and barriers of real-estate developers on building with flood adaptation measures and how do they anticipate that changing after implementation of a Climate label?"
4. "Given a housing value shift caused by Climate labelling, what are the consequences of decision-making dynamics of real-estate developers in terms of where and how (adaption measure(s) or not) new residential houses are built?"

To address these questions, an Agent-Based Modeling (ABM) approach was adopted, which is well-suited for analyzing complex interactions within socio-economic systems. Various empirical methods were utilized to create the ABM, including literature reviews, interviews with real estate developers, and an interview with a soil and water system expert. The iterative modelling cycle framework of Nikolic (2013) guided the development of the ABM, ensuring a structured and comprehensive analysis.

In the Netherlands, the policy under discussion is a mandatory formal Climate label for all houses. However, the design and implementation of this label are still debated. An analysis of the discourse surrounding the policy design revealed several potential designs. Given the numerous possible designs for a Climate label, a hypothetical Climate label was established for the purposes of this study.

Satisficing behavior and Prospect Theory were identified in the literature and in interviews with developers as fitting behavioral theories for their decision-making dynamics. The interviewed developers mentioned that they tend to satisfice around pre-established profit margins in their decision-making processes.

Interviews with real estate developers revealed a spectrum of attitudes towards flood-resilient construction and identified several barriers to adopting flood-resistant measures. Significant factors influencing the decision to build more flood-resilient houses included the developer's view of their role in building flood-resilient, an equal playing field for implementing adaptation measures/no disadvantages when met with competition, building flood-resilient is financially feasible or more profitable, certainty in flood risk data and what is deemed as (acceptable) resilience. Among these, financial profitability was identified as the factor through which a Climate label could most influence developers' decision-making.

The ABM simulations indicated that a flood information disclosure policy, such as Climate Labeling, can alter the development patterns of new residential houses. However, the distribution of flood risks depends greatly on the magnitude of the price shift, whether developers perceive it as a gain or loss, and the reference point they use in their project decision-making to assess gains and losses.
In a negative price effect scenario —perceived as a loss— developers, when faced with profit prediction uncertainty, tend to build highly flood-resilient houses during the initial uncertain years. Conversely, in a positive price effect scenario —perceived as a gain— developers tend to build highly flood-vulnerable houses. The uncertainty in profit prediction diminishes over the years as developers "learn" about the change in preference consumers have regarding flood risk/label. However, after uncertainty diminishes, the model results indicate that a negative price effect could still leads to distinctly different and more favourable outcomes than a positive price effect scenario. The magnitude of the housing value shift determines whether the additional revenue from building with flood adaptation measures outweighs the costs, potentially adding certainty in achieving one's reference point and resulting in the implementation of adaptation measures. The choice of reference point is crucial in determining where and how developers build, as it establishes the point of profit satisfaction. For example, large adaptation measures, even when they would relatively increase profit for developers, were rarely implemented given the reference point of regular housing.
Developers' personal importance placed on climate and societal consequences had a minor effect on the distribution of flood risk across new residential housing.

These research findings have broader implications for society and policy-making. This research contributes to the ongoing debate on organizing climate-proofing interventions and aids policymakers in implementing more sophisticated policies to foster a climate-conscious housing market. It cautions policymakers to carefully consider the potential financial impact of flood risk information disclosure policies and how real estate developers will perceive them when designing such policies and determining their potential effects on the supply of new residential properties. Moreover, a flood information disclosure policy could also raise equity issues. The results of the simulation model showed that, while prices increased in both cities, an affluent city was prioritized for housing development as housing prices for resilient houses increased more significantly there, thus outweighing the costs of building with adaptation measures.

Due to time restrictions, this research and its results were subjected to numerous limitations. For example, this research was conducted in the context of a hypothetical Climate label, for which significant assumptions were made regarding its design. Conducting research in such a context raises potential issues for the external validity and generalization of the results. Additionally, the developer interviews had a small sample size of three. With a larger and richer sample of interviews, bias and outliers in the results can be controlled for. Lastly, the created ABM was highly stylized and based on several assumptions due to simplification purposes. One of the challenges of creating the ABM was translating qualitative data from the interviews into quantitative formal behavior rules when coding.
Overall, to validate the model's dynamics and findings, an empirical analysis of the actual Floodlabel effect on the flood risks of new residential houses should be conducted, and an empirical model using the dynamics presented in this research should be created to evaluate if the model can reproduce the empirical findings.

Contents

List of Figures

List of Tables

Nomenclature

Abbreviations

Abbreviation	Definition
ABM	Agent-Based Model
DOE	Design Of Experiments
DGBC	Dutch Green Building Council
KPI	Key Performance Indicator
MAE	Mean Absolute Error
ODD	Overview, Design concept, and Details
PT	Prospect Thoery
RQ	Research Question
SQ	Sub-research Question
WTA	Willingness-To-Accept
WTP	Willingness-To-Pay
OFAT	One Factor At a Time

Introduction

The consequences of climate change come in many forms, a few being sea-level rise and increased rainfall. This consequently results in increased flood risks. A direct physical risk of flooding is damage to properties, such as structural damage as well as flooded or damp basements and mould. In the Netherlands, about 51% of the homes are currently at risk of flooding (Calcasa, 2023).

In literature, it has been indicated that properties in high-risk flood zones often face declining demand and reduced values due to safety concerns and potential damage (Contat et al., 2023; Hino and Burke, 2021; Mutlu, Roy, and Filatova, 2023). However, this effect of perceived flooding risk on property value is only evident in areas where information about climate risks was more readily available and acknowledged (i.e. where there are more informed buyers) (Hino and Burke, 2021).
In many European countries, households are not aware of existing flooding risks and the vulnerability of houses. For example, in the Netherlands, 61% of at-risk homeowners were not aware of flood risks when they bought their homes (AMF, 2023). Consequently, flood risks are barely factored into house prices and, therefore, leading to flood-prone homes being overpriced (ABN-AMRO, 2023; AFM, 2023; Calcasa, 2023). The potential value loss of the housing stock in the Netherlands, if flood risks were factored in, amounts to €179 billion (Calcasa, 2023).
This lack of flood risk awareness and its misrepresentation in housing value can subsequently misguide policy decisions on where to develop and build new housing -potentially building in flood-prone areas- and on climate adaptation strategies (Glas, 2021).

A policy in the Netherlands that is momentarily under discussion, is providing houses a ‘Climate label’ (‘Klimaatlabel’) that could give insight into its vulnerability to climate risks, such as flooding (=”Flood labelling”) (NOS, 2023). In doing so, as people become more flood risk aware, properties in the housing market will consequently shift in value. This will ensure that people will not be left with unforeseen costs and that these costs will be well reflected in the value of the property. Moreover, it would stimulate households to invest in property-level flood precautionary measures (ABN-AMRO, 2023; Davids, Boelens, and Renaat De Sutter, 2021; Meyer and Hartmann, 2023)

However, the question remains whether such a policy would also stimulate the supply of new resilient housing by either building less in flood-prone areas or by constructing houses with adaptation measures. The body of literature examining the impact of flood risks and policies, such as flood insurance schemes, on the supply of new housing and the extent to which relevant actors incorporate flood resilience into their decision-making processes is notably limited. Existing research indicates that real estate developers often do not recognize the threat of climate change and continue to develop houses in flood-prone areas if they remain profitable (Buckman and Sobhaninia, 2022; Colby and Zipp, 2021; Dubbelboer et al., 2017). However, research has yet to be conducted on the effect of flood risk capitalization in the housing market through information disclosure—such as a Climate Label—on the distribution of flood risks across newly constructed houses. Moreover, limited research exists regarding “flood labelling,” with most studies focusing on its effectiveness in stimulating property-level adaptation measures for existing houses and none focusing on its effectiveness concerning newly constructed houses.(Davids, Boelens, and Renaat De Sutter, 2021; Hartmann and Scheibel, 2016).

This research aims to help bridge this existing gap in literature by describing the decision-making dynamics of real estate developers and their perspectives on building with flood adaptation measures. It will explore how a hypothetical Climate Label, through decision-making processes, might influence the distribution of flood risks among new residential houses. Consequently, this research contributes to the fields of flood risk management, housing development, and policy-making. It will add to the debate on how climate-proofing interventions should be organized and help policymakers implement more sophisticated policies to create a more climate-conscious housing market.
To achieve this, the research involves interviews with multiple real estate developers to gain a better insight into their decision-making processes, their current perspectives on building with flood adapta-

tion measures, and how these perspectives might change with the implementation of a Climate Label. These findings, combined with insights from the literature, will be used to build a highly stylized and simplified Agent-Based Model (ABM), focused on describing where and how developers build.

This is a worthy topic for an EPA Master Thesis as it consists of a grand challenge within a complex sociotechnical system, for which a policy is analysed and from which advice can be subtracted. A “broader perspective” approach must be taken in which systems are decomposed, components are analysed through quantitative (simulation and data analysis) and qualitative (literature and interviews) approaches, and the implications on society are determined.

Thesis outline

This thesis is structured as follows: Chapter 2 provides the state of the art of flood risk literature, particularly its implications for the housing market. Chapter 3 outlines the main and sub-research questions that arise from the knowledge gap identified in the state of the art. Chapter 4 details the research methods and presents the research framework that guides the study. Chapter 5 discusses the Climate Label policy, highlighting the ongoing debate surrounding it. In Chapter 6, the housing market system, the role of real estate developers within it, and the literature on their respective project decision-making processes are described. Chapter 7 presents and discusses the findings from the developer interviews, concluding the system decomposition phase. Chapter 8 provides the (concept and model) formalisation. Chapter 9 shows the results of the experiments performed with the Agent-Based Model (ABM). Lastly, Chapters 10 and 11 conclude the thesis by answering the research questions and discussing the relevance of this study to science, society, and policy, as well as its limitations and suggestions for future research. The appendices provide further details.

1

Literature review

This section will provide the state of the art of flood risk literature, especially its implications on the housing market. This is illustrated by first discussing briefly the broader direct physical risk associated with flood risks, followed by gradually narrowing down on its indirect effects on the housing- and financial market and its understudied effects on actors responsible for the supply of new houses. Lastly, the current body of literature regarding flood management policies is discussed, particularly highlighting the flood labelling of houses.
The search strategy used for the establishment of this literature review can be found A.

1.1. Physical risks of flooding

A vast amount of literature discusses the physical risk aspect of flood risks to properties. In literature, the (physical) consequences of flood risks are often discussed in the context of coastal flooding. Literature considering other types of flooding, such as river flooding (fluvial), flooding caused by heavy rainfall (pluvial) or all three types, exists but is -compared to coastal flooding- more limited (Pricope et al., 2022). Direct physical risks of flooding include permanent structural damages to properties, such as destruction or foundational cracks, or less permanent damages, such as mould. The degree of exposure to flooding and the level of property resilience, determines the physical impact flooding can have on a property (Yeo, Roche, and Mcaneney, 2015).

1.2. Housing market risks

These property damages, or the risk of these damages occurring, can have an effect on the value of the respective property. In literature there seems to be a consensus that the negative effects of flooding or the risk of flooding can decrease property value and, therefore capitalising in flood risks in the housing market (Bin and Landry, 2013; Contat et al., 2023; Mutlu, Roy, and Filatova, 2023; Ratnadiwakara and Venugopal, 2020). However, this effect of flooding (risk) on property value, is only evident in areas where information about flood risks was more readily available and acknowledged (i.e. where there are more informed buyers) (Contat et al., 2023; Hino and Burke, 2021; Votsis and Perrels, 2016). Meaning, that the effect of flood risk on property value is not determined by the actual risk but by the perceived flood risk. Risk perception is regarded as an assessment of the perceived probability of a hazard and by the perceived probability of the (negative) results (Lechowska, 2018).

In a systematic literature review of Lechowska (2018), the relevant factors behind flood risk perception and its characteristics are assessed. From his findings, it seems that direct flood experience has the biggest influence, followed by information/knowledge of flood risks (through communication). However, the exact magnitude of the impact of the factors differs across studies, as the results partly depend on social determinants (i.e. different countries with different histories, cultures or political systems).

When assessing literature that views the effect on property values, this distinction between ‘the effects of actual flooding on property value’ (e.g. Bin and Landry, 2013; McKenzie and Levendis, 2010; Ratnadiwakara and Venugopal, 2020; Z. J. Taylor and Knuth, 2023) and ‘the effect of flood risk information

disclosure on property value' can also be found (e.g. Hino and Burke, 2021; Pope, 2008; Shr and Zipp, 2019). The former being to most widely discussed, while studies on the latter being relatively more scarce. In the studies concerning the effect of actual flooding, it has been established that, as time passes after the flood incident, the effect the flood (risks) have on the property values decays as people tend to 'forget' about the flooding and its negative consequences. Therefore, leading to only short-term shocks to the housing market (Chandra-Putra and Andrews, 2020; Thompson et al., 2023). How fast this effect diminishes is context-specific (Rajapaksa et al., 2017). For example, markets with only a few properties in hazard zones quickly recover, whereas when many people have experienced flooding or property damage the price drop is significant and lasting (De Koning and Filatova, 2020).
The research of Rajapaksa et al. (2016) is the first of its kind by studying the impact of the release of flood risk map information to the public compared with an actual flood incident. His results confirm that, while both effects are significant, property buyers are more responsive to the actual incidence of floods than to the disclosure of information to the public on the risk of floods.

On the other hand, while flood risks are evident and acknowledged, flood adaptation measures can be a positive determinant of property values. In a study by McKenzie and Levendis (2010), they state that before the storm Katrina, housing elevation was insignificantly associated with housing prices, but after the storm, residential buyers in the flood-prone area paid a 4.6% premium for one foot of elevation. Musli et al. (2023) confirm this by stating that flood adaptation measures, specifically nature-based solutions, provide a 15% premium to nearby residential property prices.
Moreover, Thompson et al. (2023) found that more flood-resilient areas are more attractive for homebuyers, and real-estate investors because of the lower risk of losses from physical damage and insurance claims".

1.2.1. Influence on housing market actors

Changes in property value also pose indirect implications to the financial market: risks to homeowners' financial status, as well as to the insurance and mortgage industries, bank portfolios, and thereby financial systems (Ratnadiwakara and Venugopal, 2020; Thompson et al., 2023).
This indicates that flooding and flood risks, directly and indirectly, affect many actors in the housing market system. Much literature discusses the implications of flooding and/or flood risks on the existing housing stock, as they study the capitalization of such risks in house prices through changes in buyer perceptions and preferences, as well as through increased or decreased premiums and mortgage rates (such as the papers discussed above). However, significantly less literature discusses how actors responsible for the supply of new houses in the housing market, such as real estate developers, are influenced by flood risks or their effect on housing value. Oyetunji et al. (2023) studied the factors that influence investors' decisions to invest in property in areas with the probability of flooding. Studies targeting the perspective and response of developers to climate change in the context of urban planning are rare (Storbjörk, Hjerpe, and Isaksson, 2018). A noteworthy paper is that by Buckman and Sobhaninia (2022) in which, through a survey, they garner how the real estate development community view climate change impacts, and what they are doing to address these impacts. Results showed that commercial developers are slow to recognize the threat of climate change impacts as they "believe that the minimalist approach is enough to make financial partners and governmental entities happy". The study demonstrates that developers will continue to build in areas prone to climate change impacts if it is profitable. The papers of Colby and Zipp (2021) and Dubbelboer et al. (2017) study the influence of a national flood insurance scheme on the housing stock in flood-prone areas. They both find an increase in houses developed in flood-prone areas. According to Dubbelboer et al. (2017) developers prefer building in areas where they can achieve the highest returns, even if these areas are subjected to higher flood risks.
The above papers indicate and discuss the need for financial incentives to ensure flood risks are taken into developers' decision-making.

This lack of literature and the fact that developers barely take flood risks into account in their housing development could potentially be explained by the fact that the effect of flood risks on housing value diminishes after several years. Since the process of housing supply is time-consuming, this may not provide sufficient incentive for developers to respond. However, implementing a policy such as a Climate Label, which discloses flood information, could hypothetically stabilize the effect on housing value and make it more uniform across households. This, in turn, could incentivize financially oriented developers to take flood risk into account in their decision-making, thereby affecting the supply of resilient new houses.

1.3. Flood management policy

To limit the direct and indirect consequences of flood (risks), policymakers can implement various measures and regulations. Policies/measures could be government-led flood protection (e.g. dykes) or stimulation of individual building-level protection. In literature, it is stated that traditional government-led flood protection measures need to be complemented with measures aimed at increasing the resilience of cities (Klijn, Samuels, and Van Os, 2008). Haer et al. (2020) discuss how government-led flood protection can reduce the incentive for adaptation by local households, which paradoxically results in more severe consequences if an extreme flood event strikes. They advise implementing policies that motivate individual building level adaptation. Li and Grant (2022) conclude their paper regarding the multifaceted dynamics of climate gentrification in Miami with the recommendation to include a risk assessment of flooding in homebuyer contracts.

A policy currently on the agenda of the Dutch government is providing houses with a Climate label, which would, among others, indicate the level of vulnerability a house has to flood (=Flood label). This policy is a form of flood risk information disclosure and is in line with the above-mentioned policy recommendations. It will ensure that people will not be left with unforeseen costs and that these costs will be well reflected in the value of the property. Moreover, it would stimulate households to invest in individual building-level measures (Davids, Boelens, and Renaat De Sutter, 2021; Meyer and Hartmann, 2023).
However, there is limited research concerning the (potential) effects of flood labelling. The found body of literature regarding flood labelling was limited to the following papers and their findings: The paper of Hartmann and Scheibel (2016) was the first to discuss flood labelling and its potential, as at the time it was being prototyped in Germany. They illustrated that it has the potential to effectively communicate individual flood risks and motivate households to implement building-level flood risk adaption. These findings were shared in the study of Davids, Boelens, and Renaat De Sutter (2021). Shr and Zipp (2019) review the effect of assigning a 'flood status' to properties that reside in flood zones to isolate the effect of flood risk on housing values from other (dis-)amenities associated with the location in a flood plain. They found that property values are (negatively) affected by the flood status, but do not rebound when flood zone status is removed. Lastly, Meyer and Hartmann (2023) conclude that flood labelling constitutes a social innovation in flood risk management.

1.4. Knowledge gap

The body of literature examining the impact of flood risks and flood and flood risk management policies on the supply of new housing and the extent to which relevant actors incorporate flood resilience into their decision-making processes is notably limited. Existing research indicates that developers often do not recognize the threat of climate change and continue to develop houses in flood-prone areas if they remain profitable. This can lead to new houses being subjected to increased flood risks. This literature emphasizes the need for financial incentives to ensure that flood resilience is integrated into developers' decision-making processes. One potential policy solution is the implementation of a Climate Label. By raising flood risk awareness due to information disclosure, it will cause adjustments in housing prices, consumer demand, and sales activity. However, no existing study examines how a form of flood risk information disclosure could influence developer decision-making and consequently alter the distribution of flood risks in newly constructed houses.
Research addressing the potential effect of a flood risk information disclosure policy -such as a Climate Label- on the decision-making processes of real estate developers regarding the supply of flood-resilient housing would address this gap and contribute to the limited body of literature on flood labelling.

2
Research Questions

2.1. Main research question

From the knowledge gap identified in section 1.4, two goals are established for this study: 1.) To analyze the decision-making dynamics of real estate developers and their perspectives on a flood risk information disclosure policy; 2.) Describe and explore how a flood risk information disclosure policy, through developer decision-making processes, might influence the distribution of flood risks among new houses.
These objectives lead to the following research question:

”How would a flood risk information disclosure policy influence the decision-making dynamics of real-estate developers and, consequently, the distribution of flood risks across new residential houses?“

2.1.1. Research context

This study is conducted in the context of utilizing a Climate Label as a ’flood information disclosure policy’. Given the absence of a definitive design and the pending implementation of the proposed Climate Label policy (in the Netherlands), the ability to conduct an empirical analysis to study its effects is limited. Therefore, this study is confined to utilizing a ’hypothetical’ Climate Label.
Moreover, this research is scoped to single-family owner-occupied houses as residential houses. Single-family houses because the impacts of flooding on these houses are more direct and visible compared to multi-family houses. Owner-occupied houses are chosen primarily for simplicity, as the revenue models for developers generally differ significantly between rental and ownership, leading to different decision-making processes. Additionally, since owner-occupied houses are directly linked to individuals, the flood risks to which these houses are subjected are also individualized. Through aspects such as flood insurance premiums and individual risk perception, owner-occupied houses will be affected differently in the housing market relative to rentals. This, in turn, will also result in different revenue models. Moreover, this approach enables future research to explore how flood risk policies might impact various socio-economic groups.

To answer the research question, a highly stylized and simplified Agent-Based Model (ABM) is created, with developer decision-making at its core. The (limited) empirical data used to construct the model is primarily derived from findings in the Netherlands.

2.2. Sub-questions

To develop the ABM model and address the main research question, the following sub-questions are posed:

SQ1. *“Which information will the Flood label disclose and in what degree of granularity?”*

In the Netherlands, the policy under discussion is a mandatory formal flood label for all houses. However, the exact information the flood label will disclose (e.g. flooding risk and/or risk of foundation damage) is still debated. Moreover, the granularity of the information regarding the flood risks is not evident yet. The energy label, for example, has ten categories of energy efficiency. In case Flood labelling will be given the same design, how many categories will it encompass?
It is important to first establish the information the flood label discloses and its degree of granularity to be able to describe its effects. By answering this sub-question, a 'hypothetical Climate label' can be established which will be used as the context of this study to represent a "flood information disclosure policy".

SQ2. *"What are relevant project decision-making dynamics of developers?"*

This sub-question relates to the first goal set out of this research. It aims to determine what developers' project decision-making dynamics entail and what they find relevant in deciding where and how to build. The following working definition is used to determine and structure the decision-making dynamics: "Decision-making dynamics refer to the processes, interactions, and contextual factors that influence decision-making within a given context." (Cheney et al., 2010; Harris, 2009)
The findings can consequently be used to create a theoretical framework of their decision-making dynamics and the (potential) role of flood risks in such.

SQ3. *"What are the current perspectives and barriers of real-estate developers on building with flood adaptation measures and how do they anticipate that changing after implementation of a Climate label?"*

Sub-question 3 relates to the first goal of this research as well. This question seeks to understand the current experiences and perspectives of real estate developers regarding flood-adaptive construction, as well as to identify any barriers they may encounter. Additionally, it aims to investigate whether the introduction of a Climate label could help overcome these barriers (e.g. if it could make building more resilient houses more profitable). This also provides an opportunity to assess other possible incentives for developers to build more flood-resilient houses.

SQ4. *"Given a housing value shift caused by Climate labelling, what are the consequences of decision-making dynamics of real-estate developers in terms of where and how (adaption measure(s) or not) new residential houses are built?"*

This last sub-question relates to the second goal of this study. Given the identified decision-making dynamics of the developers and the potential incentives to build more flood resilient, the opportunities and effects a Climate label could have on building more resilient properties (i.e. in flood-resilient areas or with adaption measures) can be explored.
As a Climate label has not yet been implemented, this research will work with a hypothetical Climate label and, accordingly, with hypothetical effects of the Climate label on housing value.

3 Methodology

The aim of the research is to explore and describe the effect the provision of flood risk information has on developer behaviour in the housing market and consequently on the distribution of flood risks among new residential houses. This research has a rather quantitative nature, as studying the potential shift in the housing value, consequently, adjustments of housing project's profitability, and changes in the distribution of risk and assets involves more exact analyses.

Answering the main research questions requires analysing a phenomenon that arises as a result of multiple overlapping systems and markets. It requires touching upon and integrating a variety of elements such as spatial elements -e.g. land use-, social -subjectivity in decision-making-, and economic -e.g. housing market, price valuation-. Moreover, it includes determining the behaviour and interaction of the various relevant actors within these systems (e.g. households, investors, real-estate developers).

Considering the above, a fitting methodology is Agent-Based Modelling (ABM). They are particularly strong in integrating socio-economic and environmental modelling, regularly within a spatial landscape, across scales, as well as exploring various market phenomena (Filatova, 2015). Moreover, ABMs have the capability to study the aggregated effects and dynamics of adaptive behaviour of interacting heterogeneous agents (Bonabeau, 2002).

ABMs are constructed using various empirical methods, such as surveys, stylized facts, census data, and expert knowledge.Besides literature studies on various subjects and aspects of the system under study, interviews with real estate developers and a water- and soil expert are conducted to gain valuable additional insights into real estate developer behaviour and their potential response to climate labelling. To create the Agent-Based Model (ABM), the iterative modelling cycle framework proposed by Nikolic (2013) will be used as a guideline. The following section briefly explains each step of the modelling cycle as discussed in Nikolic (2013), followed by an explanation of how each step will be implemented in this research to address the sub-research and main research questions (section 3.1). In the subsequent section, section 3.2, the utilization of the interviews is discussed in more detail. At the end of this section, a visualization of the research framework is provided, linking the research questions to research and modelling steps, thesis chapters, methodologies, and inputs/outputs.

3.1. Research framework: ABM Modelling cycle

How and when the various methods are utilized throughout the research, are detailed in the modelling steps below.

3.1.1. Problem definition

What: Establish topic relevance, knowledge gap and research questions

How: This is done by an extensive literature review of the effect of flood risks and flood risk information disclosure on the housing market and its respective actors as performed in previous Chapter 1, which to is used derive the knowledge gap and research questions as mentioned in Chapter 2.

3.1.2. System identification and decomposition

What: Establish relevant concepts, actors and objects, behaviours, interactions or flows, and states or properties. These are consequently structured into agents, interactions and environment for the ABM.

How: This modelling step consists of two parts: 1.) Identification of the to-be-used hypothetical Climatelabel; 2.) Identification and decomposition of the system taking the viewpoint of a real-estate developer.

1.) This part begins with a brief description of the current discourse surrounding the design and implementation of the Climate label in the Netherlands. Various "existing designs" by independent companies are analyzed and discussed. Additionally, a soil- and water system expert, frequently consulted by various parties for advice on the Climate label design, is interviewed to provide an external perspective on the Climate label debate. By doing so, potential designs for the Climate label can be identified, addressing SQ1 (Chapter 4). These findings facilitate the establishment of a hypothetical Climate label, which will be used as context for this study to examine the effect of flood information disclosure on developers' project decision-making.

2.) Markets, processes, and actors associated with developers are identified. To achieve this, a literature review on housing development processes is conducted. From these findings, concepts relevant to developers' decision-making regarding flood resilience are included in the scope of the study and model. Furthermore, a literature study is conducted to establish a theoretical framework for the internal decision-making processes of real-estate developers. Moreover, by consulting literature regarding the effects of similar policies (such as energy labelling), an estimate can be made of the behaviour regarding flood labelling. These literature studies and their findings are described in Chapter 5.
To validate this theoretical framework and hypothetical behavior, and to achieve a more detailed system definition, interviews with three real estate developers with varying backgrounds are conducted (view 3.2 for more details). This helps in answering SQ2 and SQ3.

3.1.3. Concept and model formalisation

What: For this step, the data structures approach of Nikolic (2013) is taken, in which the concepts of the previous steps are converted into computer-understandable analogues. Moreover, a model narrative (in pseudo-code) is created.

How: It is intended to create a highly stylized model in which real-estate developers operate in a fictitious landscape, with their decision-making processes at the forefront. As the developers develop in a fictitious landscape filled with fictitious cities, exact empirical data regarding inhabitant and housing attributes will not be used. Instead, this data is abstracted and simplified to help shape the model and its landscape. This approach captures key patterns and dynamics without needing detailed real-world data.
The paper of Parker and Filatova (2008), which provides approaches to model various housing market agents, and other housing- or land market ABMs (Filatova, 2015; Magliocca et al., 2014) are used as inspiration to formalise the concepts.

The conceptual and formalised model is highlighted among others with flow charts, which can be found in Chapter 7. Moreover, an extensive model description is created following the ODD protocol by Grimm et al. (2006, 2010), found in Appendix D.

3.1.4. Software implementation

What: Implementing formalised components into a programming software suited for ABM.

How: Programming software Python with its respective package Mesa is utilized for coding the model.

3.1.5. Verification

What: Verify if the model corresponds with conceptualised intentions.

How: To verify if we have "built the thing right," various unit tests are implemented throughout the model to ensure that the intended processes correspond with the conceptualised intentions. The verification of the model can be found in Appendix E.

3.1.6. Experimentation

What: Experimental design, experiment execution and sensitivity analysis.

How: In this step, experiments are conducted using the computational model to answer SQ4. Chapter 8.2 details the parameters and model structures adjusted for the experiments, while Appendix D.1.2 provides the base values for the remaining model parameters. The robustness of the findings is subsequently tested through a regional sensitivity analysis.

3.1.7. Analysis results

What: Examining and interpreting metrics and KPI results

How: As we aim to understand how the decision-making dynamics of developers are influenced by a Climate label and how this leads to a specific distribution across new residential houses, fitting Key Performance Indicators (KPIs) are tracked during the experiments. By analyzing descriptive statistics regarding the development behavior of developers (where and how they build), the emergent distribution of flood risks across new houses can be determined, thereby answering SQ4. Additionally, secondary metrics such as housing prices and housing project profitability are tracked to gain a deeper understanding of the results..

3.1.8. Validation model and results

What: Check if the model and its results are in line with reality and sufficient in answering research question.

How: During validation, it is determined whether the conceptual model is a reasonably accurate representation of the real world and whether the output is consistent with real-world outcomes. Since a Climate label has yet to be implemented, empirical validation is not feasible. Additionally, validation for stylized models is primarily theoretical, focusing on ensuring internal logical consistency and coherence with general principles.
To validate both the model and its output, an extensive analysis of the model's assumptions and their implications for reality is provided in Appendix D.4. Moreover, protocols described in the studies of de Koning and Filatova, 2020; Troost et al., 2023 are followed, with an emphasis on theoretical validation.

3.1.9. Model use

What: Concluding results and raising new questions.

How: In Chapter 8.4 the insights derived from the experimentation phase are used to answer the main research question and draw conclusions regarding the relevancy of the findings in terms of scientific, societal and policy.
As the research scopes itself to a specific hypothetical Climate label as flood risk provision policy, there could be some limitations to the external validity of the results. In the last chapter, Chapter 8.4, the limitations of the research are discussed, and recommendations for future work are given.

3.2. Interviews

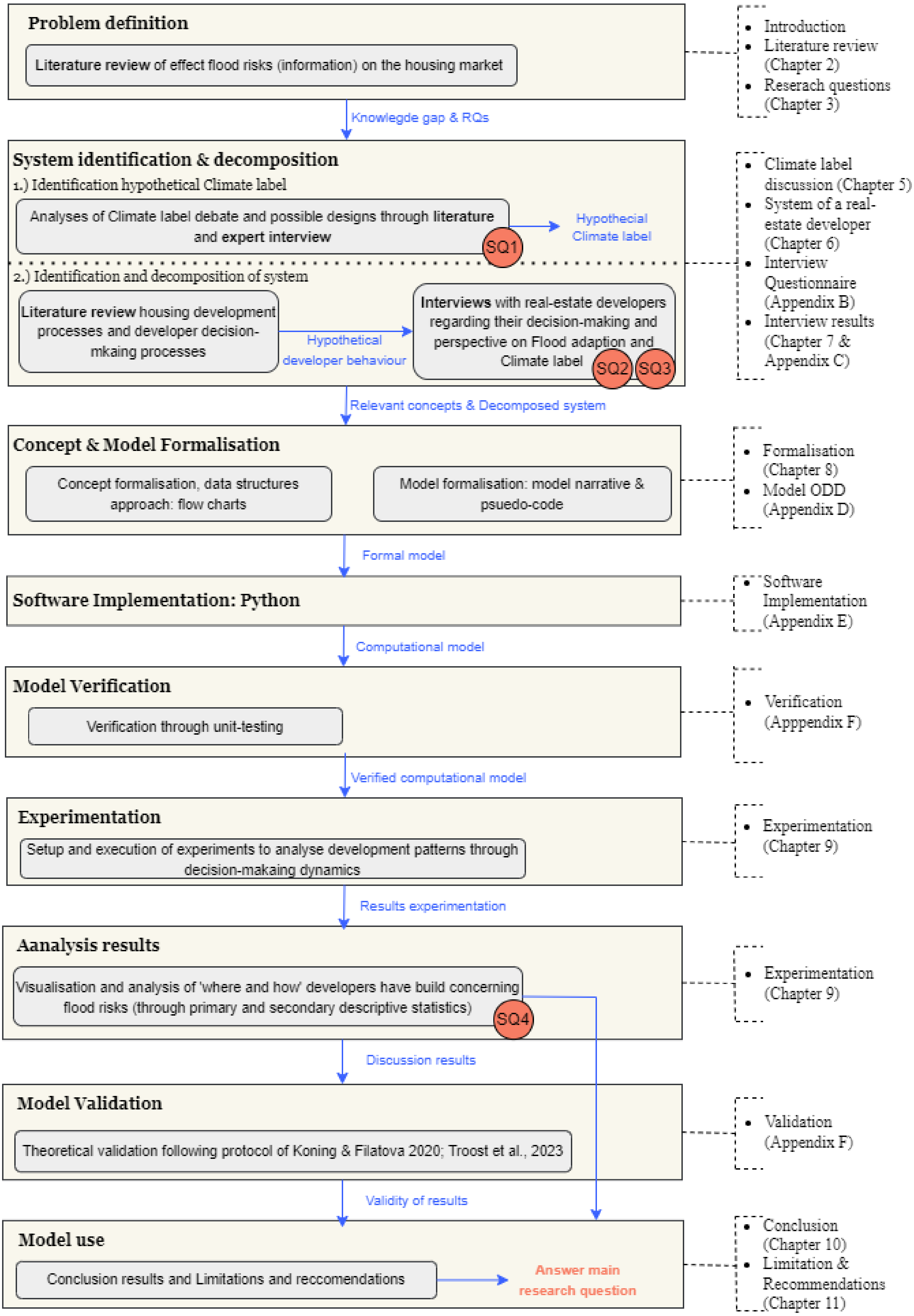
As mentioned in the previous section, literature studies are conducted to establish a theoretical framework of the system in which a developer operates and its hypothetical behaviour in response to a Climate label. However, given the rarity of studies targeting the perspective and response of developers to climate change in the context of urban planning (Storbjörk, Hjerpe, and Isaksson, 2018) and considering that SQ3 encompasses gathering perspectives that are potentially subjective and personal, it is best to capture developers' perspective and behaviour through additional interviews. By doing so, a more extensive understanding of the system can be gathered, and a more valid answer to SQ2 and SQ3 can be proposed.

Interviews with three real-estate developers are conducted. For these interviews, a questionnaire is designed based on the theoretical framework and hypothetical behaviour, with questions regarding their investment profile, factors they consider important in their project decision-making, their perceived uncertainties in decision-making, and their current views on building more flood/climate-resilient structures. The questionnaire also addresses the barriers they face in implementing flood adaptation mea-

sures (Appendix B). This approach provides a nuanced understanding of how developers currently perceive flood risk in their decision-making and how it might be influenced by a Climate label (Chapter 6).
Moreover, an interview with a soil and water system expert is conducted. This expert is frequently approached by real-estate developers for consultation, providing additional and third-party insights into developer behavior.

These interviews help in answering SQ2 and SQ3 and are unique in themselves as they highlight the perspective of an underrepresented stakeholder group in the discourse on climate resilience and housing policy.

Figure 3.1: Research framework: Flow between modelling steps (Nikolic, 2013) and in/output, with the respective chapters



4
Climate label discourse

This chapter marks the beginning of the system identification and decomposition stage, starting with the identification of the hypothetical Climate label to be used as the case of this research. It first provides a brief situational context that led to the development of policies such as a Climate label. Secondly, it examines the discourse surrounding the design and implementation of the Climate label in the Netherlands, derived from grey literature and an interview with a water- and soil expert. Based on these findings, an answer is provided for sub-question 1, facilitating the establishment of a hypothetical Climate label. This label will serve as the context for this study to examine the effect of flood information disclosure on developers' project decision-making.

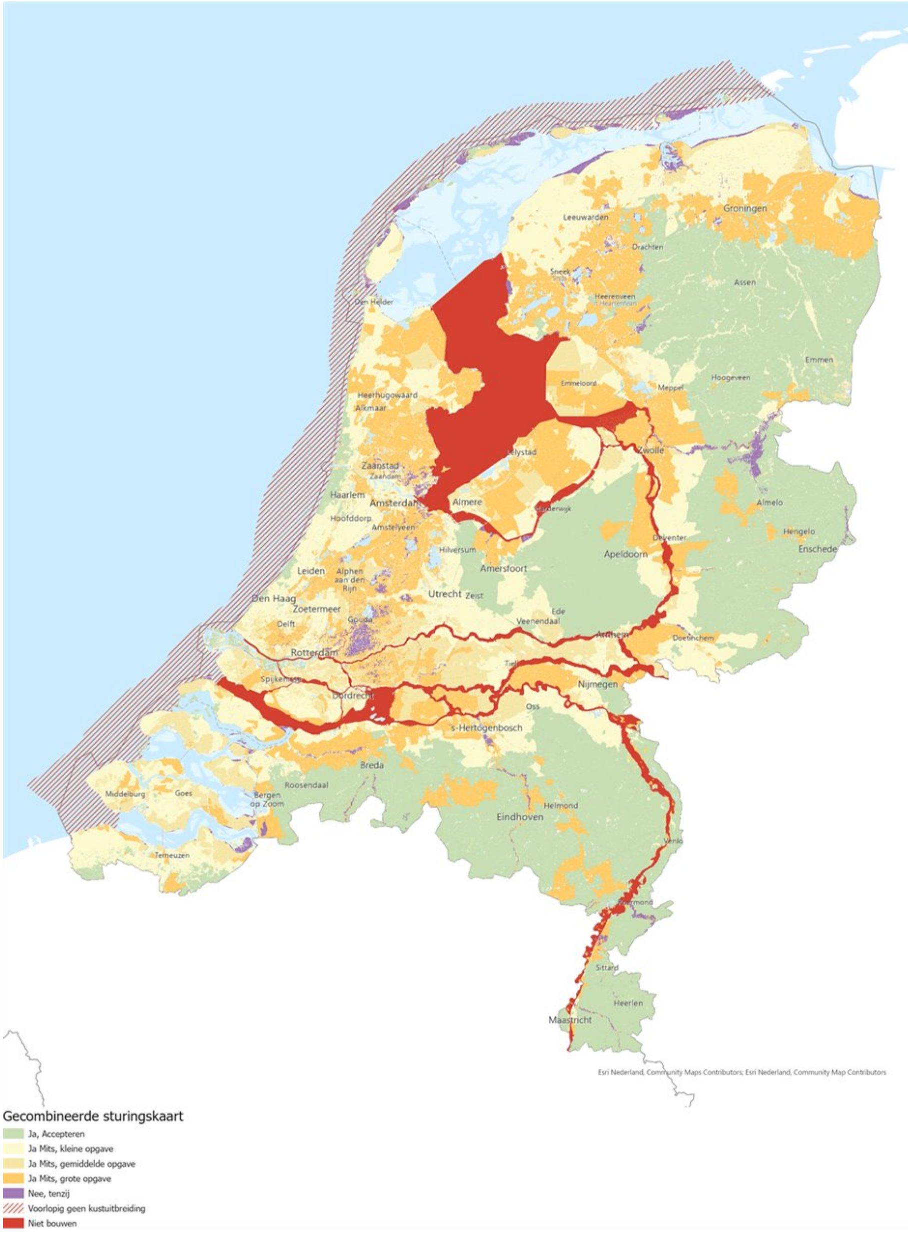
4.1. The context in which the Climate label emerged

At the end of 2021, the Dutch government indicated, in its coalition agreement, its intention to take more account of water and soil characteristics in spatial planning (VVD et al., 2021). This meant, among others, taking flood risks more into account, particularly in the planning of housing and other land uses vulnerable to flooding

This led to extensive flood data collection and the subsequent use of this data to design regulations and policies, as well as to inform various stakeholders comprehensively about respective risks.
An example of such data is the flood maps presented by Deltares (2023), which spatially display information concerning flood zones and local potential hazards caused by flooding.
Examples of guidelines and policies derived from such data include the 'Maatlat Klimaat adaptief bouwen' (Benchmark Building Climate Adaptive), introduced in early 2023. This tool provides guidance to municipalities and other stakeholders involved in housing development on what climate-adaptive building entails. It describes objectives and performance requirements and offers guidelines for climate risk mitigation without prescribing specific measures, making it non-binding (Arcadis and Tauw, 2022).
Another example is the 'Ruimtelijke afwegingskader klimaatadaptieve gebouwde omgeving' (Spatial Assessment Framework for Climate-Adaptive Built Environment), introduced in April 2024. This framework assists municipalities and provinces in site selection for new housing developments. It serves as a decision-support tool in the form of a map that indicates site suitability for development through risk categories. Like the previous tool, it does not prescribe specific measures and is non-binding (Kolen et al., 2023). Figure 4.1 displays the map.

The Dutch government is currently exploring ways to provide households with information regarding flood risks to increase awareness when buying or selling homes and to offer a framework for action. This initiative aims to encourage households to invest in property-level flood precautionary measures. Inspired by the success of the property-level Energy label, the concept of a Climate label emerged to further these efforts in promoting the construction of more flood-resilient houses. (ABN-AMRO, 2023; Hoogvliet, Slager, and Dolman, 2023)

Figure 4.1: Ruimtelijke afwegingskader klimaatadaptieve omgeving (Kolen et al., 2023): indicates through risk categories (left bottom corner) how suitable a site is for development



4.2. Discourse surrounding the design and implementation of the Climate label

The Dutch government has not presented a proposed design for the Climate label, therefore the sections below discuss the different already existing designs created by independent parties, followed by describing the discourse and critique of various actors associated with the policy, housing development and water- and soil systems. To derive this, particularly the latter, the findings of the interview with the water- and soil system expert are used. In this interview, equations involved the expert's view on the design and implementation of a Climate label, and questions regarding perceived points of view when approached by multiple parties for advice regarding water- and soil systems.

4.2.1. Existing labels

Assigning houses or assets a 'score' or a label based on their vulnerability to various climate risks is not a new concept. Multiple tools and frameworks designed by various companies exist to provide consumers with relevant information and advice. These consumers are often banks or insurance companies seeking to assess the risk and therefore the value of their portfolios.
For example, Royal HaskoningDHV and Sweco developed their own 'Climate labels' and scoring cards a few years back (Bluelabel, 2020; Sweco, 2017). Additionally, the Dutch Green Building Council is currently collaborating with 30 different entities, including government bodies, banks, and insurance companies, to develop a uniform methodology for climate labelling homes (Kadijk et al., 2023).

The table below provides an overview of various existing climate labels, detailing who created them, the categories they encompass, and their definitions. These labels offer insights into the flood risks faced by individual properties or how properties and their plots score within a specified scale or classification.

Name label	Company	Number categories	Definition categories
BlueLabel	Achmea & RHDHV	5	[A, ..., E]
Waterlabel	RIONED & STOWA	9	[A++, ..., G]
Framework for Climate Adaptive Buildings	DGBC	6	[no (risk/score), ..., very high]
Mijn waterrisicoprofiel	HKV	5	[A, ..., E]
Staat van je straat	Sweco	5	[A, ..., E]
Vlaanderen: Perceelscore en gebouwscore	Government	4	[A, ..., D]
EA Flood zones (England)	Government	4	[zone1 .., zone4]
Fema Flood zones (America)	Government	4	[zone1 .., zone4]

4.2.2. Critique on property-level Climate labels

As aforementioned, banks and insurance companies already make use of labels and are, therefore, proponents of the government implementing a mandatory Climate label for individual houses. For example, according to ABN AMRO (2023), Climate labels would comprehensively provide climate risk information to all buyers in the housing market, thereby reducing information asymmetry and 'levelling the playing field' between buyers and sellers.
Even though the idea of the Climate label emerged with good intentions and has various proponents, such as ABN-AMRO, it has also faced criticism regarding its implementation and design. Some parties do not see it as feasible or are concerned about its potential inequality effects. Below, we outline the arguments of those opposing the implementation of Climate labels for all individual houses.

Feasability, data uncertainty:
Multiple parties question the feasibility of assigning a Climate label to houses on an individual scale, as this requires highly detailed and precise flood risk data. According to a water and soil system expert, such data is currently unavailable. There is considerable uncertainty in hydrologic models, making it very difficult to provide accurate and reliable risk nuances at an individual level. Data on larger, area scales are more feasible and reliable. When evaluating the different existing methods of assigning a flood vulnerability score to houses, such as BlueLabel and DGBC, the water- and soil system expert noted significant discrepancies between their results. This indicates a significant sensitivity and variability in assigning a label to a house.
Moreover, hydrologic models can only provide one side of the story. To determine a more certain and valuable "flood vulnerability status", individual houses must be inspected by professionals to determine a more nuanced status.

"What's actually been the driving force in the whole climate label discussion is not so much the suitability of the information, but rather looking at what we have. And then they just started using that. So, they used what was available, as opposed to what was suitable." [-A water- and soil system expert]

One of the developers interviewed for this research for their perspective on Climate labels (elaborated in the next chapter, chapter 5.4), shared the view that Climate labels should be assigned on a large area scale rather than on an individual housing scale (see Appendix C).
Furthermore, according to Deltares (2023), an institute specializing in water and the subsurface, all water and climate risks cannot be captured in a single label because there are too many factors on which a house or plot could be assessed.

According to Vereniging Eigen Huis (2023), an organization that advocates for homeowners' rights, providing only a rough or global estimation of climate risks can substantially impact the value of a property, especially those in vulnerable areas. Below, we go into more detail regarding the arguments concerning the possible inequality effects.

Inequality effects:
Multiple parties have highlighted the inequity effects that implementing a Climate label could have, noting that a decrease in the value of vulnerable houses due to a Climate label could mainly affect the most unaffluent parts of society (Deltares, 2023; Moerland, 2024). They point out that, simply put, when it comes to property risks, there is potential for financial loss for some parties and financial gain for others.
The soil- and water system expert expressed concerns about implementing a Climate label on existing houses, as homeowners cannot significantly alter the fact that their house has been given a poor label. For example, while the energy label has encouraged people to improve home insulation, there are fewer substantial measures one can take to mitigate flood risk. Homeowners would effectively receive an almost fixed "stamp" on their house, indicating vulnerability. New houses are likely to receive good labels while existing houses will receive relatively low ones.
The three developers interviewed for this research also shared concerns about the impact of the Climate label on existing housing. Some were worried about its potential effect on housing prices, while others argued that it is unjust to label older houses, as there is little that can be done to make them more flood-resilient.

Overall, the soil and water system expert was skeptical about the effectiveness of a Climate label in incentivizing households and developers to include flood adaptation measures. He mentioned that the key incentive would be regulation from the government or municipality.
In general, he believed that flood/climate labels should be assigned at an area level, rather than an individual level. This approach would primarily serve to inform what risks could be evident in certain areas. Such area-level labels would be sufficient to provide current homeowners with information on the flood risks their homes face.

