Master Thesis

The Effect of Wildfire Risk on Residential Property Values in the Netherlands

A hedonic pricing study in the province of Noord-Brabant

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Management Summary

Research idea

Anthropogenic climate change has led to increased drought and heat in the Netherlands. As a result of these new weather conditions, more and larger wildfires have taken place. Wildfires affect flora and fauna, but also infrastructure and real estate. Literature on this topic is still scarce and mainly US focussed. This paper is the first to study the relation between wildfire risk and residential property values in the Netherlands.

Method

A sample of 186,685 observations in Noord-Brabant transacted between 2000 and 2017 is used to perform a hedonic model and an event study on the fire in the Strabrechtse Heide on July 2nd, 2010. Fire risk areas and property locations are mapped to measure the distance between each house and the nearest risk area. As wildfires mostly take place in natural areas, a natural amenity factor is added to control for a positive price effect from nearby nature. The event study tests for a risk perception change among homeowners in Brabant, the Strabrechtse Heide, and the natural area of Maashorst with comparable natural characteristics.

Results

First, when studying the distance between homes and natural areas, a price premium for properties located closer to nature is observed. Second, there is no significant price effect of wildfire risk on property transaction values in Noord-Brabant. The fire in the Strabrechtse Heide in 2010 did not affect the risk perception of local homeowners. This fire event did have a negative price effect on observations in the area of Maashorst, implying that these homeowners might expect a similar fire in the future. Third, the climate risk perception among the public is still low as transaction prices in the sample are not affected by wildfire risk obtained from publicly available sources.

Implications

The wildfire risk perception among Dutch real estate investors, homeowners, insurance firms, and policy makers has to increase if the Netherlands wants to be prepared for a future with more intense wildfire conditions. The analysis in this paper has shown that it is possible to incorporate wildfire risk in the valuation process of real assets. This method can be adopted by real estate investors and academics. Additionally, investors and insurance companies can incorporate local fire risk maps when building their portfolio.

Keywords: Wildfires; Hedonic property analysis; Climate change; Asset prices; Real estate

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1. Introduction

The Fifth Assessment Report from the United Nations Intergovernmental Panel on Climate Change (IPCC, 2014) confirms that climate change is undeniable at this point and concludes that the world will face an increase in the amount of climate risks. Large fires in Australia and California left a mark on flora, fauna, and infrastructure in 2019, destroying 9000+ and 732 structures, respectively. Indirectly, natural hazards negatively impact the value of real assets and academics find such evidence for flooding (Eichholtz et al., 2019), wildfires (Loomis, 2004; Huggett et al., 2008; Stetler et al., 2010), and severe storms (McNamara and Keeler, 2013). Even tough climate risks are increasing in severity and occurrence in the Netherlands (CBS, 2019; KNMI, 2018a), literature on the impact of these risks on real estate, is scarce. This paper aims to increase the climate risk awareness in the real estate market in the Netherlands by studying the impact of wildfires on nearby residential housing transactions.

Wildfire risk has increased in the Netherlands as a result of dry summers and extreme heat. The Royal Netherlands Meteorological Institute (KNMI, 2018b) stated that the summer period of 2018 was the hottest summer in the last three centuries. At the end of the first four months of 2020, the Netherlands already copes with an even larger precipitation deficit compared to 2018. Moreover, soft winters without snow are likely to become a standard phenomenon in the future (KNMI, 2020a). Data on wildfire activity in the Netherlands from Statistics Netherlands (CBS, 2019) shows that the number of wildfires doubled in 2018 compared to the year before. During April, the first uncontrollable wildfire of 2020 already occurred, showing that the wildfire season started relatively early due to the extreme drought. This fire turned out to become the largest Dutch wildfire in the history, burning an area of 800 hectares. Given the increased occurrence of wildfires and the absent link to real estate in the Netherlands, Dutch real estate investors, insurers, and policy makers are likely to benefit from the conclusions of this paper.

This study aims to analyse the Dutch residential real estate market using a combined set of methodologies from the existing literature discussed below. Similar to methods used in PricewaterhouseCoopers (PwC, 2001) and Loomis (2004), an event study on a large fire in the Strabrechtse Heide (Province Noord-Brabant) in 2010 will be performed to inspect a risk perception change of local homeowners. This fire is seen as a significant event not only because of its size, but also because of the political and media attention on the wildfire preparedness and expertise of Dutch fire brigades. A similar natural area, Maashorst, acts as a control sample. Similar to studies by Stetler et al. (2010) and Hansen et al. (2014), an environmental amenity factor will be included in the model to correct for the price premium of properties closer to a natural area. Where Donovan et al. (2007) used fire risk data from the Colorado Spring Fire Department, this study will use geographical risk data from risicokaart.nl to perform a spatial analysis using residential housing transactions from the Dutch Realtor's Association (NVM). The geography of this study is limited to the province of Noord-Brabant and evaluates the time period 2000-2017. This geographical study area is characterized by high wildfire risk close to residential locations, previous large fires, and town evacuations as a result of uncontrollable fires.

The findings of this paper are relevant because of the increasing wildfire risk and occurrence in the Netherlands. The majority of the current literature on the relation between wildfire risk and housing prices study fire events in the US. This paper will provide the first analysis on the influence of wildfires in the Dutch residential real estate market. The subsequent conclusions are of importance for real estate investors, managers, and insurance providers in the Dutch housing market and aim to increase climate risk awareness.

First, we identify no effect of fire risk on transaction prices when studying the full sample of Noord-Brabant. When focussing on the local area of Strabrechtse Heide, we find a significant value premium for properties closer to fire risk areas. For the comparable natural area of Maashorst we observe a price discount. Second, the analysis for the fire event does not significantly change the fire risk perception in Noord-Brabant and the local area of the Strabrechtse Heide. The fire did have a significant effect on the risk perception in the comparable natural area of Maashorst, where the natural amenity premium disappeared after the fire. A possible explanation for this finding is that homeowners close to Maashorst expect a similar fire event in their area in the future. Third, an analysis of annual post-fire effects in Strabrechtse Heide does not add more significant findings. All in all, the used sample, time period, and fire event do not allow us to conclude on a significant fire risk effect on residential property values in the province of Noord-Brabant, location-specific effects do occur.

This paper builds on current empirical evidence which focuses on American data and which uses a diverse set of data analysis methods. The first study on the relationship between wildfire occurrence and real estate was conducted by PwC (2001) after being assigned by the Federal Emergency Management Agency's Office of Cerro Grande Fire Claims. They study the Cerro Grande Fire that occurred in May 2000. As a result of high winds and long-term drought conditions, this uncontrollable fire burned an area of more than 610 km^2 and destroyed around 280 homes. PwC evaluates the prices of houses within the vicinity of the fires, but which were not directly affected by the fire. Using a pre-post fire regression analysis, a 3% to 11% decline in single family residential property values is observed.

Later studies mainly perform event studies using a more sophisticated hedonic pricing model. This model, first demonstrated by Rosen (1974), states that a good can be valued using its characteristics instead of purely the good itself. In the case at hand, the price of a house is a function of its characteristics such as neighbourhood and house attributes. The first study to use such a hedonic pricing model evaluates the impact of the 1994 Wenatchee National Forest fires on the residential housing sales in nearby located Chelan County, Washington (Huggett, 2003). The hedonic model incorporates forest amenity effects by taking into account that wildfires can reduce such amenity premium. The author observes a six-month period in early 1995 where the willingness to pay for housing drops. This price drop occurs one year after the fire and is only short-lived. Loomis (2004) performs a similar study in the small town Pine, Colorado, nearby a fire in Buffalo Creek in May 1996. Loomis finds that homeowners in the unburned town adjust their risk of forest fires through the observation that sales prices five years after the fires are 15% to 16% below a 'no fire scenario'. More recent literature finds similar conclusions where homeowners observe a 21.9% decrease in price after the large Fourmile Canyon forest fire in Colorado (Kiel and Matheson, 2018). Note that this large effect was observed in the area with the largest risk. Moreover, the fire event caused over $200 million in property damage, making it the most expensive fire in Colorado at that time.