4.3. Conclusion: Hypothetical Climate label

The above sections illustrate a variety of opinions on how a Climate label should be designed and implemented in the Netherlands. The number of categories ranges between 4 and 9 across the existing labels, and the definition of each score/category differs among them. Furthermore, critiques are made against a policy such as a Climate label due to the possible unjust consequences it could have and feasibility concerns. There appears to be a dichotomy between proponents of assigning a Climate label to individual houses and those who prefer it to be implemented on an area scale.
The findings show that there is no consensus on which information the Climate label will disclose and what degree of granularity. Therefore, regarding the answer to the SQ1 *"Which information will the Flood label disclose and in what degree of granularity?"* remains ambiguous and, rather a range of answers could be applied.

Given the variety of designs for the Climate label, a hypothetical design is established based on the above findings. First, the "proponent side" of the property-level Climate label is adopted, as most evidence (including existing labels and the stance of the Dutch government) suggests this is the most likely implementation of a Climate label. This approach provides the most opportunity for future empirical validation of the research's findings. Second, the hypothetical Climate label will consist of six categories. This number is chosen as it represents approximately the average number of categories in existing labels, and aligns with existing flood maps and the 'Ruimtelijke afwegingskader klimaatadaptieve omgeving,' which also utilize six categories for flood risks (Deltares, 2023; Kolen et al., 2023).
This design will be utilized as the flood information disclosure policy to provide context for this research.

5

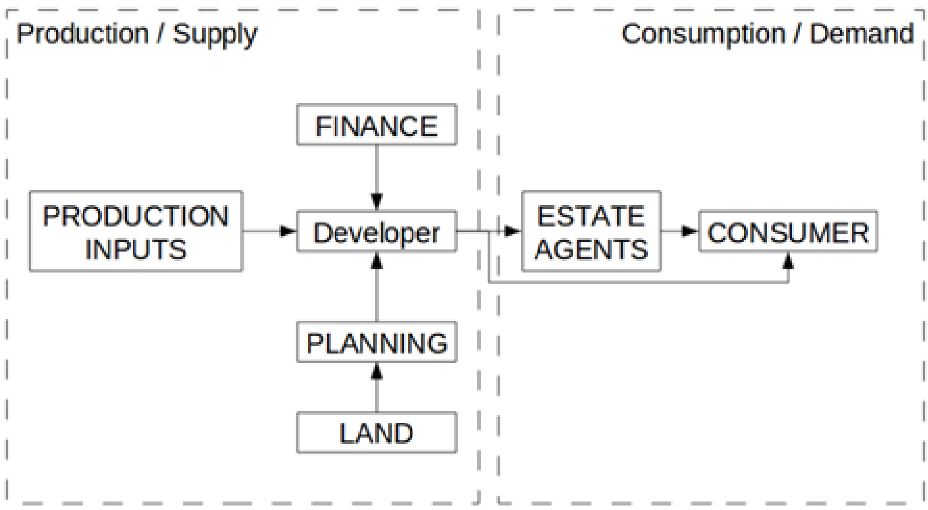
Real-estate developer system

In this chapter, the system identification and decomposition stage continues with the identification of relevant system concepts. Given that the real estate developers and their decision-making processes are central to this research, the system concepts associated with developers are identified. Consequently, of those concepts, those that may influence the decision to build flood-resilient properties are taken into account in this research and in the model.
The chapter begins by providing background information on developers, implicitly identifying other relevant actors, processes, and states. In section 5.2, literature concerning decision-making theories and dynamics of developers is discussed to identify relevant processes and behaviours for the developer agent. However, this literature only provides a theoretical framework to estimate the behaviour of developers when confronted with the implementation of a Climate label (section 5.3). Therefore, interviews with real estate developers will be conducted to validate the findings of this chapter and gain a deeper understanding. The questionnaire for these interviews is established and discussed in section 5.4.

5.1. Background real-estate developer

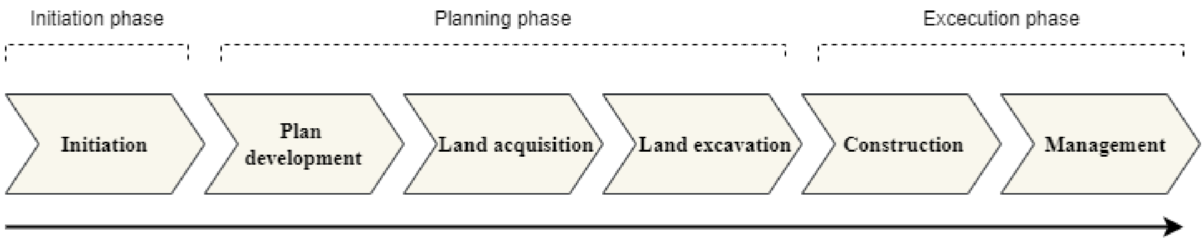
Developers play a key role in the housing market as they are responsible for the inflow of new houses. They identify potential building sites, arrange financing, handle legal issues and oversee construction. The figure below (figure 5.1), derived from Zöllig and Axhausen (2011), illustrates the position of real-estate developers in a market framework.

Figure 5.1: The position of real-estate developers in a market framework (Zöllig and Axhausen, 2011)



In figure 5.2 below, the entire housing development process is visualized. Various phases within this process can be undertaken by different public (e.g., municipalities) or private parties (developers or investors). When public and private parties collaborate to develop land and houses, either by carrying out the development phases separately or together, it is referred to as a Public Private Partnership (PPP). An example of this is a tender process, where municipalities acquire or own land, excavate it, and then invite different developers to propose plans and bid for the respective land. The developer with the highest score, based on the plan criteria and bid, is awarded the land to develop (Planbureau voor de Leefomgeving, 2021; Vlek and Rust, 2020).
The concepts in figure 5.1 and the steps of the development cycle (figure 5.2) will be elaborated below in a backward fashion.

Figure 5.2: The housing development process and its phases and respective steps (inspired by Vlek and Rust (2020))



What happens after construction—whether the house is sold to residential households, investors/housing corporations, or managed by the developers themselves—varies(Heurkens et al., 2020). There is also a distinction between public and private/commercial developers. The latter are more profit-oriented (build-to-sell), while the former take on a more social and managerial role. (Ge, 2017; B. M. Taylor et al., 2012).
To develop houses, developers require land for construction, as well as building materials and manpower (production inputs). This necessitates a significant investment of financial resources. While developers often contribute their own funds, securing funding from investors, typically banks, is frequently crucial. In many cases, this funding takes the form of a loan with annual interest. (Heurkens et al., 2020)

To obtain land for construction, it must be purchased from the landowner, who is often a farmer, investor or the government/municipality (CPB, 2019). Land that is bought can be serviced land, in which the respective land has been excavated and is therefore ”build-ready”, or land can be unserviced, in which the land has not been excavated yet and for which the zoning plan does not permit housing development yet (as its function is still e.g. agriculture). The latter is often bought speculatively, for which the developer/buyer hopes for a change in the zoning plan, as the value of the land increases significantly after it is assigned residential use.
Spatial planning, particularly zoning plans, dictates permissible land uses (e.g. agricultural, residential, or commercial, but also specific building attributes). In cases where land is designated for residential housing, land prices are influenced by house prices rather than vice versa (Planbureau voor de Leefomgeving, 2021). The value of the land is often determined by the use of land and its revenue. The most common method used in various countries such as England and the Netherlands, is the residual land value method: the land value –the residue- is what results when the costs of development (the building (and the additional) costs and intended profit margin) are deducted from its revenues (the expected house prices).(Buitelaar and Witte, 2012; Planbureau voor de Leefomgeving, 2021)

Once a suitable land parcel is identified, developers prepare a development proposal outlining their plans for the site. This proposal includes details such as the number and type of houses to be built, site layout, building designs, amenities, and any other relevant information. Subsequently, this development proposal is submitted to a local planning authority or governing body responsible for land use regulations. They review the proposal and, if it meets all requirements, the planning authority grants development approval. (Brown, 2015)
What kind of housing will be constructed can differ (single-family homes, multi-family homes, their respective attributes, etc). Besides the availability of the above-mentioned resources, the type of housing

depends on where the developer's interest lies, his area of expertise (their existing housing portfolio), and/or where the most return can be made (demand from the consumer)(Heurkens et al., 2020). Section 5.2 dives deeper into this decision-making process behind the development plan.

All in all, various "types" of real estate developers exhibit a range of attributes and behaviours, which can consequently result in respective opportunities or constraints in responding to policies such as Climate labelling. Distinguishing between the different types of property developers is relevant (Shearer et al., 2016). However, due to constraints caused by time and by necessary model simplification, an all-encompassing approach can not be taken. This research limits itself to private developers who construct single-family owner-occupied homes and consequently sell them to households. These developers engage in build-to-sell practices and therefore have a short time horizon regarding their investment in the houses. This research focuses on private developers rather than other types of developers, as private developers play an increasingly important role in urban development (Heurkens, 2012). Additionally, because private developers are often more profit-oriented, they are more susceptible to policies that could impact revenue and house prices, and consequently, their profit margins.

5.1.1. Developers relationship to various markets

As indicated in the above section, developers operate in a variety of markets: (owner-occupied) housing market, land market, capital market (to acquire project financing), and planning market (to acquire permits from the municipality) (Gehner, 2008).
Due to time restrictions, not all markets in which a developer operates will be considered in this research and model. Only the key markets within the developer system concerning flood-resilient homes will be taken into account. Design markets, where architects create designs for developers and construction material markets are excluded (only the costs of adaptation measures are considered), as it is assumed that these have a relatively limited role in restricting or possibly incentivizing developers to build more flood-resilient structures. In the interviews with real estate developers, this scoping will be validated by asking them about the incentives and barriers they experience regarding building flood-resilient homes and linking these to the markets in which developers operate. Moreover, this research excludes the asset market in which developers construct residential properties for investors who consequently rent out the properties, as the scope of this research is single-family owner-occupied housing.

5.2. Literature decision-making behaviour developer

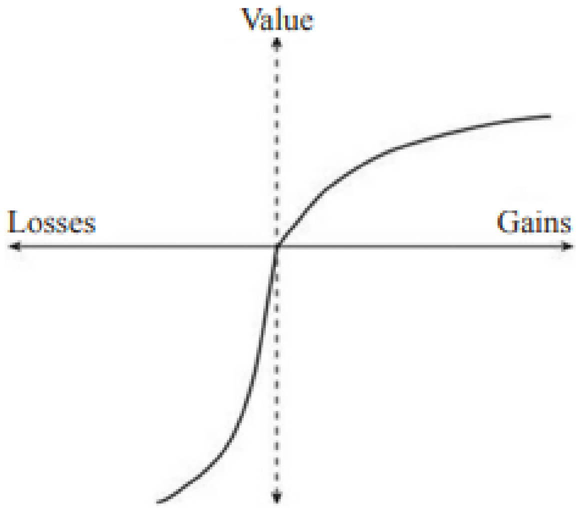
After having identified the more external system elements of the developer, such as actors and markets a real-estate developer associates themselves with and the general housing development process, more internal system processes of the developer are discussed. This section delves into the decision-making processes of real estate developers regarding their supply of houses. It explores key considerations such as their objectives, opportunities, market perceptions, and risk attitudes.

As mentioned in the previous section, commercial real estate developers are profit-oriented and build-to-sell. This means that houses are preferably built in regions with relatively high housing prices and low construction costs (Ge, 2017). Developers have a shorter time horizon than homeowners, as their investment is limited until the moment the product is sold. Predicting future demand and profitability for certain houses at completion is problematic, as it depends on factors such as interest rates, consumer tastes, and the untested appeal of new/innovative products. Predicting outcomes becomes even more challenging when dealing with products that the developer lacks experience with. By maintaining a short time horizon, developers limit the uncertainty surrounding these tasks. Moreover, selling a property quickly reduces costs associated with loan interest and potential carrying costs. (Poorvu and Cruikshank, 1999; Shearer et al., 2016; B. M. Taylor et al., 2012)

However, real estate developers being profit-oriented does not necessarily mean that they also pursue profit-maximizing behaviour. If developers had unlimited time and resources, they would be able to acquire complete information about their opportunities and the consequences of their actions, and the ability to process all this information, resulting in them behaving rationally, and optimizing their utility. Nevertheless, given the complex nature of the system, developers often lack the time and capacity to process such vast amounts of information and determine the optimal set of decisions. Furthermore, issues such as incomplete information may arise, where e.g. developers do not correctly perceive the

'Willingness-to-pay' (WTP) of consumers, resulting in the misinterpretation of the profitability of certain projects. (Kosavinta, Krairit, and Khang, 2017; Storbjörk, Hjerpe, and Isaksson, 2018)
Even more notable is the previously mentioned uncertainty in determining future market conditions. This, in combination with additional uncertainty caused by zoning regulations, lengthy approval processes, and difficulties accessing finance, can result in real-estate developers demonstrating satisficing behaviour (Mohamed, 2006). Satisficing behaviour entails opting for the first satisfactory solution encountered, as the pursuit of optimal solutions in situations of high uncertainty or limited information incurs significant transaction costs. This behaviour reflects a form of 'bounded rationality' in human decision-making, as described by Simon (1957). Satisficing behaviour typically results in a preference for housing types with short construction and sales times, which consequently limits the choices available to consumers. Moreover, it has been suggested as an explanation for why developers sometimes persist in building conventional housing even when alternative designs might be more profitable (Mohamed, 2006).

Figure 5.3: Value function of gains and losses according to Prospect theory (Kahneman and Tversky, 1979)



The aforementioned incomplete information and potential lack of developers' experience with a particular type of housing, or their ability to navigate uncertainty, only partly explain the tendency towards satisficing behaviour. According to Magliocca et al. (2014), prospect theory provides a complementary explanation for this behaviour among developers.
Prospect theory argues that the level of wealth is not the key factor in explaining individuals' economic behaviour; rather, it is the relevant changes in wealth relative to a reference point that are important. A central concept of prospect theory is loss aversion, wherein losses loom larger than gains, leading people to generally prefer avoiding losses over acquiring gains of the same magnitude (see figure 5.3). Moreover, individuals are often willing to accept a lower expected value or return in exchange for reducing the variability or uncertainty associated with an outcome. An extension of this concept is known as the 'endowment effect'. Hereby, once a person obtains a certain level of wealth, they tend to place more value on retaining that wealth than they did on acquiring it. This endowment effect is particularly relevant in explaining the tendency of individuals to select a previously chosen choice as familiarity with it makes it seem more "certain" (familiarity bias), even if it may not be the most favourable option. This phenomenon helps to understand why real estate developers continue producing mainstream housing, as they are most familiar with such, even though it may not always be the most profitable option (Kahneman, Knetsch, and Thaler, 1991; Kahneman and Tversky, 1979).
In the study by Kosavinta, Krairit, and Khang (2017), which investigates the rationality of decision-making among residential developers in Thailand using interviews and surveys, it was found that loss-averse behavior had a statistically significant impact on the decisions of developers. This finding supports the idea that developers exhibit behavior in line with prospect theory. Bao, Meng, and Wu (2021) also identified that developers' evaluation of land transactions exhibits reference dependence and loss

aversion. They state that developers with prior land transaction losses set higher house prices than those without prior losses, which is another concept of prospect theory.

In section 5.1, it was noted that real estate developers require a significant amount of funding for their projects. Investors, such as banks, assess the credibility of the project before deciding to provide the loan. Risk-based lending rates, which are interest rates based on the perceived risk associated with lending money to a particular borrower, are common in real estate development. Lenders can reinforce developers' satisficing behaviour as they prefer to extend credit to 'tried and tested' housing types (Ball, 1999). Therefore, the risk attitude of the investor also influences the decision-making of the developer. Moreover, as risk-based lending rates are determined based on creditworthiness and financial stability, smaller firms are more constrained by risk-based lending than larger firms. Consequently, risk-based lending could reinforce satisficing behaviour more in smaller firms than in larger ones (Magliocca et al., 2014; Shearer et al., 2016). Therefore, if investors prefer conventional housing (which does not include flood adaptation measures), it is the larger development firms that could be relatively more promising in incorporating flood resilience into their housing developments.

5.3. Hypothesis developers response to Flood labelling

When examining empirical studies concerning real estate developers' behaviour regarding climate-conscious housing, evidence can be found that aligns with the decision-making factors mentioned earlier. Studies indicate that despite a growing willingness to pay (WTP) for climate-conscious or innovative housing, developers often adhere to conventional market assessments and continue to produce mainstream housing. They perceive limited profitability and profit certainty in constructing resilient housing, thus considering it unlikely to meet short-term profit targets. Additionally, they view implementing adaptation/mitigation measures as expensive investments that may pay off in the long run but are not seen as financially viable in the short term (Eriksson et al., 2017; Magliocca et al., 2014; Shearer et al., 2016; Storbjörk, Hjerpe, and Isaksson, 2018; B. M. Taylor et al., 2012). Furthermore, the paper of Buckman and Sobhaninia (2022) showed that commercial developers are slow to recognize the threat of climate change impacts as they "believe that the minimalist approach is enough to make financial partners and governmental entities happy".

Research investigating real estate developers' response to similar policies, such as energy labelling, reveals that developers only find it worthwhile to invest in obtaining a green/energy label if the premium they gain from it compensates for the additional costs incurred. Furthermore, some developers strategically aim for the cut-off point for a certain certification level to exploit the point scheme. Risk-averse developers tend to adopt a cautious approach and seek to secure a certification level more conservatively, while risk-taking firms aim for the minimum requirements to achieve a more favourable position relative to the threshold value. (Atasoy, 2020; Delisle, Grissom, and Högberg, 2013)

Following the findings in the literature, the following hypothesis of real-estate developers' behaviour in response to the implementation of Climate labelling can be drawn.
Hereby, the theory of developers exhibiting satisficing behaviour, explained by prospect theory, is taken as a guideline. The role of incomplete information is hypothesized to play a smaller role in satisficing as Climate labelling would result in a market that more strongly discloses the WTP of consumers for resilient properties.

Implementation of the Climate label will cause a shift in housing values, discounting more flood-vulnerable houses and/or increasing the value of more resilient housing. Therefore, in theory, it could become more profitable for a real-estate developer to invest in more flood-resilient housing as their respective revenue will relatively increase. This can be done by constructing properties with adaptation/mitigation measures such as building houses on elevation or by building houses in less flood-prone areas.
However, there will be a significant probability that developers will continue building conventional and mainstream housing and possibly build them in flood-prone areas, not taking into account the respective flood risks. Satisficing behaviour, due to the previously stated uncertainties in predicting demand and uncertainties in the development process, will be assumed here as an explanation. For this hypothesis of behaviour, Magliocca et al. (2014) findings are taken as a guideline and protect theory -next to incomplete behaviour and limited cognitive processing capacity- is assumed to explain this satisficing behaviour. This hypothesis of satisficing behavior will be validated through interviews with develop-

ers. However, space will be provided for other explanations, such as developers believing it is not their responsibility to ensure flood-resilient homes, for continuing to build conventional and mainstream housing.
It is estimated that developers, especially those with a more niche housing portfolio, will prefer to continue their usual developing behaviour as they perceive investing in resilient housing as more uncertain due to their lack of experience in such housing (exhibiting risk-averse behaviour). They would prefer to secure a steady and safe inflow of profit rather than risk losses (endowment effect). In other words, developers are loss-averse and place more value on maintaining wealth and avoiding losses than on potential additional profits.
Depending on the developer's characteristics and existing housing portfolio, there will be varying degrees of uncertainty in investing in resilient properties.

5.4. Interviews

Interviews with three real-estate developers are conducted to validate and extend the above findings. The goal of these interviews is to validate the above-mentioned decision-making theories (satisficing and prospect theory) and see if and how they would apply to the construction of flood/climate resilient housing. Questions are asked to uncover developers' experience, the perspective of profitability, risk and uncertainty regarding building flood-resilient. Moreover, questions regarding their perspective and potential response to a flood risk information disclosure policy such as Climate labelling. Lastly, more "static" questions are asked that could be used as parameters for the ABM (e.g. regarding construction costs and time)
The questionnaire established for the interviews can be found in Appendix B.

Currently, the Netherlands is experiencing significant pressure on the housing market due to a severe housing shortage. Additionally, increased material and personnel costs, higher interest rates, and nitrogen regulations have made it more difficult for developers to secure financing. Since only Dutch developers are interviewed for this study, efforts will be made to account for the influence of current economic conditions and the housing market on their responses. Developers will be asked if their answers would remain the same if the housing market and environment were more favourable. This will ensure that the results of the interviews are more generalizable and provide a clearer picture of the barriers and incentives developers face regarding building more flood-resilient housing.

6

Interview Results

This chapter highlights the key findings of the interviews with the developers and their implications. An extensive analysis of the answers per question can be found in Appendix C. Three real-estate developers were interviewed using the questionnaire found in B. They were asked questions about their investment profile, including factors they consider important in their project decision-making, their risk attitude, and their perceived uncertainties in decision-making. Followed by questions concerning their current view of building more flood/climate resilient, their experience with flood adaptation, and what have been 'barriers' in implementing flood adaptive measures. Finally, they were asked about their viewpoint on the Climate label and how it would potentially influence their behaviour regarding building new houses in a flood-resilient manner.
Besides real-estate developers, the aforementioned soil and water system expert (in Chapter 4), who has a good grasp on the current Climate label discussion and who is often approached by real-estate developers for advice concerning water, soil and flood matters, was consulted. This provides this individual with a valuable "third-party" perspective, aiding in gaining a deeper understanding of the ongoing Climate label discussion and the flood risk and resilience system. It also serves to validate the findings obtained from the interviews with the developers.

A significant limitation of the results of the interviews is the sample size of three. With a large and richer sample of interviews, bias and outliers in the results can be controlled for. The section 'limitations' at the end of this chapter will go into more extensive detail on how the results of certain questions could have validity issues.

6.1. Discussion results

6.1.1. Investment profiles

The developers can be divided into "commercial" developers (Developer 1 and Developer 3) and a "societal" developer (Developer 2). The former expressed to be mainly profit-oriented, while the latter's key drivers were climate and societal benefits. When validating these findings with the expert, it was mentioned that most developers are financial/profit-driven and that "social" developers are not very common. This does not discredit the relevance of Developer 2's responses; rather, it underscores the importance of appropriately representing their perspective in the ABM model.
Nevertheless, all developers expressed not to be profit-maximising, as illustrated in the quote below. Their main importance was meeting their profit margin and return goals, which often were established at the initiative stage of the project and partly based on the anticipated risk of a project. This supports the theory/hypothesis of developers illustrating satisficing behaviour in their project decision-making. Moreover, given that Prospect Theory is presumed to explain satisficing behaviour, the tendency to satisfice around profit margins suggests that profit margins serve as a suitable reference point for applying Prospect Theory in the ABM model.

"We have yield requirements and profit requirements, but it is not that we optimise or maximise profits, I must say. When we have achieved those profit margins, then I am not going to take

additional risks to increase profits. If it's right, it's right." [Developer 3]

Furthermore, the location of a project plays a major role for all developers as it is intertwined with the housing demand, revenue and familiarity, but also with climate risks and the possible adaptation measures one can implement in the area. There also was a consensus among the developers regarding the importance of certainty in acquiring construction approval. All three developers assigned it a score of 5/5: very important. Developers 1 and 2 also deemed acquiring such approvals as very uncertain.

The majority of the projects acquired by all three developers were through a tender or by buying land speculatively (with the hope that the zoning plan will be altered in the future, allowing houses to be developed on the respective land). However, each developer did not have a similar distribution of tenders or speculative land acquisitions in their project acquisitions. For instance, Developer 1 primarily obtained projects through tenders, whereas Developer 2 was more speculative in their approach to acquiring projects. Consequently, this difference influenced how uncertain the developers perceived estimating revenue, demand, and costs: Developer 2 perceived these factors as much more uncertain compared to Developer 1 and Developer 3. This heightened uncertainty for Developer 2 stems from the longer timeframe associated with buying land speculatively: Such a process involves waiting for a change in zoning plans and subsequently excavating the land before building houses can commence. For buying land speculatively, apart from the planning-related risks, the extended timeframe makes it more challenging to forecast demand and sales prices accurately at the time of project completion. In contrast, with tenders, the municipality has already completed the excavation of the land, making it "build-ready" land. Moreover, it was noted that single-family owner-occupied housing projects, in particular, exhibit relatively low uncertainty and risk regarding demand and profit. Even within this housing category, variations in housing types or housing attributes did lead to a difference in (low) uncertainty or risk.
So, even though certainty in demand, revenue and costs were moderately important in their project decision-making, the developers currently did not experience much uncertainty in the situation of developing single-family owner-occupied housing on "build-ready" land. However, these results regarded prior investments, made before the implementation of a Climate label or heightened awareness of flood risks. One developer noted that their market benefits from predictable behaviour, implying that sudden changes in preferences regarding housing attributes -such as flood risks disclosed by a Cliamte label- could introduce uncertainties in market demand predictions.

When evaluating the answers concerning the risk attitudes of the developers, no concrete evidence was found that indicated the applicability of Prospect Theory in their decision-making. However, these findings could be constrained by the limited number of questions addressing the risk attitude of the developers or by the framing of the questions. Additionally, the interpretation of the scale used in the questionnaire could have also influenced the results. However, since a variety of literature supports Prospect Theory as an explanation for satisficing behaviour (e.g. Kosavinta, Krairit, and Khang, 2017; Magliocca et al., 2014), the theory is still accepted as a valid explanation and will be incorporated into the ABM model.
Lastly, all developers mentioned to be at least somewhat risk-taking, with Developer 1 expressing themselves as most risk-taking. This is exemplified in the fact that this developer would start construction at 30% of the houses sold instead of at 70% as the other two developers.

6.1.2. Current view climate and flood adaptation & Influence Climate label

From the interviews, it is evident that the behaviour of developers regarding flood-resilient housing and their response to the Climate label is significantly influenced by the behaviour of other actors. Besides households, who are responsible for buying and selling behaviour, thus determining demand and sales price based on previous transactions, municipalities, banks, and insurance companies were identified as key actors that could impact developers' project decision-making. This influence is apparent in the current barriers to building flood-resilient housing and the potential incentives a Climate label could provide, as described below.

Current view climate and flood adaptation

"Well, I think it (climate adaptive building) was not on the agenda at all until recently, wasn't it? So It was not a common thing, was it? Unknown is undesired, so that plays into it. The second thing is, it

does increase costs. So if you are in a competition and it is not asked, yes, you are actually shooting yourself In the foot." [Developer 1]

Developer 1 had mentioned mainly financial barriers as to why they had not realised housing projects yet with flood adaption measures. They mentioned that, currently, these are often not a criterion in tenders. Therefore, this places one in a disadvantageous position when building with climate adaptive measures as they would be receiving a lower "score" for their tender submission due to increased costs for such measures. Hence, Developer 1's main barrier is the lack of demand and assigned added value to flood-resilient housing by the consumer (household and municipality).
The fact that Developer 2 was predominately societal and climate-driven in their project decision-making was evident in their stance regarding flood risk and flood adaptation measures. They were most progressive in their answers: their company has a (future) strategy to cease building houses in areas prone to climate-related risks like flooding. Instead, they opt to focus on constructing in the east of the Netherlands. One exception to this is their willingness to continue building within urban areas. However, outside the cities, they only intend to build in "high and dry" areas. Their current barriers were therefore not necessarily financially driven, but predominantly data-driven: lack of flood risk data and the reliability of this data. This issue was also brought up by the soil and water expert: Most hydrology models are based on a variety of scenarios, and there is considerable uncertainty surrounding flood risk estimations, particularly at a small scale such as individual housing. Just as Developer 1, they recognized that building with flood adaption measures is more costly. However, as they intend to build mostly in naturally resilient areas, the realisation of such measures in their projects is more limited. Moreover, they place significant value on assuring consumers that their homes remain safe and resilient over 50+ years.

"Now suppose we buy a piece of land somewhere tomorrow. Then the houses must remain standing for at least 75 years. Given the knowledge we have now, we have to determine whether then that location can still function decently and not stand 3m of water or has sunk 1.5m or eh? Because, say, the buyer is working hard for 30 years to pay off his mortgage. And maybe who wants to hand over his/her house to your children one day. But then again, it might not be there in 50 years, because now it's all sunk or something." [Developer 2]

The barriers expressed by Developer 3 were mostly responsibility- and uncertainty-driven. They believed that it is the municipality or government's responsibility to ensure resilience against large-scale flooding, not those of developers or individual households. For small-scale flooding (such as heavy rainfall), they did see individual building adaptation measures play a role in ensuring resilience. Moreover, the developer mentioned uncertainty in hydrologic models and variating views of flood adaptation between municipalities as issues, resulting in uncertainty in where to build as well as how to build. Furthermore, the accumulation of ambitions of the public was also seen as a barrier. With existing goals and regulations like energy neutrality and circularity, adding climate adaptation ambitions further complicates matters. Besides the barriers, Developer 3 believed that most of their existing projects already sufficed to a sufficient level of climate and flood resilience a house should have (illustrated in the quote below). This resulted in them believing they were quite well-prepared for the implementation of a Climate label, and that they would not have to change their project planning and decision-making significantly.

"And yes, that does tell me that as far as I am concerned, the regular development process can already be given a grade of 6 on climate-adaptive building." [Developer 3]

A limitation of the questionnaire was that these barriers were not assigned magnitude or ranking, therefore making it difficult to assess the relative severity of each barrier.

The findings above underscore the key role of the municipality and government in overcoming barriers to build more climate adaptive. They indicate the necessity for reliable flood data, effectively communicated in an accessible manner, to be used for the creation of a rigorous national standardization/framework dictating where and how to construct new homes. These should in turn be used uniformly across municipalities to prevent confusion regarding climate/flood adaptive building requirements. Moreover, by enforcing such standards, constructing with adaptive measures would no longer result in a competitive disadvantage. If executed properly, a climate label could be a beneficial tool to help achieve this as it can offer a readily available standardisation regarding flood-resilient housing.

Influence Climate label policy on the housing market and development behaviour regarding flood risks

From the responses of Developers 1 and 2, it can be derived that policies concerning flood adaptive housing, such as the Climate label, should be introduced gradually, considering the adaptation speed of developers and their existing projects located in areas that may be labelled as vulnerable or "poor." Based on their past experiences with previous policies, they emphasized the necessity of a transition period, as they cannot significantly alter nearly completed housing projects.

Currently, loan or mortgage lenders or insurance companies do not play a significant role in discouraging nor incentivizing investment for developers and households in investing in flood-resilient houses. However, all three developers noted that this could change in the future, especially after the implementation of a Climate label. They believe it will affect their project perception twofold: 1.) It will become easier for developers to obtain project financing for flood-resilient housing projects, or that projects subjected to flood risks and/or not incorporating sufficient adaption measures will receive smaller loans; 2.) Households could potentially secure larger mortgages for flood-resilient housing, and the insurance premiums for flood-vulnerable houses may be higher, or insurance companies might even be unwilling to insure them altogether.
Yet, Developers 2 and 3 are subsidiaries of larger companies with a significant amount of financial resources and can, therefore, finance most projects internally. Subsequently, they are less sensitive to fluctuations in interest rates.

"Households could potentially get more loans and finance for climate-resilient homes. So as soon as climate label is on the way, financiers and insurers are going to respond to that. That has a direct impact on housing revenue and therefore making up for the investments you have to make to make more resilient homes." [Developer 2]

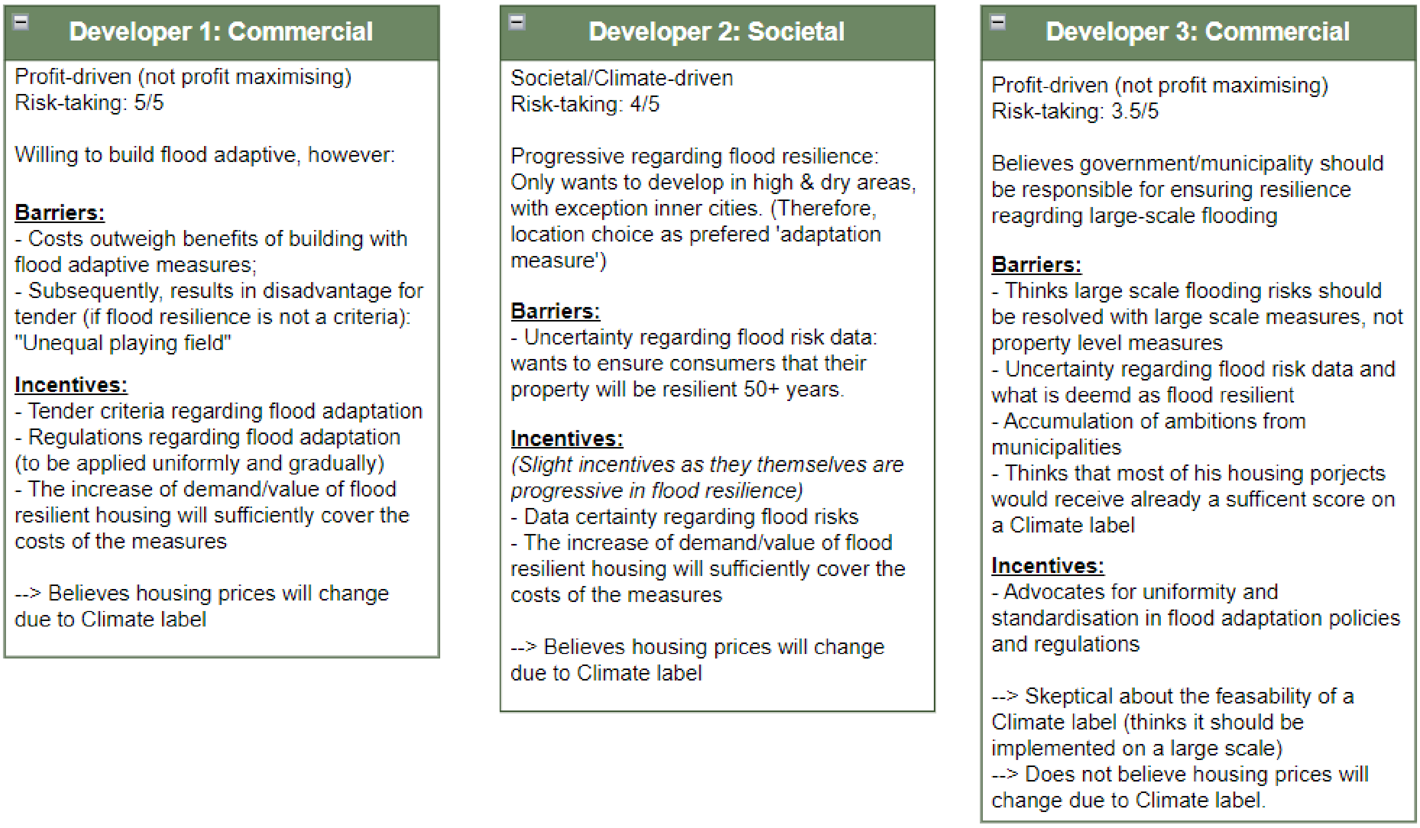
When analysing the answers regarding the developers' perception of how the Climate label could affect the buying and seller behaviour of households regarding flood-resilient houses, diverse and distinct views were provided. Developer 1 believed a Climate label would change housing values. This would be a potential stimulant for him to build more flood-adaptive houses, however, only if the increased value given by the consumer to flood-adaptive measure would sufficiently cover their costs.
Developer 2 also anticipated a shift in housing values according to flood vulnerability, however this would mainly have implications for existing houses. Since they are a 'societal developer', a climate label would mainly affect their decision-making in the sense that they could use the increased awareness and information to locate flood-resilient places for new housing projects.
Developer 3 did not believe that a climate label would cause a shift in housing value. They also felt that most of their existing projects would receive a satisfactory label category, and therefore, their current conventional housing development practices would suffice (However, this stance is sensitive to the definitive definition/categorization of climate and flood adaptiveness). Moreover, they did not think individual houses should have labels, but rather areas should be assigned such. This is also in line with their opinion that large-scale flooding should also be solved with large-scale solutions -the responsibility of the municipality- rather than individual housing adaptation measures. From the answers provided. Developer 3 seemed to anticipate relatively few changes (needed) in their decision-making after the implementation of a Climate label.
These differing perspectives on the impact of a Climate label or increased awareness of flood risks on housing values support the argument that predicting demand and revenue based on a house's flood risk or flood label category will be subjected to uncertainty.

6.2. Conclusion: stylized overview

The interview findings reveal that the three developers exhibited different investment profiles and held distinct views on developing flood-resilient housing and the potential impact of a Climate label. The findings of the interviews respective to the developer are summarized in figure 6.1. In this figure barriers and incentives regarding building flood resilient housing are listed.

Overall, it seems that the two commercial developers were more passive and reactive as they were especially reliant on the action of the municipality/government or the housing demand of households, while the social developer (Developer 2) seemed to be actively progressive in creating flood-resilient housing. Developer 3 was most passive as they were quite sceptical of the effect and feasibility of a flood label. Especially, as they considered flood adaptation measures for dyke failure and river flooding not the responsibility of the developer but required large-scale adaption measures implemented by the municipalities/governments. Therefore, it is apparent that even among profit-oriented developers, there is a difference in how flood risks would influence their decision-making. This difference is evident in the role and importance they assign to incorporating flood adaptation in their projects, as well as in the financial impact it could have.

Figure 6.1: Summary of interview results per Developer



Although the stances, barriers and incentives mentioned are inherent to the interviewed developers, they globally illustrate various baseline incentives for incorporating flood resilience in their decision-making:

- Own interest/view of own role in flood resilience: Societal and Commercial (active and passive Commercial).
- Influence of competition: if not requested by the consumer (household or municipality), implementing flood adaptive measures will lead to disadvantages in project acquisition or risk of vacant houses.
- Financial influence (due to consumers, loan lenders and insurance companies):
  - Consumers will give value to flood resilient houses (=covering cost adaption measures).
  - Influence of loan/mortgage lender and insurance companies: This influence is two-fold. First, developers will be able to secure larger loans for flood-resilient projects. Second, mortgages and insurance premiums for flood-resilient homes will be more favourable, incentivizing consumers to purchase these properties. This, in turn, increases the demand and price for

flood-resilient housing.

- Certainty in flood risk data and what is deemed as (acceptable) resilient.

Regarding the investment profiles of the developers, all developers mentioned not to be profit-maximizing. Rather, their main importance was meeting their profit margin and return goals, which often were established at the initiative stage of the project and partly based on the anticipated risk of a project. This supports the theory/hypothesis of developers illustrating satisficing behaviour in their project decision-making.
Evidence of Prospect Theory as an explanation for their satisficing behaviour was not found in the interviews. However, these findings could be constrained by the limited number of questions addressing the risk attitude of the developers or by the framing of the questions. since a variety of literature supports Prospect Theory as an explanation for satisficing behaviour (e.g., Kosavinta, Krairit, and Khang, 2017; Magliocca et al., 2014), the theory is still accepted as a valid explanation and will be incorporated into the ABM model.
The tendency to satisfice around profit margins suggest that profit margins can serve as a suitable reference point for applying Prospect Theory in the ABM model.

Regarding uncertainty in decision-making, it was noted that, even though certainty in demand, revenue and costs were moderately important in their project decision-making, the developers currently did not experience much uncertainty in the situation of developing single-family owner-occupied housing on ”build-ready” land. However, these results regarded prior investments, made before the implementation of a Climate label or heightened awareness of flood risks. One developer noted that their market benefits from predictable behaviour, implying that sudden changes in preferences regarding housing attributes -such as flood risks disclosed through Climate labels- introduce uncertainties in market demand predictions. Moreover, the different views of whether flood risk or a Climate label will alter housing prices substantiate this argument of (increased) uncertainty in market demand (and price) regarding resilient housing due to uncertainty in the preference for such an attribute.

The results above answer SQ2 and SQ3 of this research. Furthermore, the results above helped acquire a more profound understanding of developers' project decision-making and the system in which they operate, therefore, ending the stage of system decomposition. These findings validate various aspects of the theoretical framework established in Chapter 5, including the relevance of the land, capital, and planning markets, and the satisficing behavior that could potentially lead to the continuation of developing conventional housing. Additionally, Developer 3 expressed that a minimalist and conventional development approach would be sufficient, as he did not view it as his responsibility to ensure flood resilience. This finding aligns with the observations of Buckman and Sobhaninia (2022).

In the following chapter(s) of this report, the interview results will be used for the definitive version of the concept- and formalisation. The results can be used as guidelines for creating agents, giving structure to the model and certain results can be used as input for parameters. The model will consequently be used to explore the effect a Climate label has on the distribution of flood risks across new residential housing and whether the continuation of developing conventional houses is evident in this.
Some of the above-mentioned influences on developer decision-making will be explicitly modelled, and others, due to simplification and time constraints, will be more modelled implicitly or even omitted entirely (see Chapter 7).

6.3. Limitations

As mentioned in the introduction, the main limitation of these findings is the sample size of three interviewees. This limited sample size makes it unable to control for bias, such as regional bias, or outliers, such as unique stances. Additionally, the three developers interviewed hold a significant market share in the owner-occupied housing market, meaning the decision-making and behaviour of relatively small developers have not been accounted for. Furthermore, since the interviews were conducted with Dutch developers, the results may have limited generalizability to other contexts.

Besides the limited sample size, the question remains whether the developers interviewed are also representative of the company's decision-making. The three participants were all part of sectors within their company that were concerned with sustainability and climate. Therefore, the results could also include bias toward being more climate-resilient.

Moreover, even though the participants were asked to be truthful in their answers (as compensation they were anonymized), it can never be certain to what degree they were adhering to this. The possibility remains that they answered sensitive questions untruthfully due to company confidentially or to ”save face”.

Furthermore, certain questions were interpreted differently by developers. Moreover, the answers of one developer were not cross-referenced in the interviews of the others. For instance, some barriers mentioned by Developer 3 were not brought up by Developer 1. While Developer 3 might have different perspectives from Developer 1, it cannot be fully confirmed since the researcher didn't specifically inquire about these barriers from Developer 1. This implies that Developer 1 might not have considered such barriers, but could potentially agree with them. Consequently, these two implications resulted in the interview results being less uniform and rigorous.

The above limitations stem from the constrained timeframe of this research, which prevented interviewing a larger number of developers or conducting more extensive development and testing of the questionnaire. It is recommended for future work to revise and reconstruct certain questions in the questionnaire -such as those on risk attitude- and subsequently, to pilot-test the revised questionnaire before conducting the actual interviews. Furthermore, a larger and richer sample size for the interviews would ensure increased validity and control bias and outliers.

7
Formalisation

During this formalisation stage, the previously discussed bounded system and its respective concepts are converted and structured into computer-understandable analogues. Due to time limitations, it is aimed to capture the essence of the housing market and developers' decision-making dynamics. As such, a highly stylized model has been created. This means that only the most important and general elements of the complex system are taken into account, and numerous assumptions are made to strip away non-essential details. In the context of this research, this entails that project-decision-making factors and incentives, as described in Chapter 6.2 (e.g., the influence of competition, banks, and insurance), are simplified, modelled very implicitly, or even omitted entirely. Similarly, concepts of the housing development process, as discussed in Chapter 5.1, are also simplified or excluded.
Creating a highly simplified and stylized model also limits the amount of empirical data involved in the model, resulting in a rather abstract representation.

The papers of Filatova (2015), Filatova et al. (2013), Magliocca et al. (2014), Nikolic (2013), and Parker and Filatova (2008) have consulted for inspiration and guidelines for structuring and formalisation.

This chapter will first start off by providing a global overview of the model's entities -such as the agents, spatial units, and environment- and their respective states and mechanics, followed by a more detailed description of the formalisation of the developer decision-making.
For an extensive and detailed overview of the model's Overview, Design Concepts, and Details (ODD) (Grimm et al., 2006, 2010), as well as the assumptions made, please refer to Appendix D.

7.1. Model Overview

Below, a description of the model narrative can be found. Moreover, figure 7.1 provides an overview of the model entities, their state variables and their respective processes.

7.1.1. Model narrative

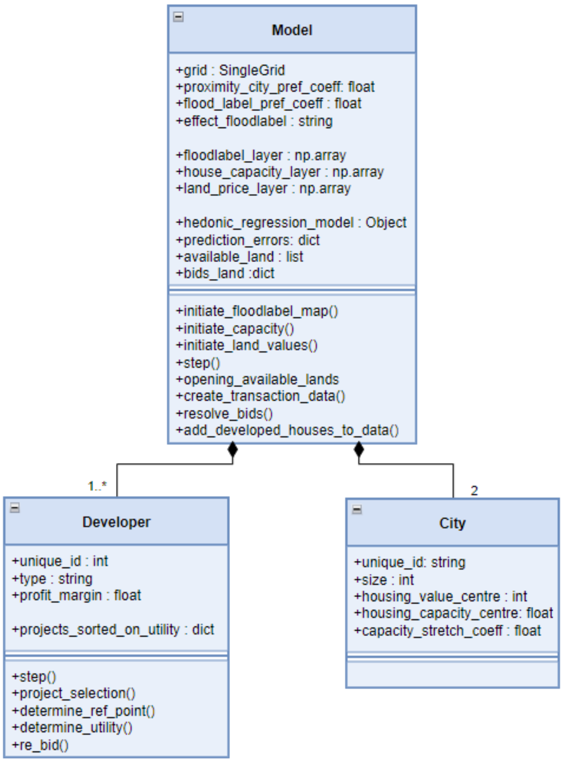
The model has scoped itself to several developer agents that operate in a fictitious and stylized landscape in which there are two cities present: 1. a 'left' city in which demand and prices of houses are high and flood risks are high; 2. a 'right' city that is relatively small, has lower demand and housing prices and is subjected to lower flood risks (see figure 7.2). Even though this landscape is based on very little empirical data, it intends to mimic the trade-off between high housing demand, high flood risks and low housing demand, low flood risks which can, among others, be found in the Netherlands (=Randstad and non-Randstad/East of other Netherlands).
In timestep 1, the Climate label policy is "implemented," and its effects on housing prices become evident.

Due to simplification reasons, developers can only develop houses within two specific cities, and not outside of them. At each timestep, several serviced/"build-ready" plots of land become available for development within these cities. The owners of these lands are not modelled; instead, the land is presented with fixed asking prices determined using the residual land value method.

For each plot of land, developers assess the ”business case” of developing houses by evaluating the potential gains and losses on their expected profit margin (see section 7.2.2 for more detail). Developers can choose between four types of houses: ’regular’ (conventional housing with no adaptation measures), ’small adaptation’, ’moderate adaptation’, and ’large adaptation’, each with its respective costs and reductions in flood risks/labels. In the model, houses are characterized by the attributes ’proximity to city centre’, ’respective city’, and ’flood label’ (which are determined by the inherent flood risks of the location and the potential adaption measures implemented). For simplification purposes, all other housing attributes are assumed to be homogeneous across all types of housing.

After assessing the business case for each land and housing type combination (referred to as a ’project’), the developers place a bid on the combination with the best business case. When all bids are collected, some land properties may receive multiple bids. In such cases, the developer with the highest bid wins the land, while the other developer(s) ”rebid” for the land where their next best business case applies. This process continues until all developers have land to develop. At the end of the timestep, developers ”construct” the houses (not modelled), which means that the houses will be considered ”built” at the start of the next timestep. The entire process of assessing the business case, bidding, rebidding, and ”constructing” occurs within one timestep, which is equivalent to one year.
This process is a simplified version of reality. In practice, assessing the business case of a project and submitting a bid and project plan can be quite time-consuming. Developers do not continuously re-plan and rebid for projects within a short timeframe, such as less than a year. Often, more extensive bidding strategies and project planning are part of this process, particularly after losing a bid. However, for the purposes of this model, the process has been simplified to focus on the core decision-making dynamics within a manageable timeframe.

Figure 7.1: Visualisation of entities, respective state variables and behaviour in the form of a Unified Modeling Language (UML)

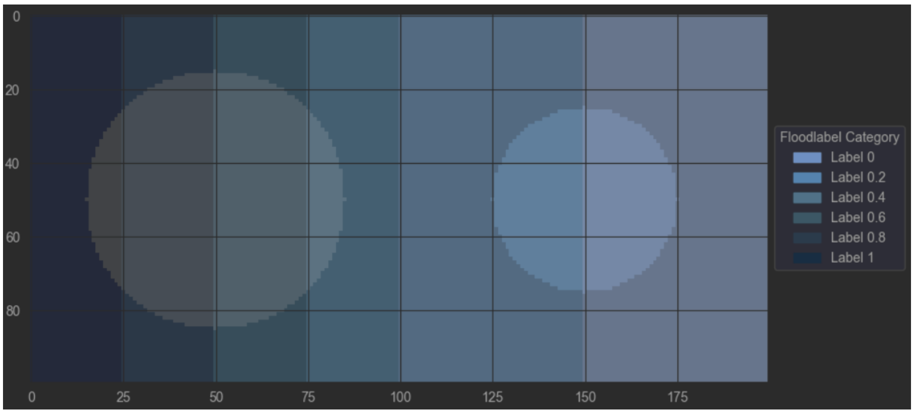


7.1.2. Flood risks and Flood label

The landscape of flood risks/labels in the model is not based on empirical data but is inspired by existing flood maps (**Kolen2023RuimtelijkOmgeving**; Deltares, 2023) to create a gradient from high to low flood risk/label landscape. Flood risks themselves are not explicitly modelled; instead, the Floodlabel a house would have when subjected to the respective flood risks is modelled. The hypothetical Climate

label, established in Chapter 4.3, has six categories that disclose the degree of flood risk to which a house is subjected. The Floodlabel is formalized through labels ranging from 0 to 1, with an interval of 0.2, where Label 0 represents the best rating and Label 1 the worst.
In Figure 7.2, the model grid with the two cities and the flood landscape is illustrated. The landscape has been divided into six levels of flood risk, resulting in the corresponding six Floodlabel categories.

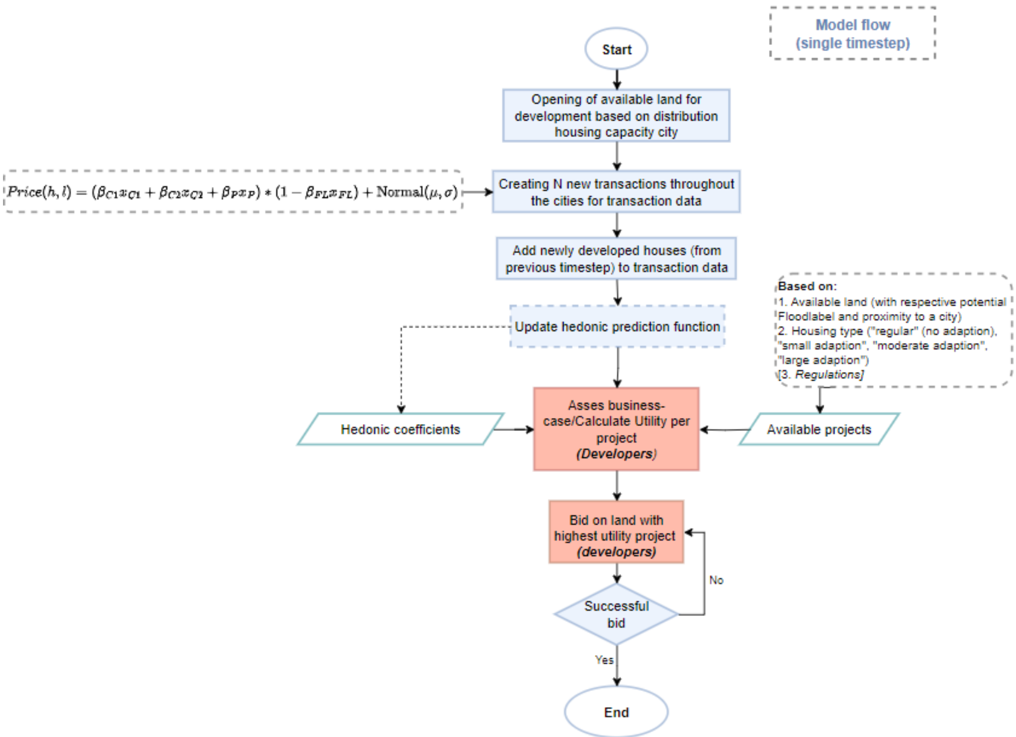
Figure 7.2: Grid model: two cities on a landscape with high to low flood risks



7.2. Main model processes/sub-models

In the below figure (figure 7.3), the global processes within the model and their flow is visualised. These processes have been partly described in the model narrative. In the following sections, the two main processes are discussed: 1.) The setting of transaction prices & the creation of transaction data, which are used to create a hedonic prediction function; 2.) Developers use this prediction function to assess the business case of projects as part of their decision-making. For more details regarding the processes, their mathematical functions and parameters, view Appendix D.

Figure 7.3: Global overview of Model processes represented in a flowchart



7.2.1. Creating transaction data

An essential part of the system in which the developer operates is the transactions occurring within the housing market: the buying and selling behaviour of consumers that determine demand and sale price. Previous ABM models concerning the housing market have demonstrated that ABMs are well-suited for simulating this market (Filatova, 2015; Parker and Filatova, 2008). The ability of ABMs to incorporate adaptive, heterogeneous agents (regarding income and housing preferences) allows for the simulation of the dynamic and strategic nature of the housing market. This capability enables a natural emergence of sale prices through the resulting housing demand and supply.

However, due to time restrictions and because developer project decision-making is central to this research, consumer agents performing buying and selling behaviour were not modelled. Instead, transaction data for sales were generated using a more opaque method, employing functions that assume constant market equilibrium.
The following function represents the market clearing price for a specific housing type at a particular location. (Thereby assuming that the market consistently maintains equilibrium, where demand equals supply.)

$$Price(h,l) = (\beta_{C1}x_{C1} + \beta_{C2}x_{C2} + \beta_P x_P) * (1 - \beta_{FL}x_{FL}) + \text{Normal}(\mu, \sigma) \tag{7.1}$$

The coefficients ($\beta_{C1}, \beta_{C2}, \beta_P, \beta_{FL}$) of the function represent the willingness to pay (WTP) of the consumer for the given respective housing attribute 'city left', 'city right', 'proximity to city centre' and 'Floodlabel category'. According to the urban land use model by Alonso (1964), households choose locations at a certain distance from the Central Business District (CBD) based on the utility they receive from amenities and other consumption goods. For this research model, it is assumed that the city centre is the CBD. Additionally, amenities often increase as one gets closer to the city centre (D'Acci, 2019). This gives rise to the factor 'proximity to the city' (x_P), which aggregates and simplifies these relationships between distance and price. It is assumed that the proximity to the city centre has a linear relationship with house price.
x_{C1} and x_{C2} are categorical variables representing two cities: city left and city right, respectively. These variables of price are multiplied by the 'Floodlabel factor' $(1-\beta_{FL}x_{FL})$ to increase or decrease the price given the Floodlabel category. It is assumed that this factor has a linear relationship with Floodlabel category.
For simplicity, the WTP for the attributes is assumed to be homogeneous for all "consumers". The variation caused by variables drawn from a normal distribution at the end of the equation is intended to mimic variation in transaction prices due to strategic buying and selling.

At the initialization of the model (t=0), transaction price data from the previous 10 years —before implementation of a Floodlabel— is created using function 7.1 to reduce runtime. Every timestep, a number of transaction data points are added to the "historical" transaction data using the price function. The price function does not vary over time, as it is assumed that the WTP for the attributes does not change over time. Only the WTP for a Floodlabel is initially zero before policy implementation, and after implementation, it promptly establishes itself at a fixed value. Subsequently, all new transaction data points will reflect this WTP. Thus, we maintain the assumption of homogeneity in WTP for a specific Floodlabel, as mentioned earlier.

A significant limitation of modelling the housing market in such a manner is that it loses a big part of its dynamic, adaptive and heterogeneous nature. For example, by hard-coding the WTP, sale prices do not react to an excess of supply or demand. Moreover, the assumption of a linear relationship between the 'Floodlabel multiplication factor' and Floodlabel category is a notable limitation , as it assumes linearity in preference/WTP for the Floodlabel categories. (For more elaborate discussion, view section 7.4)

"Prediction" model: Hedonic regression function

Parker and Filatova (2008) provide two approaches on how to model the consumer WTP estimations that appear in developers' profit function. One approach states that boundedly rational developers estimate inductive hedonic demand curves based on information about agent characteristics and recent sales. As in this research's model, a constant market equilibrium is assumed, this approach can be simplified and the sale price of a house given its attributes can be predicted through a singular hedonic regression function.

Every timestep, based on the previous N years of historical transaction data, a hedonic regression function is created (by the model). This function and its coefficients (and the uncertainties around the coefficients) are used by all developers to determine the potential expected revenue $E[Price]$ one could get from housing type h on land l at timestep t. It must the noted that this function is dubbed a ”prediction” function, however, it does not perform any extrapolation.

$$E[Price(h, l, t)] = \beta_0 + \beta_{C1}x_{C1} + \beta_{C2}x_{C2} + \beta_{FL}x_{FL} + \beta_P x_P + \varepsilon \quad (7.2)$$

The description of the coefficients and factors as described under equation 7.1 also applies to the above function.

In essence, the model incorporates ”two” hedonic regression functions (7.1 and 7.2). Initially, the function 7.1 is utilized at the beginning of a timestep, where the consumer WTP for each housing attribute is hard-coded to generate transaction price data points. Subsequently, the second function 7.2 is derived using the resulting transaction data, offering ”estimations” of the predefined WTP per housing attribute meant for revenue forecasts. Prior to the introduction of a Floodlabel, the WTP estimations will logically very closely mirror the actual hard-coded values due to the homogeneity in the first function. However, with the implementation of a Floodlabel, housing transaction prices shift as preferences emerge for flood-resilient houses. Since the hedonic prediction function 7.2 relies on past transaction data, especially during the initial stages, it may inaccurately estimate the WTP coefficient for a Floodlabel. This discrepancy leads to ”mispredictions” in transaction prices and consequently introduces uncertainty in forecasts associated with a Floodlabel category. Over the years, as more transactions reflecting changes in consumer WTP regarding flood risk and labelling are introduced, the hedonic prediction function becomes more accurate in predicting WTP. As developers utilize this function, it mirrors their learning process over time about the change in WTP of consumers, potentially leading to alterations in their development behaviour accordingly.

The function will still very accurately predict the WTP coefficient of proximity to the city centre, as no change occurs in the preference for such. This is arguably valid, as the interview findings state that currently—without Floodlabel—developers experience very little uncertainty in their price predictions for conventional housing.

7.2.2. Developer decision-making: business case of where & how to build

Figure 7.4: Flowchart: Developer (decision-making)

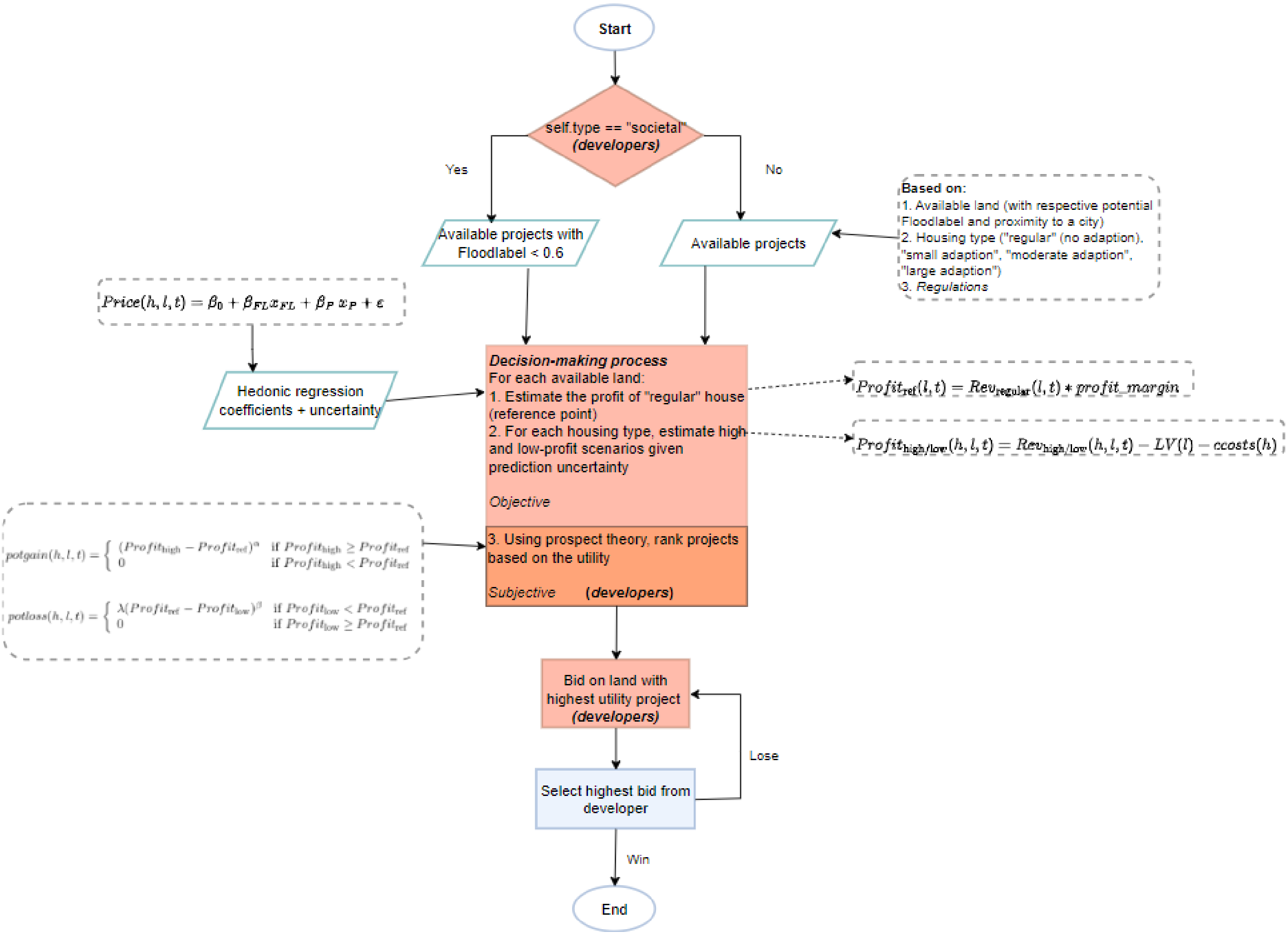


Figure 7.4 visualises the processes a developer agent performs each timestep. These processes and the agent's attributes are based on the literature discussed in 5 and the findings of the interviews with the developers.
Developers are divided into commercial and societal developers. Their distinction is simplified by having societal developers only pursue projects that would result in at least a Floodlabel score of 0.6 or lower.

For each available land and housing type combination, every developer assesses the potential gains and losses in terms of profit. They do so by using the hedonic regression function (7.2) the model provides them to asses the potential revenue (price=revenue) for a 'high' and 'low' revenue scenario, accounting for the prediction uncertainties σ (equations 7.3 & 7.4).
As a result, developers are quite simple because they rely solely on their prediction model's estimates for that year. They do not take into account that people's preferences might have changed beyond what the prediction model coefficients suggest.

$$E[Rev_{\text{high}}(h,l,t)] = E[Rev(h,l,t)] + \sigma \tag{7.3}$$

$$E[Rev_{\text{low}}(h,l,t)] = E[Rev(h,l,t)] - \sigma \tag{7.4}$$

The developers can take two reference points to measure gains and losses. The first reference point is the profit a developer was accustomed to making before the implementation of the Floodlabel $(t = 0)$ from building a conventional 'regular' house on land l. The second reference point, while similar to the first, considers the influence the Floodlabel has on the housing price by taking into account the potential profit of constructing a 'regular' house on land l at timestep t (equation 7.5). This makes the second reference point a more adaptive reference point.
These approaches are based on interview findings where developers indicated they aim to meet their pre-established project profit margins. Furthermore, since developers are currently most familiar with building without flood adaptation measures, building 'regular' houses is assumed to be their status quo, and they could treat potential profits of such housing as endowments (Kahneman, Knetsch, and Thaler, 1991)

$$\text{Profit}_{\text{ref}}(l,t) = Rev_{\text{regular}}(l,0) \times profit\_margin \quad \text{OR} \quad \text{Profit}_{\text{ref}}(l,t) = E[Rev_{\text{regular}}(l,t)] - LV(l) - ccosts(h) \tag{7.5}$$

$$E[\text{Profit}_{\text{high/low}}(h,l,t)] = E[Rev_{\text{high/low}}(h,l,t)] - LV(l) - ccosts(h) \tag{7.6}$$

The high- and low-profit scenarios are determined by subtracting the costs of land LV and construction costs $ccosts$ from the respective revenue (equation 7.6). In this calculation, it is assumed that land value remains constant over time and that landowners are solely concerned with breaking even, thus they do not strategically adjust their asking price. Furthermore, due to time constraints and for simplicity, the aspect of project financing through a loan and associated costs such as interest rates are not included in the model.
These profit scenarios are subsequently utilized to compute the potential gains $potgain$ and losses $potloss$ through a risk-aversion value function conforming to prospect theory, in which $alpha$ is 0.89, $beta$ 0.92 and lambda -2.29 (Kavya and Christopher, 2023) (equation 7.7 & 7.8).

$$potgain(h,l,t) = \begin{cases} (E[\text{Profit}_{\text{high}}] - \text{Profit}_{\text{ref}})^{\alpha} & \text{if Profit}_{\text{high}} \geq \text{Profit}_{\text{ref}} \\ 0 & \text{if Profit}_{\text{high}} < \text{Profit}_{\text{ref}} \end{cases} \tag{7.7}$$

$$potloss(h,l,t) = \begin{cases} \lambda(E[\text{Profit}_{\text{ref}}] - \text{Profit}_{\text{low}})^{\beta} & \text{if Profit}_{\text{low}} < \text{Profit}_{\text{ref}} \\ 0 & \text{if Profit}_{\text{low}} \geq \text{Profit}_{\text{ref}} \end{cases} \tag{7.8}$$

After establishing the potential gain and loss, the Utility for the respective land and housing type combination is determined by using the following function (7.9).

$$E[Utility(h,l,t)] = \frac{potgain(h,l,t)}{potgain(h,l,t) + potloss(h,l,t)} \tag{7.9}$$

All land and housing type combinations are ranked from highest to lowest utility, excluding those with negative expected returns. Subsequently, developers "bid" on the land with the highest expected utility (for more detail, see Appendix D). If multiple potential projects have a Utility of 1 (zero potential loss), one of the projects is chosen. If they are either the sole bidder or the highest bidder, they acquire the land and start "construction". Otherwise, they continue to bid for the second-best land opportunity (with the constraint that they cannot rebid for the same land with a different housing type). Developers will always bid for land, even if buying the land means delivering on their profit margin ($Utility(h,l,t)$ =0). This process of evaluating the business case of a project occurs at each time step and involves calculating and comparing the price/revenue and respective profit of a single house. Therefore, the potential quantity of sales is not considered in their decision-making. However, each developer "constructs" a fixed number of multiple houses for each project. In the consecutive timestep, the houses are "completed" and the developer can start a new project. The new houses are added to the aforementioned historical transaction data, by using equation 7.1.

7.3. Model Evaluation

The model has been implemented in Python 3.10, using the package Mesa. The Python packages used for the model and their respective version can be found in the requirements.txt file in the repository (https://github.com/AnnedeKoeijer/Master_Thesis_ABM)
The model and its processes have been verified through unit testing to check if it does what it conceptually intended to do. For a full verification analysis, view Appendix E.

The validation for stylized models is mainly theoretical, ensuring internal logical consistency and coherence with general principles. The section below (7.4) highlights some of the validation issues of the concept and model formalisation. Moreover, in Appendix D.4 a list of the model assumptions can be found.

7.4. Limitations model and future recommendations

Throughout this chapter, multiple limitations resulting from the degree of model simplification and stylising have been mentioned or hinted at. Below, a complete analysis of the model's structural limitations, their implications on validity and potential recommendations for future work are given.

In this research and model, certain assumptions are made regarding the design of a Floodlabel and its impact on sale prices. The Floodlabel's effects on demand and price are assumed to be uniform and linear. Firstly, it is assumed that areas inherently deemed "high and dry" could receive the same 'high' Floodlabel score as a house in a flood-vulnerable area with extensive adaptation measures. Since there's no definitive Floodlabel design, this assumption may not necessarily be unrealistic, however, time will tell if it is valid. Secondly, the model does not account for heterogeneity in willingness-to-pay (WTP). Incorporating such heterogeneity could enhance the model's coherence with general housing market principles and enable the simulation of spatial heterogeneity. For instance, individuals accustomed to living in flood-resilient areas may not necessarily give increased value to flood-resilient (high climate label) houses, thereby causing minimal changes in housing prices in such resilient areas.
Moreover, as previously mentioned, a linear relationship is assumed between the 'Floodlabel multiplication factor' and Floodlabel category, which is formalised as an equal interval scale. In reality, flood risks are given as ratio scales, e.g. 1/30, 1/300, 1/3.000 etc. Assuming a linear relationship between the 'Floodlabel multiplication factor' and Floodlabel category is a notable limitation of this model, as it assumes linearity in preference/WTP for the Floodlabel categories. Furthermore, this means that the Floodlabel can only have a strictly positive or negative effect on the price (i.e., a scenario where a high Floodlabel positively affects the price while a low Floodlabel negatively affects it cannot be created.) In future work, Floodlabels should take on an ordinal scale and each given an individual WTP coefficient.

Another notable limitation of this model is the "hard-coding" of consumer WTP for housing attributes to create transaction price data. Modelling the housing market transactions in such a manner results in it losing a big part of its dynamic, adaptive and heterogeneous nature. In future work, this should be replaced with consumer agents who use a budget-maximizing utility function to determine their WTP for certain houses and strategically form their bids. This can be achieved by employing one of the many approaches described in Parker and Filatova (2008).
Moreover, the hedonic prediction function does not extrapolate and is always based on transactions from a fixed number of previous years. In future work, diverse prediction functions could be used. This would allow for heterogeneity, as different developers could employ different prediction functions.

In future models, more sophisticated social developers could be created. Although their options for building locations are limited by their interest in flood resilience, they evaluate the remaining options primarily from a financial perspective. Furthermore, the model could be expanded to include even more passive developers regarding flood adaptation, as observed in the interviews.

Even though the influence of competition in tenders was identified in the interviews as a factor in decision-making about building flood-resilient housing, it was not considered in this model. In future work, this aspect can be included by allowing developers to "sense" each other's bids and/or strategically align their development plans (in terms of housing type) to ensure their bids are accepted. This could be linked to Prospect Theory, as the developer's risk attitude could be crucial: for example, they are willing to take on more profit-uncertain projects to increase their chances of winning the tender.
Lastly, the amount of learning and adaptability in the developer agents is very limited. In addition to

the aforementioned strategic planning and bidding, a process of learning from previous failed projects could be added. This could potentially be linked to risk attitude and Prospect Theory through mental accounting mechanisms.

Overall, to further validate the model's dynamics and findings, an empirical analysis of the actual Flood-label effect after implementation should be performed. Based on this data, an empirical model should be created to reflect the observed effects more accurately

8

Experiments

In this chapter, the experimental design for this research and its results are given and discussed. For the design of the experiments (DOE), the systemic procedure described in Lorscheid, Heine, and Meyer (2012) is followed. Following this procedure would increase the transparency of simulation model behaviour and the effectiveness of reporting simulation results.

To produce and analyse simulation data, so that SQ4 and the main research question can be answered, the model analysis process can be divided into two phases: a pre-experimental phase and the experimental analysis. Part of the pre-experimental phase is building a bridge between the simulation model and the simulation experiment. On this basis, the actual simulation experiment is planned and conducted. (Montgomery, 2009)

8.1. Pre-experimental phase: Objectives and relevant variables

In the pre-experimental phase, the objective of the simulation experiment is formulated. In the context of this research, the objective of the experimentation is to answer SQ4 *"Given a housing value shift caused by Climate labelling, what are the consequences of decision-making dynamics of real-estate developers in terms of where and how (adaption measure(s) or not) new residential houses are built?"*. This will in turn help answer the main research question for this research.

Furthermore, in the pre-experimental phase, the model variables are classified into dependent, independent and control variables. Below, the classification is given:

Dependent
To answer the SQ and main research question, the spatial location of the developed houses and the respective flood risks of that location (the 'where') and the housing type (the 'how') are key. This leads to the aggregate result of the resulting flood risk/label given the 'where' and the 'how' of the developments. These are the dependent variables of the model as they provide answers for the where and the how (SQ4) and the distribution of flood risks across new residential houses (main research question).

Independent variables
The independent variables are the $flood\_label\_pref\_coeff$ used to create the magnitude of housing price shift due to introduction of a Floodlabel; $effect\_floodlabel$, which determines whether the effect of a Floodlabel on price will be positive (resilient houses will increase in price) or negative (vulnerable houses will decrease in price) and, therefore, whether this price shift will be interpreted as a gain or loss. Lastly, as the reference point used to evaluate gains and losses plays a crucial role in shaping developer decision-making dynamics, we analyse the effect of two modelled reference points (a reference point of regular/conventional housing before implementation of a Climate label and -the more adaptive- reference point of conventional housing after Climate label implementation).

Control variables
The control variables are all the remaining variables in the model. Their value will remain fixed to their base value as described in Appendix D.1.2.

8.2. Experimental design

After defining the model variables, they must be transferred into factors, factor level ranges, and response variables for the simulation experiment. Response variables are essential for measuring the experimental outcome, i.e., estimating the dependent variables (Lorscheid, Heine, and Meyer, 2012). The response variables for this research include the 'mean number of housing types developed' overall simulation replications (the 'how'), which will be assessed over time (mean count per timestep) and at the end of a run (mean total count). Additionally, the response variables include the 'mean number of projects per floodlabel category for the location (not accounting for possible adaptation measures)' over all simulation replications (the 'where' regarding flood risks) and the 'mean number of projects per floodlabel category after adaptation measures' over all simulation replications (the 'where' and 'how' regarding flood risks). These variables will also be assessed over time and at the end of a run.
To study the aforementioned independent variables, they are transferred into factors, each with their respective level value ranges. The independent variable $flood\_label\_pref\_coeff$ is not transferred into a factor but is used as a scenario for the experimentation. Here, it is assumed that providing houses with a climate label will affect the price of the house. The value for the scenarios will be a 10% increase or decrease. This value is based on the average price effect of actual flooding (e.g. Bin and Landry, 2013; Contat et al., 2023; Niu, 2024; Ratnadiwakara and Venugopal, 2020).
The other two independent variables are transferred into factors. Furthermore, in the interview with the soil and water system expert, they mentioned that a key incentive for ensuring that developers include flood resilience in their development would be regulation from the government or municipality (see Chapter 4). Similarly, some findings from the interviews with developers also indicated that government regulation would incentivize them (see Chapter 6). Due to these findings, a policy specifying where and how developers can build is also analyzed. This policy stipulates that developers must build with a Floodlabel score of 0.6 or lower. This policy variable is also transferred into a factor consisting of two levels ('implemented' and 'not implemented'). Since all the independent variables can only take on two values, a 2k factorial design is used for experimentation:

Table 8.1: Experimental setup: 2k factorial design, with 'Floodlabel price effect', 'PT reference point' and 'Where&How Policy' as factors

	Floodlabel price effect	**price effect magnitude**	**PT Reference point**	**Where&How Policy**
Experiment0: Base	-*	0%	regular_before_floodlabel	no
Experiment1	negative	-10%	regular_before_floodlabel	no
Experiment2	negative	-10%	regular_after_floodlabel	no
Experiment3	positive	+10%	regular_before_floodlabel	no
Experiment4	positive	+10%	regular_after_floodlabel	no
Experiment5	negative	-10%	regular_before_floodlabel	yes
Experiment6	negative	-10%	regular_after_floodlabel	yes
Experiment7	positive	+10%	regular_before_floodlabel	yes
Experiment8	positive	+10%	regular_after_floodlabel	yes

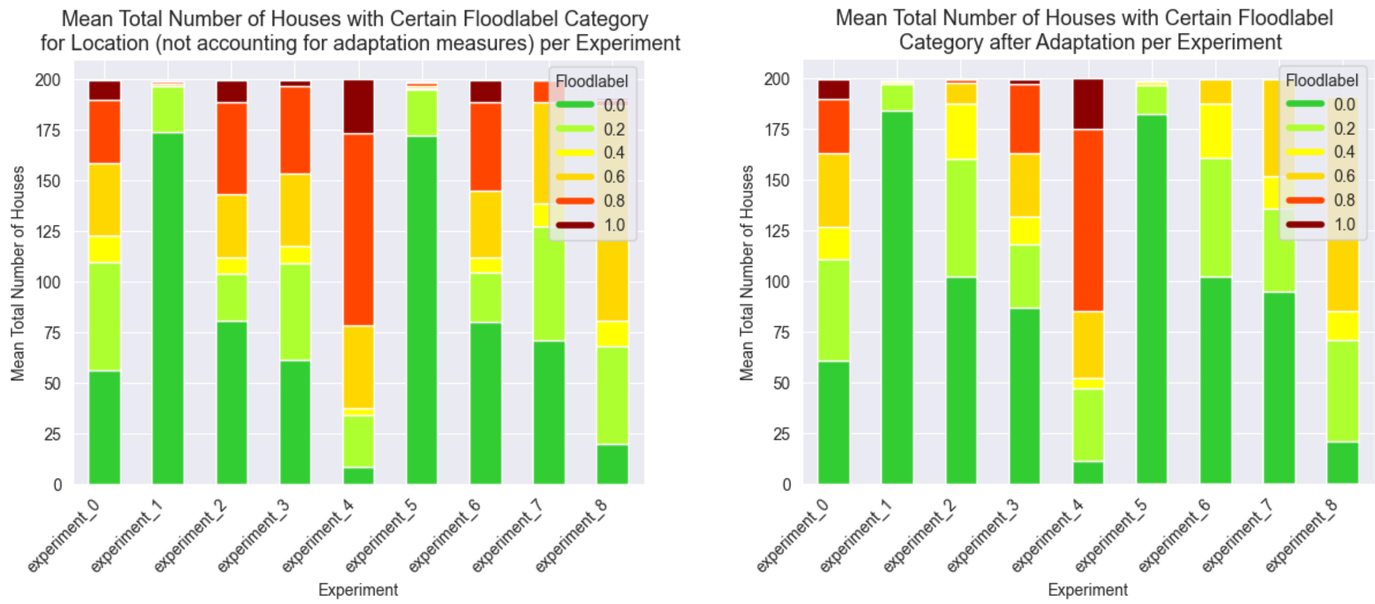
Experiment0 is the baseline experiment in which a Climate label is not introduced (therefore there is not price effect). This experiment functions as an illustration of the current and conventional behaviour of developers and can be used as a reference point to assess the effects of the various factorial design points/experiments.

Besides the response variables, additional, secondary outputs are tracked to gain a deeper understanding of the effects of the independent variables and understand the (emergent) behaviour of the model. These outputs are the developers' predicted WTP/preference for a Floodlabel, the predicted price given a Floodlabel category and the uncertainty surrounding the predictions. These outputs can be found in Appendix F.2.

8.2.1. Experiment run details

Each simulation run is executed for 20 timesteps (=20 years). No model "warm-up" time is included as the housing market is "hard-coded" (see 7.2.1), therefore, no form of "balance" has to first be established in the model. Moreover, the Climate label is introduced at the start of timestep 1.
The number of replications/simulation runs per experiment is 160. This number is established by analysing the coefficient of variance for an increasing number of simulation runs (see Appendix F.1).

8.3. Results



(a) (b)

Figure 8.1: Aggregate results of Floodlabel distributions across new residential houses per experiment

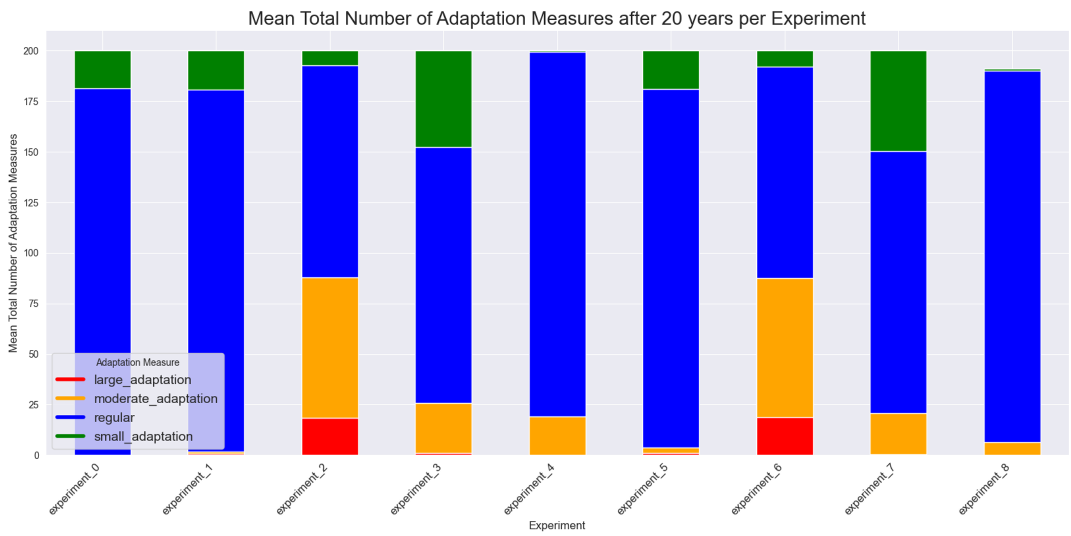


Figure 8.2: Mean total number of housing types build at the end of the runs (after 20 years) per Experiment

Figure 8.1 and figure 8.2 visualize the mean aggregate results per experiment. In figure 8.1a, for the baseline experiment, it can be seen that houses are developed almost uniformly throughout the entire map. This uniformity is reflected in the distribution of the mean number of houses with a certain flood label/risk, which corresponds to the size of the city in the respective flood zone (Floodlabel zone 1.0 and 0.4) and the amount of available land throughout the map (Floodlabel zone 0.0 and 0.2 are located in the left city, where more land is available for development, resulting in relatively more development than in Floodlabel zones 0.6 and 0.8). Moreover, in the baseline, approximately 10% of houses are built with small adaptation measures.
Relative to the base case, in all following experiments, the houses are on average subjected to less flood risks / lower floodlabel (figure 8.1b). The expectation of this is experiment 4.

According to the aggregate results, the 'negative' price scenario, where developers use the reference point of regular houses adapted to the price change due to Climate labelling (experiments 1 and 5), results in the most development in the flood-resilient areas Floodlabel zone 0.0 and 0.2 (figure 8.1a) and results in the most resilient houses (figure 8.1b).

The positive price effect (experiments 3 and 4) significantly increases the number of houses developed in flood-vulnerable areas (figure 8.1a) and the overall flood label score is worse (figure 8.1b) compared to the 'negative' price effect counterpart (experiments 1 and 2).
Changing the PT reference point to regular housing adaptive to price changes due to Floodlabelling significantly affects the distribution of flood risks across the new residential houses. For both the 'positive' and 'negative' price scenarios (experiments 2 and 4), houses are developed in more flood-vulnerable areas, and the gross Floodlabel score is overall worse compared to their PT reference point of 'regular housing before Floodlabel' counterpart (experiments 1 and 3). In the 'negative' scenario (experiment 3), developers at least build a significant number of adaptation measures, while this remains relatively small in the 'positive' scenario (experiment 4) (figure 8.2).

The 'where and how' policy seems to have little to no difference in the case of a 'negative' price effect (experiments 1 & 2 and policy experiments 5 & 6). However, in the case of a positive scenario (experiments 3 & 4 and policy experiments 7 & 8), they do have an effect. In the cases where the PT reference point is the profit of regular houses before the implementation of a climate label (experiments 3 and 7), implementing the policy significantly reduces the number of houses planned to be developed in areas with Floodlabel 0.8 (figure 8.1a). Moreover, it decreases the number of houses receiving Floodlabel 0.8 and improves the overall Floodlabel score (figure 8.1b).
In the cases where the PT reference point is the adaptive reference point (experiments 4 and 8), this same effect is evident but even more significant, as in experiment 4, the number of houses built in flood-vulnerable areas (Floodlabel zones 1.0 and 0.8) is larger.

Below, some of the results per experiment are highlighted in more detail and discussed in terms of how they have come to be. This is achieved by, among other methods, analyzing the dependent variable distributions per timestep/year. By doing so, we aim to better understand these aggregate results.

8.3.1. Experiment0: Baseline

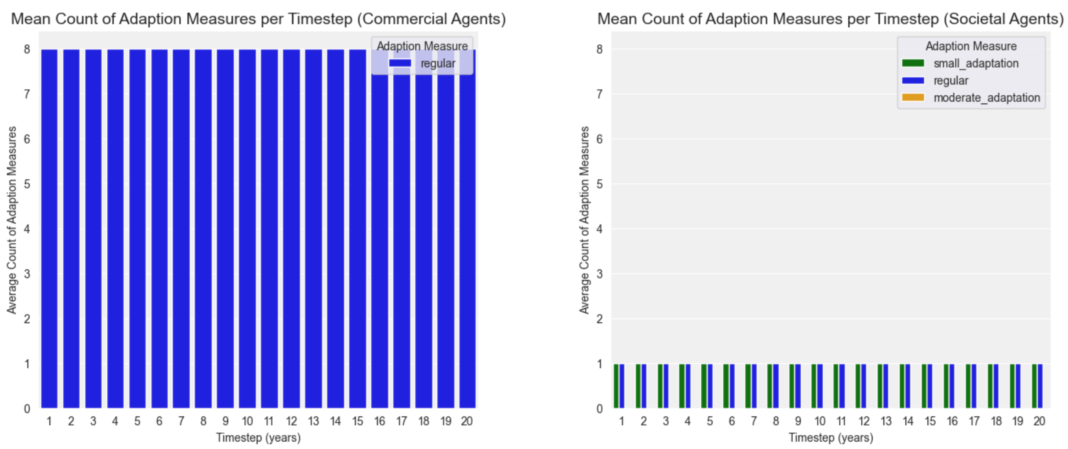


Figure 8.3: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

In the baseline scenario, since the Climate label is not introduced, developers can accurately predict the sale prices for the houses, leading to limited uncertainty in their decision-making (see Chapter F.2 for more details).

Figure 8.4 visualizes where and how developers have developed houses at timestep 15 for the baseline scenario. It shows that houses are developed almost uniformly throughout the two cities. The most common housing type built is regular/conventional housing, with a few societal developers building houses with small adaptation measures throughout both cities (see Figure F.4).

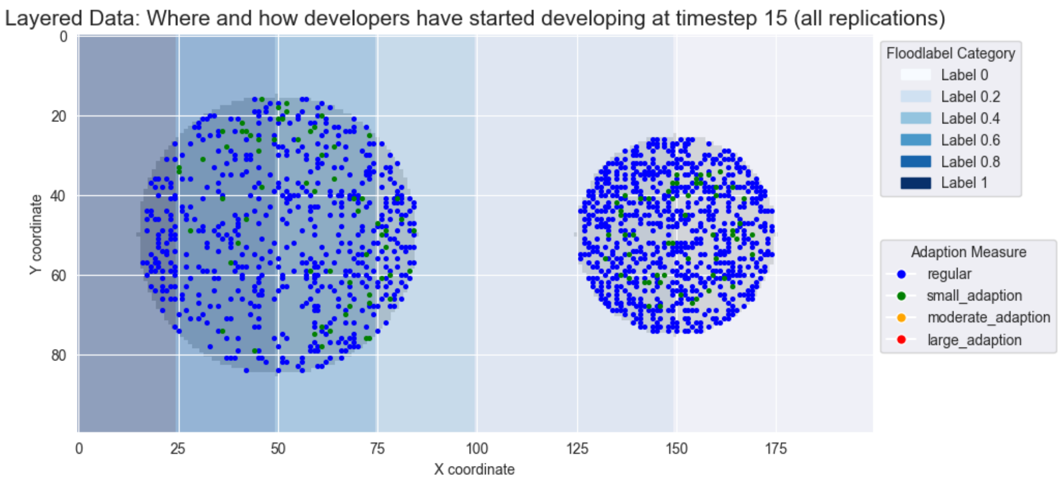


Figure 8.4: Where and how developers have built houses across the grid at timestep 15 for all 160 replications

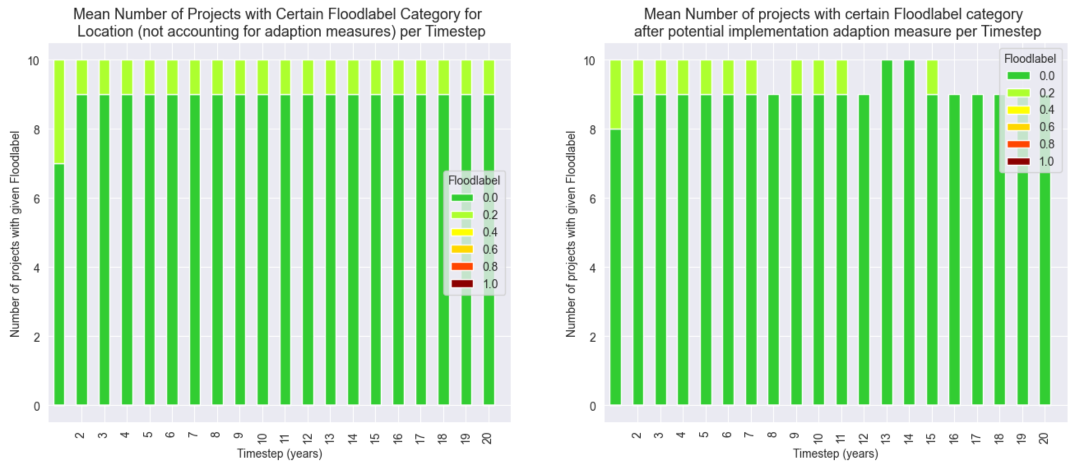
Societal developers build houses with small adaptation measures because the expected utility for both regular houses and houses with small adaptation measures for all projects is 1. As one of the two is then randomly chosen, this results in societal developers developing houses in a 50/50 ratio of regular to small adaptation. The utility for both types of houses being 1 is due to the 7% profit margin that societal developers have (compared to 10% for commercial developers). Since the price of land is calculated using, among other factors, the 10% profit margin, societal developers can more confidently achieve their 7% profit margin (see equation 7.6 and equation D.2). This allows them to cover the slight extra costs for small adaptation measures while still having certainty in achieving their profit margin reference point. Commercial developers do not build with adaption measures as this logically does not result in any increased profit, resulting in them delivering on their profit margin reference point.

The reason why developers build uniformly throughout the cities instead of choosing projects closer to the city centre —where one might expect higher profitability— is because the PT reference point is location-bound. This means that when assessing the utility for a project at location (x, y), the PT reference point is the profit achievable from building a regular house at that location. Therefore, since there is almost no uncertainty in estimating the willingness to pay (WTP) related to proximity to the city, proximity to the city does not influence decision-making.
In Figure 8.4, it can also be seen that societal developers build houses with small adaptation measures in locations that are not subject to flood risk. This occurs due to a simplification in the model mechanism where societal developers assess the business case for (small) adaptation measures even in zones that do not require them.