Instead of performing a single fire event study, Donovan et al. (2007) use wildfire risk data published by the Colorado Springs Fire Department. This dataset was published on the fire department's website and contained 35,000 structures including building material, local vegetation, and risk area proximity, among other. Their study concludes that wildfire risk offsets any increases in house prices from improved amenity information. Furthermore, wildfire related housing characteristics, such as wooden roofing, reduce the price of that house after the publication of the fire risk data. Other studies perform multiple hedonic models by taking numerous fires in a larger geographical area and study the sales price effect with regards to the distance between the homes and the wildfires. Mueller and Loomis (2009) find a positive relation between fire distance and single-family residential home sales. Additionally, the authors conclude that the occurrence of a second fire will result in a more significant price drop. They hypothesize that the fire reoccurrence assures the wildfire risk and potential future physical risks. Stetler et al. (2010) confirm that homes closer the wildfires have a reduction in value by studying the effect of 256 wildfires in northwest Montana. Moreover, when the aftermath of the wildfire is out of sight from the house, the owners or buyers do not seem to take its risk into account. A similar 'burn scar' analysis is performed by Garnache and Guilfoos (2018) by studying the housing prices in Los Angeles and San Diego and their views of burned nature. The authors show a 4.5% decrease in asset value for properties with a burn scar view. Furthermore, by studying the same geographical area, Tanner and Garnache (2017) conclude that properties closer to forest areas have a larger price decrease post-fire, up until 20km from a natural park border.

While the majority of the literature agrees on a negative relation between wildfires events and real estate values, Hansen and Naughton (2013) only find such a link for small fires. On the other hand, large fires had an unexpected positive effect where assets within 0.1 km of a large fire have a 19% value increase. Lowered risk perception of future reoccurrence is one possible explanation the authors put forward for their finding. Additionally, burned forests can open up other natural views of lakes and mountain areas, which in turn increases property values. Rossi and Byrne (2016) document that nearby property prices are insensitive to wildfire events in their study in Colorado.

The remainder of this paper will first introduce wildfire characteristics and trends in the Netherlands. Section 3 provides information on climate change, its risks, and the impact of such risks on real estate. Data on Dutch property transactions and fire weather risks and events are described in section 4. The hedonic pricing methodologies and spatial analysis are explained in section 5. Section 6 presents the results. A discussion including limitations, future research proposals, and implications is provided in section 7. Section 8 concludes this paper.

2. Wildfires in the Netherlands

The Netherlands is largely situated below sea-level and is often thought of as a rainy and wet country. With common flood risk along the coast and mainland rivers, and a large polder area, a study on wildfire risk seems out of place. Yet, large wildfire occurrences in 1976, 2010, and 2014, and recent meteorological developments point to a need for clarification concerning the risk of wildfires and its societal consequences. This section will give an insight in the different types and the behaviour of wildfires, the underlying risk factors and their trend over time, and past fires in the Netherlands. The goal of this section is to inform the reader and increase awareness of the presence of wildfire risk in the Netherlands.

2.1 Definitions

'Wildfire' is a general term, but the definition used by fire departments is the most common version: "Wildfires are fires burning in natural or agricultural areas and vegetation, including forest, grass, heather, dune, cane, and peat areas." (Brandweer Nederland, 2014). Fires show varying behaviour among vegetation types. Thus, these separate forms of wildfire all need a brief explanation. First, forest fires occur on forest parcels with either conifers or deciduous trees. Second, grass fires occur on grass patches during longer periods of extreme heat when the top layer of the grass has died. Grass fires tend to spread fast, making them difficult to control. Cane fires occur in cane fields and also spread fast. Third, heather fires can occur below and above the surface and are dangerous during periods of extreme wind. Similarly, peat soil fires spread below the surface making it difficult to follow and target. *Figure 1* below shows how a ground or surface fire can create a crown fire through the so-called 'ladder effect'. A crown fire spreads fast as it has enough oxygen and wind to travel from tree to tree. Moreover, a crown fire emits a large amount heat and can even form fire tornados.