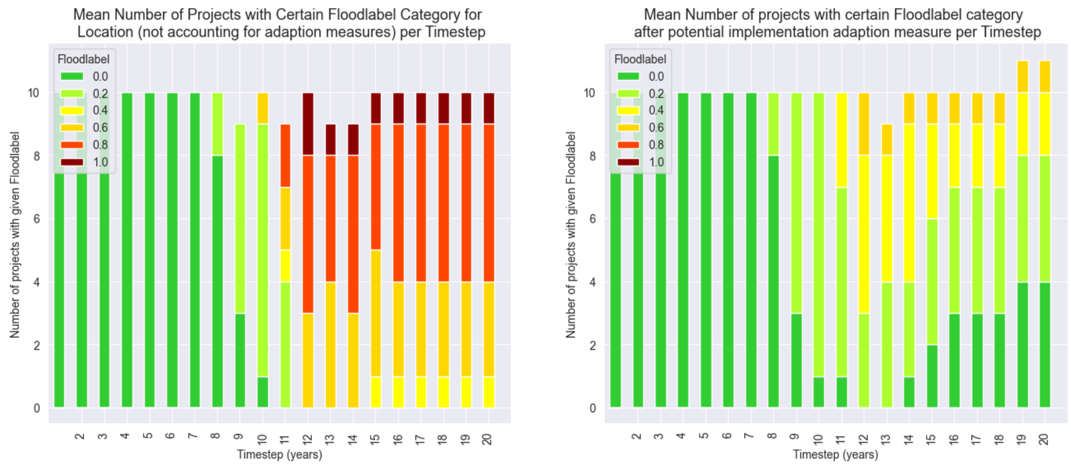
8.3.2. Experiment1 -Experiment 4: Floodlabel price effect

Experiment1 -Experiment 2: negative price effect

In the negative price effect scenario, after the Climate label is introduced, the prices for all houses -besides those in the Floodlabel zone 0- drop in price. induces uncertainty in the profit estimations of the developers. The higher the flood risk/label, the more uncertain profit predictions are in those areas. This uncertainty is highest at the beginning of the run, immediately following the implementation of the Climate label, and it diminishes over time, reaching nearly zero after approximately 11 years. (view Appendix F.2 for more details)
In both experiments 1 and 2, developers initially build in flood-resilient areas during the first 10 years, without implementing any adaptation measures, as they have the most certainty in achieving their profit margin reference point in these areas (figure 8.5). However, when the uncertainty diminishes, the developers in experiment 2 start developing in flood-vulnerable areas (view figure 8.6b). Despite beginning to incorporate adaptation measures, the overall Floodlabel scores for the houses are worse than those in experiment 1 (figure 8.5b). In experiment 1, the initial development patterns remain consistent. Below, the mechanics behind both reference points are dissected further to understand this emergent behaviour:



(a) Experiment1: reference point regular housing before Floodlabel

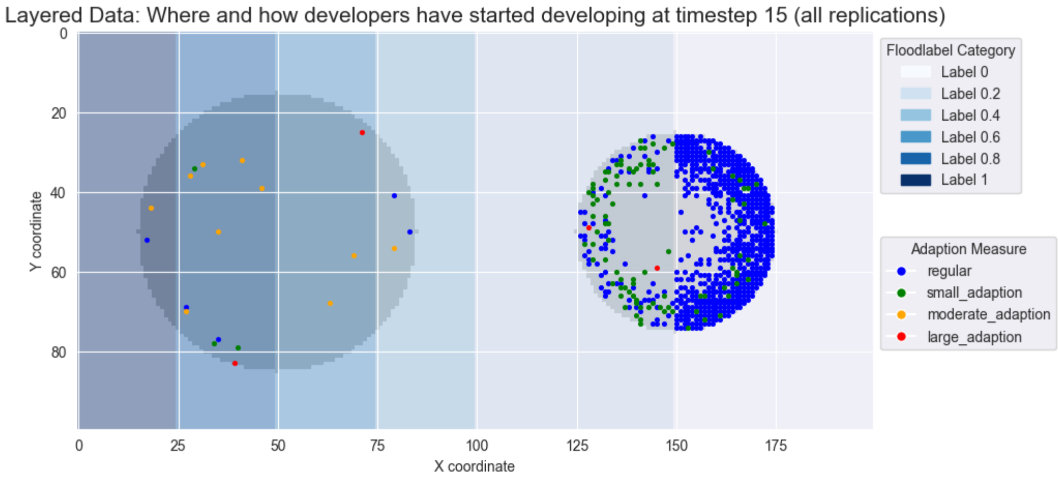


(b) Experiment2: reference point regular housing adapted to price change due to Floodlabel

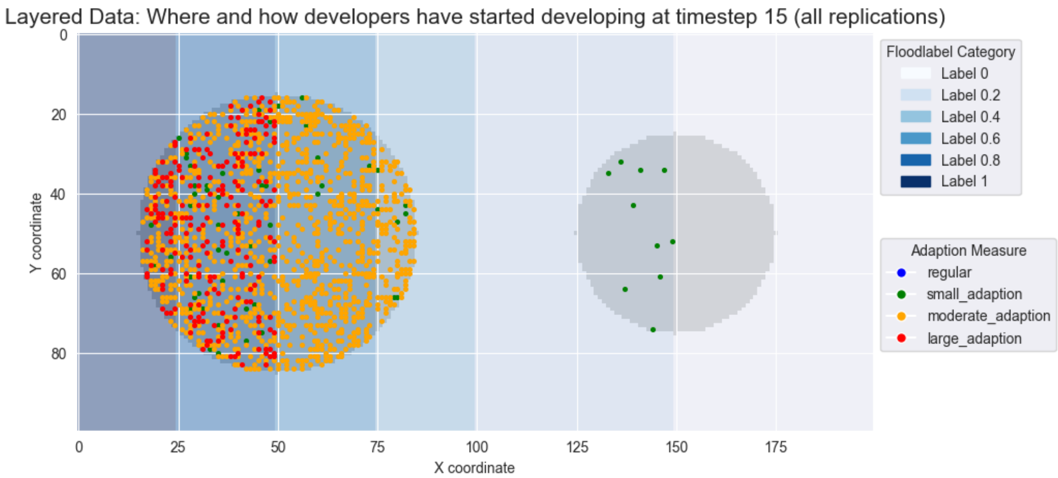
Figure 8.5: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep for both reference points

Profit regular housing before influence Climatelabel: Using this reference point and under a negative price scenario, developers consistently opt to build in areas where a regular house would receive a Floodlabel of 0.2 or 0. This constant development pattern in flood-resilient areas can initially be attributed to the relatively lower uncertainty mentioned previously. However, it is the land value that plays a more crucial role, causing developers to maintain this development pattern. As the revenue for these locations declines, and due to the initial land value being based on the revenue before the influence of the Floodlabel, developers are forced to give up more and more on their profit margin if they build there. Since their profit margin reference point is also based on the profit of (regular) houses before the influence of a Climate label, the expected profit for flood-vulnerable houses often falls below their profit margin reference point, resulting in a loss even when there is no uncertainty in price predictions. Therefore, developers choose locations where the expected revenue is closest to the revenue it had before implementing a Climate label, as this strategy minimizes their losses.
In figure 8.6a, it can be seen that some development happens in Floodlabel zone 0.2. These developments are done by societal developers who have more margin to build there (and with small adaption measures) due to their profit margin being 7%, as explained in experiment1.

Profit regular housing adaptive to price changes due to Climate label: When using this reference point, the results appear more sensitive to changes in price and the associated prediction uncertainties. In the initial years, all developers—including societal developers—focus on building in the most flood-resilient areas. In contrast to the previous reference point, when the uncertainty diminishes, the development patterns of the developers shift. This is due to their adaptive reference point that accounts



(a) Experiment1: reference point regular housing before Floodlabel



(b) Experiment2: reference point regular housing adapted to price change due to Floodlabel

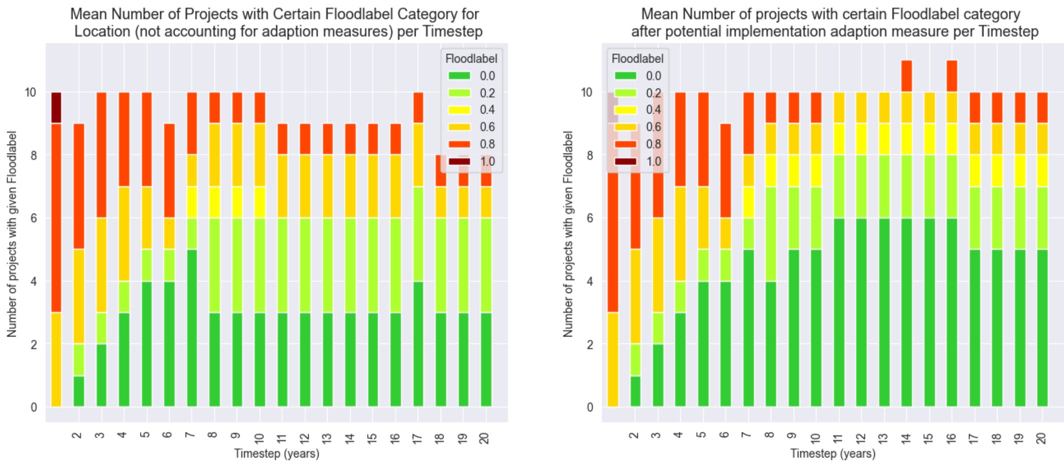
Figure 8.6: Where and how developers have built houses across the grid at timestep 15 for all 160 replications for both reference points

for the price drop in flood-vulnerable areas. As seen in figures 8.5b, and 8.6b, when the prediction uncertainties are approximately zero, developers surprisingly concentrate their building efforts in flood-vulnerable areas (Floodlabel zones 1.0 to 0.6). They do, however, incorporate moderate and large adaptation measures.

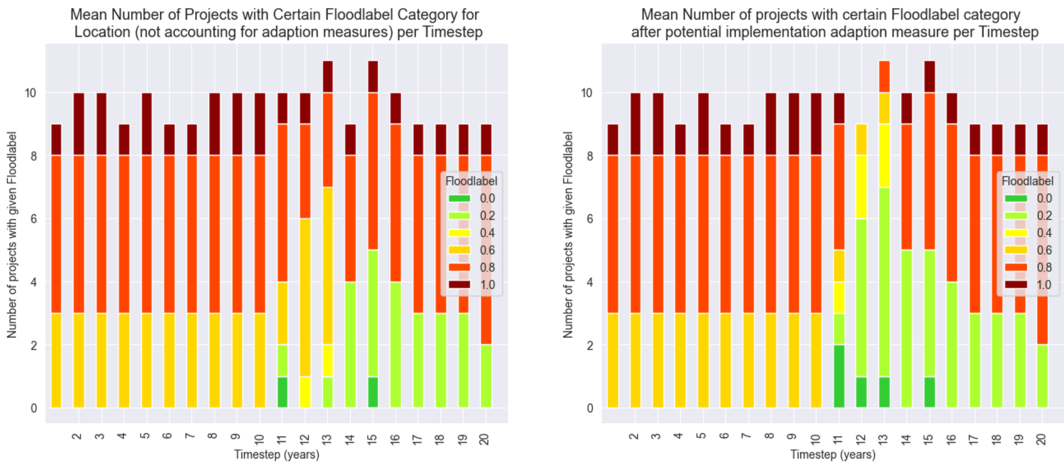
The reason developers do not also build in the more resilient right city, despite the almost complete absence of prediction uncertainty, is due to the reference point being a regular house at the given location. They avoid building in Floodlabel zone 0 because the only housing type they can build there is a regular house (the Floodlabel cannot be improved), which also serves as their reference point. As prediction uncertainties approach but never fully reach zero, there remains a slight chance of incurring losses relative to the reference point when building regular houses. Building with adaptation measures can provide more certainty in achieving the reference point if the additional revenue gained outweighs the respective costs. This seems to be the case in the left city, but not in the right city. This discrepancy is likely due to the left city having generally more expensive houses, resulting in a relatively larger price increase when upgrading the Floodlabel compared to the right city.

Experiment3 - Experiment4: positive price effect

A positive price effect significantly increases the flood risks to which newly developed houses are subjected. This is especially evident in the first 10 years (figure 8.7). This increase in flood risk is due to the uncertainty in predictions. Unlike the negative price effect scenario, this uncertainty drives developers



(a) Experiment3: reference point regular housing before Floodlabel

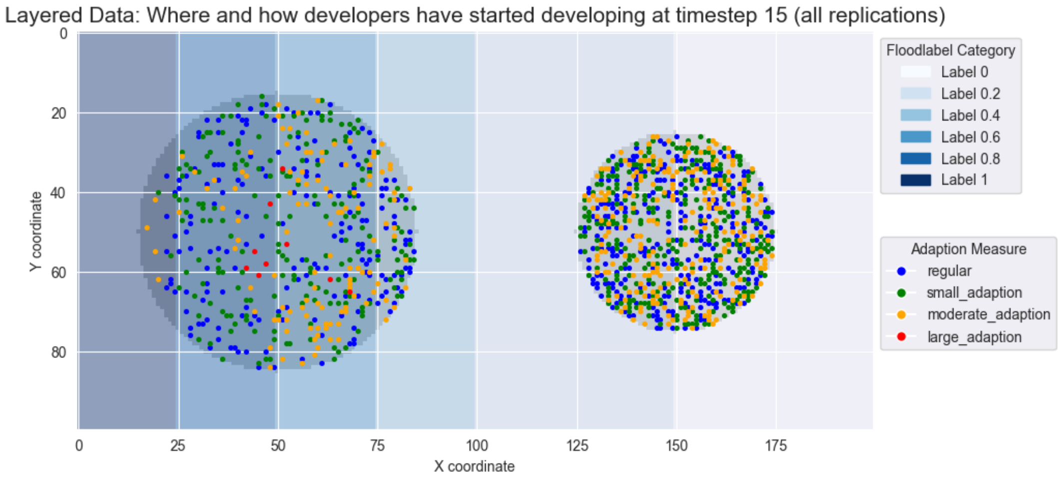


(b) Experiment4: reference point regular housing adapted to price change due to Floodlabel

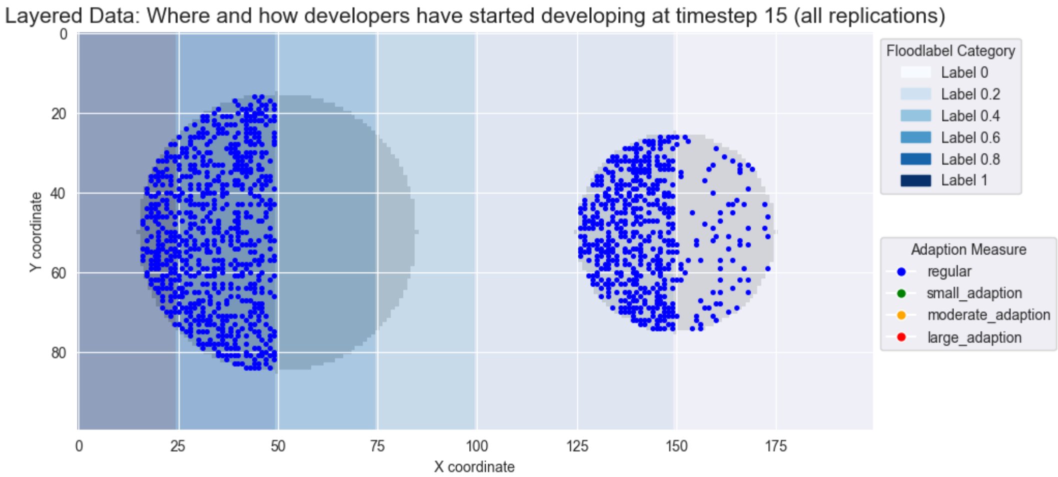
Figure 8.7: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep for both reference points

to gravitate towards more vulnerable areas because predicting the profit for these areas is more certain due to experiencing relatively little price change.
Yet, in the positive price effect scenario, developers using the profit of regular houses before the implementation of a Climate label as their reference point(figure 8.7a) do adjust their development patterns over time (compared to the results of experiment1). This adjustment occurs because almost every project becomes significantly more profitable relative to the period before the implementation of the Climate label (their reference point). As developers are satisficing, they start building in a nearly random and uniform manner across both cities(figure 8.8a). Floodlabel zone 1.0 is however generally secluded from development (figure 8.7a) because the price of regular houses in this area has remained unchanged (thus presenting a slight chance of losses). While building with adaptation measures in this area would increase the gains relative to the reference point, it would not be as profitable as building in more flood-resilient areas. Moreover, the developers do not implement large adaptation measures in their houses.

In Experiment 4, as the uncertainty around the price predictions diminishes, developers begin building in more resilient areas and develop more resilient houses (figure 8.7b). From timestep 11 to 13, the developers adopt a development pattern similar to that observed in experiment 3 (figure 8.7, right figures). However, interestingly, at timestep 14, developers shift their development focus exclusively to the left side of both cities (figure 8.8b). This shift is caused by a sudden spike in estimated Floodlabel WTP, followed by increased uncertainty in predictions regarding Floodlabel 0.4 and 0.6 (view Appendix F.2). Since this uncertainty is greater than the uncertainties for other Floodlabels, these areas are con-



(a) Experiment3: reference point regular housing before Floodlabel



(b) Experiment4: reference point regular housing adapted to price change due to Floodlabel

Figure 8.8: Where and how developers have built houses across the grid at timestep 15 for all 160 replications for both reference points

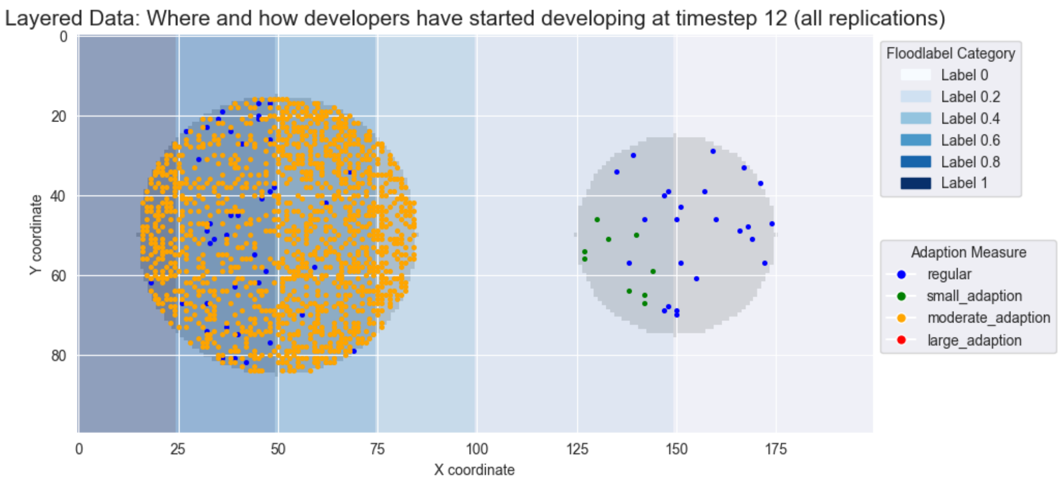


Figure 8.9: Experiment4: Where and how developers have built houses across the grid at timestep 12 for all 160 replications for reference point regular housing adapted to price change due to Floodlabel

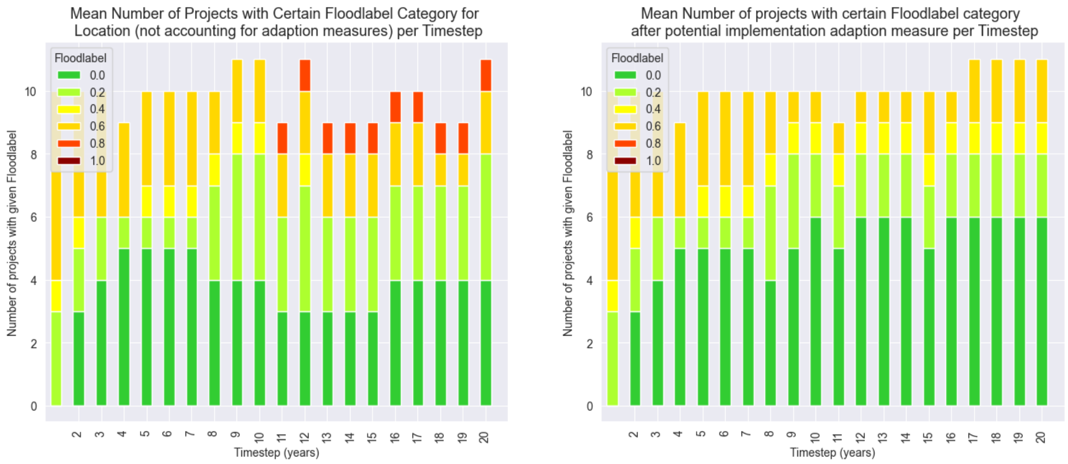
sistently avoided for development. This spike in uncertainty is likely caused by the hedonic prediction function failing to adequately control for intercorrelation, which significantly occurs as there is a spontaneous increase in buildings in the left city with houses receiving a Floodlabel of 0.4 during timesteps 11 and 12. Although this spike is a result of a model limitation, it effectively highlights the importance of uncertainty in developer decision-making.
When viewing the development patterns at timestep 12, when the price prediction uncertainty for all Floodlabels becomes approximately zero, a development pattern similar to that in experiment 2 becomes evident.

8.3.3. Experiment5 - Experiment8: Where&How policy

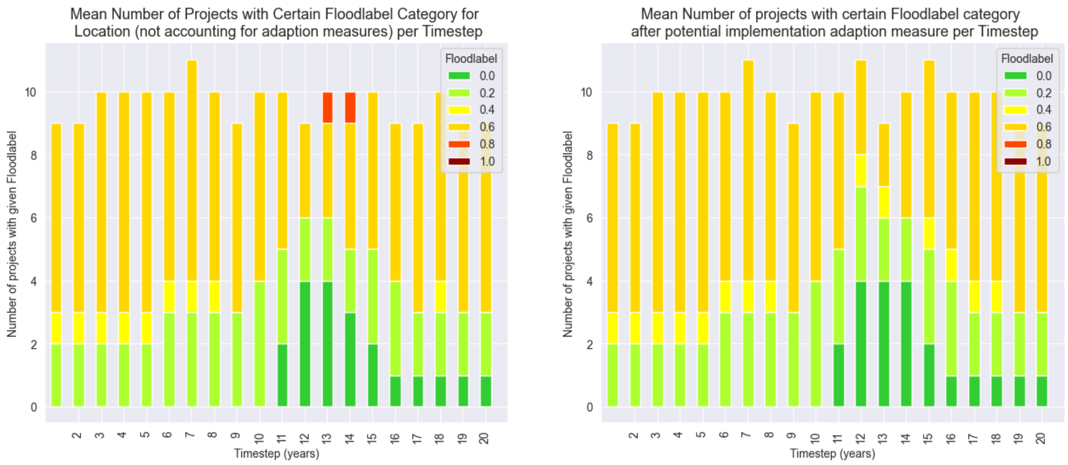
Experiment5 -Experiment6: negative price effect

Since the policy does not alter the model results compared to experiments 1 and 2, these will not be discussed in further detail. For the plots regarding the results of these experiments, refer to Appendix F.2.

Experiment7 - Experiment8: positive price effect



(a) Experiment7: reference point regular housing before Floodlabel

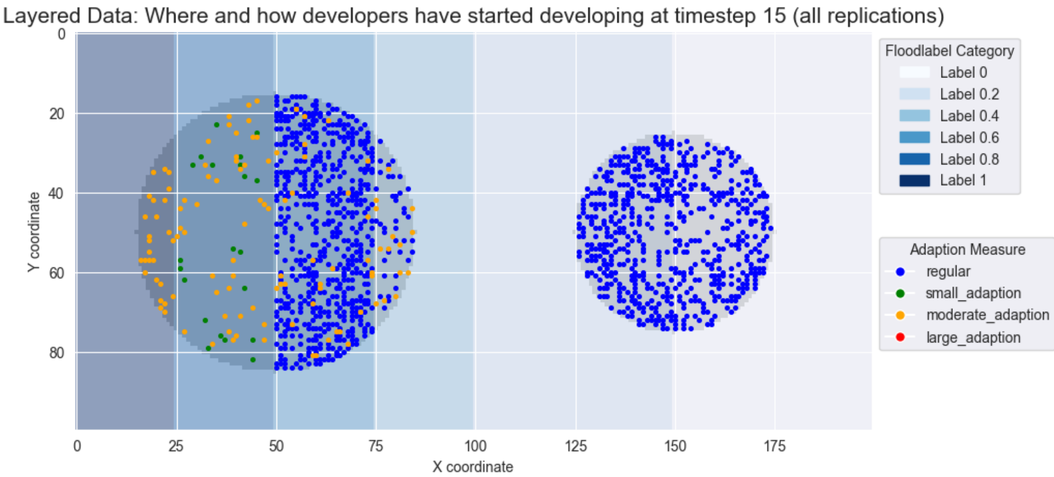


(b) Experiment8: reference point regular housing adapted to price change due to Floodlabel

Figure 8.10: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep for both reference points

As aforementioned, implementing a policy that requires developers to build houses that, with adaptation measures included, receive a Floodlabel of 0.6 or lower does have an impact in a positive price effect scenario.
In Experiment 7, the previously almost uniform development pattern has decreased as developers are no longer allowed to build regular houses in Floodlabel zone 0.8 (8.10a and 8.11a). They are only

(a) Experiment7: reference point regular housing before Floodlabel



(b) Experiment8: reference point regular housing adapted to price change due to Floodlabel

Figure 8.11: Where and how developers have built houses across the grid at timestep 15 for all 160 replications for both reference points

permitted to build in this zone if the houses incorporate at least a small adaptation measure. However, the policy has not led to an overall increase in developments incorporating adaptation measures.

Moreover, in figure 8.11b, it can be observed that developers are building across both cities again. This occurs because, in this policy experiment, the spike in prediction uncertainty is smaller. However, developers predominantly build regular houses because the estimated willingness to pay (WTP) for Floodlabel is lower in this experiment (view Appendix F.2). Additionally, the prediction uncertainty approaches zero slightly less effectively than in Experiment 4.

Validation of the above results can be found in E.2.

8.4. Sensitivity analysis

Certain control variables have potential validity issues, as some of the respective parameters are based on assumptions. For example, in this experimentation, we assumed a 10% shift in price due to climate labeling, based on the average price effect of actual flooding. To analyze the robustness and increase the validity of the model's results, a regional sensitivity analysis was performed using a One-Factor-At-a-Time (OFAT) approach, assessing sensitivity to variations in price effect magnitude. The detailed results can be viewed in Appendix G.

It was observed that the model's results are significantly sensitive to variations in the price effect magnitude. The results indicate that as the willingness to pay (WTP) for flood-vulnerable houses increases, and consequently the price effect magnitude increases, the overall flood resistance of the houses also increases. This is likely due to the fact that in scenarios with a higher price effect magnitude, the additional revenue gained from building such houses outweighs the costs, resulting in an increase in utility as the profit margin reference point is achieved with greater certainty.
Moreover, the sensitivity analysis results indicate non-linearity between the output of flood risk distribution across new houses and the input for price effect magnitude. This suggests the possibility of a tipping point or threshold effect, where small changes in the input lead to large changes in the output. The tipping point is most likely the threshold where building with adaptation measures becomes more financially beneficial than building regular houses.

The sensitivity analysis performed for this research is subjected to numerous limitations, as it was conducted for only one variable (Jafino et al., 2021; ten Broeke, van Voorn, and Ligtenberg, 2016). Future work should incorporate other variables and consider varying multiple variables simultaneously. To achieve this, a global sensitivity analysis should be performed additionally, which can capture nonlinear and complex interactions.

Discussion and Conclusion

The consequences of climate change come in many forms, a few being sea levels rising and increasing rainfall, leading to escalating flood risks. However, many are not aware of the flooding risks and their potential effect on housing, and this risk information is currently not accounted for in housing prices. This study explored a flood information disclosure policy, namely the proposal of giving individual houses a 'Climate label', to raise awareness and incorporate flood risks into property values, potentially altering market dynamics. The focus of this study laid in describing and exploring how such a policy influences real-estate developer's decisions of where and how (with what kind of adaption measures, if any) to build new single-family owner-occupied residential houses. Moreover, what the resulting distribution of flood risks these houses would be subjected to. The main research question was:

"How would a flood risk information disclosure policy influence the decision-making dynamics of real-estate developers and, consequently, the distribution of flood risks across new residential houses?"

To answer this research question, an Agent-Based Model was created using empirical methods such as literature studies and interviews with three real-estate developers and a soil- and water system expert. Below, are the four sub-questions of this research and their answers are discussed separately, followed by the answer of the main research question.

Answering research questions

SQ1. ***"Which information will the Flood label disclose and in what degree of granularity?"***

As the main research question aimed to be answered in the context of a Climate label, it was important to first establish the manner in which such a label would disclose flood risk information. In the Netherlands, the policy under discussion is a mandatory formal Climate label for all houses. However, the design and implementation of this label are still debated. An analysis of existing Climate labels—created by independent organizations and currently primarily used by banks and insurance funds—revealed a variety of designs. The number of categories ranges between four and nine, and the definitions of each score/category differ among them.
Moreover, from an interview with a soil and water system expert—who had a good grasp on the Climate label debate—and from grey literature, it was derived that there appears to be a dichotomy between proponents of assigning a Climate label to individual houses and those who prefer it to be implemented on an area scale. The latter group raises concerns about the possible unjust consequences and feasibility of such a policy.
Given the numerous potential designs for a Climate label, a hypothetical Climate label was established, adopting the "proponent side" of the property-level Climate label and consisting of six flood risk categories. Using a hypothetical Climate label introduces certain assumptions and potential validity issues and limitations for the results derived from the ABM (see Chapter 8.4 for more information).

SQ2. ***"What are relevant project decision-making dynamics of developers?"***

Literature indicates that different types of developers assign varying levels of importance to factors influencing their decision-making processes. This research focuses on private developers who are profit-oriented, engage in build-to-sell practices, and therefore have a short time horizon regarding their investments (Ge, 2017; Zöllig and Axhausen, 2011). The three interviewed real-estate developers were categorized as two commercial developers and one societal developer. The commercial developers were primarily profit-driven, whereas the societal developer, while also profit-driven, considered societal and climate factors in their decision-making.

Literature on developer decision-making describes how developers, despite being profit-oriented, do not necessarily aim to maximize profit. Instead, due to significant uncertainty in price predictions and

housing development processes, developers exhibit satisficing behaviour (Magliocca et al., 2014; Mohamed, 2006; Storbjörk, Hjerpe, and Isaksson, 2018). According to Kosavinta, Krairit, and Khang (2017) and Magliocca et al. (2014), the economic behavioural theory of Prospect Theory (PT) (Kahneman and Tversky, 1979) provides a complementary explanation for this satisficing behaviour.
Interviews with the three real-estate developers confirmed this theory, as they mentioned they do not aim to maximize profit but rather to satisfice around a pre-established profit margin. This suggests that profit margins (for conventional housing) serve as a reference point in applying PT.

When asked about uncertainty in decision-making, the developers noted that they currently experience very limited uncertainty in demand and price estimations for serviced/”build-ready” land. However, these results pertain to prior investments made before the implementation of a Climate label or heightened awareness of flood risks. One developer noted that their market benefits from predictable behaviour, implying that sudden changes in preferences regarding housing attributes—such as flood risks disclosed by a Climate label—could introduce uncertainties in market demand predictions. More uncertainty was experienced with speculative land. For the ABM model, only build-ready land was modelled.

SQ3. ***”What are the current perspectives and barriers of real-estate developers on building with flood adaptation measures and how do they anticipate that changing after implementation of a Climate label?”***

As mentioned under SQ2, two types of developers were identified: societal and commercial. The societal developers had a more progressive perspective on building flood-resilient houses, while commercial developers seemed more passive, primarily building flood-resilient houses when it was financially advantageous.
The following (contextual) factors influencing the decision to build more flood-resilient houses were identified during the interviews with developers:

1. Own interest/view of own role in flood resilience: Societal and Commercial.
2. Influence of competition: if not requested by the consumer (household or municipality), implementing flood adaptive measures will lead to disadvantages in project acquisition or risk of vacant houses.
3. Financial influence (due to consumers, loan lenders, and insurance companies):
    - Consumers valuing flood-resilient houses, covering the cost of adaptation measures.
    - Influence of loan/mortgage lenders and insurance companies: This influence is two-fold. First, developers will be able to secure larger loans for flood-resilient projects. Second, mortgages and insurance premiums for flood-resilient homes will be more favorable, incentivizing consumers to purchase these properties. This, in turn, increases the demand and price for flood-resilient housing.
4. Certainty in flood risk data and what is deemed as (acceptable) resilience.

Factor 1 would not be directly influenced by a Climate label, as it indicates that societal developers will build flood-resilient houses out of their own interest. Only if a Climate label significantly increases the profitability of houses would commercial developers be persuaded to build with adaptation measures. Similarly, Factor 2 would only be resolved through increased profitability in flood-resilient housing or by regulations from the municipality, which would level the playing field. Thus, the factor through which a Climate label could potentially influence developers’ decision-making the most is Factor 3: financial influence.
If executed properly, a Climate label could be a beneficial tool to help provide certainty and standardization regarding flood-resilient housing (Factor 4).

Based on the answers to SQ1 to SQ3, the ABM was created. However, due to time limitations, a highly simplified and stylized model was created in which the developer and their decision-making were central. Due to these simplifications, decision factors such as competition and the influence of loan/mortgage lenders and insurance companies were implicitly modeled or omitted entirely.

SQ4. ***”Given a housing value shift caused by Climate labelling, what are the consequences of decision-making dynamics of real-estate developers in terms of where and how (adaption***

measure(s) or not) new residential houses are built?"

For the ABM, two PT reference points were modelled, both based on the profit margin for a conventional/regular house, which represents the developers' status quo (Kahneman, Knetsch, and Thaler, 1991). The first reference point is the profit currently gained from regular houses before the implementation of a Climate label. The second is a more adaptive reference point that considers the potential profit of a regular house given the housing price shift due to the Climate label.
The effect of a 10% gain (for the most flood-resilient houses), or 10% loss (for the most flood-vulnerable houses), combined with one of the two PT reference points was analysed. This resulted in four experiments to test the effect of a housing value shift.

Relative to the base case (no Climatelabel scenario), only in a negative price effect scenario using the reference point of profit before the Climate label did developers build more frequently in flood-resilient areas. In all other three experiments, they build in equal or more flood-vulnerable areas. However, in all other three experiments, the developers were incentivized to implement more adaptation measures. Particularly in a negative price scenario using the Floodlabel adaptive reference point, there was a notable increase in moderate and large adaptation measures, especially in the left, more affluent city. This indicates that, given a price decrease of 10, more affluent and vulnerable cities are prioritized because 1) the expected additional revenue from adaptation measures outweighs their costs, and 2) greater gains can be achieved by building in flood-vulnerable areas with adaptation measures. A larger housing price decrease would resolve this as -due to their satisficing nature- developers would also be satisfied with building in less affluent cities.
Interestingly, this pattern was significantly less pronounced in the positive price effect counterpart experiment. This was likely due to the WTP for Floodlabel being estimated slightly lower on average in the positive price effect experiment, resulting in scenarios where the expected additional revenue from adaptation measures did not outweigh the costs. This sensitivity in the distribution of flood risks across new houses to the magnitude of the shift in housing value was corroborated in a sensitivity analysis.

As alluded to above, the different reference points can lead to completely divergent results regarding where and how developers build. The adaptive Floodlabel profit reference point resulted in developers building in more flood-vulnerable areas and constructing more flood-vulnerable houses compared to the other reference point.
Furthermore, uncertainty in price predictions following the drop or increase in housing values had a significant impact on development patterns. In the negative price effect experiments, this uncertainty caused developers to predominantly build in flood-resilient areas, as these provided the most certainty in achieving their profit margin reference point until the uncertainty diminished after several years as developers learned about the change in consumer preference regarding flood risk/label. In the positive price effect experiments, the opposite occurred: in the initial years, developers predominantly built in flood-vulnerable areas.

Four additional experiments, which included a policy mandating the development of houses with a Floodlabel score of 0.6 or lower, were conducted, as interviewees identified regulations as an incentive for building more flood-resilient houses. Only in the positive price effect experiments did this policy result in developers building in significantly less flood-vulnerable areas, but not incorporating more adaptation measures. This is likely due to the estimated additional revenue from adaptation measures not outweighing the costs, causing developers to prefer building in more resilient areas.

The societal developers, despite being previously identified as more progressive in ensuring flood-resilient housing, did not exhibit markedly different development patterns compared to commercial developers.

Answering main research question

Multiple factors and barriers have been identified as playing a role in the decision of developers to incorporate flood resilience into their projects. Among these, the potential financial effect that a Climate label could have on housing prices and demand appeared to be the most influential in incentivizing developers to build in flood-resilient areas or incorporate flood adaptation measures. Moreover, a small but significant number of developers were found to be progressive in their stance on developing flood-resilient housing, even in the absence of financial incentives.

Behavioral theories suggesting that developers exhibit satisficing behavior, with Prospect Theory providing an explanatory framework, were identified in the literature as significant in developer decision-making behavior and were validated through interviews with real estate developers.

Using this information, a stylized ABM was created to explore development patterns given a housing value shift due to the implementation of a Climate label. From the results, it can be concluded that a housing value shift due to flood risk disclosure can cause a change in the development patterns of new residential houses. However, the distribution of flood risks is highly dependent on the magnitude of the price shift, whether developers perceive it as a gain or loss, and the reference point they use in their project decision-making to assess gains and losses.
In a negative price effect scenario—perceived as a loss—developers, when faced with profit prediction uncertainty, tend to build highly flood-resilient houses during the initial uncertain years. Conversely, in a positive price effect scenario —perceived as a gain— developers tend to build highly flood-vulnerable houses. The magnitude of the housing value shift determines whether the additional revenue (if predicted correctly) from building with flood adaptation measures outweighs the costs, potentially adding certainty in achieving one's reference point and resulting in the implementation of the adaptation measures. The choice of reference point is crucial in determining where and how developers build, as it establishes the point of profit satisfaction. For example, large adaptation measures, even when they would relatively increase profit for developers, were rarely implemented given the reference point of regular housing.
Developers' personal importance placed on climate and societal consequences had a minor effect on the distribution of flood risk across new residential housing.

Due to the highly simplified and stylized ABM used for this research, there are significant caveats to these results. For example, this research was conducted in the context of a hypothetical Climate label, with significant assumptions made regarding its design and effects on housing prices. These assumptions, along with other limitations and recommendations, are more thoroughly discussed in the next chapter.

Scientific relevance

Much literature discusses the implications of flooding and flood risks on the existing housing stock. However, significantly less literature addresses how actors responsible for the supply of new houses in the housing market, such as real estate developers, are influenced by flood risks or their effect on housing value (Oyetunji et al., 2023). Studies focusing on the perspective and response of developers to climate change in the context of urban planning are rare (Storbjörk, Hjerpe, and Isaksson, 2018). This study contributes to the limited body of literature examining the impact of flood risk management policies on the supply of new housing and the extent to which relevant actors, such as developers, incorporate flood resilience into their decision-making processes. Existing literature emphasizes the need for financial incentives to ensure that flood resilience is integrated into developers' decision-making processes. Through interviews with real-estate developers, financial gain was confirmed as a relevant incentive for including flood resilience in their housing developments.

In the studies by Colby and Zipp (2021) and Dubbelboer et al. (2017), which examine the influence of a national flood insurance scheme on the housing stock in flood-prone areas, both found an increase in houses developed in these areas due to their profitability. Similarly, the findings of this research indicate that, in most scenarios, developers tend to build in more flood-vulnerable areas following a housing value shift. However, this research also shows a willingness to build with adaptation measures, as long as it compensates for the costs, potentially leading to an increase in overall flood resilience in new houses.

From this research, it can be concluded that when flood information disclosure causes a shift in housing value, flood risks are taken into account in developer decision-making. The consequences of such decisions can be better understood through behavioural theories of satisficing behaviour and Prospect Theory.

This research was conducted in the context of a Climate label as a flood risk information disclosure policy, with assumptions made regarding its design and its effect on housing value. These assumptions, such as uniformity and linearity, were simplified for the ABM (see Chapter 8.4 for the limitations).

This notably limits the external validity of the research findings. However, the goal of this study was not to empirically evaluate the influence of a flood disclosure policy on the supply of new residential houses, but rather to describe its potential influence on developer decision-making and to explore the consequences for the distribution of flood risks across new residential houses.
This research contributes to the fields of flood risk management, housing development, and policy-making. It helps fill the gap regarding how a flood information disclosure policy could alter the flood risk new houses are subjected to by understanding real estate developer decision-making.

Moreover, the limited existing literature on flood labeling predominantly focuses on its effectiveness in stimulating households to invest in property-level flood precautionary measures (Davids, Boelens, and Renaat De Sutter, 2021; Hartmann and Scheibel, 2016; Meyer and Hartmann, 2023). This research adds to this limited body of flood labeling literature and suggests that flood labeling could also be an effective measure in stimulating developers to invest in property-level flood precautionary measures.

Societal and Policy relevance

This research contributes to the ongoing debate on organizing climate-proofing interventions and aids policymakers in implementing more sophisticated policies to foster a climate-conscious housing market. Creating a more resilient housing stock is of great societal importance, as houses represent the most significant asset for homeowners. If not dealt with properly, these assets could endure great damages due to climate risks, resulting in abrupt price drops, which could subsequently reverberate throughout the broader economy and financial system.

The findings of this research provide a deeper understanding of how developers can be incentivized to build more flood-resilient houses. This research highlighted the significance of the financial effects of a flood information disclosure policy in influencing developers' decisions.
Although this research pointed out that an information disclosure policy could effectively alter housing development patterns, it is crucial to consider its impact on developer decision-making. This study emphasizes the need to assess not only the objectivity but also the subjectivity in developer decision-making when determining the potential effects of policies intended to capitalize on risk or any negative shifts in housing value. When designing such policies and determining their potential effects on the supply of new residential properties, it is essential to carefully establish their potential financial impact and how real-estate developers will perceive it. The results of this research indicate that a negative price effect could lead to distinctly different and more favourable outcomes than a positive price effect scenario. In a positive price effect scenario, such a policy could result in "worse" development patterns than in a do-nothing scenario. This could be steered in the right direction by implementing additional policies that restrict building in vulnerable areas. However, it seems likely that such a policy alone would be effective enough, potentially rendering a flood information disclosure policy redundant.
Furthermore, this research demonstrates that developers adopt different development patterns when faced with uncertainty in achieving their profit margin reference points. This uncertainty is particularly pronounced in the initial years following the implementation of a climate label and gradually decreases as developers learn about the changed consumer preferences regarding flood risk/label. In a positive price effect scenario, this could result in more unfavourable development patterns during the initial years. Therefore, when implementing a flood disclosure policy, it is crucial to accompany it with additional measures to further incentivize developers during these uncertain times. For example, offering subsidies for incorporating adaptation measures in construction could be an effective strategy.

Moreover, a flood information disclosure policy could also raise equity issues. The simulation model results showed that, while prices increased in both cities, the affluent city was prioritized for housing development as housing prices for resilient houses increased more significantly there, thus outweighing the costs of building with adaptation measures. If this happens, it could be resolved by offering subsidies for building with adaptation measures in less affluent areas.

Other barriers to building flood-resilient housing identified in this research were not perceived to be solvable by a Climate label alone. However, these findings suggest various other policies that could help create a more climate-conscious housing market. For example, regulations regarding building with adaptation measures seem promising as they could level the playing field for developers who currently face financial disadvantages when intending to build with adaptation measures in a competitive market.

Limitations and Recommendations for future work

Due to time and resource constraints, the methods used in this research were not able to be executed to full sophistication. Assumptions and simplifications had to be made throughout this work, resulting in certain limitations and validity issues for the results. Below, per the performed method the applicable limitations are discussed, their implications for the found results and recommendations for future work.

8.5. Research context

This research has been conducted in the context of a hypothetical Climate label as a flood risk information disclosure policy. Moreover, this research focuses on single-family owner-occupied houses as residential properties. Case studies or research conducted in specific contexts face challenges regarding the external validity and generalization of the results (Yin, 2013).
The Climate label is a property-level rating based on the climate risks (including flood risks) a house is subjected to. Flood risk information disclosure policies can come in many forms and do not necessarily have to be limited to individual houses. The analysis of the discourse around the Climate label showed the diversity in potential implementations of such a label. Whether a policy discloses flood risks on an area-wide or individual housing scale and how it communicates this information (e.g., through "stamping" a rating or disclosing flood maps) can affect individuals' perceptions, potentially having different implications for the housing market.
Interviews with real estate developers revealed that decision-making for the development of multi-family rental houses could differ significantly. The interviews indicated that there is currently limited uncertainty in the development of single-family owner-occupied homes, whereas there is significantly more uncertainty for multi-family rental homes.

The generalizability of this work could be tested by examining the effects of other flood risk disclosure policies that aim to capitalize on flood risks in housing value. Furthermore, this research could be extended to include multi-family rental houses.

8.6. Interviews

As mentioned in Chapter 6.3, the main limitation of the interviews, was the small sample size of three interviewees, all from companies with a large market share in the owner-occupied housing market. Additionally, the participants were from sustainability-focused sectors within their companies, potentially introducing a bias towards more climate-resilient perspectives. Therefore the decision-making findings drawn from these interviews come with validity issues, as decision-making behaviour from other kinds of developers is not incorporated. Additionally, since the interviews were conducted with Dutch developers, the results may have limited generalizability to other contexts. Furthermore, certain questions were interpreted differently by different developers, leading to difficulty in comparison of the answers.
For future research, it is recommended to revise and refine certain questions in the questionnaire and to pilot-test the revised questionnaire before conducting the actual interviews. Moreover, increasing the sample size and diversity of interviewees would enhance the validity of the findings and help control for bias and outliers.

One of the challenges of creating ABMs is the translation of qualitative data into formal (behaviour) rules when coding (Filatova, 2015). In this research, this translation process was critical for accurately modelling the decision-making processes of real estate developers and ensuring that the model reflected insights gained from the interviews. Due to time limitations, some of the findings of the interview, such as contextual factors of influence on their decision-making, were modelled very implicitly or omitted entirely.

8.7. ABM

Simulation is always an approximation of reality. This research utilized a highly simplified and stylized ABM, which introduced limitations and potential (internal) validity issues.

Besides bounding itself to single-family owner-occupied houses, the model also exclusively focused on serviced/"build-ready" land, omitting speculative land development. This omission was due to the additional complexity and uncertainty speculative projects introduce in developer project decision-making, as suggested by the interviewed developers.

The results showed that the housing price shift (positive or negative), its magnitude, and the developers' reference points were key in determining flood risk distribution across new residential houses. However, these mechanics were simplified. First of all, the model assumed binary housing price shifts based on Floodlabel categories, which is not reflective of real-world housing price dynamics. Future work should incorporate heterogeneous adaptive consumer agents using a budget-maximizing utility function to determine their WTP for certain houses. and strategically form their bids. Currently, the emerged housing transaction price is "hard-coded".
Furthermore, the assumptions regarding homogenous and linear preference for Floodlabels are major limitations of this work. People do not all have similar preferences for certain housing attributes. Incorporating heterogeneity in housing attribute preferences could enhance the model's coherence with general housing market principles and enable the simulation of spatial heterogeneity. For instance, individuals accustomed to living in flood-resilient areas may not necessarily value flood-resilient (high Climate label) houses more, thereby causing minimal changes in housing prices in such resilient areas. Existing work on the capitalization of energy labels shows no linear relationship between the category and the WTP an individual has for it (Kahn and Kok, 2014). Moreover, flood risk data are often discussed through a ratio scale with unequal intervals (e.g., 1/30, 1/300, 1/3000 years). Therefore, assuming linearity in preference for flood risks/labels is a notable limitation. The model should be expanded with each Floodlabel category assigned an individual WTP coefficient to better reflect the non-linear nature of flood risk perception and valuation. This could have a significant impact on the resulting flood risks, as the shift in the value of houses would differ.

Secondly, the ABM in this research used two simplified reference points for developers to assess the gains and losses of their projects: a fixed reference point (the profit of regular houses before the introduction of the Climate label) and a more adaptive reference point (the profit of regular houses adapted to the shift in housing price). These reference points are limited as they do not incorporate an element of learning. Developers are quite simple in the model as they, besides blindly following what their prediction model tells them, do not alter their reference point to other kinds of housing. After building a significant number of houses with adaptation measures and successfully acquiring more profit from such, developers do not 'learn' and change their reference point to the profit from those houses with adaptation measures (= their new status quo).
Furthermore, for both reference points, the profit of building a regular house at that location was used. Therefore, since there was almost no uncertainty in estimating the willingness to pay (WTP) related to proximity to the city, proximity to the city did not influence decision-making. The reference point being location-bound is an assumption of the model. However, a reference point based on one specific location or an overall fixed value of profit would result in developers taking into account housing attributes such as proximity to the city centre, substantially changing the development patterns and subsequently the flood risks to which new houses are subjected. For future work, a less location-bound but more specific profit margin should be explored.

Overall, to validate the model's dynamics and findings, an empirical analysis of the actual Floodlabel effect on the flood risks of new residential houses should be conducted, and an empirical model using the dynamics presented in this research should be created to evaluate if the model can reproduce the empirical findings.

Lastly, a local sensitivity analysis was performed to examine emergent patterns and model robustness. However, this analysis is subjected to numerous limitations, as only it was performed for one variable. Future work should incorporate also other variables and vary multiple variables at the same time. To do so, a global sensitivity analysis should additionally be performed, which will also be able to capture nonlinear and complex interactions.

References

ABN AMRO. (2023). *STAPELING KLIMAATRISICO'S EN FINANCIËLE DRAAGKRACHT OP DE WONINGMARKT* (tech. rep.). ABN AMRO BANK.

ABN-AMRO. (2023, November). Prioritise climate-vulnerable neighbourhoods. https://www.abnamro.com/en/news/prioritise-climate-vulnerable-neighbourhoods

AFM. (2023). *Inprijzen klimaatrisico's woningmarkt* (tech. rep.).

Alonso, W. (1964, December). *Location and Land Use*. Harvard University Press. https://doi.org/10.4159/harvard.9780674730854

Arcadis & &flux. (2021). *Kosten en bekostiging klimaatbestendige nieuwbouw* (tech. rep.).

Arcadis & Tauw. (2022). *Bouwstenen Maatlat groene klimaatadaptieve gebouwde omgeving* (tech. rep.). Ministeries van BZK, IenW en LNV.

Artioli, F. (2012). *Public Real Estate between administrative reforms and financial constraints. A comparative analysis of the re-use of military assets in Italy and France* (tech. rep.). http://blogs.sciences-po.fr/recherche-villes/

Atasoy, A. T. (2020). Behavioral responses of green builders to discontinuous certification schemes. *Resource and Energy Economics*, *60*. https://doi.org/10.1016/j.reseneeco.2019.101141

Ball, M. (1999). Chasing a snail: Innovation and housebuilding firms' strategies. *Housing Studies*, *14*(1), 9–22. https://doi.org/10.1080/02673039982975

Bao, H. X., Meng, C. C., & Wu, J. (2021). Reference dependence, loss aversion and residential property development decisions. *Journal of Housing and the Built Environment*, *36*(4), 1535–1562. https://doi.org/10.1007/s10901-020-09803-y

Bin, O., Kruse, J. B., & Landry, C. E. (2008). Flood hazards, insurance rates, and amenities: Evidence from the coastal housing market. *Journal of Risk and Insurance*, *75*(1), 63–82. https://doi.org/10.1111/j.1539-6975.2007.00248.x

Bin, O., & Landry, C. E. (2013). Changes in implicit flood risk premiums: Empirical evidence from the housing market. *Journal of Environmental Economics and Management*, *65*(3), 361–376. https://doi.org/10.1016/j.jeem.2012.12.002

Bluelabel. (2020). BlueLabel. https://bluelabel.net/

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the national academy of sciences*, *99*(3), 7280–7287. www.pnas.orgcgidoi10.1073pnas.082080899

BouwblokNederland. (2023). ZELF HUIS BOUWEN KOSTEN. https://bouwbloknederland.nl/zelf-huis-bouwen-kosten/

Buckman, S. T., & Sobhaninia, S. (2022). The Impact of Sea-Level Flooding on the Real Estate Development Community in Charleston SC: Results of a ULI Member Survey. *Journal of Sustainable Real Estate*, *14*(1), 4–20. https://doi.org/10.1080/19498276.2022.2095699

Buitelaar, E., & Witte, P. A. (2012). *Understanding the costs and revenues of land development An empirical analysis into the financial effects of location features* (tech. rep.). https://www.researchgate.net/publication/280490062

Calcasa. (2023). *The WOX ® Quarterly Q3 2023* (tech. rep.).

Chandra-Putra, H., & Andrews, C. J. (2020). An integrated model of real estate market responses to coastal flooding. *Journal of Industrial Ecology*, *24*(2), 424–435. https://doi.org/10.1111/jiec.12957

Cheney, G., Christensen, L., Zorn, T., & Ganesh, S. (2010). *Organizational Communication in an Age of Globalization*. Waveland Press.

Colby, S., & Zipp, K. (2021). EXCESS VULNERABILITY FROM SUBSIDIZED FLOOD INSURANCE: HOUSING MARKET ADAPTATION WHEN PREMIUMS EQUAL EXPECTED FLOOD DAMAGE. *Climate Change Economics*, *12*(01). https://doi.org/10.1142/S2010007820500128

Contat, J., Hopkins, C., Mejia, L., & Suandi, M. (2023). *When Climate Meets Real Estate: A Survey of the Literature* (tech. rep.). FEDERAL HOUSING FINANCE AGENCY. Washington, DC. https://www.fhfa.gov/papers/wp2305.aspx.

CPB. (2019). *Het bouwproces van nieuwe woningen* (tech. rep.). Centraal Planbureau.

D'Acci, L. (2019). Quality of urban area, distance from city centre, and housing value. Case study on real estate values in Turin. *Cities*, *91*, 71–92. https://doi.org/10.1016/j.cities.2018.11.008

Davids, P., Boelens, L., & Renaat De Sutter, .-. (2021). *Rethinking Floodlabel: A Situational Approach to Homeowner Involvement in Flood Risk Management* (tech. rep.).

De Koning, K., & Filatova, T. (2020). Repetitive floods intensify outmigration and climate gentrification in coastal cities. *Environmental Research Letters*, *15*(3). https://doi.org/10.1088/1748-9326/ab6668

de Koning, K., & Filatova, T. (2020). Multi-scale Validation of an Agent-Based Housing Market Model. *Springer Proceedings in Complexity*, 135–140. https://doi.org/10.1007/978-3-030-34127-5{_}12

de Leve, E., & Kramer, I. (2020). *Wat is grond waard? Onderzoek naar gemeentelijk grondprijsbeleid* (tech. rep.).

Delisle, J., Grissom, T., & Högberg, L. (2013). Sustainable real estate: An empirical study of the behavioural response of developers and investors to the LEED rating system. *Journal of Property Investment & Finance*, *31*(1), 10–40. https://doi.org/10.1108/14635781311292953

Deltares. (2023, January). Overstromingsgevaar. https://storymaps.arcgis.com/stories/e2f85f5d60c24965b93913e0b044e19c

Dubbelboer, J., Nikolic, I., Jenkins, K., & Hall, J. (2017). An Agent-Based Model of Flood Risk and Insurance. *Journal of Artificial Societies and Social Simulation*, *20*(1).

Eriksson, C., Cheng, I., Pitman, K., Lamond, J. E., Bhattacharya Mis FRGS, N., Chan, F., Kreibich, H., Montz, B., Proverbs, D. G., & Wilkinson, S. J. (2017). *Flood risk mitigation and commercial property advice: an international comparison* (tech. rep.). RICS Research Trust. www.rics.org

Filatova, T. (2015). Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models. *Computers, Environment and Urban Systems*, *54*, 397–413. https://doi.org/10.1016/j.compenvurbsys.2014.06.007

Filatova, T., Verburg, P. H., Parker, D. C., & Stannard, C. A. (2013). Spatial agent-based models for socio-ecological systems: Challenges and prospects. *Environmental Modelling and Software*, *45*, 1–7. https://doi.org/10.1016/j.envsoft.2013.03.017

Ge, J. (2017). Endogenous rise and collapse of housing price: An agent-based model of the housing market. *Computers, Environment and Urban Systems*, *62*, 182–198. https://doi.org/10.1016/j.compenvurbsys.2016.11.005

Gehner, E. (2008). *Knowingly taking risk: Investment decision making in real estate development*. Eburon.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S. K., Huse, G., Huth, A., Jepsen, J. U., Jørgensen, C., Mooij, W. M., Müller, B., Pe'er, G., Piou, C., Railsback, S. F., Robbins, A. M., … DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, *198*(1-2), 115–126. https://doi.org/10.1016/j.ecolmodel.2006.04.023

Grimm, V., Berger, U., DeAngelis, D. L., Polhill, J. G., Giske, J., & Railsback, S. F. (2010). The ODD protocol: A review and first update. *Ecological Modelling*, *221*(23), 2760–2768. https://doi.org/10.1016/j.ecolmodel.2010.08.019

Haer, T., Husby, T. G., Botzen, W. J., & Aerts, J. C. (2020). The safe development paradox: An agent-based model for flood risk under climate change in the European Union. *Global Environmental Change*, *60*. https://doi.org/10.1016/j.gloenvcha.2019.102009

Harris, A. (2009). Attributions and Institutional Processing: How Focal Concerns Guide Decision-Making in the Juvenile Court. *Race and Social Problems*, *1*(4), 243–256. https://doi.org/10.1007/s12552-009-9020-4

Hartmann, T., & Scheibel, M. (2016). Flood Label for buildings - a tool for more flood-resilient cities. *European Conference on Flood Risk Management*.

Heurkens, E., Hobma, F., Verheul, W. J., & Daamen, T. (2020). *Financiering van gebiedstransformatie : Strategieën voor het toepassen van verschillende financieringsvormen bij binnenstedelijke gebiedsontwikkeling*. Platform31.

Heurkens, E. (2012). *Private Sector-led Urban Development Projects Private Sector-led Urban Development Projects Department of Real Estate & Housing* (tech. rep.).

Hino, M., & Burke, M. (2021). The effect of information about climate risk on property values. *Proceedings of the National Academy of Sciences*, *118*(17). https://doi.org/10.1073/pnas.2003374118/-/DCSupplemental.y

Hoogvliet, M., Slager, K., & Dolman, N. (2023, December). *Verkenning waterlabel* (tech. rep.). Deltares.

Jafino, B. A., Kwakkel, J. H., Klijn, F., Dung, N. V., van Delden, H., Haasnoot, M., & Sutanudjaja, E. H. (2021). Accounting for Multisectoral Dynamics in Supporting Equitable Adaptation Planning: A Case Study on the Rice Agriculture in the Vietnam Mekong Delta. *Earth's Future*, *9*(5). https://doi.org/10.1029/2020EF001939

Kadijk, J., Prijden, R., Van Eekelen, J., Steenstra, M., Van Der Heijden, P., & Ligterink, J. (2023). *FRAMEWORK FOR CLIMATE ADAPTIVE BUILDING: De gebouwscore* (tech. rep.). Dutch Green Building Council.

Kahn, M. E., & Kok, N. (2014). The capitalization of green labels in the California housing market. *Regional Science and Urban Economics*, *47*(1), 25–34. https://doi.org/10.1016/j.regsciurbeco.2013.07.001

Kahneman, D., Knetsch, J. L., & Thaler, R. H. (1991). *Anomalies The Endowment Effect, Loss Aversion, and Status Quo Bias* (tech. rep.).

Kahneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. *Econometrica*, *47*(2).

Kavya, R., & Christopher, J. (2023). Interpretable systems based on evidential prospect theory for decision-making. *Applied Intelligence*, *53*(2), 1640–1665. https://doi.org/10.1007/s10489-022-03276-y

Klijn, F., Samuels, P., & Van Os, A. (2008). Towards flood risk management in the eu: State of affairs with examples from various european countries. *International Journal of River Basin Management*, *6*(4), 307–321. https://doi.org/10.1080/15715124.2008.9635358

Kolen, B., Thonus, B., Valkenburg, L., Zwaan, J., & Loes Nillesen, A. (2023, September). *Ruimtelijk afwegingskader klimaatadaptieve gebouwde omgeving.* (tech. rep.). Ministeries van IenW en BZK.

Kosavinta, S., Krairit, D., & Khang, D. B. (2017). Decision making in the pre-development stage of residential development. *Journal of Property Investment and Finance*, *35*(2), 160–183. https://doi.org/10.1108/JPIF-05-2016-0030

Lechowska, E. (2018). What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. *Natural Hazards*, *94*(3), 1341–1366. https://doi.org/10.1007/s11069-018-3480-z

Li, H., & Grant, R. J. (2022). Climate gentrification in Miami: A real climate change-minded investment practice? *Cities*, *131*. https://doi.org/10.1016/j.cities.2022.104025

Lorscheid, I., Heine, B. O., & Meyer, M. (2012). Opening the 'Black Box' of Simulations: Increased Transparency and Effective Communication Through the Systematic Design of Experiments. *Computational and Mathematical Organization Theory*, *18*(1), 22–62. https://doi.org/10.1007/s10588-011-9097-3

Magliocca, N., Brown, D., McConnell, V., Nassauer, J., & Elizabeth Westbrook. (2014). Effects of alternative developer Decision-Making models on the production of ecological subdivision designs: Experimental results from an agent-based model. *Environment and Planning B: Planning and Design*, *41*(5), 907–927. https://doi.org/10.1068/b130118p

McKenzie, R., & Levendis, J. (2010). Flood hazards and urban housing markets: The effects of Katrina on New Orleans. *Journal of Real Estate Finance and Economics*, *40*(1), 62–76. https://doi.org/10.1007/s11146-008-9141-3

Meyer, H., & Hartmann, T. (2023). The FLOODLABEL as a social innovation in flood risk management to increase homeowners' resilience. *Journal of Flood Risk Management*. https://doi.org/10.1111/jfr3.12962

Moerland, M. (2024, February). Uitslag Stelling: 'Klimaatlabel geldklopperij'. https://www.telegraaf.nl/watuzegt/743985640/uitslag-stelling-klimaatlabel-geldklopperij

Mohamed, R. (2006). The psychology of residential developers: Lessons from behavioral economics and additional explanations for satisficing. *Journal of Planning Education and Research*, *26*(1), 28–37. https://doi.org/10.1177/0739456X05282352

Montgomery, D. (2009). *Design and analysis of experiments*. Wiley.

Mutlu, A., Roy, D., & Filatova, T. (2023). Capitalized value of evolving flood risks discount and nature-based solution premiums on property prices. *Ecological Economics*, *205*. https://doi.org/10.1016/j.ecolecon.2022.107682

Nikolic, I. (2013). *Agent-Based Modelling of Socio-Technical Systems: Chapter 3* (Vol. 9). Springer. www.springer.com/series/7188

Niu. (2024). Niu et al_2024_Overstromings_ informatie verandert koopgedrag van woningeigenaren.

NOS. (2023, November). Toezichthouder: neem klimaatrisico's mee in huizenprijzen. https://nos.nl/artikel/2496981-toezichthouder-neem-klimaatrisico-s-mee-in-huizenprijzen

Oyetunji, A. K., Amaechi, C. V., Dike, E. C., Ayoola, A. B., & Olukolajo, M. A. (2023). Factors Influencing Stakeholders' Decision to Invest in Residential Properties: A Perceptual Analysis of Flood-Risk Areas. *Buildings*, *13*(6). https://doi.org/10.3390/buildings13061560

Parker, D. C., & Filatova, T. (2008). A conceptual design for a bilateral agent-based land market with heterogeneous economic agents. *Computers, Environment and Urban Systems*, *32*(6), 454–463. https://doi.org/10.1016/j.compenvurbsys.2008.09.012

Planbureau voor de Leefomgeving. (2021). *DE WERKING VAN DE GRONDMARKT EN DE ROL VAN DE OVERHEID* (tech. rep.). Planbureau voor de Leefomgeving. Den Haag.

Poorvu, W., & Cruikshank, J. (1999). *The Real Estate Game*. Simon & Schuster.

Pope, J. C. (2008). Do Seller Disclosures Affect Property Values? Buyer Information and the Hedonic Model. *Land Economics*, *84*(4), 551–572. https://about.jstor.org/terms

Pricope, N. G., Hidalgo, C., Pippin, J. S., & Evans, J. M. (2022). Shifting landscapes of risk: Quantifying pluvial flood vulnerability beyond the regulated floodplain. *Journal of Environmental Management*, *304*. https://doi.org/10.1016/j.jenvman.2021.114221

Rajapaksa, D., Wilson, C., Managi, S., Hoang, V., & Lee, B. (2016). Flood Risk Information, Actual Floods and Property Values: A Quasi-Experimental Analysis. *Economic Record*, *92*, 52–67. https://doi.org/10.1111/1475-4932.12257

Rajapaksa, D., Zhu, M., Lee, B., Hoang, V. N., Wilson, C., & Managi, S. (2017). The impact of flood dynamics on property values. *Land Use Policy*, *69*, 317–325. https://doi.org/10.1016/j.landusepol.2017.08.038

Rakhmatulloh, A. R., Buchori, I., Pradoto, W., Riyanto, B., & Winarendri, J. (2018). What is the Role of Land Value in the Urban Corridor? *IOP Conference Series: Earth and Environmental Science*, *123*(1). https://doi.org/10.1088/1755-1315/123/1/012033

Ratnadiwakara, D., & Venugopal, B. (2020). Do Areas Affected by Flood Disasters Attract Lower-Income and Less Creditworthy Homeowners? *Journal of Housing Research*, *29*(1), 121–143. https://doi.org/10.1080/10527001.2020.1840246

Rijksdienst voor Ondernemend Nederland. (2024). Maatregelen klimaatadaptatie en natuurinclusiviteit in de gebouwde omgeving. https://infographics.rvo.nl/klimaatadaptatie/maatregelen/#miirvokam-bouwen-en-renoveren

Shearer, H., Coiacetto, E., Dodson, J., & Taygfeld, P. (2016). How the structure of the Australian housing development industry influences climate change adaptation. *Housing Studies*, *31*(7), 809–828. https://doi.org/10.1080/02673037.2016.1150430

Shr, Y., & Zipp, K. (2019). The Aftermath of Flood Zone Remapping: The Asymmetric Impact of Flood Maps on Housing Prices. *Land Economics*, *95*(2), 174–192.

Simon, A. (1957). Models of Man: Social and Rational. *Mathematical Essays on Rational Human Behavior in a Social Setting*.

Storbjörk, S., Hjerpe, M., & Isaksson, K. (2018). 'We cannot be at the forefront, changing society': exploring how Swedish property developers respond to climate change in urban planning. *Journal of Environmental Policy and Planning*, *20*(1), 81–95. https://doi.org/10.1080/1523908X.2017.1322944

Sweco. (2017). 'Staat van je Straat': Een klimaatlabel voor iedere straat. https://www.sweco.nl/portfolio/staat-van-je-straat/

Taylor, B. M., Harman, B. P., Heyenga, S., & McAllister, R. R. (2012). Property Developers and Urban Adaptation: Conceptual and Empirical Perspectives on Governance. *Urban Policy and Research*, *30*(1), 5–24. https://doi.org/10.1080/08111146.2011.639178

Taylor, Z. J., & Knuth, S. E. (2023). Financing “climate-proof” housing? The premises and pitfalls of PACE finance in Florida. *Journal of Urban Affairs*. https://doi.org/10.1080/07352166.2023.2247503

ten Broeke, G., van Voorn, G., & Ligtenberg, A. (2016). Which Sensitivity Analysis Method Should I Use for My Agent-Based Model? *Journal of Artificial Societies and Social Simulation*, *19*(1).

Thompson, J. J., Wilby, R. L., Hillier, J. K., Connell, R., & Saville, G. R. (2023). Climate Gentrification: Valuing Perceived Climate Risks in Property Prices. *Annals of the American Association of Geographers*, *113*(5), 1092–1111. https://doi.org/10.1080/24694452.2022.2156318

Troost, C., Huber, R., Bell, A. R., van Delden, H., Filatova, T., Le, Q. B., Lippe, M., Niamir, L., Polhill, J. G., Sun, Z., & Berger, T. (2023). How to keep it adequate: A protocol for ensuring validity in agent-based simulation. *Environmental Modelling and Software*, *159*. https://doi.org/10.1016/j.envsoft.2022.105559

Vereniging Eigen Huis. (2023). Informatie funderingsrisico belangrijk, Eigen Huis kritisch over klimaatlabel. https://www.eigenhuis.nl/nieuws/funderingsrisico-belangrijk-veh-kritisch-over-klimaatlabel

Vlek, P. J., & Rust, W. (N. (2020). *Investeren in vastgoed, grond en gebieden*. SPRYG Real Estate Academy.

Votsis, A., & Perrels, A. (2016). Housing Prices and the Public Disclosure of Flood Risk: A Difference-in-Differences Analysis in Finland. *Journal of Real Estate Finance and Economics*, *53*(4), 450–471. https://doi.org/10.1007/s11146-015-9530-3

VVD, D66, CDA, & ChristenUnie. (2021). *Omzien naar elkaar, vooruitkijken naar de toekomst* (tech. rep.).

Xiang, X., Kennedy, R., Madey, G., & Cabaniss, S. (2005). Verification and Validation of Agent-based Scientific Simulation Models. *Agent-directed Simulation*.

Yeo, S., Roche, K., & Mcaneney, J. (2015). EFFECTS OF DISCLOSURE OF FLOOD-LIABILITY ON RESIDENTIAL PROPERTY VALUES: AN UPDATE. *Floodplain Management Association National Conference*.

Yin, R. K. (2013). Validity and generalization in future case study evaluations. *Evaluation*, *19*(3), 321–332. https://doi.org/10.1177/1356389013497081

Zöllig, C. ; & Axhausen, K. W. (2011). A conceptual, agent-based model of land development for UrbanSim Conference Paper. *Land use real estate and housing markets session*. https://doi.org/10.3929/ethz-a-006620736

A

Literature Search Strategy

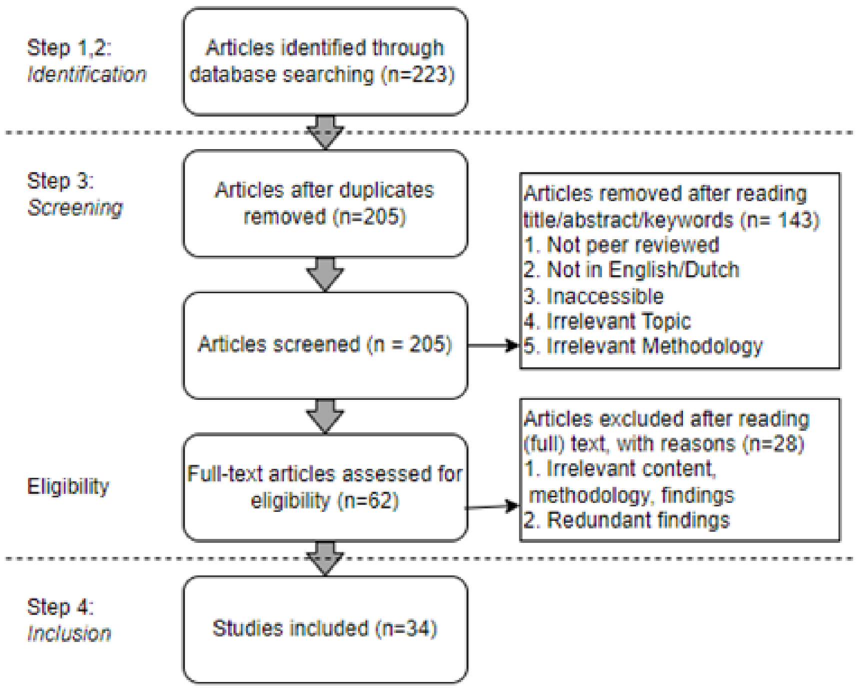
To determine the current state of literature multiple search engines were consulted: keyword-search-based databases Google Scholar and Scopus, and semantic (AI) database Scispace. Below, a table is provided with the keywords and strings used in the keyword-search-based databases and the exact search queries used in Scispace. For both databases, only papers from the past 0-10 years were identified (as the focus of a state of the art mainly revolves around recent literature). For Scispace, only the papers were “identified” in which the ‘Insights’ column mentioned that the paper (partly) answered the question.

Table A.1: Search queries for the various databases

Section	Search queries key-search-based	Search questions Scispace
Physical risks	(Physical) AND (Risk(s) OR Damage(s) OR Impact) AND (Houses OR Housing OR Property) AND (Flood OR Flooding) AND (Coastal OR Inland OR River OR Pluvial)	-
Housing market risks	((Flood OR “Flood risk”) OR “Flood risk perception”) AND (“Housing market”) AND Capitalising AND “Property Value”	-“ What papers distinguish between the effect of direct experience of flooding and the effect of information disclosure of flood risk on property values?”
Housing market actors	(”Flood”OR ”Flood risk”) AND ((”supply housing market” OR ”supply houses”) OR (”developer” OR ”development”))	how do flood risks influence housing market actors behind the supply of new houses
Policy	- ((Flood OR Flooding OR “Disclosing flood risk information”) AND ((Adaptation AND (Policy OR Measures) OR “Flood management”) AND Housing) OR ”Flood label”	-“What is the effect of Flood labelling houses on the affordability of homeownership?”

To select which articles to include the approach proposed by Xiao and Watson (2017) is taken. During this approach papers were included whose topic and/or content was of value for the scope of this research. For example, studies regarding the housing market/values were included, while papers regarding other property markets were excluded. Moreover, papers that focused on irrelevant methodologies were excluded. For example, when searching for papers for the Policy section, multiple papers were found that focus on the effectiveness of using participatory modelling in designing flood adaptation measures. As the aim of that section is to describe the state of the literature regarding which type of flood adaptation policy is advisable (so not how to design them) and the state of the flood label, these papers were excluded. No exclusion was performed by region of study. Figure A.1 visualises this approach and its results.

Figure A.1: Visualization literature search



B

Appendix: Interview Questionnaire

This interview will ask questions regarding your view on climate conscious housing and how you can help produce more flood-resilient homes. Becoming flood-resilient is part of the boarder goal of becoming climate-resilient, but as the Netherlands has a notorious relationship with water and as the limits of the water and soil system are increasingly tested, more emphasis is put on flood-resilience is this interview.
A policy in the Netherlands that is momentarily under discussion, is providing houses a ‘Climate label’ (‘Klimaatlabel’) that could give transparency and insight into its vulnerability to climate risks, such as flooding. This has goal that people will not be left with unforeseen costs and that these costs will be well reflected in the value of the property. Moreover, it would stimulate investing in (flood) adaptation measures.

This interview will start off with some global questions regarding your current standard housing development process and how you make investment/project decisions, followed by your current view of building climate-resilient housing and how you perceive your role in this process. After this, we will discuss how the introduction of Climatelabelling could change your development and investment behaviour regarding climate/flood-resilient housing.

My research limits itself to the effect Climatelabelling has on “eengezins koopwoning”, as multiple family homes are not (as much) prone to flooding and as individuals (homeowners) would bare all the risk. You are asked to keep this in mind will answering the questions.

B.0.1. Current housing development process and decision-making

1. “Please explain how the process of housing development generally unfolds for your company”: Who are the key actors with whom you come in contacts with in this process? (From initiation and planning (land acquisition (from whom) and potential land excavation) to possibly your role in usage/maintenance))

Investment decision-making

2. “From the factors below, please indicate on the scale their level of importance in your current investment decision-making (project selection & design).”

   [1- not of importance .... 5 – very important]

   - Potential profit [1- not of importance .... 5 – very important]
   - Certainty in estimation revenue and costs
   - Certainty in estimation of demand
   - Certainty a (construction) approval will be obtained
   - Impact on the climate
   - Societal benefits

- Company reputation
- Location (inner- or outer-city)

Risk attitude

3. “Is your company generally willing to take risky investments or do they avoid risks?”

   [1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]
4. “When faced with a high probability of gains, is your company willing to make more risky investments to obtain even more gains (however, with the potential of losing your gains)?”

   [1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]
5. “When faced with a high probability of losses, is your company willing to make more uncertain/risky investments to lower the losses (however, with the potential of more loses)”

   [1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]

Revenue & cost estimation, and project uncertainty

6. “How do you generally predict the future housing revenue for your potential projects? What factors/indicators are important in this assessment?”
7. “What kind of uncertainties does your company generally face during its investment decision making? And how big would you rate that uncertainty?”

   [1- no uncertainty ... 5 – extremely uncertain]

   - Uncertainty in (estimating) future housing demand/revenue
   - Uncertainty in (estimating) construction costs (material, labour)
   - Uncertainty construction time
   - Uncertainty in obtaining land
   - Uncertainty in obtaining a loan
   - Uncertainty in obtaining approvals or permits
   - Uncertainty due to policy (think of nitrogen taxes, building regulations)
8. “When faced with a project that encompasses higher uncertainty in terms of revenue, costs or time, would you set a higher profit margin (to buffer the risk of lower and anticipated profit)? If so, would you be able to indicate for the follow uncertainties how high you would set the profit margin?”

   - No uncertainty ...
   - Slight uncertainty ...
   - Uncertain ...
   - Very uncertain ...
   - Extremely uncertain ...
9. “Do you agree that your company’s familiarity in a project (housing type and/or location) lowers the uncertainty (in profitability) of a project.”

   [1- strongly disagree .... 3 – neutral ... 5 – strongly agree]
10. ”How do interest rate changes affect your decision to start a new development project?”

B.0.2. Current behaviour and view climate-conscious housing

Measures

11. “Within your development process, how do you think you as a developer can help with producing climate-resilient buildings in the Netherlands?”
12. ”What (exact) measures do you think you may implement during the construction stage to reduce the flood risks of buildings?”
13. “How much (in % or in absolute value) do you think these measures will add to your construction costs?”
14. “What percentage of your projects in the past five years have already incorporated such flood/climate-resilient features?”
15. “Would implementing flood-resilient features in a housing project influence the development time-line of houses? If so, what is the impact (in terms of % or absolute value)?”
16. “At what moment in the housing development process do you generally start putting the houses up for sale? Per stage, what percentage of houses from the project sold?”
    - Before construction ....
    - During construction ....
    - After construction is finished. ....

Barriers

17. “What barriers, if any, currently have prevented you from committing to more climate-resilient projects?” (for example):
    - To high costs compared with revenue
    - Uncertain/no demand
    - Limited knowledge of the climate risks
    - Influence of other actors (e.g. Uncertainty in acquiring a loan)
18. “Do you currently view investing in making houses climate-resilient as more, equal or less risky than conventional/non-resilient housing?”

As the majority of the costs for a project are financed by taking out a loan, loan lender play a key role in the feasibility of a project. If they do not have confidence in a proposed housing project, the project can be discontinued. OR the lender would only provide the loan under a higher (risk-based) interest.

19. “Are loan lenders (such as banks, pension funds etc) currently more reluctant to provide loans for potential housing projects with climate-resilient measures (in comparison to one without)?” If so, does this form a barrier in your decision to invest in climate-resilient houses?

B.0.3. Influence Climate label policy of development behaviour regarding flood risks

Global Questions

20. ”If it were announced that within two years, all new projects must align with Climate label standards, how would this influence your project planning starting today?”
21. “Could you give examples of how government incentives have shaped your past development projects?” (for example, the implementation of the energy label)

Incentives

22. “If any, in what way do you think Climate labelling will incentivize you to build more flood-resilient houses (Would it for example):”
    - Ensure an (relative) increase in value of more resilient properties

- Reduce uncertainty regarding demand
- o OR Not necessarily encourage climate-resilient housing, but rather discourage conventional/non-resilient housing

23. ”Would the (relative) value increase in climate resilient houses potentially lead to you preferring housing projects in more climate resilient areas (e.g. none flood risk zones)?”
24. “When the Climate label would be introduced, do you think loan lenders would be more willing to give out loans to climate-resilient housing”

B.0.4. Influence of Municipalities: cooperation and regulations

In housing development, the different stages within the process can be carried out by public (often municipality) and private parties (among other, you, the developer). Municipalities can take on a very active role, a passive role, or a form in between the two (PPP). The type of collaboration between public and private could dictate the amount of responsibilities and risks you, the developer, could bare in a certain housing project. Moreover, the “degree” of collaboration with public could result in constraints in type of housing you could develop, as initiative and plan have already been accounted for or as certain agreements must be abided.

25. ”Do you think that introducing the climate label alone (without additional regulations from certain municipalities) will give you enough incentive to ensure that all your future projects will be flood-proof?”
26. ”Or do you see this happening only in situations where the municipality:
    - ”Taking an active role/ground policy, i.e. taking the lead by, for example, already partially assuming the costs and risks regarding flood measures during the land development phase”
    - ”And/or strictly enforce it through rule and legislation (e.g. set a certain climate label as standard in the zoning plan)”

C

Interview results

C.0.1. Investment profile

Question 1: *["Please explain how the process of housing development generally unfolds for your company": Who are the key actors with whom you come in contact with in this process? (From initiation and planning (land acquisition (from whom) and potential land excavation) to possibly your role in usage/maintenance))]*

Three ways of acquiring projects were mentioned by the developers: through tenders, buying ground speculatively, and acquisitions. The first two were most predominantly mentioned. In the case of tenders, municipalities have an active land policy, in which they buy/have land, excavate it (when desired to develop new houses/buildings on), and then invite different developers to propose a plan and bid for the respective land. The developer with the highest score (based on the plan criteria and on bid), will be given the land to develop on it. This means that the municipality often has requirements for what may be built. Buying land speculatively has inherently more risk than acquiring a project through a tender. This is because speculative land buying entails the risk of never obtaining a change in zoning plan (necessary for housing development) and the risk of a decline in the land's value, such as during an economic crisis. In contrast, a tender process primarily faces market risks. Therefore, municipalities play key role in determining where and/or how developers can build houses.
One developer noted that Public-Private Partnerships (PPPs) are relatively uncommon in the Netherlands nowadays. This could explain why project acquisition tends to be either very public or very private, with few intermediaries.

The entire trajectory of a project in the case of a tender can be 1-10 years and in the case of buying land speculatively (and therefore having to excavate the land), can take 10-20+ years.
All developers mentioned that they only take on large projects: 50+ houses to be developed

Question 2: [*"From the factors below, please indicate on the scale their level of importance in your current investment decision-making (project selection & design)."*]

Table C.1: Importance factors for investment decision-mkaing

	Developer 1	Developer 2	Developer 3
Potential profit	5	3	5
Certainty in estimating revenue and costs	3	4	4
Certainty in estimating demand	4	4	5
Certainty in acquiring a construction approval	5	5	5
Impact on Climate	4	5	3
Societal benefits	4	5	4
Company repuatation	4	5	3
Location (inner- or outer-city)	5	5	5

In table C.1, the given scores for the factors in project decision-making on a scale of 1-5 are provided (1- not important at all ... 5- very important). It is important to recognize that certain factors intersect with each other. For instance, certainty in demand often corresponds to greater certainty in revenue estimation, given demand is part of the function of revenue. Furthermore, the location of the housing project (inner-city or outer-city) can impact the certainty in revenue and demand, with properties in the heart of a popular city almost ensuring sales. However, location also ties into climate considerations: building outside the city allows for more space for nature-based adaptive measures. This could serve as an explanation for the consensus the developers had regarding the importance of location.
Certainty in acquiring construction approval was also given the highest score by all developers. This stems from the fact that construction approval is a decisive factor in project viability. Failure to secure approval would essentially halt development, presenting a substantial bottleneck in the process.

From the interview was gathered that Developer 1 and Developer 2 were commercial developers who were in essence finacial/profit driven. Developer 2 was more a "societal" developer, who took societal and climate influence as a key driver in their projects. This can be seen in the above table.
Yet, it was noted that profit is not straight-forward as profit a marge is often combined with a risk marge:

"That's a bit hard to say because you always combine it with risks, which are very much in proportion to each other. So if we enter a competition where we actually have reasonable certainty from the politicians what we are allowed to plan, which is actually quite nice, because then you know we are up to you need to prognosticate very little profit. It's not even profit, is it? But less risk hedging." [Developer 1]

Nevertheless, none of the developers said (and seemed) to be profit maximising. Their main importance was meeting their profit marge and return goals, which often were established at the initiative of the project. When acquired, they did not feel the need to "go for more". This supports the theory/hypothesis of developers illustrating satisficing behaviour in their project decision-making.
Even though not assigned the max score, a crucial task is determining how the costs and benefits flow over time, as one developer mentions:

"If you can do this best, properly assess that housing demand, yes, then you will become the biggest in the Netherlands. Then you can make a profit" [Developer 3]

All three developers mentioned that climate impact and adaption is a factor that especially in the past 5 years has increased in importance in their decision-making. When validating these findings with the expert, it was mentioned that most developers are financial/profit driven and that "social" developers (such as developer 2) are not very common. This doesn't discredit the relevance of developer 2's responses; rather, it underscores the importance of appropriately representing their perspective into the ABM model.

Risk attitude

Question 3: [*"Is your company generally willing to take risky investments or do they avoid risks?"*]

[1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]

The developers indicated to be quite risk taking (score 4/5 on the scale). However, willingness to take risks is something different than having to take risks. As mentioned in question 1, buying land speculatively inherently has much more risk than acquiring housing projects through tenders. In explaining their answers, it seemed that their 'willingness to take risks' was more an indication of their willingness to take on speculative projects and to what degree of speculation. Moreover, it was noted by one of the developers that their company is of sufficient size to have 'risk capital', which allows them to make decisions with risk and uncertainty.

Question 4: [*"When faced with a high probability of gains, is your company willing to make riskier investments to obtain even more gains (however, with the potential of losing your gains)?"*]

[1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]

All developers answered with a score of ’3-risk neutral.’ As mentioned under question 2, The developers indicated not to be profit-maximising, and therefore do not feel the need to take more risks to potentially acquire more profit. Interestingly enough, they do not become risk-averse.
This result is not in line with the characteristics of PT, in which is mentioned that one becomes risk-averse when confronted with high-probability gains.

Question 5: [*“When faced with a high probability of losses, is your company willing to make more uncertain/riskier investments to lower the losses (however, with the potential of more losses)”*]

[1 – not willing to take any risks ... 3- neutral ... 5- very willing to take risks]

The answers of the developers varied between ’1-not willing to take risks’ (Developer 3) and ’3-risk neutral’ (Developer 2 and 3). It was mentioned that they know beforehand the risks of the project. For example, in buying land speculatively, they know there is a planological risk of the zoning plan not changing to allow housing development. Taking on such a project means accepting this risk and the losses it could bring
This result is not in line with the characteristics of PT, in which is mentioned that one becomes risk-seeking when confronted with high-probability losses.

From the answers to questions 3, 4, and 5 it can be concluded that the developers illustrate satisficing behaviour. Yet, the results do not indicate Prospect Theory as an explanation for this behaviour. The developers seem quite risk-neutral regarding gains and losses, with Developer 3 even tending to be risk-averse towards losses. However, these findings could be due to the limited number of questions addressing the risk attitude of the developers or due to the framing of the questions. In the questions, gains was framed as profit, therefore, excluding any other type of valued gain. Additionally, the interpretation of the scale could be of influence.

Costs and benefits estimation, and project uncertainty

Question 6: [*“How do you generally predict the future housing revenue for your potential projects? What factors/indicators are important in this assessment?”*]

The main factor in estimating the revenue is the demand in an area for a specific house. This is determined by the attractiveness of the area and the financial capacity people have (average income). The former is a function of employment opportunities and the various existing facilities of the area, such as infrastructure and recreational facilities. Additionally, developers try to take into account future city developments (such as anticipated infrastructure projects) in their estimation of demand. This makes the estimation of demand very location-specific.

Developers mentioned they extensively analyse the market to gain information regarding the sale price and demand of a certain location. In areas where the developer is more familiar, they can more extensively (and with more certainty) gather such information and future opportunities than in areas they are not familiar.

When deciding to place a bid land/potential project, the estimation of the costs and benefits is subjected to multiple scenarios to capture potential risks and uncertainties. For these scenario analyses they use a discount rate of 5%.

Question 7: [*”What kind of uncertainties does your company generally face during its investment decision-making? And how big would you rate that uncertainty?”*]

[1- no uncertainty ... 5 – extremely uncertain]

The table below shows the scores the developers provided to how uncertain they deem certain aspects of a project.

Table C.2: How uncertain the developers score certain factors of project decision-making

	Developer 1	Developer 2	Developer 3
Uncertainty in (estimating) future revenue	1	4	2
Uncertainty in (estimating) future costs (material, labour)	2	4	2
Uncertainty construction time	1	2	1
Uncertainty in acquiring land/project	2	2	1
Uncertainty in acquiring a loan/financing for a project	2	1	2
Uncertainty in acquiring a (contruction) approval	5	4	3
Uncertainty due to policy (e.g. nitrogen tax, building codes)	3	4	4

The difference in the scores the developer assigned to the uncertainty in estimating demand, revenue and costs could be explained by the degree a developer invests speculatively. Developer 2 relatively often speculatively bought land, while Developer 1 did not and most often acquired their projects through tenders. This can also be given as an explanation why Developer 1 did not assign 'the certainty of estimating revenue and costs' a high value in question 1 as they do not perceive much uncertainty of it in the first place. One developer had the following to say concerning the certainty of tenders and buying speculatively:

"So then (in the case of tenders) there is more planning clarity that construction can take place and so it is much less speculative and so you run much less risk and then you also have fewer return requirements to cover those risks a bit. Then you can be much more certain that you can make a plan. You still have market risk though." [Developer 1]

"If we buy land speculatively, you don't yet have any agreements with each other. What exactly you are going to make, you can go either way with that, whereas if you buy land from the municipalities, they often say, well this is what I want. You apply to that, so that has a completely different risk profile than if we initiate it."[Developer 1]

Acquiring a construction approval and the influence/emergence of policy were deemed overall most uncertain. Regarding the latter, the developers found it uncertain as it is quite difficult to anticipate the emergence/implementation of policy years ahead. Adaptation to certain policies has not always been easy.

Question 8: [*"When faced with a project that encompasses higher uncertainty in terms of revenue, costs or time, would you set a higher profit margin (to buffer the risk of lower and anticipated profit)? If so, can you indicate for the following uncertainties how high you would set the profit margin?"*]

The commercial developers (Developers 1 and 3) indicated an average profit/risk margin of around 10%, while the social developer mentioned an average of around 7%. This difference can be explained by the fact that Developer 3 is not a profit-oriented company.
As mentioned under question 2, the more certain a project is the less profit/risk margin one has to forecast.

"If you run your higher risks, you literally have to make more profit, right? So in that regard I agree with you, but we are actually just satisfied if we achieve our margin." [Developer 1]

Increasing the risk marge, means lowering the bid that can be placed on the land. This may prove disadvantageous, especially in the case of a tender. Therefore, there is a trade off between taking the risk and winning the tenders or 'playing safe'.

However, it was also noted by a developer that owner-occupied single-family homes are not inherent to much differentiation in risk. Moreover, these types of homes are barely subjected to any risk at all as most of them are sold before construction and as their construction time is relatively short. Especially, in the case of a tender, the risk that could emerge during an owner-occupied single-family housing project is very limited, making it quite a safe investement.
Therefore, the uncertainty difference between conventional owner-occupied single-family houses and

a climate-adaptive one will probably not be very big. Consequently, this means that the lack of climate-adaptive single-family owner-occupied housing can not be attributed to its possible uncertainty in profit. The reasoning behind it could lie in objective cost differentiation or other reasons. (The section 'Current view flood/climate adaptation' goes into detail about what uncertainties and barriers are evident for building with flood adaptation)

Question 9: [*"Do you agree that your company's familiarity in a project (housing type and/or location) lowers the uncertainty (in profitability) of a project."*]

[1- strongly disagree .... 3 – neutral ... 5 – strongly agree]

All developers assigned a high score to this question (score of 4/5). When asked to elaborate on their answer, they mentioned that having existing projects in an area makes it easier to assess the demand and potential revenue for such an area.

"We just know a number of municipalities very well. Ee know the locations in that municipality very well. We have done several projects there. We know the officials, the administrators politically. We just know very much what the municipality wants how the market is. We have been pointed out with several projects there, for example, in sales, so you know very well what the asking prices are, what the good neighbourhoods are and the not so good neighbourhoods."

Upon further questioning, no evidence was discovered to suggest that their opinion that familiarity with a project reduces its risks is influenced by subjectivity. Consequently, it can be argued that familiarity bias does not apply to the investment decision-making of the developers. However, the limited evidence supporting this theory may be due to the insufficient nature of testing it with only one question.

Question 10: [*" How do interest rate changes affect your decision to start a new development project?"*]

The developers agreed that they tend to encounter higher interest rates for riskier projects. However, since two of the developers (Developers 2 and 3) were subsidiaries of larger companies with a significant amount of financial resources, they could finance most projects internally. The third developer noted that while higher interest rates don't discourage them from pursuing a project, it does affect the terms under which they undertake it. Increased interest rates translate to less available capital for purchasing land.

C.0.2. Current view flood/climate adaptation

Question 11 & 12: [*"Within your development process, how do you think you as a developer can help with producing climate-resilient buildings in the Netherlands?"*] & [*"What (exact) measures do you think you may implement during the construction stage to reduce the flood risks of buildings?"*]

The responses to this question offer several valuable insights. Foremost, the societal developer was most progressive in his answer: their company has a (future) strategy to cease building houses in areas prone to climate-related risks like flooding. Instead, they opt to focus on constructing in the east of the Netherlands. Therefore, their main flood adaptive "measure" would be the choice of location. One exception to this is their willingness to continue building within urban areas. However, outside the cities, they only intend to build in "high and dry" areas.

"We are now reluctant in e.g. building on a mound or floating houses etc. We very much believe in those adaption models of Delatares. So we have become much keener on that so that we will no longer start new projects and invest in those very vulnerable areas." [Developer 2]

Developer 3 expressed that his company should have a role in building more climate-adaptive. However, when asked specifically about flood adaption, they mentioned that it was primarily the duty of the municipality/government to ensure flood-resilient areas as such issues require to be addressed on a bigger scale (through dykes and such). Only measures specifically aimed at heavy rainfall they were willing to implement. Nonetheless, it's worth highlighting that certain climate adaptive measures, such as integrating more green spaces or gardens, effectively mitigate multiple climate risks. For example, building with more greenery/gardens reduces heat stress as well as flood risks.

Potential flood adaptation measurements are very location-specific. Moreover, there is a dichotomy in the measures that can be taken: technical solutions like elevated construction or housing on stilts versus nature-based approaches such as implementing small dykes or incorporating green spaces. The commercial developers expressed a willingness to adopt both technical and nature-based measures in their projects (with Developer 3 only implementing those overlapping with other climate risks). The social developer would only do so for projects located in the inner city (as the choice of location was his main ”measure”).

”Also, the impact (on those risks and measure possibilities) of building inner-city or suburban is extreme. If you look at inner-city developments, they are very compactly built. So that means that all that water that comes, that has to be dealt with on a much smaller area. So you see that in these kinds of areas then much more towards crate solutions, so more mechanical means. Whereas on the edges, much more work is done with natural means of water runoff (e.g. Wadis and greenery).” [Developer 2]

Question 13: [*“How much (in % or in absolute value) do you think these measures will add to your construction costs?”*]

The extra costs adaptive measurement would bring for a project are very project-dependent. 5 % increased construction costs and 3000 euros were provided as an answer. However, it was noted that the latter was subjected to many assumptions.

Question 14: [*”What percentage of your projects in the past five years have already incorporated such flood/climate- resilient features?”*]

While most developers could cite multiple projects where they claimed to have implemented climate adaptive measures, when specifically questioned about flood adaptation implementation, few to none of their projects had already integrated such measures. The existing measures primarily focused on addressing heavy rainfall. Developer 1 stated a commitment to considering flood adaptive measures in future projects, Developer 2 adopted a strategy of exclusively building in resilient areas, and Developer 3 acknowledged the potential inclusion of such measures in their future plans but believed the responsibility should lie with the government or municipality.

Question 15:

All developers were of the consensus that building with flood adaptive measures would not significantly increase the project duration.

Question 16: [*“Would implementing flood-resilient features in a housing project influence the development timeline of houses? If so, what is the impact (in terms of % or absolute value)?”*]

All developers indicated their intention to start construction only after a specific percentage of houses are sold. Developers 2 and 3 would start construction after 70% is sold, while Developer 1 (who seemed most risk-taking) would start construction at 30%. All developers hoped that the remaining houses would be sold during construction.

Question 17: [*“What barriers, if any, currently have prevented you from committing to more climate-resilient projects?”*]

Among the developers, a variety of answers were provided.
Currently, constructing flood-resilient buildings isn’t a requirement in the tenders issued by municipal-

ities for developers to bid on. Consequently, developers intending to incorporate flood adaptive measures would face higher costs, thereby reducing the competitive value of their land bids. As a result, their tender scores would be lower since they don't receive recognition for integrating adaptive measures in their proposals. Including flood resilience as a tender criterion by municipalities would help 'level the playing field' for implementing flood adaptive measures.

A second barrier mentioned was the past lack of demand and awareness of consumers (households, but also municipalities). Developers respond to demand. If there is no demand for it from the consumer, (commercial) developers will not respond.

"Well, I think it (climate adaptive building) was not on the agenda at all until recently, wasn't it? So It was not a common thing, was it? Unknown is undesired, so that plays into it. The second thing is, it does increase costs. So if you are in a competition and it is not asked, yes, you are actually shooting yourself In the foot." [Developer 1]

The lack of flood risk data and the reliability of this data were identified as significant barriers. The societal developer highlighted this as their primary concern, emphasizing the importance of assuring consumers that their homes remain safe and resilient over 50+ years. The introduction of maps like the 'Ruimtelijke afwegingskader klimaatadaptieve gebouwde omgeving' (a map giving insight into where and how to build regarding flood and soil risks) in April 2024 has made such information more accessible. Previously, developers had to rely on their interpretation of hydrology and elevation maps to assess flood vulnerability in certain areas. However, the reliability of these maps remains questionable, given that flood risk calculations are based on various assumptions and uncertainties in hydrology models. This concern was also highlighted by the water and soil expert.

"The biggest barrier in that case would actually be more the certainty of the data on where exactly is it then climate proofing. Actually identifying the risks in the long term would then be the biggest barrier." [Developer 2]

Developer 3 did not necessarily consider the costs of flood adaptive measures as a barrier. Instead, they highlighted a different concern: when implementing climate adaptive measures, the available space for houses reduces, resulting in a lower quantity of houses that can be realised. This is due to the fact that, during the development of the area for the houses, measures like adding extra greenery to mitigate heat stress or flooding impact might occupy space that could otherwise be used for building houses.
The accumulation of ambitions of the public was also seen as a barrier. With existing goals and regulations like energy neutrality and circularity, adding climate adaptation ambitions further complicates matters. Furthermore, tthese ambitions vary across municipalities due to the lack of national guidelines. This creates uncertainty about what constitutes resilience in each locality and may drive up transaction costs for verification. A national approach or framework providing standardization and certainty in climate adaptive building practices was deemed preferable.

The findings above underscore the key role of the municipality and government in overcoming barriers to build more climate adaptive. They indicate the necessity for reliable flood data, effectively communicated in an accessible manner, to be used for the creation of a rigorous national standardization/framework dictating where and how to construct new homes. These should in turn be used uniformly across municipalities to prevent confusion regarding climate/flood adaptive building requirements. Moreover, by enforcing such standards, constructing with adaptive measures would no longer result in a competitive disadvantage.
Such data and frameworks already exist in the form of 'Ruimtelijke afwegingskader klimaatadaptieve gebouwde omgeving' and 'Maatlat Klimaat adaptief bouwen'. However, criticism was placed on these methods as they encompassed uncertainty and lacked clarity around the execution of the recommendations these maps indicated.

A limitation of this question is that no magnitude was assigned for the barriers, therefore making it unable to assess the severity of each barrier. Moreover, the barriers mentioned by one developer were not discussed with other developers and, therefore, it is unknown if developers do have overlapping barriers or simply because they did not think of mentioning them.

Question 18: [*“Do you currently view investing in making houses climate-resilient as more, equal or less risky than conventional/non-resilient housing?”*]

The answers to these questions were a summary of what was answered under questions 11, 12 and 17.
Developer 1 indicated that currently building with flood adaptive measures is riskier as it would decrease the chances of winning the tender. They interpreted risk here as project acquisition risk.

”It is becoming more and more mandatory (to build climate and/or flood-proof), so then the risk also diminishes. If everyone has the same playing field, it is no longer a risk.”[Developer 1]

Developer 2 (societal developer) interpreted the risk as climate/social impact risk. Considering their goal to ensure flood-resilient housing, they expressed that they see more risk in developing houses in vulnerable areas. Even if such houses would have (technical) flood adaptive measures implemented, there will always remain some uncertainty about whether those measures are enough to combat the risk.
Developer 3 did not see more or less risk, as they were of the opinion that most of his existing projects already had elements of climate adaptation and they did not see it as his responsibility to resolve certain flood risks (due to dyke failure).

Question 19: [*”“Are loan lenders (such as banks, pension funds etc) currently more reluctant to provide loans for potential housing projects with climate-resilient measures (in comparison to one without)? If so, does this form a barrier in your decision to invest in climate-resilient houses?”*]

This question was answered/interpreted in two ways: 1.) from a developer perspective: the loan necessary for a project 2.) from a household perspective: the loan/mortgage required to buy a house.

Loan for the developer: According to one developer, banks say they are reluctant to provide loans to flood-vulnerable projects, but they have yet to see such a thing.
Loan/mortgage for households: Currently, loan lenders do not take climate change in their mortgage lending practises (in a positive or negative way).

However, the developers thought that for both parties this could change in the future due to increased transparency in the risks.

Q: ”So, suppose you were to start a project like this now, wouldn’t you have trouble getting funding because it’s a projct with climate adaptive measures?”
A: ”No, I think it actually works the other way around, so that it will get easier and easier” [Developer 1]

C.0.3. Influence Climate label policy of development behaviour regarding flood risks

Question 20: [*”If it were announced that within two years, all new projects must align with Climate label standards, how would this influence your project planning starting today?”*]

It was indicated by Developers 1 and 2 that two years is too short of a timeframe, due to most projects taking longer than two years. This would have implications for existing projects, as the plans and construction would need to be revised. Small adjustments such as vertical escape routes could be realised, but buildings with elevation would not. A longer time period (5-10 years) would be much more suitable. Additionally, current projects set to be realized could potentially face a decline in value as they may suddenly be stigmatized with a negative label.

”Yes, look, our market benefits from predictable behaviour. That’s not doable for us to switch, because that also means you have to gather that knowledge every time. And if there is repetition in it, then it becomes less risky for you than if something changes every time. And if the same thing is not applied everywhere in the Netherlands, it becomes very complicated for us” [Developer 1]

"So I have no problem with a climate label. I certainly do see it as a good thing, but in a predictable way" [Developer 1]

According to Developer 3, they are quite well prepared for the implementation of a policy such as the Climate label. It would not change much for their current operations. However, this really depends on the categorization such a label will have. If there are big difference in the definitions/categorization of climate and flood adaptive, it could have significant consequences for their business. This highlights again the need for certainty and standardisation in determining what is climate and flood resilient.

It was noted that the adaption speed in general is also very depended on the conditions of the market. In an upward market adaption can happen quickly (as financial costs are easily compensated). In a downward market, the first things that will be cut of are these "extras" regarding climate adaptive development.

From the answers of developers, it can be derived that policies regarding flood adaptive housing (such as the Climate label) should be implemented gradually, taking into account the adaption speed of developers and their existing projects located in areas that will be labelled as vulnerable/"bad".

Question 21: [*"Could you give examples of how government incentives have shaped your past development projects?" (for example, the implementation of the energy label*]

The request for a suitable transition period and uniformity was also alluded to in their examples:

"We already had that with the energy label. We had to go gas-free at some point. That casues you to revise the projects that you already have all worked out, doesn't it? So there's also questions to put in time towards some kind of transition moment." [Developer 2]

The success of a label could be very context-dependent. For example, in light of the big gas price spike, we were able to sell tgas-free homes better" [Developer 3]

Question 22: [*"If any, in what way do you think Climate labelling will incentivize you to build more flood-resilient houses"*]

A wide variety of answers are provided by the developers, ranging from financial stimulants to social stimulants. Moreover, the behaviour of a variety of actors was key in stimulating the developer in developing flood resilient houses.
When asked if they would anticipate an increase in the value of flood-resilient houses and/or a decrease in the value of flood-vulnerable houses, Developer 1 and 2 believed in shift of housing values, while Developer 3 did not think it would be of influence. Developer 3 noted that way more factors, and more important factors go into determining the demand and price for a house.
Developer 2 expressed that they would build houses with flood adaptive measures if the increased costs would be sufficiently compensated by the increased value. Key in this is the value the consumer will give to flood resilience.

"We develop for the consumer. So if others derive added value from it in the long run. With us, it will always have to translate into higher revenue. If the customer doesn't value it, he's not going to pay for it either. That's a bit of how it works for a developer. So if the customer doesn't appreciate having a higher climate label is going to yield more in the long run, then I can't get rid of that cost." [Developer 1]

The response of loan/mortgage could also play a significant role in stimulating developers to build flood-resilient houses. (In question 24 this stimulant is discussed more elaborately)

"Households could potentially get more loans and finance for climate-resilient homes. So as soon as climate label is on the way, financiers and insurers are going to respond to that. That has a direct impact on housing revenue and therefore making up for the investments you have to make to make more resilient homes." [Developer 2]

All and all, Developers 1 and 2 believe that not building flood adaptive in the future (after implementation of a Climate label) would result in higher project risk than building without.

Developer 3 already thinks they can acquire a sufficient score for the climate label for his existing conventional projects. Moreover, they believe that most newly constructed houses will have a relatively high label if compared with old houses.

“And yes, that does tell me that as far as I am concerned, the regular development process can already be given a grade of 6 on climate-adaptive building.” [Developer 3]

Criticism was also placed on the Climate label. Developer 3 and the soil and water expert expressed that assigning labels on an individual housing scale would not be feasible and worried about the implications it could have for exiting vulnerable housing. Households would be stamped with a less valuable house, while there is little on can do to an existing house to make it substantially more flood resilient. They preferred seeing it applied on a much larger area scale. This worry about the effect of the Climate label on existing houses located in vulnerable areas was shared by all developers.

”It is rather that we see it as a threat. That for places that are not climate-resiliently developed -and therefore climate vulnerable houses- the insurer will in future say, we are not going to insure those anymore.”[Developer 1]

There appeared to be varied and distinct perspectives among the developers regarding how a Climate label or heightened flood risk awareness would impact the housing market and their project decision-making. Developer 1 expressed the belief that a Climate label could alter housing values. This could potentially incentivize them to construct more flood-adaptive houses, but only if the increased value attributed by consumers to flood-adaptive measures sufficiently offsets their costs.
Developer 2 also anticipated a shift in housing values according to flood vulnerability, however, they think this would mainly have implications for existing houses. A climate label would only affect his decision-making in a more social sense: they could utilize the heightened awareness and information to identify flood-resilient areas for new housing projects.
Developer 3 did not believe that a climate label would cause a shift in housing value. They believed that most of their existing projects would receive a satisfactory label grade, indicating that conventional housing development would suffice for them (assuming their understanding of climate and flood adaptation proves accurate). This suggests that Developer 3 exhibits satisficing behaviour regarding flood adaptive building. Additionally, they argued against individual houses receiving labels, proposing instead that areas should be assigned such a label. This aligns with their belief that large-scale flooding should be addressed with municipality-led solutions rather than individual housing adaptation measures. From the answers provided. Developer 3 seemed to anticipate relatively few changes (needed) in his decision-making after the implementation of a Climate label.
All developers agreed that the response of loan lenders and insurance companies on the climate label could alter household and (therefore) developer decision-making regarding flood-resilient housing. (See question 24 for more elaboration)

Question 23: [*”Would the (relative) value increase in climate resilient houses potentially lead to you preferring housing projects in more climate resilient areas (e.g. none flood risk zones)?”*]

This question was not applicable for Developer 2 and Developer 3, as both did not mention it as a stimulant for building flood resilient housing. Developer 1 believed it would not lead to such a result:

”No, I don’t think so. Look it’s a utopia to think that you can’t be at risk, right? So there will always be places where people want to live and where you have an increased risk with regard to flooding and flooding. I don’t think that means that people suddenly don’t want to live in Amsterdam, for one thing.”[Developer 1]

Moreover, the soil and water expert did not think that in certain areas developers will not build in vulnerable areas because the label they will receive is low.

Question 24: [*“When the Climate label would be introduced, do you think loan lenders would be more willing to give out loans to climate-resilient housing”*]

All developers highlighted the potential significant role that loan and mortgage lenders could play in encouraging households to purchase flood-resilient housing or developers to construct such housing. This could be achieved by making it easier for both parties to obtain a loan or mortgage for such properties, or by offering higher loan amounts. Additionally, insurance companies could opt not to insure flood-vulnerable houses or to charge a higher premium for such coverage.

”But you can see insurers and banks contemplating: What about our collaterals? Will insurers still insure these risky houses? So it is not only socially responsible, but we also think it is economically irresponsible to continue doing so” [Developer 2]

”So it works two ways: from the investment side and so the consumer, so the household who then has to get the loan to buy a house. That would be easier for climate-proof house. And from our perspective, it might also be easier to get one for building. The negative scenario is that banks themselves would put a penalty on houses that are not climate-resilient, resulting in a smaller loan. And you’re going to get that with a climate label too, that banks are just less likely to lend less. Or possibly at a higher interest rate.” [Developer 2]

“I also find it logical that bike insurance is more expensive here in the city than in a village. ”Well analogy, I would find it logical If I live in a high-risk flood risk area that home insurance is more expensive.” [Developer 3]

Question 25 & 26: [*”Do you think that introducing the climate label alone (without additional regulations from certain municipalities) will give you enough incentive to ensure that all your future projects will be flood-proof?”*] & [Or do you see this happening only in situations where the municipality takes an active role/ground policy AND/OR strictly enforce it through rule and legislation]

The role of the municipality was emphasized throughout the interviews. As Developer 1 mentioned earlier, by implementing regulations and/or tender criteria regarding flood resilience, the playing field would be levelled for developers interested in incorporating flood adaptation measures. Therefore, without regulations, developers may not be sufficiently incentivized to implement such measures unless a Climate label results in a significant increase in value, covering the additional costs of flood adaptation measures.
However, in what regard the municipality should take an active role in flood adaptive building remained dubious. One developer mentioned that the municipality taking an active role and, therefore, taking over certain stages of the housing development process, would make investing in the respective project more attractive.

”It’s highly dependent on the specific site. If the municipality commits to ensuring that the ground is at grade, implements a robust drainage system, and enforces measures against flooding, it significantly improves the risk profile for building in that location. This removes a significant risk for developers, who will then adjust their pricing accordingly. So, such measures can certainly be beneficial.”[Developer 1]

However, one developer was sceptical if leaving many responsibilities to the municipality would be a good thing for climate/flood adaptive housing, as they mentioned that the municipalities often act as profit-driven developers who are under even more financial pressure than his own company. This results in municipalities cutting corners in projects.

D

Model Overview, Design Concepts, and Details (ODD)

Following the ODD framework first described in Grimm et al. (2006) and updated in Grimm et al. (2010). A table listing all model assumptions can be found at the end of this appendix under section D.4.

D.1. Overview

D.1.1. Purpose

The purpose of the model is to understand and explore how findings regarding overall developer decision-making and their perspective on flood risks and Climate labelling would influence the degree they take flood resilience and adaptation in their housing projects. The key to this is to evaluate where and how they will build.

Due to time limitations, a highly stylized and simplified model has been created, in which these two aspects of developer decision-making and flood resilience are central. Therefore, certain aspects and actors of the housing market, such as transactions through buying and selling households and insurance companies, are highly simplified, modelled very implicitly, and/or excluded from the model. In 7.1.1 in the main text the model narrative can be found.

D.1.2. Entities, state variables, and scales

The model consists of two ”agent types”: a developer agent that operates in a fictitious and stylized landscape in which there are two cities in the form of agents present: 1. a 'left' city in which demand and prices of houses are high and high flood risks; 2. a 'right' city that is relatively small, has lower demand and housing prices and is subjected to lower flood risks. Even though this landscape is based on very little empirical data, it intends to mimic the trade-off between high housing demand, high flood risks and low housing demand, low flood risks which can, among others, be found in the Netherlands (=Randstad and non-Randstad/East of other Netherlands). In section 7.1.1 in the main text, a Unified Modeling Language (UML) visualising the model's entities, respective state variables and behaviour can be found. In the sections below, more detail regarding these entities is provided, particularly their parameters.

Agents

80 % of the developer agents are commercial developers and 20 % of the agents are societal developers. The number of developer agents in the model can be variable, but there are always two city agents ('left' and 'right). In table D.1 the agents, their states and their respective parameters are given.

Table D.1: Agent types and their respective state variables

Agent Type	Attribute	Description	Type	Value range/Base value
Developer	unique_id		int	[0 ... inf)
	type	As derived from the interviews, developers can be divided into commercial developers who are mostly profit-oriented and societal developers who are more societal and climate-oriented have a personal interest in ensuring flood-resilient.	string	societal, commercial
	profit_margin	All developers have a fixed profit margin (% of the revenue) which they intend to achieve each project	float	[0 ... 1] societal: 0.07 commercial: 0.10
	projects_sorted_on_utility	To maintain a record of the utility associated with each available land and housing type combination, a dictionary is utilized. In this dictionary, project characteristics such as location (x,y), housing type, and bid serve as keys, while the corresponding expected utility is stored as the associated value.	dict	{[(x,y) , house_type , bid] : utility}
	risk_attitude_gain_coeff	The coefficient representing sensitivity to gains, utilized in the Prospect Theory-conforming value function formula, is indicative of an individual's responsiveness to positive outcomes or gains. Derived from	float	0.89
	risk_attitude_loss_coeff	The coefficient representing sensitivity to losses, utilized in the Prospect Theory-conforming value function formula, is indicative of an individual's responsiveness to negative outcomes or losses. Derived from	float	0.92
	loss_aversion_coeff	The coefficient representing how averse one is to losses. Derived from	float	-2.25
City	unique_id		string	left, right
	size	The radius of the city. This is a fictious value, but intends to be used to show relative size difference between the left and right city.	int	left: 35 right: 25
	housing_value_centre	The price of a house located in the city centre. As housing price has a linear relationship with proximity to city centre, these houses are the most expensive in the city. In our model, we depict two stylized cities: one affluent and high in demand, and the other less popular. The relative price values between these cities are inspired by real cities in the Netherlands. Specifically, the left city is based on Rotterdam, The Hague, and Amsterdam, while the right city is modeled after Nijmegen, Arnhem, and Maastricht.	int	left: 800 right: 580
	housing_capacity_centre	Land available in the city centre is relatively scarce, especially in big and highly popular cities. This results in limited supply of new houses. To mimic this, available land for housing development projects open up based on the capacity of the cell, which is set based on a linear function using this coefficient and capacity_stretch_coefficient (see equation D.1). The capacity in the left, highly demanded city is on average closer to their max than that in the right city.	float	left: 0.998 right: 0.994
	capacity_stretch_coeff	”	float	left: 0.0001 right: 0.0005

Environment

The tables (D.2 below illustrate the overall environment (the overarching model) and its global parameters that drive the behaviour and dynamics of the developer agents. The base values are given for the parameters, some of which are fixed, and some are altered for experimentation and sensitivity analysis. The model attributes are showcased in table ... are used for landscape initialisation -assigning attributes to the cells- and used to keep track of entities or mechanics.

Table D.2: Model parameters

Category	**Parameter**	**Description**	**Type**	**Base value/value range**
Developer initilisation	number_developer	The number of developer agents active in the model	int	range: [1 ... inf) base: 10
	chance_dev_commercial	The chance that a developer agent is of the type 'commercial'. If they are nto of the type commercial they become of the type 'societal'.	float	range [0 ...1] base: 0.8
Transaction price	city_centre_pref_coeff	According to the urban land use model by (Alonso (1964)), households choose locations at a certain distance from the Central Business District (CBD) based on the utility they receive from land and other consumption goods. For this research model, it is assumed that the city centre is the CBD. Additionally, amenities often increase as one gets closer to the city centre (D'Acci (2019)). This gives rise to the factor 'proximity to the city', which aggregates and simplifies these relationships between distance and price. This coefficient is used in the price function to create housing transaction price data (equation 7.1).	float	range [0 ...] base: 8.4
	flood_label_pref_coeff	It is assumed that Floodlabel will have a multiplication effect on the price (e.g. an increase or decrease of 10%). This coefficient represents the willingness to pay (WTP) consumers will have for a flood-resilient property. As there is only one Floodlabel coefficient, it is assumed that the "preference difference" between the categories is equal. The base value of this coefficient, which is also used for the experiments is based on various papers describing the discount to increase of housing value du to actual flooding (e.g. Bin, Kruse, and Landry (2008), Niu (2024), Rajapaksa et al. (2017), and Ratnadiwakara and Venugopal (2020))	float	range [0 ...] base: 0.10
	effect_floodlabel	A Floodlabel might cause flood-resilient housing to rise in value, but it could also cause a discount in flood-vulnerable houses. The model simplifies this by having the relationship between Floodlabel category and price be positive or negative	string	positive or negative
	mean_price_variation	To mimic variation in transaction prices due to strategic buying and selling, samples are drawn from a normal distribution and added to the transaction price.	int	range: [0 ...] base: 0
	std_price_variation	"	int	range: [0 ... inf) base: 3
Policy	where_policy_threshold	For exprimental purposes. Policies that restrict housing development in areas with high flood risks/label could be implemented. All locations above this threshold will be excluded from development.	float	range[0 ...1] base: 1
	how_policy_threshold	For experimental purposes. Policies could be implemented that require houses to be built with at least a certain Floodlabel. All locations and housing type combinations above this threshold will be excluded from development.	float	range[0 ...1] base: 1

Table D.3: Model parameters [Continued]

Prediction function	years_tdata_for_prediction	The number of previous years of transaction data that are used to create the hedonic prediction function used by developers to estimate their expected revenue.	int	range: [1...] base:10
Misc	quantity_dev_houses	The number of houses a developer "construct". Its main purpose is to have multiple data points added to the transaction as approximately 20% of the houses on the market are newly constructed houses (de Leve and Kramer, 2020). By having multiple datapoints, this hardcodes this balance between sold newly constructed houses and sold "existing" houses created by the transaction data creation process each timestep.	int	range: [1...] base:10

The hedonic coefficient for proximity to the city centre is fixed and is equal for both cities (as it is a global parameter and not an attribute of a city). This is a limitation of the model as in reality this coefficient differs between cities.

Table D.4: Model attributes

Attribute	**Description**	**Type**
floodlabel_layer	A Propertylayer to assign the cells their flood risk/label attribute	np.array
housing_capacity_layer	A Propertylayer to assign the cells their capacity attribute	np.array
land_price_layer	A Propertylayer to assign the cells their land value attribute	np.array
hedonic_regression_model	The hedonic prediction regression function based on the transaction data. This model is updated each timestep and is "provided" to the developers.	Object
prediction_errors	The prediction errors of the hedonic prediction function are tracked for each floodlabel category each timestep. The dictonary has the floodlabels as keys and the uncertainties as values.	dict
available_land	Each timestep, new land bcomes available for housing development. This list keeps track of them.	list
bids_land	Each timstep, the bids that developers place on land for which they rank the respective project the highest are tracked.	dict

Inherent to the environment are the grid property layers that assign attributes to the cells to, among others, create the flood risk/label landscape. The following functions are used to assign these attributes per cell.

$$Capacity(l) = HCC_{txtC1/C2} - CS_{txtC1/C2} * x_P \tag{D.1}$$

Capacity and proximity to CBD/city centre (x_P) have a linear relation (Rakhmatulloh et al., 2018). The capacity of a cell is determined by having the housing capacity value of the city centre (HCC) of the given city substracted by the capacity stretch coefficient (CS) multiplied by the proximity to the city centre.

$$LV(l) = (\beta_{C1}x_{C1} + \beta_{C2}x_{C2}\beta_P x_P) * (1 - profit\_margin) - ccosts_{\text{regular}} \tag{D.2}$$

The land value LV is calculated using the residual land method de Leve and Kramer, 2020. The first part of the equation, which is in brackets, is the revenue one could achieve at timestep 0 by selling a regular house on the respective land. The "costs" are the expected profit margin (assumed to be 10% for all developers) and the costs of building a regular house. By subtracting the costs from the revenue, land value is determined.
It is assumed that the "land owner" bought their land before the implementation of the Flood label or increased awareness of flood risks and, therefore such a coefficient is not taken into account in determining the possible revenue one could achieve from developing on the land. Moreover, therefore, the revenue calculations are based on regular houses (instead of adaption measures).

The landscape of flood risks in the model is not based on empirical data but is inspired by existing flood maps (Deltares, 2023; Kolen et al., 2023). These maps typically categorize flood risks into six levels of severity, each with its corresponding probability of flooding. For simplicity, the actual flooding probabilities from these maps are not used as input for the model's flood risk. Instead, the categorization of flood risks into six levels is utilized. As there is no definitive design for the Climate label policy, it is assumed that the "score categories" regarding flood risks (i.e., Floodlabel categories) will also be divided into six levels, each corresponding to a flood risk severity. This approach aligns with the DGBC, which also divides flood risk/resilience scores into six label categories. The Floodlabel is formalized through labels ranging from 0 to 1, with an interval of 0.2, where Label 0 represents the best rating and Label 1 the worst.
The flood risk/label attribute is assigned dividing the first half of the grid into four equal-sized compartments, and the second half into two equal-sized compartments. All cells in one compartment are assigned the same flood risks/label. From 'left to right' the compartments are assigned respectively the values 0, 0.2, 0.4, 0.6, 0.8, and 1. By doing so, the 'left' city is subjected to four different "degrees of flood risk", while the 'right city' is subjected to two. See figure 7.2 for a visualisation.

Spatial and Temporal Scales

The landscape of the model is based on a 100x 200 grid. No empirical scale is assigned to the model and its cells as the model are highly stylized .
One timestep in the model is equivalent to one year. Every process the same processes occur (see D.1.3). Simulation is executed for a total of 20 timesteps. No model "warm-up" time is included as the housing market is "hard-coded" (see 7.2.1), therefore, no form of "balance" has to first be established in the model.

D.1.3. Process overview and scheduling

The model starts with initialising the fixed attributes of the cells as described in D.1.2. In timestep 1 a Floodlabel is "introduced". Consequently, each timestep the following processes are conducted in consecutive order. For visualisation of all processes, view 7.3 and 7.4 in the main text.

- t = 0 : Initialisation of agents and environment (see D.1.2) and creating 10 years worth of housing transaction data (before implementation Floodlabel)
- **Opening available lands**: Opening up of land available for housing development
- **Update transaction data:** Creating N new housing transactions throughout the cities for transaction data
- **Add newly developed houses (from the previous timestep) to transaction data**
- **Update hedonic prediction function**: Based on the "historical" transaction data, a hedonic 'prediction' function is created. This function and the uncertainties it has in its predictions are consequently used by the developers to asses the business case of projects.
- **Developer decision-making:** Assessing business case/expected Utility (through Prospect theory) per available land and housing type combination (project).
- **Bidding:** Developers bidding on land for which the potential project has the highest expected Utility

- **Resolving bids:** if there is land that has received multiple bids, the highest bidder receives the land. The rest of the developers bid for their ”second-best” project. This continues until all developers have land to develop on.

D.2. Design Concepts

D.2.1. Basic Principles

The model used in this research is based on multiple principles and theories, one used more extensively than the other.
The most predominant theory used in the model is Prospect theory by Kahneman, Knetsch, and Thaler (1991) and Kahneman and Tversky (1979), which is used for the project decision-making processes of the real-estate developer agents. A detailed description of Prospect Theory and a literature review of its relevance in developer decision-making can be found in Chapter 5.2 of the main text. Further details on its application within the model are provided in Section D.1.3 of this appendix.
Other, more secondary, principles and theories used in this model include the principle of market equilibrium and the Alonso model. The principle of market equilibrium originates from conventional economic theories and describes a state where market supply and demand balance each other, resulting in stable prices. In the model, extensive market mechanics, such as shifts in supply and demand curves, are not modeled; instead, an assumption of constant and spontaneous market equilibrium is made. The Alonso model, a key theory in urban economics, seeks to explain how land use patterns and real estate prices in a city are influenced by the distance from a central business district (CBD) (Alonso, 1964). In the model, this theory is used to establish the price of houses based solely on their proximity to the CBD or city center and their Floodlabel.

D.2.2. Emergence

As housing transaction prices, prediction models, and developer decision-making dynamics come together, a choice of where an how to build houses emergencies. This results in the emergence of system-level housing development patterns.

D.2.3. Developer decision-making / Objectives

Developers make their choices based on the expected gains and losses of the various land and housing type combinations given a certain profit margin reference point. They make these decision under uncertainty concerning the profit of the respective projects. The expected utility per project is derived using value function conforming to Prospect theory (see D.3.3) for more detail. To make their decisions regarding where and how to build, they rank the projects from highest to lowest Utlity and bid on the highest one.

D.2.4. Learning

The only aspect that could be considered learning is the hedonic prediction function, which, as more transaction prices that account for the changed preference regarding the Floodlabel attribute are observed, becomes better at estimating the WTP for this housing attribute. Consequently, this also decreases the uncertainty around this estimation. For future work, it would be interesting to have the developers learn from previously acquired profits and adjust the reference points to new familiar profits.

D.2.5. Adaptation

A significant limitation of this model is that it has, besides the adaptive profit margin reference point (view D.3.3), no elements of adaptation; all agent attributes are fixed throughout the model’s run. For future work, it is recommended to implement elements of adaptivity, particularly in developers’ response to competition.

D.2.6. (Developer) prediction

The model creates a hedonic prediction function based on the housing transaction data of the previous years. Every developer can use this model to estimate the expected profit for each housing project which will come to completion the next timestep (next year). Even though this function is dubbed a

”prediction model” it does not perform any extrapolation. As the model has uncertainties in its prediction (MAE is used for this), high and low profit scenarios are predicted for the developers to use to estimate the project’s respective expected Utility.
Developers are somewhat simple because they rely solely on their prediction model’s estimates for that year. They do not take into account that people’s preferences might have changed beyond what the prediction model coefficients suggest.

D.2.7. Agent sensing

As there is limited adaptivity in the model, there is also limited agent sensing. The only elements that individuals are assumed to sense or ’know’ are the entire set of land properties available for housing development (no bounded rationality in the form of a subset of choices), the exact costs per housing type (no uncertainty in the costs), and the precise label their potential houses would receive.

D.2.8. Interactions

Very few interactions exist within the model, aside from developer agents interacting with the environment. The only developer-developer ’interaction’ is that they cannot bid on the same land. However, this may not be considered true interaction, as they do not account for the existence of other developer agents in their decision-making.

D.2.9. Stochasticy

Very little stochasticy is implemented in the model. The stochasticy in the model limits itself to minor elements in three model processes. 1.) The random selection of existing houses having flood adaption measures which are evident in the creation of transaction data. 2.) The random selection of opening a cell for housing development. The probabilities of this random selection are, however, based on the capacity attribute of the respective cell. 3.) The random normal distribution that adds various in the transaction price (view 7.1).

D.2.10. Observations

The primary metrics extracted from the model results include descriptive statistics regarding the development patterns of real estate developers: the locations they have chosen for building; the inherent flood risks/labels of those locations; the types of housing they have chosen to build; and the resulting flood labels due to both location and housing type. All of these metrics are emergent patterns resulting from developer decision-making. Additionally, to understand how these results have emerged, secondary metrics that provide insight into the developers’ decision-making processes are tracked. These secondary metrics include the locations of available land properties, the average predicted housing price per Floodlabel category, the estimated willingness to pay (WTP) for a Floodlabel, and the prediction uncertainties per Floodlabel category.
All of these metrics are stored in dictionaries and dataframes. They can be used to demonstrate their value over time or to provide more detailed results and emergent patterns for a specific timestep.

D.3. Details

D.3.1. Initialization

The model is initialised with 10 developer agents (societal and/or commercial) and two cities, by creating the flood risk/label landscape, establishing the land values, and establishing the capacity of the cities. More details and information on the initial states of the entities can be found under D.1.2.
Moreover, transaction data of the previous 10 years is created. For more details on this process see D.3.3.

D.3.2. Input data

As the model is based on limited empirical data, so is its input data very limited as well. The only ”input data” provided to this model were the costs of the different types of houses (regular, no adaptation, small adaptation, large adaptation) and the respective effectiveness in reducing flood risks of those measures. These were used to ensure a proper and realistic ratio between revenue and costs of

housing development.
The costs were based on an average single-family owner-occupied house of 120 square meters. For a 'regular' house, the costs were 240.000 (in the model 240) (BouwblokNederland, 2023). During interviews with developers, it was mentioned that adaptation measures would add approximately 5% to the costs (view C). When reviewing literature, it was found that small adaptation measures would lead to about a 5% increase, moderate measures about a 10% increase, and large adaptation measures about a 25% increase. However, the latter were noted to be significantly more effective in reducing flood risks (Arcadis and &flux, 2021; Rijksdienst voor Ondernemend Nederland, 2024.

According to the interviews, implementing adaption measures does not significantly increase the construction time of housing.

D.3.3. Sub-models

Opening available lands

Where and when lands become available for developing houses is dependent on the capacity of the cell, which is fixed during the initialisation of the model (view D.1.2). The probability of a cell becoming available for housing development is $1 - capacity$.
As capacity is higher in the centres of the cities (closer to 1), the probability of land becoming available there is smaller. This is done to mimic the limited supply of houses in the centre.

Update housing transaction data

An essential part of the system in which the developer operates is the transactions occurring within the housing market: the buying and selling behaviour of consumers that determine demand and sale price. Previous ABM models concerning the housing market have demonstrated that ABMs are well-suited for simulating this market (Filatova, 2015; Parker and Filatova, 2008). The ability of ABMs to incorporate adaptive, heterogeneous agents (regarding income and housing preferences) allows for the simulation of the dynamic and strategic nature of the housing market. This capability enables a natural emergence of sale prices through the resulting housing demand and supply.

However, due to time restrictions and because developer project decision-making is central to this research, consumer agents performing buying and selling behaviour were not modelled. Instead, transaction data for sales were generated using a more opaque method, employing functions that assume constant market equilibrium.
The following function represents the market clearing price for a specific housing type at a particular location. (Thereby assuming that the market consistently maintains equilibrium, where demand equals supply.)

$$Price(h, l) = (\beta_{C1}x_{C1} + \beta_{C2}x_{C2} + \beta_P x_P) * (1 - \beta_{FL}x_{FL}) + \text{Normal}(\mu, \sigma) \quad \text{(D.3)}$$

The coefficients ($\beta_{C1}, \beta_{C2}, \beta_P, \beta_{FL}$) of the function represent the willingness to pay (WTP) of the consumer for the given respective housing attribute 'city left', 'city right', 'proximity to city centre' and 'Floodlabel category'. According to the urban land use model by Alonso (1964), households choose locations at a certain distance from the Central Business District (CBD) based on the utility they receive from amenities and other consumption goods. For this research model, it is assumed that the city centre is the CBD. Additionally, amenities often increase as one gets closer to the city centre (D'Acci, 2019). This gives rise to the factor 'proximity to the city' (x_P), which aggregates and simplifies these relationships between distance and price. It is assumed that the proximity to the city centre has a linear relationship with house price.
x_{C1} and x_{C2} are categorical variables and represent respectively city left or city right. x_{FL} represents the aforementioned Floodlabel category. It is assumed that the preference for a given Floodlabel will act as a modifier or a factor that adjusts the influence of other variables on the price.
For simplicity, the WTP for the attributes is assumed to be homogeneous for all "consumers". The variation caused by variables drawn from a normal distribution at the end of the equation is intended to mimic variation in transaction prices due to strategic buying and selling.

At the initialization of the model, data from the previous 10 years —before implementation of a Floodlabel— is created to reduce runtime. Every timestep, a number of transaction data points are added to the

”historical” transaction data using the price function. The price function does not vary over time, as it is assumed that the WTP for the attributes does not change over time. Only the WTP for a Floodlabel is initially zero before policy implementation, and after implementation, it promptly establishes itself at a fixed value. Subsequently, all new transaction data points will reflect this WTP. Thus, we maintain the assumption of homogeneity in WTP for a specific Floodlabel, as mentioned earlier.

By simulating the housing market in such manner, an almost perfect market is simulated. The only ”imperfection” is that developers do not estimate the WTP of a Floodlabel properly (particularly right after implementation)

Update hedonic prediction function

Parker and Filatova (2008) provide two approaches on how to model the consumer WTP estimations that appear in developers' profit function. One approach states that boundedly rational developers estimate inductive hedonic demand curves based on information about agent characteristics and recent sales. As in this research's model, a constant market equilibrium is assumed, this approach can be simplified and the sale price of a house given its attributes can be predicted through a singular hedonic regression function.

Every timestep, based on the previous N years of historical transaction data, a hedonic regression function is created (by the model). This function and its coefficients (and the uncertainties around the coefficients) are used by all developers to determine the potential revenue one could get from housing type h on land l at timestep t. It must the noted that this function is dubbed a ”prediction” function, however, it does not perform any extrapolation.

$$Price(h, l, t) = \beta_0 + \beta_{C1} x_{C1} + \beta_{C2} x_{C2} + \beta_{FL} x_{FL} + \beta_P x_P + \varepsilon \tag{D.4}$$

The uncertainties/prediction errors are determined per flood label category by calculating the mean absolute error (MAE) between the actual sale price of houses of the most recent year and its respective predicted sale price.

In essence, the model incorporates ”two” hedonic regression functions 7.1 and 7.2). Initially, functions (7.1 are utilized at the beginning of a timestep, where the consumer WTP for each housing attribute is hard-coded to generate transaction price data points. Subsequently, the second function 97.2 is derived using the resulting transaction data, offering ”estimations” of the predefined WTP per housing attribute meant for revenue forecasts. Prior to the introduction of a Floodlabel, the WTP estimations will logically very closely mirror the actual hard-coded values due to the homogeneity in the first function. However, with the implementation of a Floodlabel, housing transaction prices shift as preferences emerge for flood-resilient houses. Since the hedonic prediction function 7.2 relies on past transaction data, especially during the initial stages, it may inaccurately estimate the WTP coefficient for a Floodlabel. This discrepancy leads to ”mispredictions” in transaction prices and consequently introduces uncertainty in forecasts associated with a Floodlabel category. It will still very accurately predict the WTP coefficient of proximity to the city centre, as no change occurs in the preference for such. This is arguably valid, as the interview findings state that currently—without Floodlabel—developers experience very little uncertainty in their price predictions for conventional housing.

Developer decision-making

For each available land and housing type combination, every developer assesses the potential gains and losses in terms of profit. They do so by using the hedonic regression function (7.2) the model provides them to asses the potential revenue (price=revenue) for a 'high' and 'low' revenue scenario, accounting for the prediction uncertainties σ (equations 7.3 & 7.4).
As a result, developers are somewhat simple because they rely solely on their prediction model's estimates for that year. They do not take into account that people's preferences might have changed beyond what the prediction model coefficients suggest.

$$Rev_{\text{high}}(h, l, t) = Rev(h, l, t) + \sigma \tag{D.5}$$

$$Rev_{\text{low}}(h, l, t) = Rev(h, l, t) - \sigma \tag{D.6}$$

The developers can take two reference points to measure gains and losses. The first reference point is the profit a developer was accustomed to making before the implementation of the Floodlabel $(t = 0)$ from building a conventional 'regular' house on land l. The second reference point, while similar to the first, considers the current influence of the Floodlabel on the price by taking into account the potential profit of constructing a 'regular' house on land l at timestep t (equation D.7).
These approaches are based on interview findings where developers indicated they aim to meet their pre-established project profit margins. Furthermore, since developers are currently most familiar with building without flood adaptation measures, building 'regular' houses is assumed to be their status quo, and they could treat potential profits of such housing as endowments (Kahneman, Knetsch, and Thaler, 1991)

$$Profit_{\text{ref}}(l,t) = Rev_{\text{regular}}(l,0) \times profit\_margin \quad \text{OR} \quad Profit_{\text{ref}}(l,t) = Rev_{\text{regular}}(l,t) - LV(l) - ccosts(h) \tag{D.7}$$

$$Profit_{\text{high/low}}(h,l,t) = Rev_{\text{high/low}}(h,l,t) - LV(l) - ccosts(h) \tag{D.8}$$

The high- and low-profit scenarios are determined by subtracting the costs of land LV and construction costs $ccosts$ from the respective revenue (equation D.8). In this calculation, it is assumed that land value remains constant over time and that landowners are solely concerned with breaking even, thus they do not strategically adjust their asking price. Furthermore, due to time constraints and for simplicity, the aspect of project financing through a loan and associated costs such as interest rates are not included in the model.
These profit scenarios are subsequently utilized to compute the potential gains $potgain$ and losses $potloss$ through a risk-aversion value function conforming to prospect theory, in which $alpha$ is 0.89, $beta$ 0.92 and lambda -2.29 (Kavya and Christopher, 2023) (equation D.9 & D.10).

$$potgain(h,l,t) = \begin{cases} (Profit_{\text{high}} - Profit_{\text{ref}})^{\alpha} & \text{if } Profit_{\text{high}} \geq Profit_{\text{ref}} \\ 0 & \text{if } Profit_{\text{high}} < Profit_{\text{ref}} \end{cases} \tag{D.9}$$

$$potloss(h,l,t) = \begin{cases} \lambda(Profit_{\text{ref}} - Profit_{\text{low}})^{\beta} & \text{if } Profit_{\text{low}} < Profit_{\text{ref}} \\ 0 & \text{if } Profit_{\text{low}} \geq Profit_{\text{ref}} \end{cases} \tag{D.10}$$

After establishing the potential gain and loss, the Utility for the respective land and housing type combination is determined by using the following function (D.11).

$$Utility(h,l,t) = \frac{potgain(h,l,t)}{potgain(h,l,t) + potloss(h,l,t)} \tag{D.11}$$

All land and housing type combinations are ranked from highest to lowest utility, excluding those with negative expected returns. Subsequently, developers "bid" on the land with the highest expected utility. If they are either the sole bidder or the highest bidder, they acquire the land and start "construction". Otherwise, they continue to bid for the second-best land opportunity (with the constraint that they cannot rebid for the same land with a different housing type). Developers will always bid for land, even if buying the land means delivering on their profit margin ($Utility(h,l,t)$ =0).
This process of evaluating the business case of a project occurs at each time step and involves calculating and comparing the price/revenue and respective profit of a single house. Therefore, the potential quantity of sales is not considered in their decision-making. However, each developer "constructs" a fixed number of multiple houses for each project. In the consecutive timestep, the houses are "completed" and the developer can start a new project. The new houses are added to the aforementioned historical transaction data, by using equation 7.1.

D.4. Model Assumptions

Table D.5: Summary model assumptions (part 1)

Category	Assumption	Description
General	Capacity is not updated when new houses are built	In reality when new houses are built, fewer land becomes available for future development. In the model, the capacity and, therefore available land for development, remains unchanged.
	Flood formalised with equal interval scale	In reality, flood risks are given as ratio scales, e.g. 1/30, 1/300, 1/3.000 etc.
	Besides adaption measures, all housing attributes are homogenous	Other housing attributes, such as size, number of bedrooms etc are assumed equal across all houses in the model. Therefore, these attributes are not modelled or their effect on housing prices.
Development process	No speculative buying of land	In the interviews it was indicated that most developers acquire their projects through tenders and/or buying land speculatively. In the model only serviced/ ”build ready” is modelled to simplify the housing development process. However, this approach excludes a significant part of the development process.
	Developers can only build in the city	To simplify the price functions and the development and decision-making processes, it is assumed developers only desire to build in a city.
	The number of houses per project and sold in every timestep is equal	In the model, the number of houses sold is equal in every timestep, leading to a hardcoded market equilibrium with no change in the quantity of flood-risk-prone houses sold. This setup implies that demand shifts result in an immediate new market equilibrium at a lower price, without any corresponding shift in the supply curve. This assumption does not accurately reflect real market dynamics, where both supply and demand can fluctuate and influence equilibrium prices and quantities over time.
	No construction approval process	To simplify the housing development process, it is assumed that developers will immediately and always receive construction approval. In reality, this is a lengthy and sometimes uncertain process.
Land	No variability in land prices	This is done to more easily interpret the effects of developer decision-making. However, this lack of land price variability makes it harder to capture the true market dynamics and market behaviour.
	Land-owners only care to break even	The model assumes that all landowners are only concerned with breaking even, and therefore, they will not increase or decrease their land asking prices based on flood risk or other factors. So, in the case of a positive flood risk effect scenario, ”landowners” do not drive up the prices of their land.
Transaction Price	Assumption of constant and immediate market equilibrium	The concept of market clearing conditions are often treated as an assumption in economic models, particularly in theoretical analyses of supply and demand. It is considered an assumption because it simplifies the analysis by assuming that markets automatically adjust to ensure equilibrium between supply and demand. However, in real-world markets, achieving market clearing conditions may not always be immediate or perfect due to various factors such as transaction costs, information asymmetry, government interventions, and other market imperfections. Potential validation issue: If the model adds too many flood-resilient houses, creating an excess supply, the price is not adjusted accordingly. In a real market, such an excess supply would result in some houses remaining unsold, leading sellers to lower their prices to attract buyers.
	Homogenous preferences for housing attributes	For example, one person might place great value on flood resilience, significantly more than the average person, resulting in a very high willingness to pay (WTP). However, the willingness to accept (WTA) might be lower, as the average selling price for such a house is based on the average WTP. This discrepancy could provide an opportunity for the buyer to adjust their bid price significantly lower than their actual WTP, potentially securing the property at a price lower than what they are willing to pay. Moreover, heterogeneity in WTP exists spatially. For instance, individuals accustomed to living in flood-resilient areas may not necessarily give increased value to flood-resilient (high climate label) houses, thereby, causing minimal changes in housing prices in such resilient areas.
	Assumptions Central Business District is in the city centre	To simplify the relationship between price and distance to centre and amenities.

Table D.6: Summary model assumptions (part 2)

Category	Assumption	Description
General	Proximity to the city centre has a linear relationship with price	It is assumed linear, however, in reality this relationship is slightly more exponential (Dekkers, 2009)
	Relationship price and proximity to the city and its coefficient equal for both cities	How much one is willing to pay to be closer to the city centre can differ per city (D'Acci, 2019)
	Spatial influence of heterogeneity flood risk/label preference not taken into account	People who have always lived in a flood safe area might not give value and therefore increased WTP to a flood resilient (high climate label) house in that flood-prone location
	Linear relationship between the 'Floodlabel multiplication factor' and Floodlabel category	In other ABMs, the hedonic coefficient for flood risk is split out into a coefficient per flood risk (Filatova, 2015). In this model, the flood label category is formalised into an equal interval with values ranging from 1 to 0, which are consequently used as input for the transaction price and expected price function. This means only one coefficient is used for Floodlabel preference and, therefore, this preference is to increase linearly per floodlabel category.
	One coefficient for flood risk/label preference/WTP	View the explanation given in the row above
Developer processes	The effect of project financing/ interest rates of loans not taken into account	Due to time limitations this factor influencing the developer decision-making has not been accounted for in the model.
	Complete certainty in the Flood label they will receive for a location and house	It is assumed that the developers will know with 100 % certainty which flood label a housing type in a given location will receive. Therefore, this is not a factor in the decision-making process
	Strategic bidding on land/project from developer not included	According to the interview findings, some commercial developers will not build with flood adaptive measures as it will lead to a disadvantages position when faced with competition. Due to time-contraints this has not been included in the model.
	Preference for building in a certain city/familiarity bias not taken into account	In reality developers have certain areas -parts of the country, or areas within a city- where they operate most frequently and are, therefore, most fimiliar with.
	Reference point for PT based on the revenue for a regular houses at that location	Assuming they will use their conventional housing as reference point.
	Developers are able to asses the business case of all land and housing type combinations	They have complete overview of what land is available for development and able to create plans for the lands immediately. Not entirely in line with bounded rationality
Hedonic prediction function	Developers blindly follow the prediction model	Developers are simple in the sense that they only follow their prediction model's forecast for that year. They do not consider that people's preferences might have changed beyond what the model coefficients indicate. This lack of adaptability means that developers might miss shifts in market trends or changing buyer priorities that are not captured by their static prediction model. This limitation could lead to suboptimal decision-making and missed opportunities in the housing market.
	No uncertainty in prediction conventional housing/proximity to city centre WTP	The only "conventional"/non flood-resilient housing attribute is the proximity to city centre. The WTP for this attribute is predicted (almost) perfectly by the prediction model. This assumption of perfect prediction is based on the fidnings derived from the interviews with the developers. In the interviews the developers mentiond that they currently rarely experience uncertaintybin prdicting the reveunue of (conventional) housing.
	One coefficient for flood risk/label preference/WTP	
	No extrapolation of trends	The prediction model does not consider the existence of market trends which could be extrapolated to better and more certain predict next year's revenue. The prediction model only uses transaction data of previous years and the uncertainty in prediction derived from lats year's mispredictions

E

Model Verification and Validation

According to Nikolic (2013), verification makes sure that the modeller has “built the thing right”. This process included debugging software, looking for incorrect implementation of conceptual models, and verifying calculations. During validation, we answer the question “Did the modeller build the right thing?”. It is a process that determines whether the conceptual model is a reasonably accurate representation of the real world and whether the output is consistent with real-world output (Xiang et al., 2005).

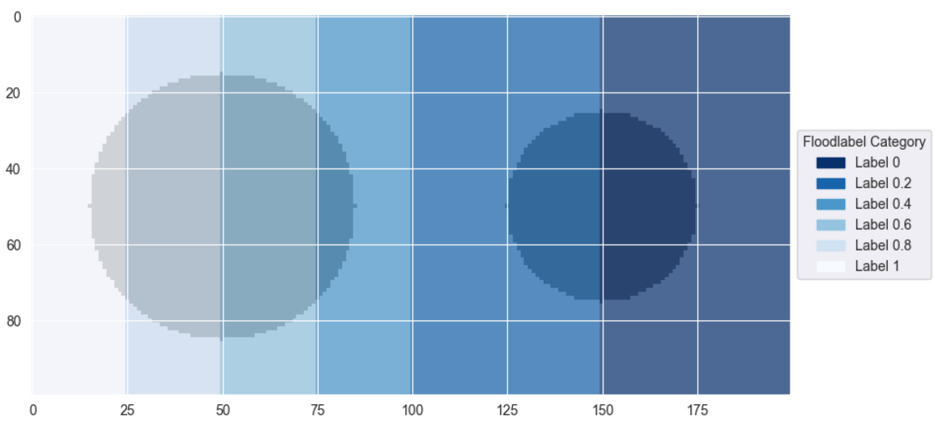
E.1. Verification

Through verification checks, it is examined if the conceptual model has been correctly translated into model code. The entities, their states and processes discussed during the concept and model formalisation phase (view chapter 7 and Appendix D) are verified through recording and tracking and single-agent testing as explained in Nikolic (2013) and through Animation and Graphical Representation as described in Xiang et al. (2005).

E.1.1. Initialisation

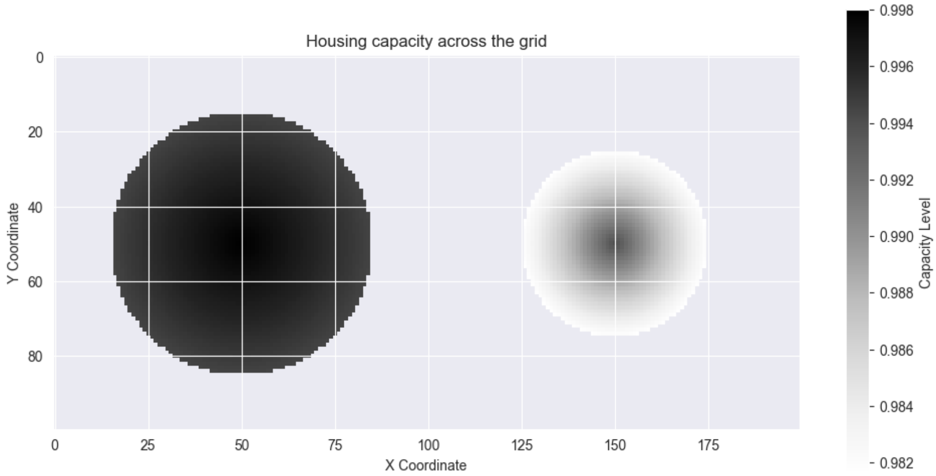
Testing Floodlabel and city landscape initialisation through animation: The grid should be divided into six compartments with flood risks/labels ranging respectively from 1 to 0 with an interval of 0.2. The shapes of the two cities should be evident.

Figure E.1: Verification of initialisation Flood risk/label landscape and the two cities



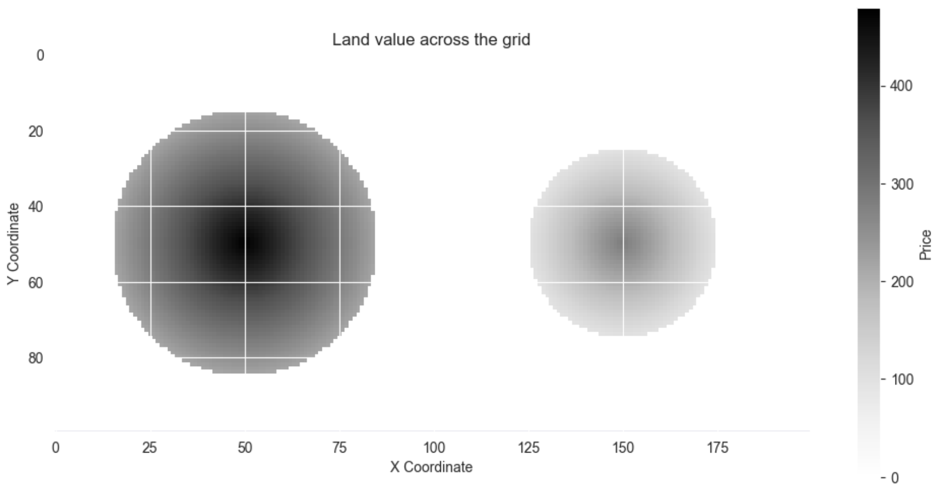
Testing housing capacity initialisation through animation: Capacity decreases further from the city centre. The left city should on average have a higher capacity than the right.

Figure E.2: Verification of initialisation housing capacity throughout the two cities



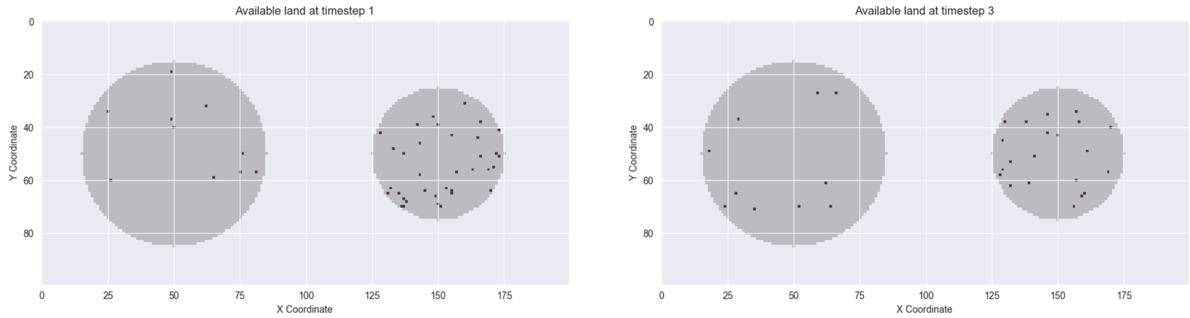
Testing land value initialisation through animation: As land value is based on the potential revenue one could get from a regular house before the effect of a Floodlabel, land value should linearly decrease the further from the city centre. Moreover, the left city should have on average higher values land, as the housing prices in the respective city are higher.

Figure E.3: Verification of initialisation land values throughout the two cities



E.1.2. Opening up of available land

Testing opening up of available land through animation(t=1 and t=3): Land for development should only become available in the cities, differing each timestep. Moreover, as it is based on capacity, relatively more land should become available on the outskirts of the cities and more land should be available in the right city.



(a) Timestep 1

(b) Timestep 3

Figure E.4: Verification of opening up available land throughout the cities.

E.1.3. Creating transaction data

Testing transaction data through Animation, tracking and graphical representation: A data frame with transaction data of the previous 10 years is created by applying the transaction price function (7.1). For each cell, there is a 10% chance a transaction has occurred that year. When implementing the Floodlabel and assigning the Floodlabel preference to have a negative effect, the prices should on average drop. Especially, in the left city, and specifically on the left side of it.

Figure E.5: Spatial verification of creation transaction data (timestep 1)

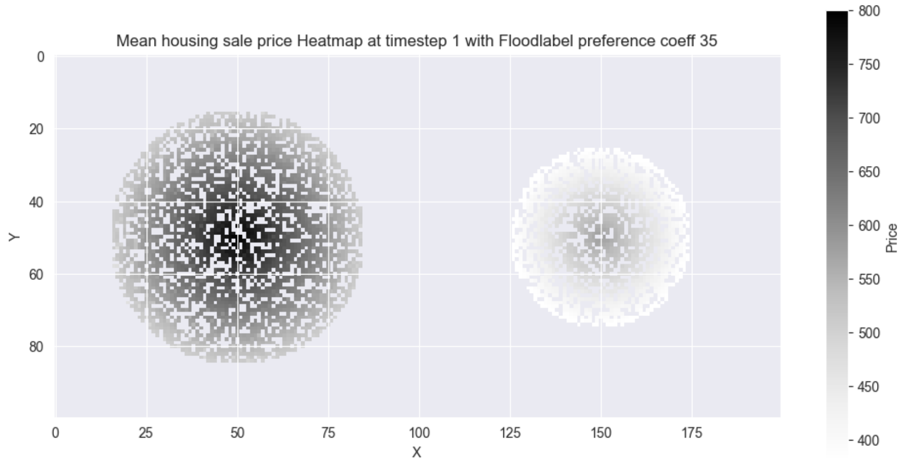
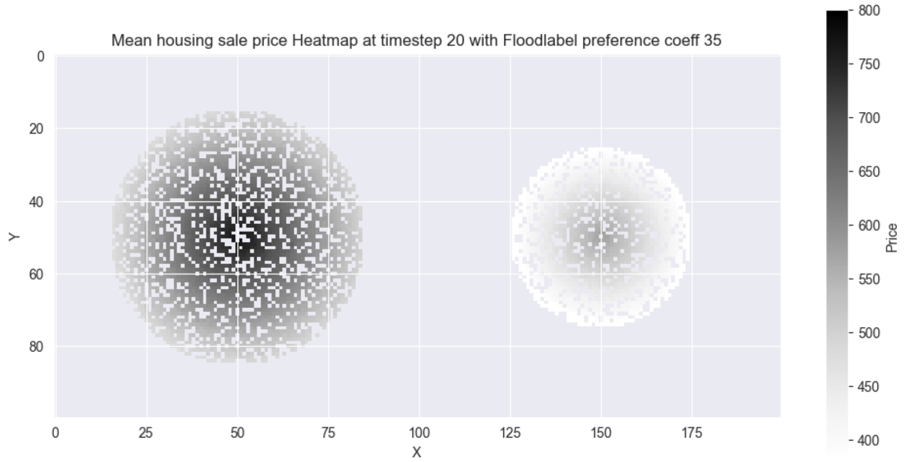
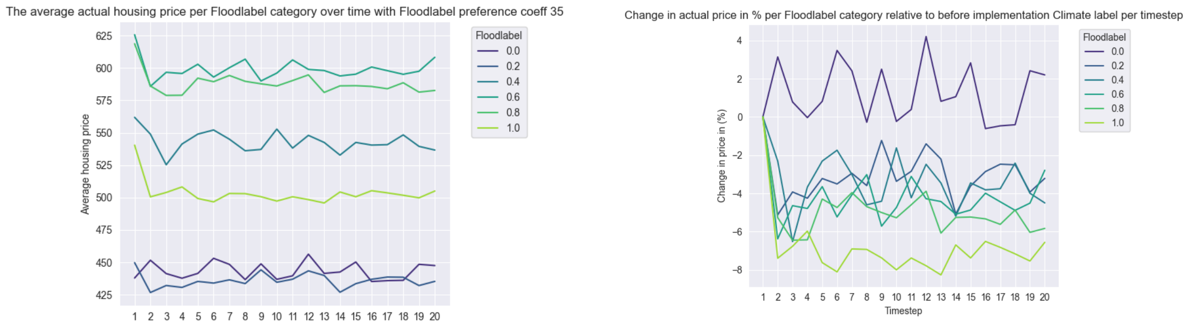


Figure E.6: Spatial verification of creation transaction data (timestep 20)





(a) Average actual housing price per time step

(b) Change in actual housing price relative to the period before the Floodlabel was implemented

Figure E.7: Verification of transaction price per Floodlabel category over time.

E.1.4. Hedonic prediction function

Testing hedonic prediction function and its Floodlabel coefficient/WTP uncertainties through tracking and graphical representation: As the transaction data always consists of the transactions of the previous 10 years, the average predicted housing price and the uncertainties regarding the predictions should stabilise shortly after those 10 years.

Figure E.8: Verification of predicted Floodlabel WTP by the hedonic prediction function

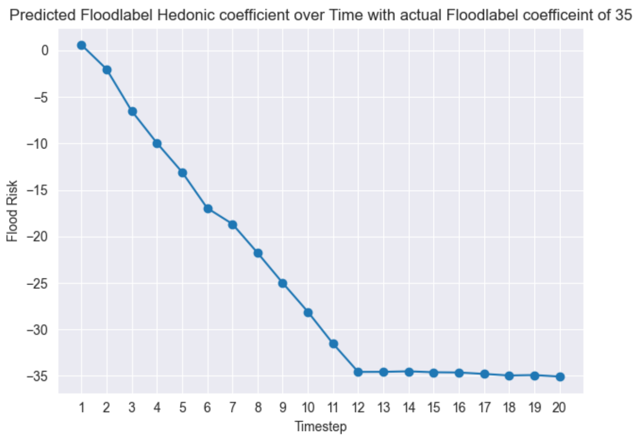
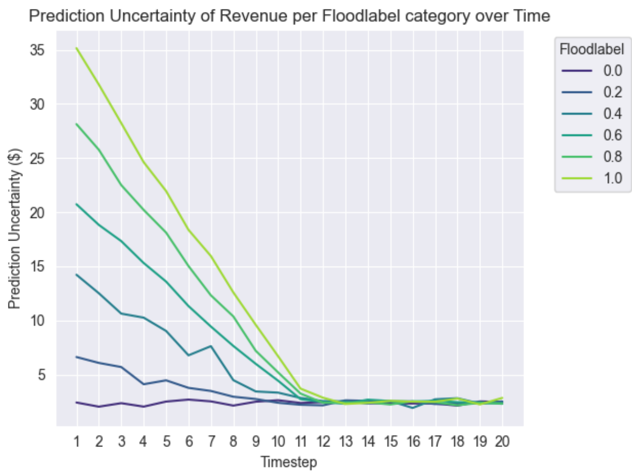
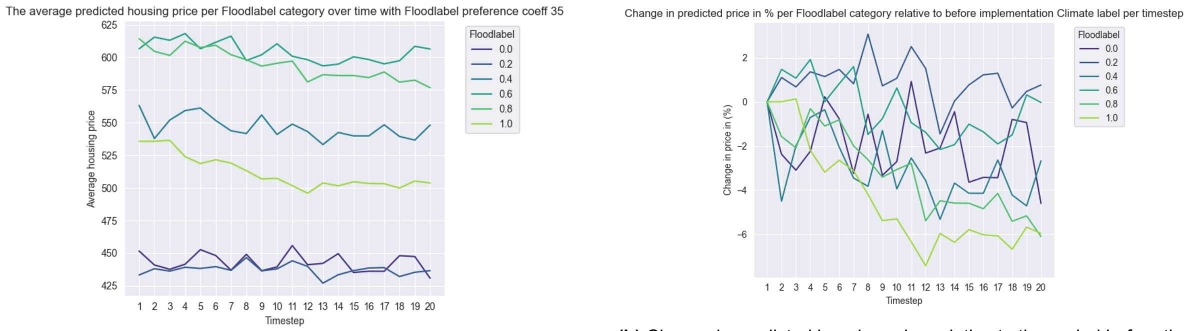


Figure E.9: Verification of uncertainties of the predicted Floodlabel WTP by the hedonic prediction function





(a) Average predicted housing price per time step

(b) Change in predicted housing price relative to the period before the Floodlabel was implemented

Figure E.10: Verification of predicted housing price by the hedonic prediction function per Floodlabel category over time

E.1.5. Developer decision-making: Utility and project selection

Testing through recording and tracking and single agent testing:

A technique called 'Unit testing' has been used to verify this process. This is a technique that checks that individual units work correctly. Small parts of the code are tested by predefining inputs and listing expected outputs, after which the tests can be run automatically to give insight into how the code responds to these tests (Nikolic, 2013).
A multitude of such unit-testing functions have been implemented in the model to test the developers' decision-making (and resolving the bids in the section below). If these unit tests detect an error, a user message appears that informs the user about the error and helps them better identify the problem.

- **Verify profit uncertainty:** Verifies if the correct uncertainty values are accounted for in the high and low revenue scenarios.
- **Verify PT:** Verifies if the potential gains and losses given the reference point are determined correctly.
- **Verify Utility:** Verifies that all projects have a utility between 0 and 1 and are, consequently, ranked best to worst.
- **Verify societal developer:** Societal developers should not have projects for which the expected Floodlabel is higher than 0.6. The list of Utility-ranked projects is checked for projects with such a Floodlabel.
- **Verify choice project:** Verifies that the highest Utility project is chosen and the respective land bid on.

E.1.6. Resolving bids

Testing through recording and tracking: If multiple bids are placed on one land, the highest bidder gets the land. The other proceed with rebidding from their second best projects. If multiple agents have exactly the same bid (as they have the same profit margin), a random agent is selected for the land.

Unit test function: The land that has been bid on with their respective bid and the developer who has placed the bid is tracked throughout each timestep. If at the end of a timestep, there still is a land with multiple bids, the model stops and an error message appears.

E.2. Validation model output

As our model is highly stylized and simplified, the validation process is mainly theoretical, ensuring internal logical consistency and coherence with general principles. In section 7.4 in the main text, the conceptualised and formalised model's limitations and their implications on validity are discussed. In this section, we briefly discuss the validity of the output of the model.

First of all, in none of the experiment results did increased revenue due to proximity to the city centre play a role. This was because, for both profit margin reference points, the profit of building a regular house at that location was used. Therefore, since there was almost no uncertainty in estimating the willingness to pay (WTP) related to proximity to the city, proximity to the city did not influence decision-making. The reference point being location-bound is an assumption of the model. However, literature points out that developers do prefer building close to the city centre due to various factors influencing property values (Artioli, 2012). More in-depth interviews with real estate developers should be conducted to better understand what real estate developers use as reference points to assess gains and losses in their investments.

Secondly, developers sometimes build with adaptation measures in areas where it is not needed. This is due to a simplification in the model code, resulting in developers also assessing the business case for houses with adaptation measures in flood-resilient areas. If the utility for all potential development projects is one, one is randomly chosen, resulting in such developments. This behaviour seems illogical, and developers would unlikely illustrate that behaviour in reality.
Throughout the experiments, developers barely built with large adaptation measures. In the interviews with the real estate developers, the societal developer mentioned not being a fan of large adaptation measures such as building on elevation. Moreover, one of the commercial developers mentioned not intending to implement large adaptation measures, as he saw ensuring flood resilience against large flooding as the responsibility of the municipality/government.

Lastly, in certain price effect scenarios, developers predominantly built in only one of the two cities. In reality, developers do not all develop in the same areas. They are rather spread out throughout the country or between cities, as they have different areas of expertise or familiarity and due to resources and manpower being location-bound. These results are caused by the lack of heterogeneity among developers, the substantial amount of land that becomes available each timestep for developers, and the fact that all developers always develop houses each timestep.

Overall, to validate the model's dynamics and findings, an empirical analysis of the actual Floodlabel effect on the flood risks of new residential houses should be conducted, and an empirical model using the dynamics presented in this research should be created to evaluate if the model can reproduce the empirical findings.

F

Experimentation details

F.1. Number of replications per experiment

As the model includes stochastic processes, it is essential to control for noise, which can distort the analysis of outcomes (Montgomery, 2009). First and foremost, it is crucial to set the seed for each replication in the experiments to ensure the results are comparable across different experiments. Secondly, it is important to analyze the variance in the results attributable to stochastic processes and determine the number of replications or simulation runs needed to achieve stable variance.

In this section, the number of replications per experiment is determined following the steps described by Lorscheid, Heine, and Meyer (2012). Specifically, the coefficient of variation for different response variables is calculated for an increasing number of simulation runs. The chosen response variable is the cumulative number of projects per Floodlabel category (after potential adaptation measures) at the end of the simulation. Each simulation run consists of 20 timesteps (20 years). The coefficient of variance is analyzed for two design points: negative price effect, reference point before Climate label (table F.1); positive price effect, reference point after Climate label (table F.2)

Table F.1: Error variance matrix for design point negative price effect and reference point before Climate label

	Number of runs							
Dependent variable (Floodlabel category)		**10**	**20**	**40**	**80**	**160**	**320**	**640**
0.0	MEAN	184.2	185.7	187.05	187.21	187.06	186.56	186.47
	VARIANCECOEFF	0.04	0.04	0.04	0.03	0.04	0.04	0.04
0.2	MEAN	14.2	12.95	11.7	11.54	11.02	12.42	12.42
	VARIANCECOEFF	0.47	0.59	0.69	0.56	0.54	0.55	0.54
0.4	MEAN	0.3	0.3	0.5	0.37	0.38	0.41	0.43
	VARIANCECOEFF	1.61	1.9	1.74	1.87	1.86	1.85	1.85
0.6	MEAN	0.8	0.7	0.5	0.51	0.43	0.38	0.22
	VARIANCECOEFF	1.15	1.47	2.03	2.08	1.7	1.71	1.69
0.8	MEAN	0.4	0.3	0.15	0.34	0.18	0.19	0.22
	VARIANCECOEFF	1.75	1.9	2.84	2.05	2.69	2.71	2.42
1.0	MEAN	0.1	0.05	0.05	0.03	0.03	0.03	0.03
	VARIANCECOEFF	3.16	4.47	4.41	6.28	5.59	5.69	5.53

Table F.2: Error variance matrix for design point postive price effect and reference point after Climate label

	Number of runs							
Dependent varible (Floodlabel category)		**10**	**20**	**40**	**80**	**160**	**320**	**640**
0.0	MEAN	6.8	6.3	7.1	7.67	6.86	7.03	7.13
	VARIANCECOEFF	0.57	0.59	0.59	0.56	0.63	0.62	0.6
0.2	MEAN	38.0	35.35	36.43	36.53	38.05	36.78	37.6
	VARIANCECOEFF	0.23	0.21	0.23	0.22	0.25	0.25	0.24
0.4	MEAN	5.5	8.45	5.5	5.55	5.83	6.03	5.72
	VARIANCECOEFF	0.7	0.53	0.84	0.79	0.71	0.69	0.71
0.6	MEAN	30.4	31.9	34.68	33.33	33.35	32.16	32.42
	VARIANCECOEFF	0.23	0.32	0.25	0.26	0.29	0.29	0.28
0.8	MEAN	95.5	92.8	90.45	91.53	90.52	92.24	91.97
	VARIANCECOEFF	0.11	0.16	0.16	0.14	0.14	0.14	0.14
1.0	MEAN	23.8	25.2	25.78	25.41	25.39	25.77	25.16
	VARIANCECOEFF	0.27	0.15	0.23	0.23	0.21	0.2	0.21

In the above tables, it can be seen that the coefficient of variances stabilises after 160 runs. Therefore, this value is subsequently used as the number of replications under which each experiment is tested.

F.2. Secondary outputs Experimentation

In this section, the secondary outputs per experiment are given to visualise the processes and outputs that lead to the results of the dependent/response variables.

F.2.1. Experiment0: Base

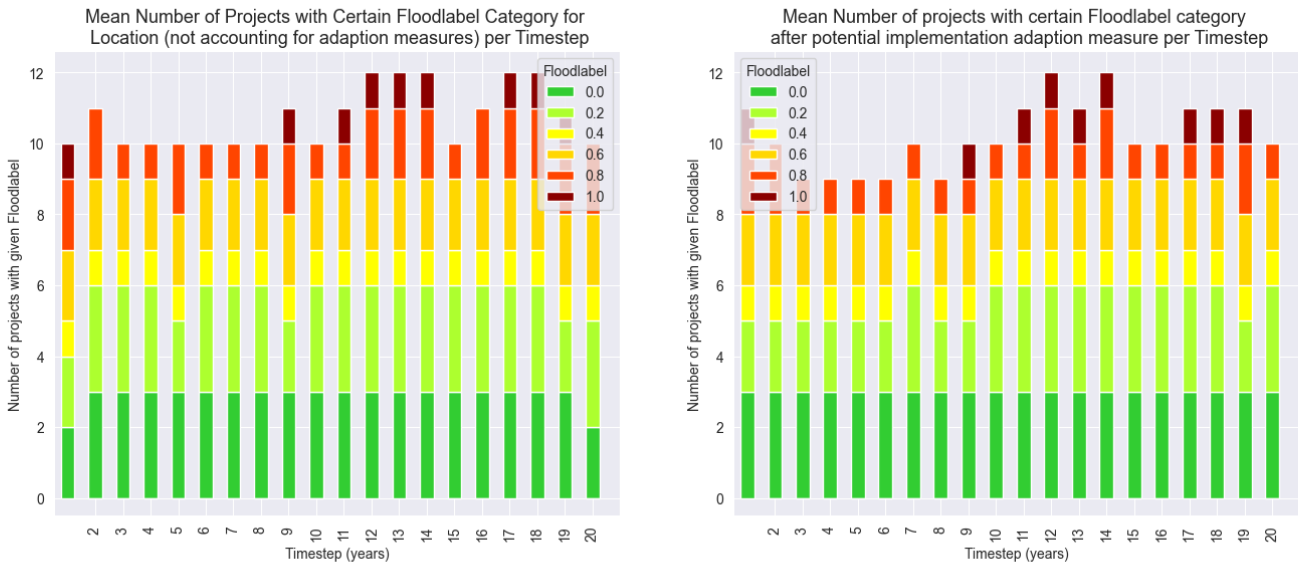


Figure F.1: Experiment0: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep for both reference points

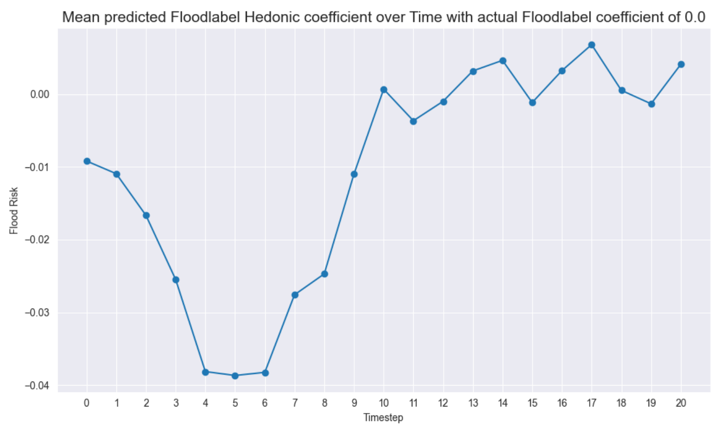
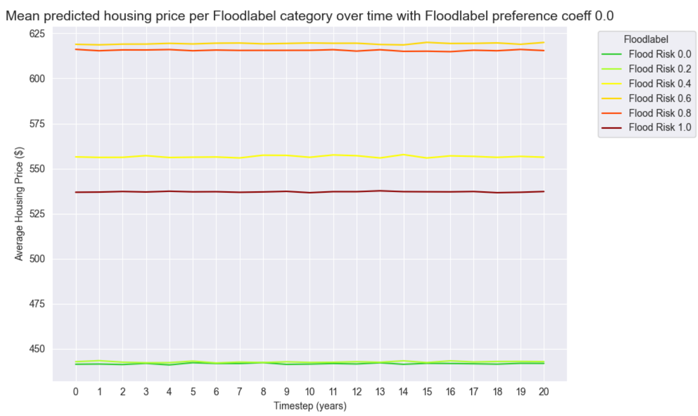
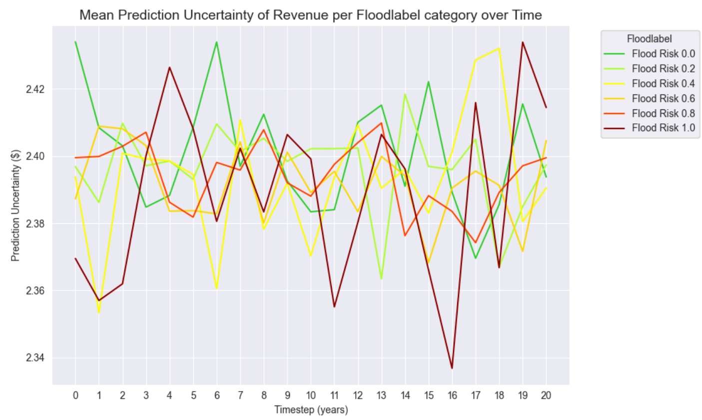


Figure F.2: Experiment0: Mean predicted Floodlabel hedonic coefficient over time with actual Floolabel coefficient of 0.0



(a) Mean predicted price per Floodlabel category over time



(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.3: Experiment0: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.2. Experiment1: negative, regular_before_floodlabel

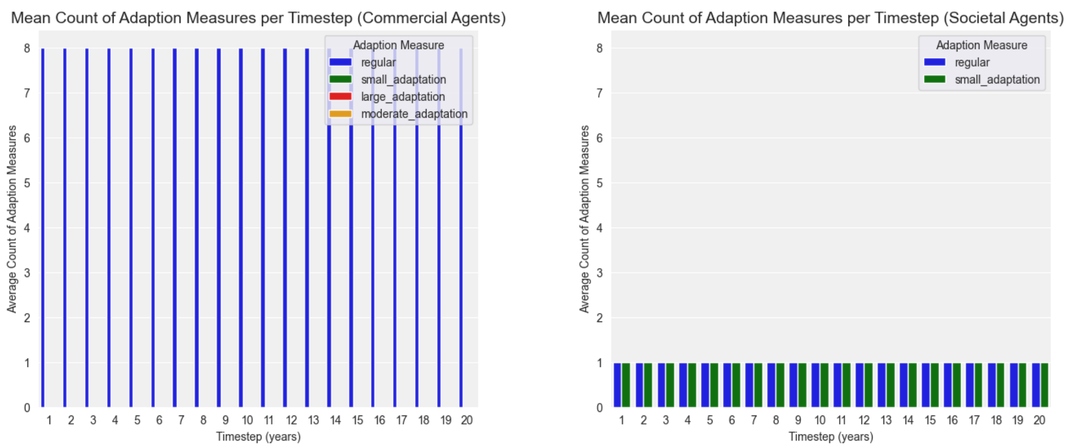


Figure F.4: Experiment1: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

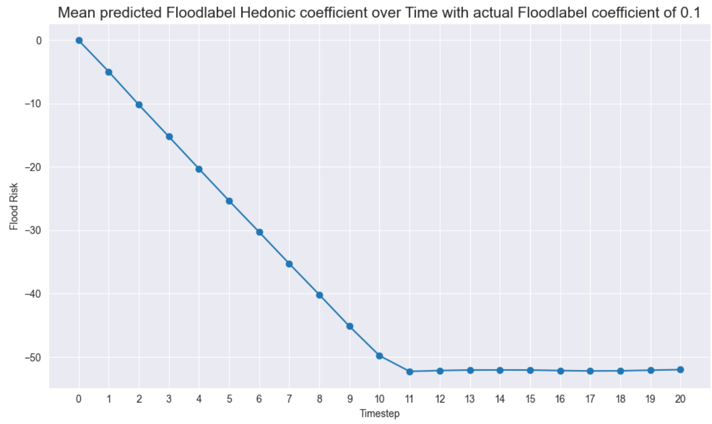
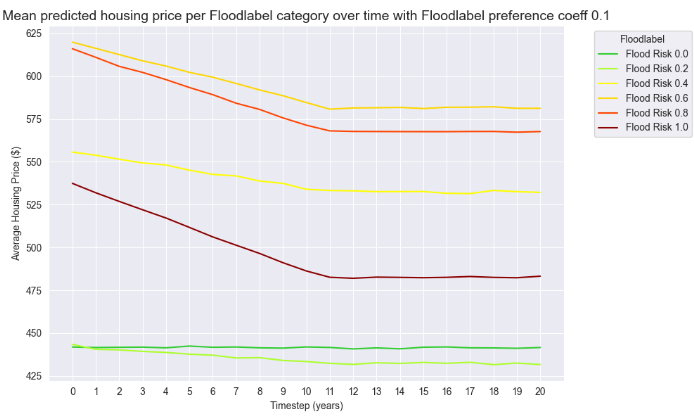
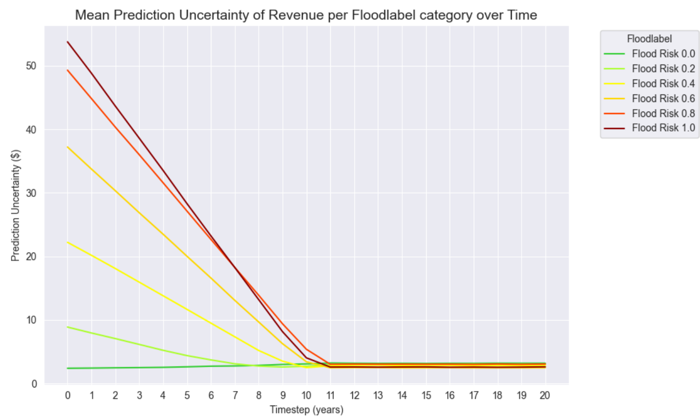


Figure F.5: Experiment1: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time



(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.6: Experiment1: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.3. Experiment2: negative, regular_after_floodlabel

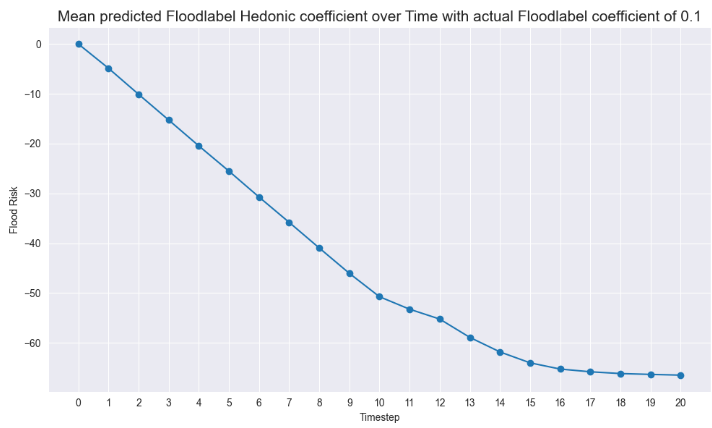
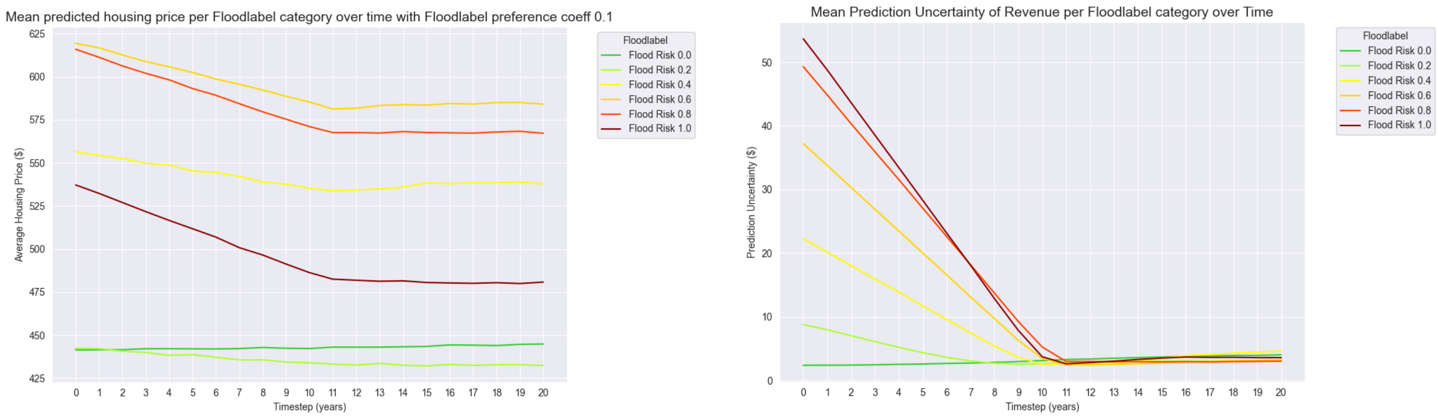


Figure F.7: Experiment2: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time

(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.8: Experiment0: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.4. Experiment3: positive, regular_before_floodlabel

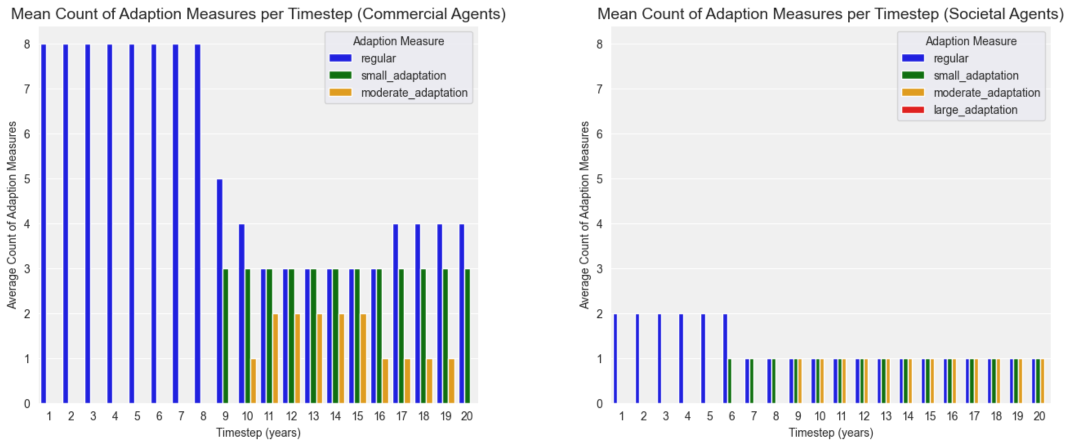


Figure F.9: Experiment3: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

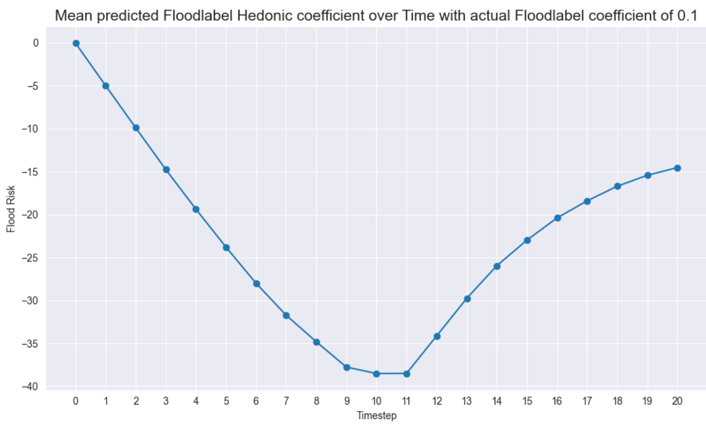
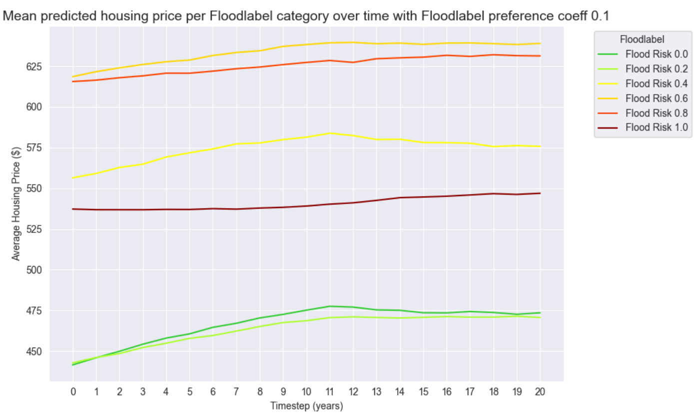
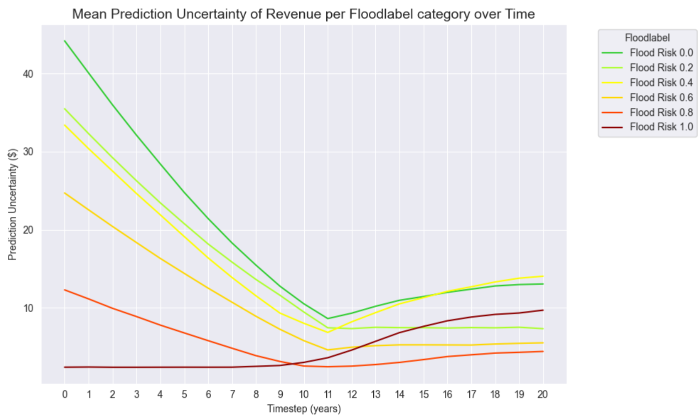


Figure F.10: Experiment3: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time



(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.11: Experiment3: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.5. Experiment4: negative, regular_after_floodlabel

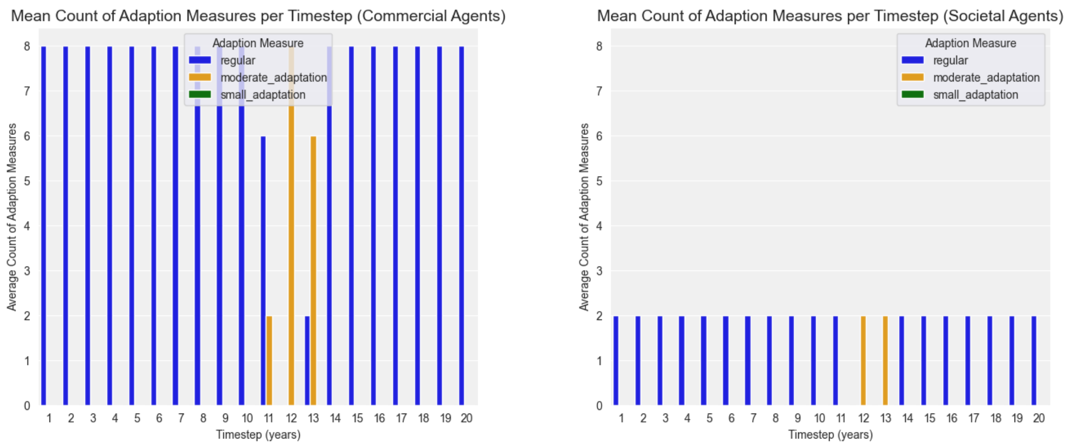


Figure F.12: Experimnt4: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

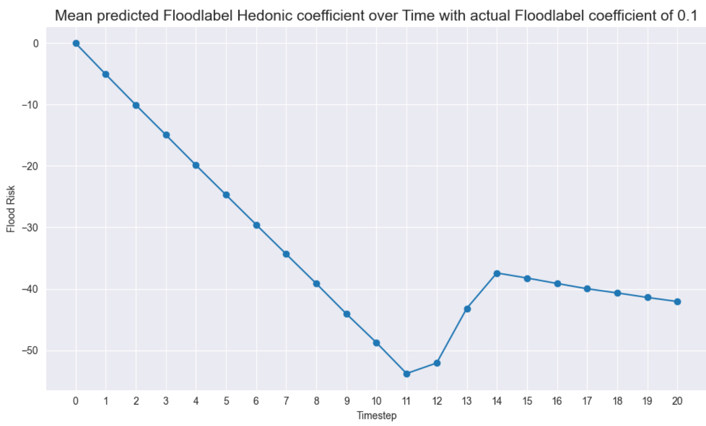
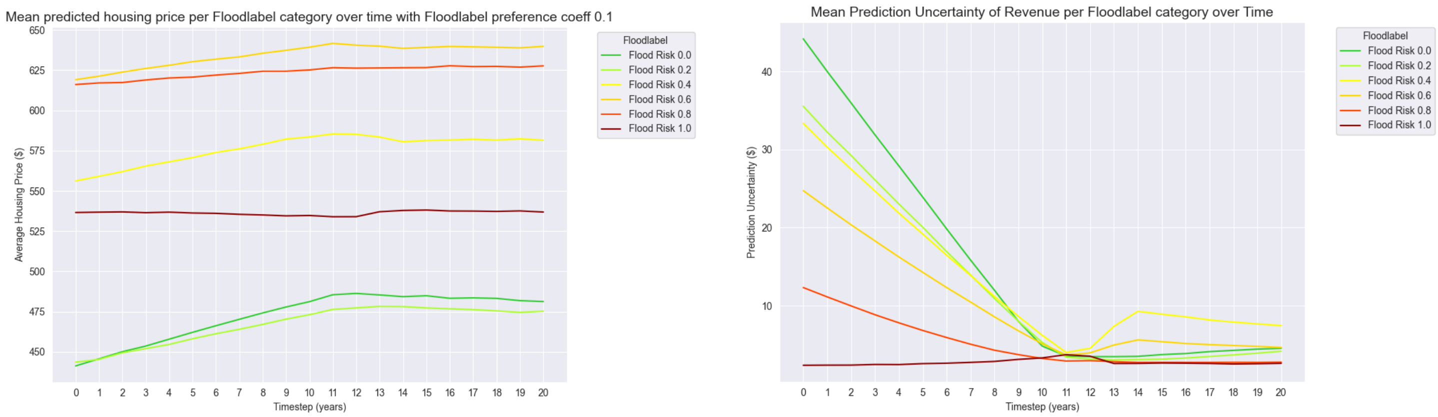


Figure F.13: Experiment4: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time

(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.14: Experiment4: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.6. Experiment5: negative, regular_before_floodlabel, WhereHow_policy

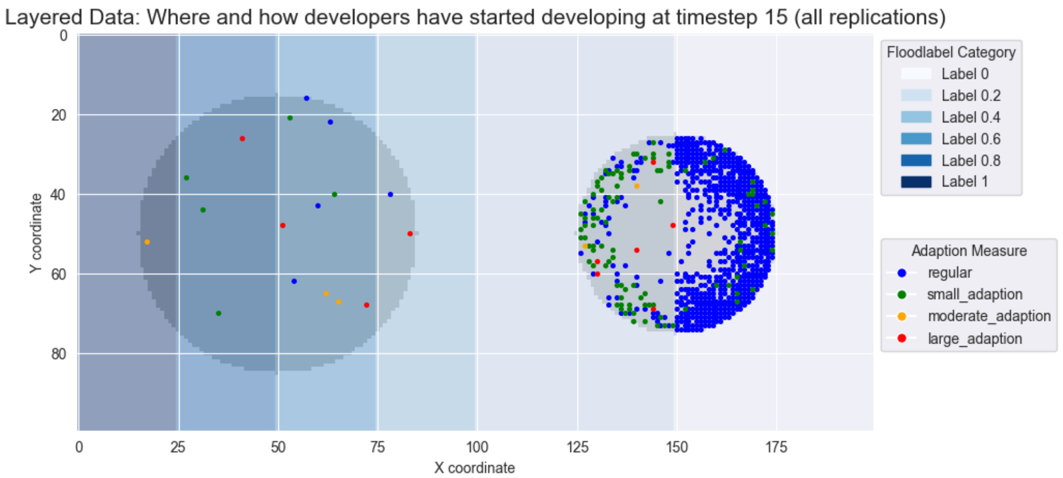


Figure F.15: Experiment5: Where and how developers have built houses across the grid at timestep 15 for all 160 replications

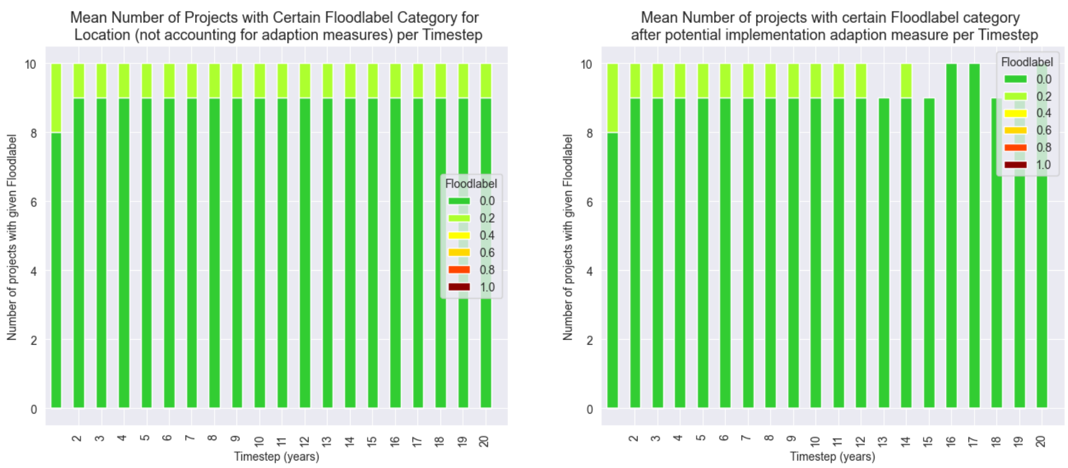


Figure F.16: Experiment6: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep

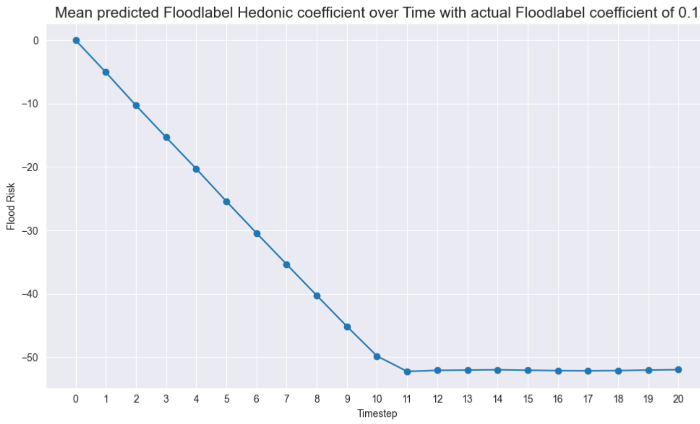
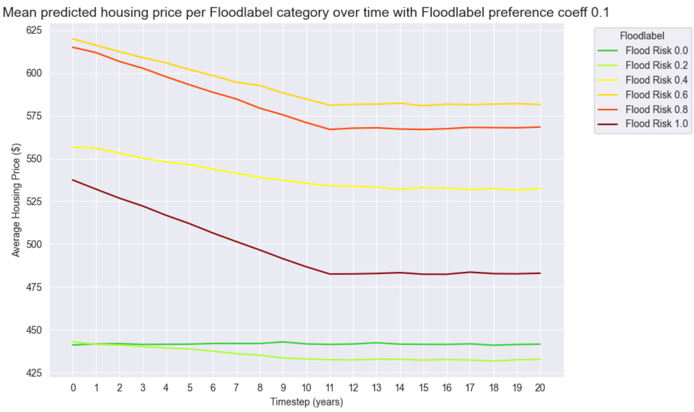
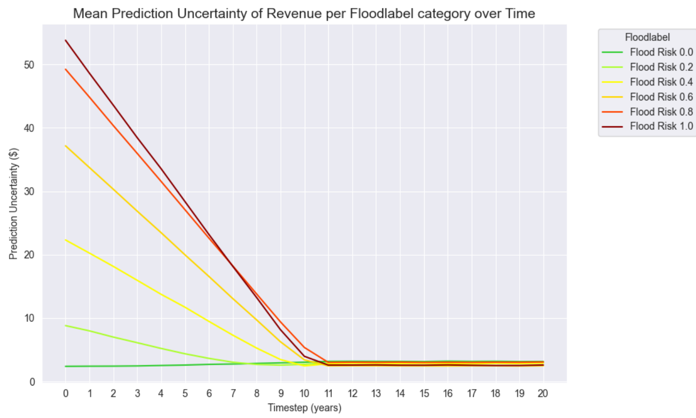


Figure F.17: Experiment5: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time



(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.18: Experiment5: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.7. Experiment6: negative, regular_after_floodlabel, WhereHow_policy

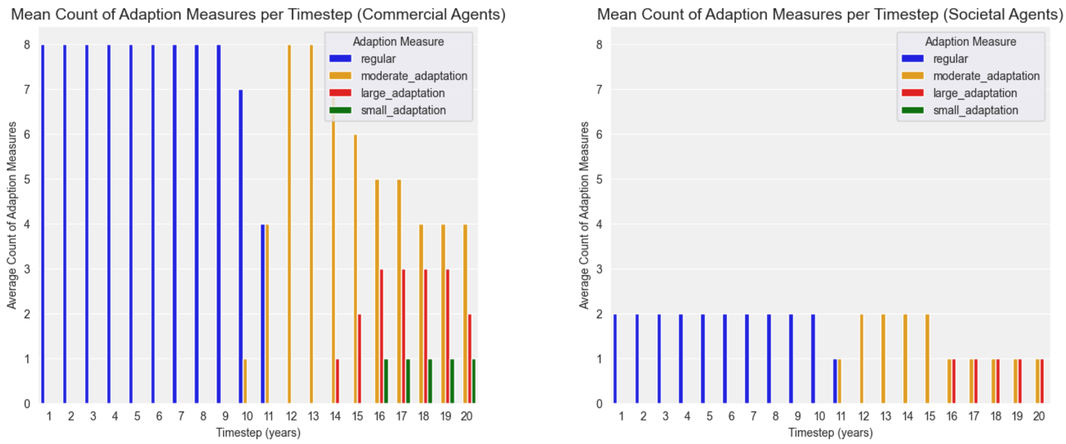


Figure F.19: Experiment 6: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

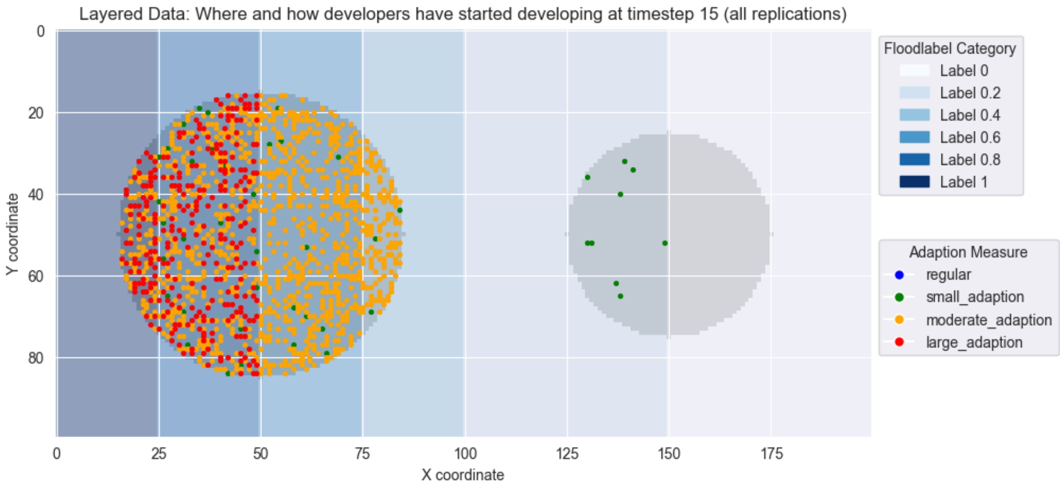


Figure F.20: Experiment6: Where and how developers have built houses across the grid at timestep 15 for all 160 replications

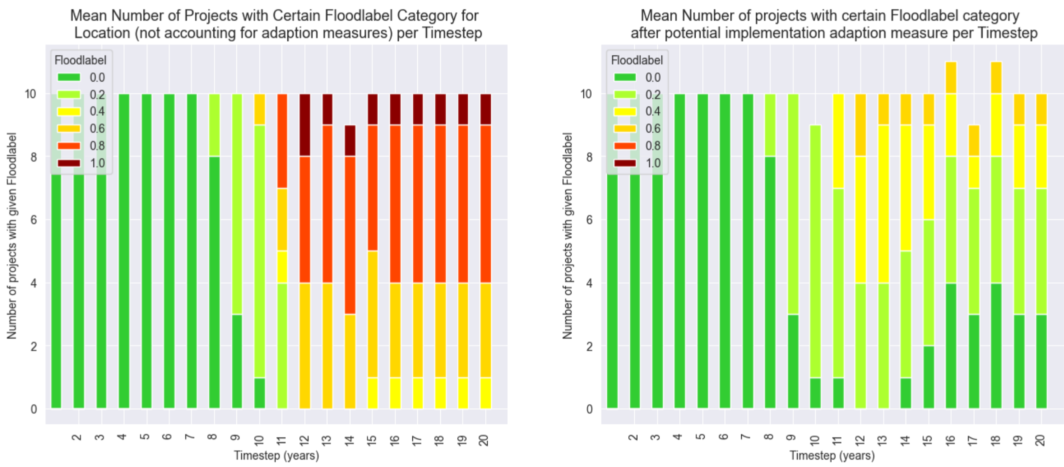


Figure F.21: Experiment7: The mean number of projects with a certain Floodlabel before adaptation measure/location (left figure) and after adaptation measure (right figure) per timestep

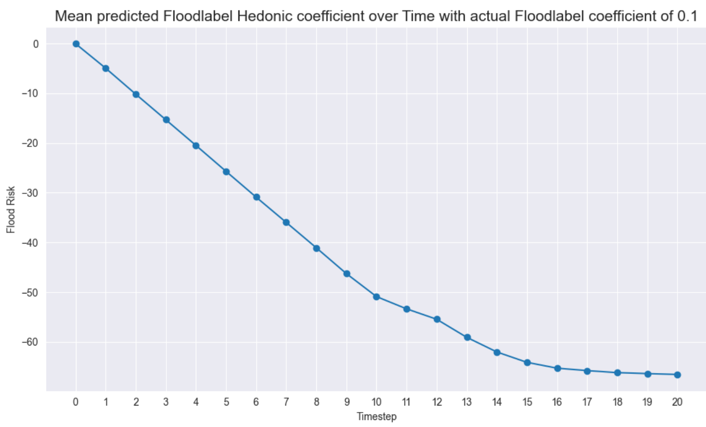
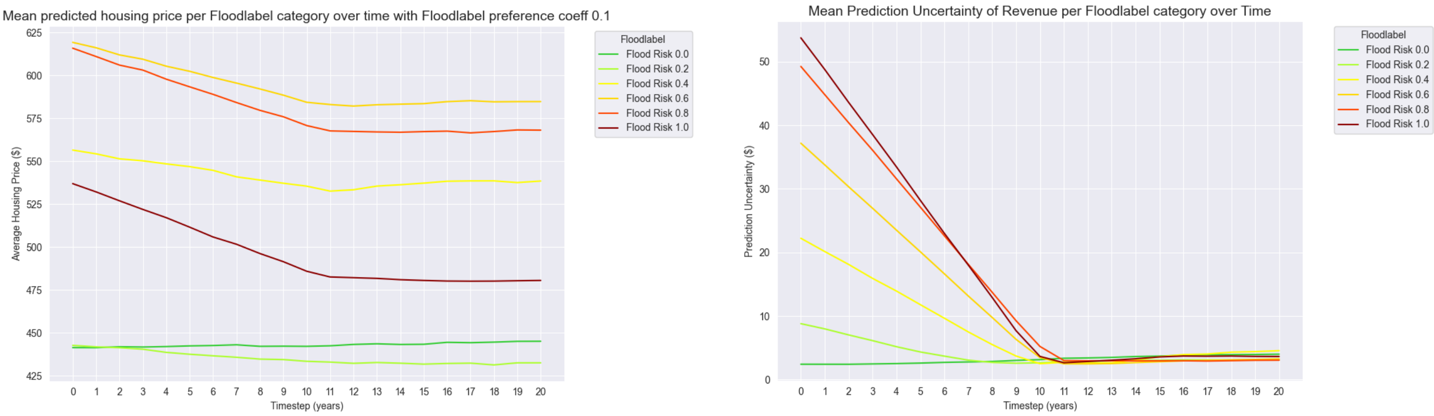


Figure F.22: Experiment6: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time

(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.23: Experiment6: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.8. Experiment7: positive, regular_before_floodlabel, WhereHow_policy

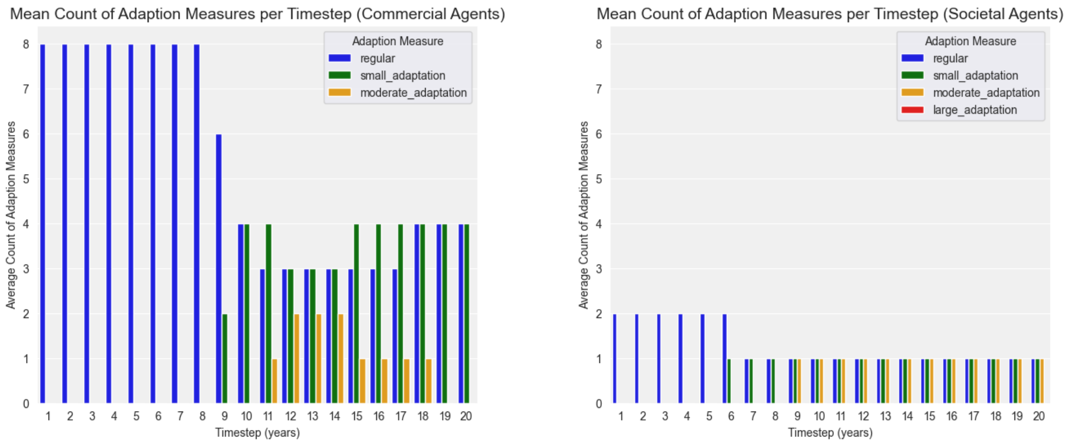


Figure F.24: Experiment7: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

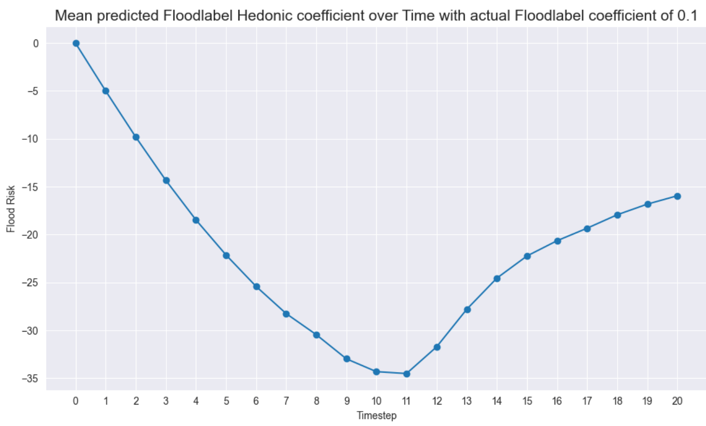
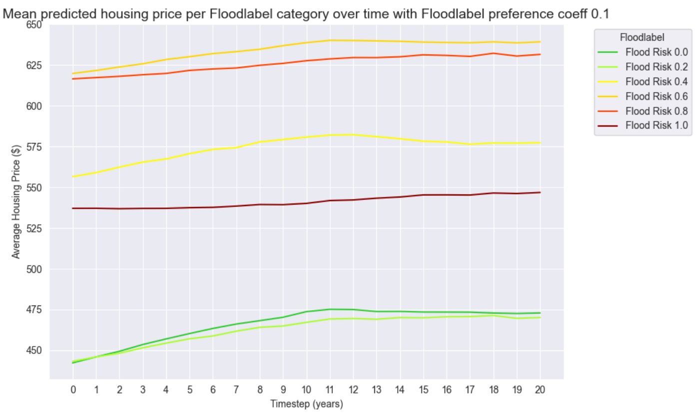
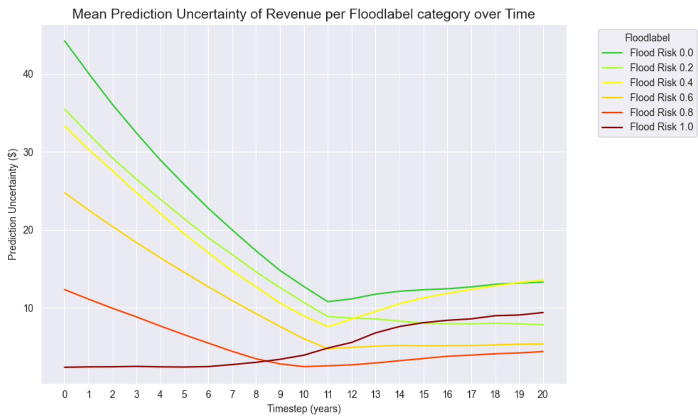


Figure F.25: Experiment7: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time



(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.26: Experiment7: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

F.2.9. Experiment8: negative, regular_after_floodlabel, WhereHow_policy

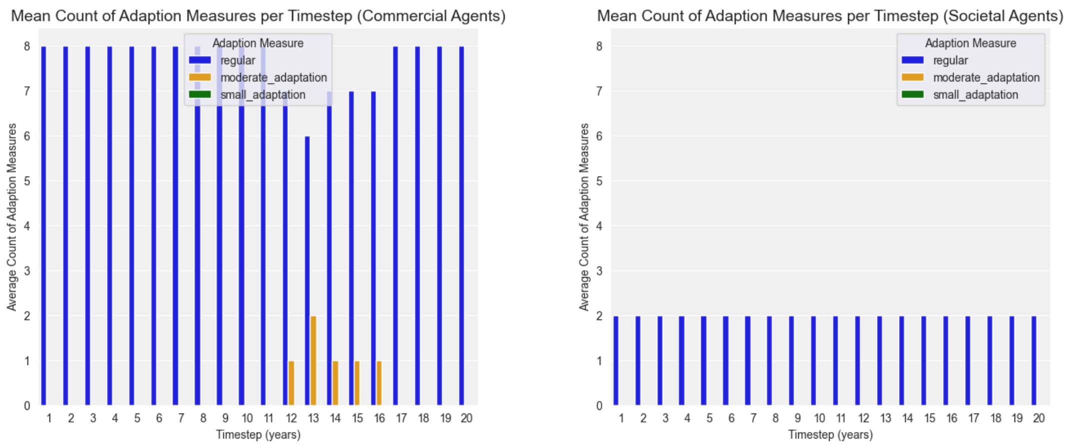


Figure F.27: Experiment8: Distribution of housing types developers build, split out between commercial developer (left figure) and societal developers (right figure)

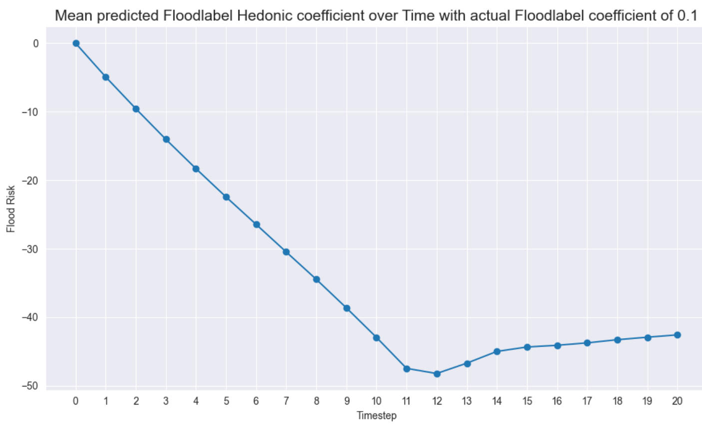
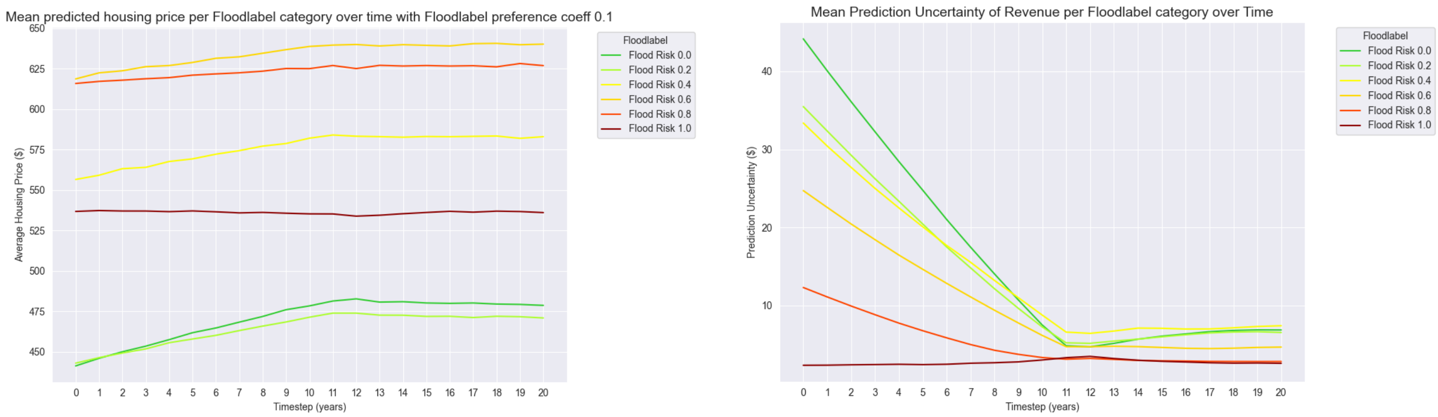


Figure F.28: Experiment8: Mean predicted Floodlabel hedonic coefficient over time with actual Floodlabel coefficient of 0.1



(a) Mean predicted price per Floodlabel category over time

(b) Mean price prediction uncertainties per Floodlabel category over time

Figure F.29: Experiment8: Mean predicted price per Floodlabel category (left) with associated prediction uncertainties (right) over time

G Sensitivity Analysis

Below, a local sensitivity analysis is conducted for the variable price effect magnitude, employing a One-Factor-At-a-Time (OFAT) approach. In the experiments, a fixed value of 10% is utilized. The sensitivity analysis evaluates the absolute difference in the resulting flood risk/label distribution (considering possible adaptation measures) for new residential houses at price magnitudes of 5% and 15%, compared with the results of the experiments using a 10% price magnitude. All other parameter values remain constant.
An OFAT approach is adopted due to its capability to examine emergent patterns and model robustness, and because, relative to a global sensitivity analysis (such as Sobol), the computational costs are lower (ten Broeke, van Voorn, and Ligtenberg, 2016). However, varying only one parameter and using an OFAT approach significantly limits the sensitivity analysis results (Jafino et al., 2021; ten Broeke, van Voorn, and Ligtenberg, 2016). In the final section, Section G.2, the limitations of this sensitivity analysis are addressed.

The sensitivity analysis is performed on the experiments with a PT reference point of profit gained from a regular house adapted to the price change induced by the Climate label (Experiments 2, 4, 6, and 8). This subset of experiments is analyzed because it is expected that the experiments with the PT reference point of the profit of a regular house before the implementation of a Climate label will be less affected by changes in price magnitude due to the reference point not being altered.

Below, boxplots for each experiment are presented to visualize the sensitivity to changes in price magnitude. They depict the absolute difference in the resulting flood risk/label distribution. Furthermore, at the end of the section, a table is provided showing the output values for the base experiment and the outputs of the sensitivity experiments, along with the significance of the sensitivity analysis results.

G.1. Sensitivity to price effect magnitude

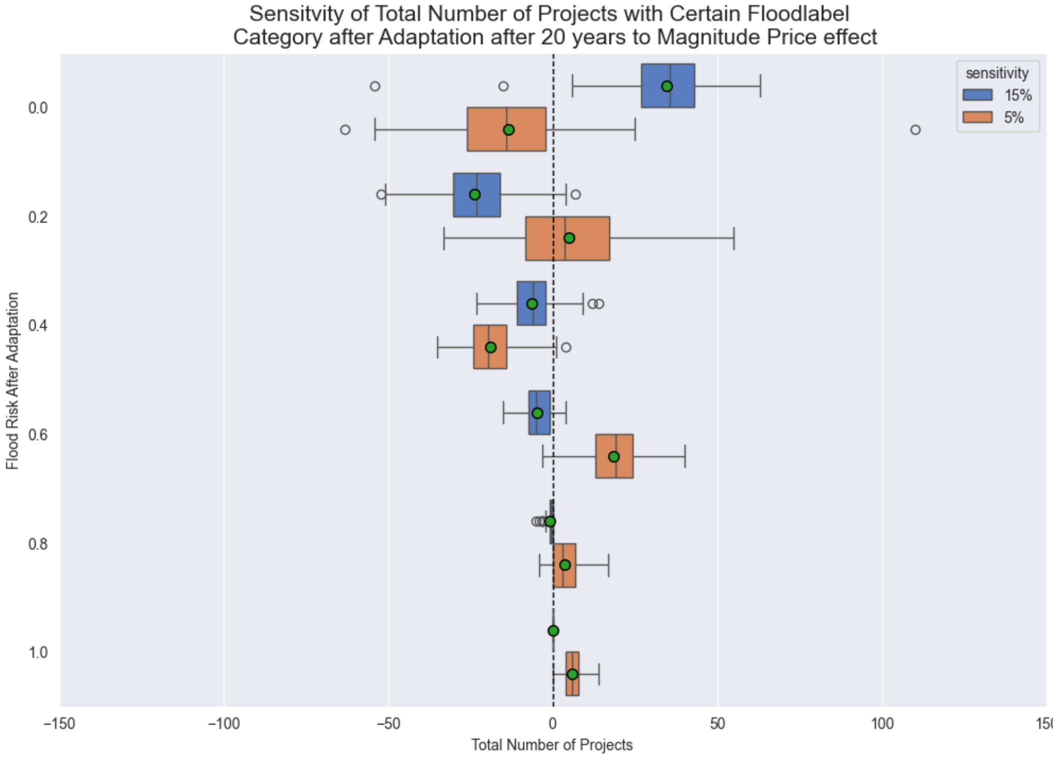
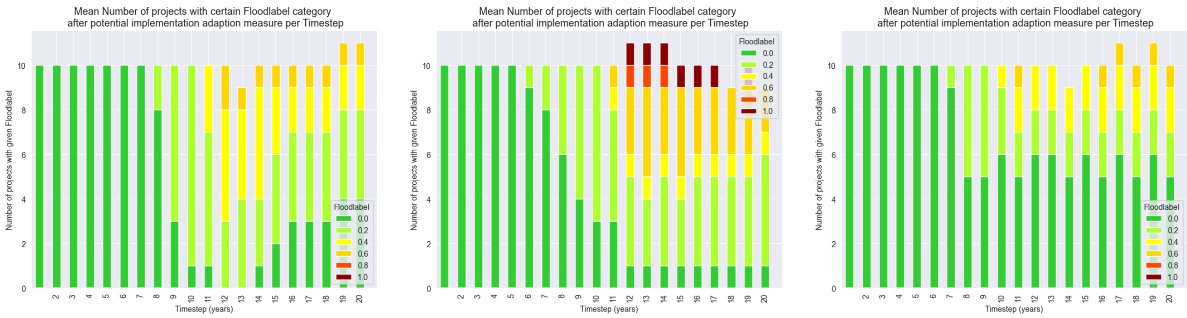


Figure G.1: Experiment2, negative price scenario: Sensitivity to a price effect magnitude of 5% (red) and 15% (blue).



(a) Base/Experiment 2 results **(b)** Results for 5% **(c)** Results for 15%

Figure G.2: The mean number of projects with a certain Floodlabel after adaptation measure per timestep for for a price effect magnitude of 10%, 5% and 15%

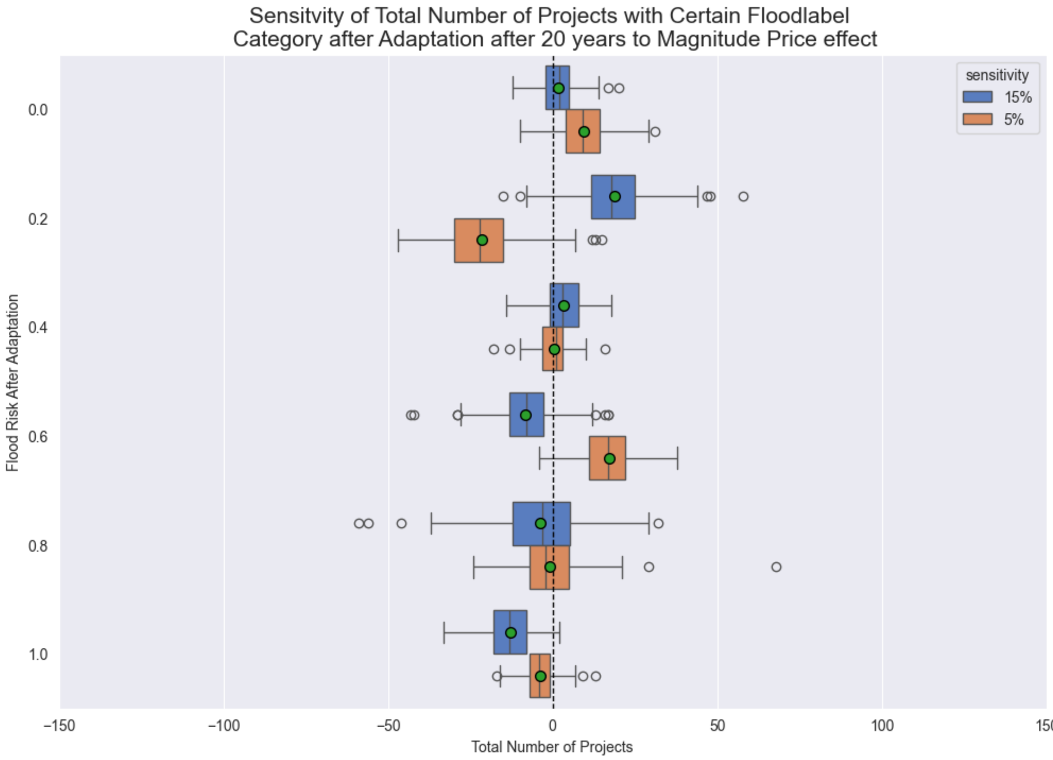
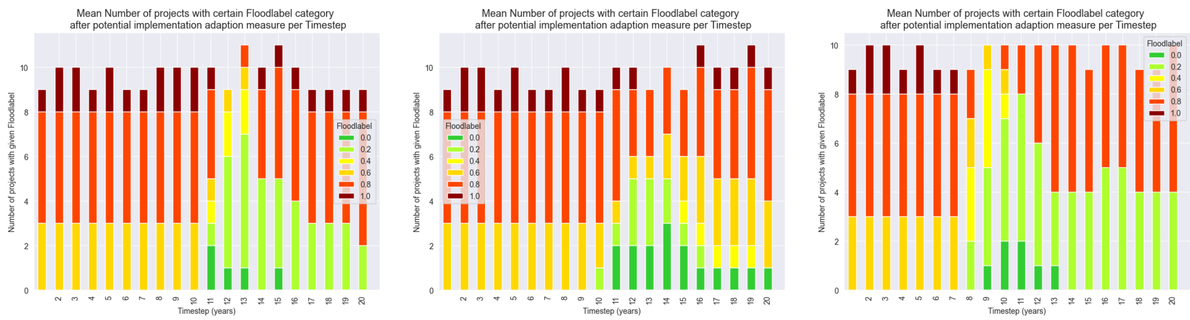


Figure G.3: Experiment4, positive price scenario: Sensitivity to a price effect magnitude of 5% (red) and 15% (blue).



(a) Base/Experiment 4 results

(b) Results for 5%

(c) Results for 15%

Figure G.4: The mean number of projects with a certain Floodlabel after adaptation measure per timestep for for a price effect magnitude of 10%, 5% and 15%

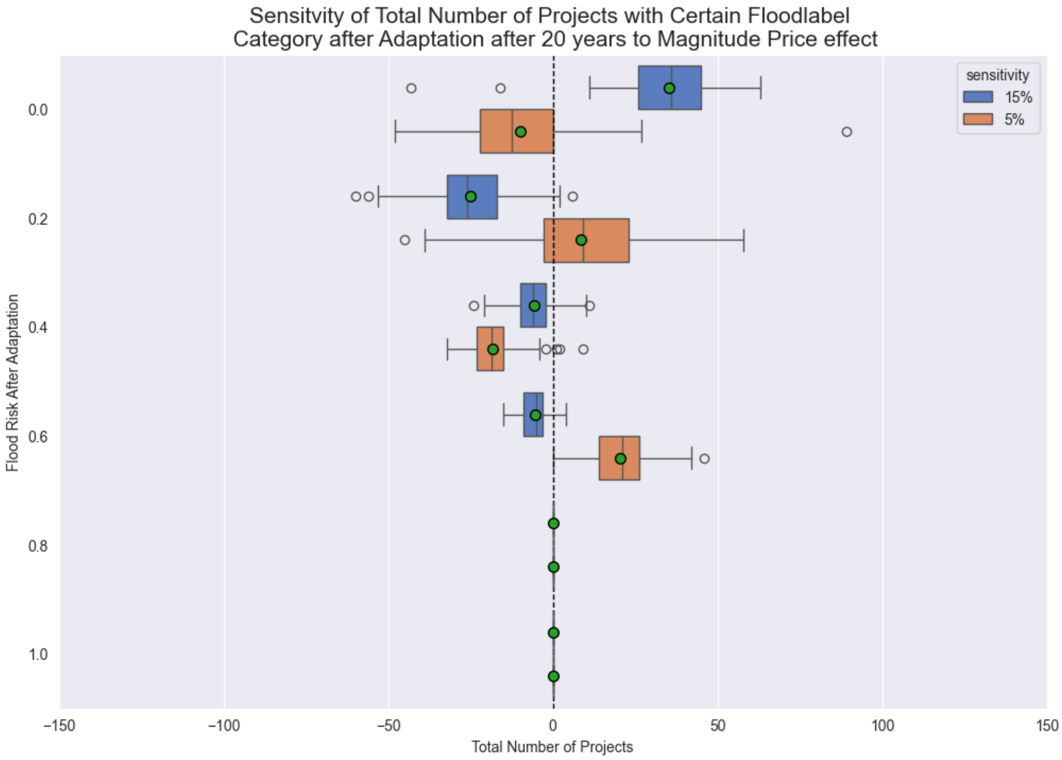
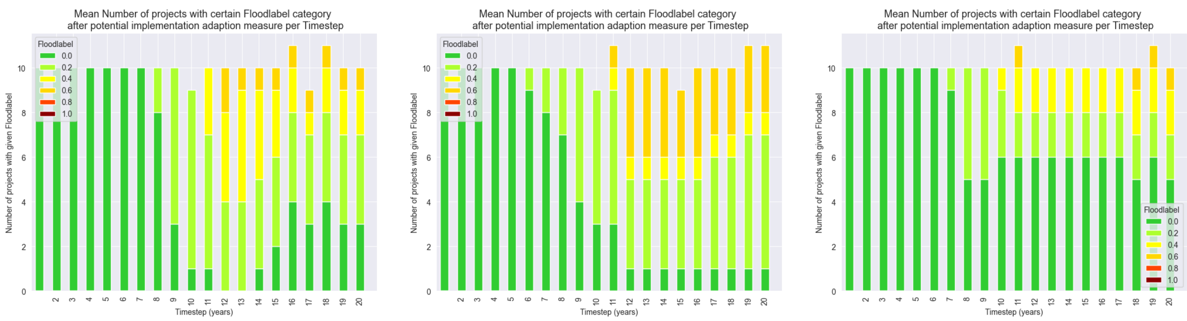


Figure G.5: Experiment6, negative price scenario with Where&How policy: Sensitivity to a price effect magnitude of 5% (red) and 15% (blue).



(a) Base/Experiment 6 results **(b)** Results for 5% **(c)** Results for 15%

Figure G.6: The mean number of projects with a certain Floodlabel after adaptation measure per timestep for for a price effect magnitude of 10%, 5% and 15%

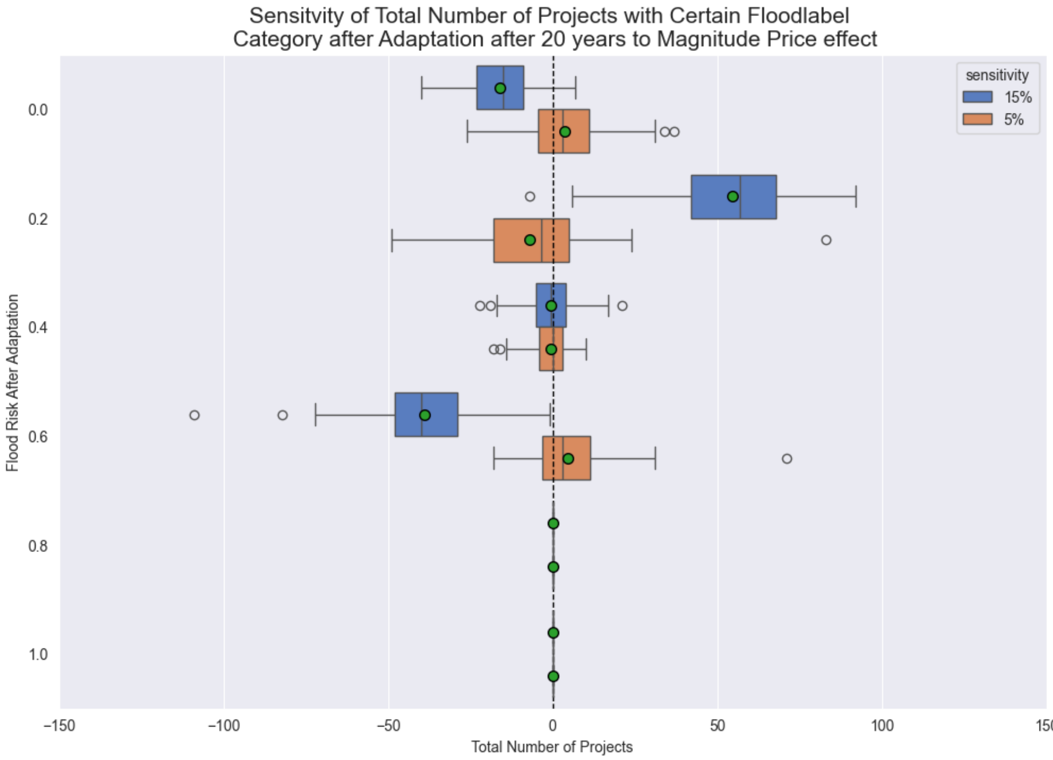
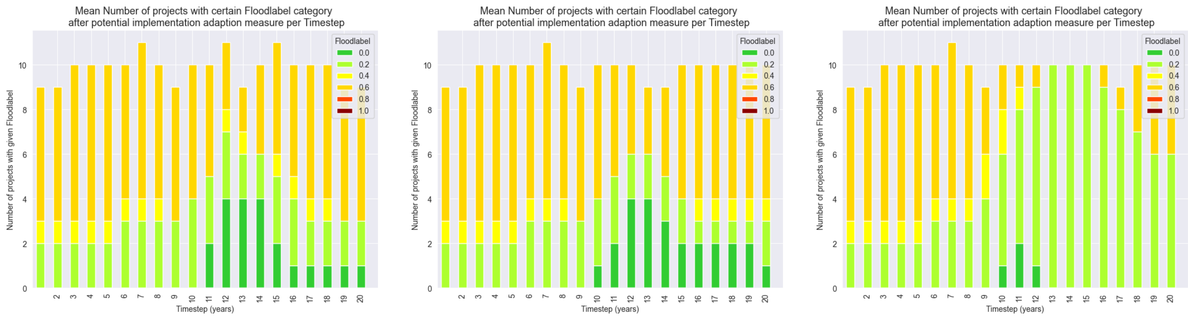


Figure G.7: Experiment8, positive price scenario with Where&How policy: Sensitivity to a price effect magnitude of 5% (red) and 15% (blue).



(a) Base/Experiment 8 results **(b)** Results for 5% **(c)** Results for 15%

Figure G.8: The mean number of projects with a certain Floodlabel after adaptation measure per timestep for for a price effect magnitude of 10%, 5% and 15%

Table G.1: Results sensitive analysis and whether they are significant per experiment

Experiment	Flood Label Category	Mean (Base)	Mean (5%)	t-statistic (5%)	p-value (5%)	Significant (5%)	Mean (15%)	t-statistic (15%)	p-value (15%)	Significant (15%)
Experiment2	**0.0**	102.6	89.2	9.8	5.76E-20	True	137.1	-23.2	2.71E-70	True
	0.2	58.1	63.1	-3.6	3.41E-04	True	34.4	23.3	1.12E-70	True
	0.4	27.5	8.6	34.2	1.46E-108	True	21.2	10.7	4.44E-23	True
	0.6	10.1	28.7	-25.8	4.47E-80	True	5.3	14.1	1.64E-35	True
	0.8	0.8	4.5	-11.5	1.14E-25	True	0.0	10.3	1.62E-21	True
	1.0	0.0	6.0	-29.5	5.90E-93	True	0.0	NaN	NaN	False
Experiment4	**0.0**	7.0	16.5	-14.7	9.64E-38	True	8.8	-3.7	2.20E-04	True
	0.2	36.0	14.6	24.6	1.42E-75	True	54.7	-17.1	6.80E-47	True
	0.4	5.5	5.9	-0.8	4.23E-01	False	9.0	-6.9	2.85E-11	True
	0.6	33.1	50.3	-16.0	7.84E-43	True	24.9	9.0	2.32E-17	True
	0.8	92.1	91.3	0.6	5.73E-01	False	88.3	2.6	9.04E-03	True
	1.0	25.2	21.4	5.8	1.78E-08	True	12.3	23.0	1.72E-69	True
Experiment6	**0.0**	102.6	92.7	6.7	9.59E-11	True	137.9	-23.2	2.45E-70	True
	0.2	59.0	67.7	-5.5	9.51E-08	True	33.9	24.1	1.23E-73	True
	0.4	26.8	8.6	34.2	1.27E-108	True	21.2	9.9	1.84E-20	True
	0.6	10.6	31.1	-29.1	1.60E-91	True	5.1	16.6	5.79E-45	True
	0.8	0.0	0.0	NaN	NaN	False	0.0	NaN	NaN	False
	1.0	0.0	0.0	NaN	NaN	False	0.0	NaN	NaN	False
Experiment8	**0.0**	21.8	25.5	-3.8	0.000151	True	5.7	20.3	2.61E-59	True
	0.2	52.0	45.2	4.6	0.000007	True	106.6	-33.2	1.75E-105	True
	0.4	14.6	14.2	0.7	0.457456	False	14.0	0.9	3.51E-01	False
	0.6	110.6	115.1	-3.3	0.001076	True	71.7	25.7	9.45E-80	True
	0.8	0.0	0.0	NaN	NaN	False	0.0	NaN	NaN	False
	1.0	0.0	0.0	NaN	NaN	False	0.0	NaN	NaN	False

In the above boxplots and Table G.1, it can be observed that the model's results are significantly sensitive to variations in the price effect magnitude. The plots indicate that as the willingness to pay (WTP) for flood-vulnerable houses increases, and consequently the price effect magnitude increases, the overall flood resistance of the houses also increases. This is likely due to the fact that in scenarios with a higher price effect magnitude, the additional revenue gained from building such houses outweighs the costs, resulting in an increase in utility as the profit margin reference point is achieved with greater certainty. In contrast, for a lower price effect magnitude (5%), building with adaptation measures is not financially feasible. A 5% price effect in Experiment 2 results in a flood risk distribution similar to the base experiment (see F.2), where housing is built almost randomly and uniformly across the two cities. This occurs because all regular housing provides approximately the same utility at any given location. The lack of similar development patterns for the 5% scenarios in both positive and negative cases can be attributed to the aforementioned uncertainty spike, which remains evident in the price effect scenarios, causing a slight bias towards more flood-vulnerable areas. This also explains why in the 15% scenario for the positive price effect, houses with a flood label of 0.8 are still being built.

When viewing Table G.1, it is evident that the number of new houses with flood labels 0.0, 0.2, 0.4, and 0.6 is most sensitive to variations in the price magnitude change. Particularly, flood labels 0.2 and 0.4 appear to be most affected by changes in the price magnitude effect.

It is also clear that the t-statistic for the 5% price scenario differs from that of the 15% scenario, indicating non-linearity between the output and the input for price effect magnitude. This suggests the possibility of a tipping point or threshold effect, where small changes in the input lead to large changes in the output. The tipping point is most likely the threshold of whether building with an adaptation measure is more (financially) beneficial than building a regular house.

G.2. Limitations sensitivity analysis and recommendations

The local sensitivity analysis performed for this research faced several limitations.
First, due to time and computational restrictions, only the sensitivity regarding price effect magnitude was assessed. This limitation constrains the understanding of the formation of emergent patterns and the robustness of these patterns. For future work, it is advisable to evaluate the model's robustness under variations of other parameters, such as sensitivity to gains and losses and the loss aversion parameter. Currently, these values in the model are derived from a single investment paper (Kavya and Christopher, 2023), while other values could be equally plausible.
Additionally, having more points of variation for the price effect magnitude (besides 5% and 15]%) would allow for a more detailed examination of the model's nonlinearity and the possibility of a tipping point.

Second, a limitation of the OFAT approach is that varying only one factor at a time while keeping other factors constant can overlook non-linear interaction effects between parameters (Jafino et al., 2021). As a result, no conclusions can be drawn about the effects of changing two or more parameters simultaneously, which limits the significance of the sensitivity results. Therefore, this OFAT sensitivity analysis should be supplemented by a global sensitivity analysis method—such as Sobol—to examine interaction effects and quantify model variability resulting from parameter variations (ten Broeke, van Voorn, and Ligtenberg, 2016).