Figure 1: Ladder effect in wildfire spread

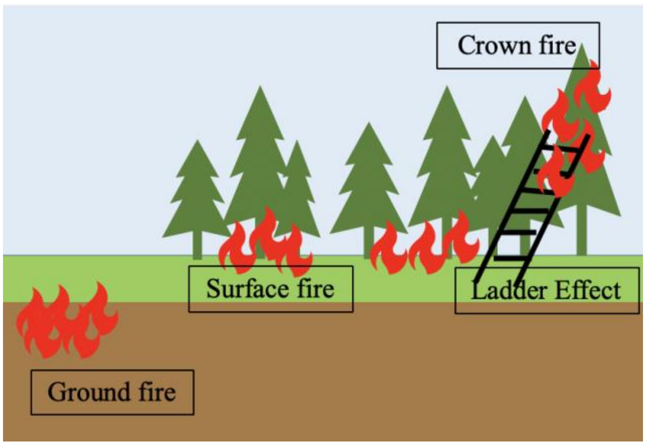
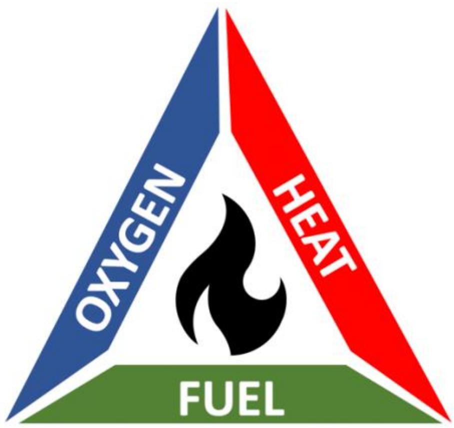


Figure 2: The fire triangle



2.2 Underlying risk factors of wildfires

Any fire requires three elements in order to start: heat, fuel, and an oxidizing agent (*Figure 2*). A fire can be viewed as an event, rather than a thing, because it won't occur if one of the fire triangle elements is absent. Logically, a fire can be stopped by taking out one of the elements from the triangle. In nature, the heat element stems from outdoor temperatures, fuel is made up of vegetation on and in the ground, and the oxidizing agent is usually oxygen. Wildfires are inevitable and will always be part of nature. Moreover, wildfires can even be good for the biodiversity and the soil in large natural areas. Therefore, most small fires are undetected or are not targeted by fire departments unless they are a threat for infrastructure or human lives.

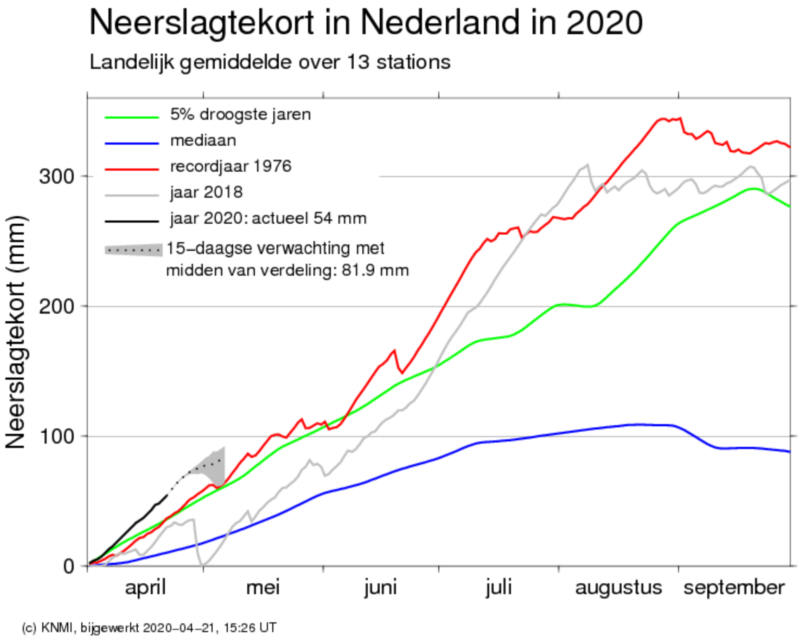
Fires become uncontrollable when they meet the '30-30-30' rule (Melita, 2020). The first '30' relates to wind speeds above 30 km per hour. Second, with temperatures above 30 degrees Celsius, fires have decreased controllability. Third, wind and heat in combination with relative humidity levels below 30 percent increase the alertness of fire departments as a result of heightened risk. During the large Australian wildfires of 2019 and beginning 2020, these factors caused the fires to expand beyond control and remain lit for a long period of time.

2.3 Risk factors in the Netherlands

The Dutch climate is not like the Australian climate where the three factors of the 30-30-30 rule are satisfied more often. Yet, by studying historical meteorological data, researchers identify trends that point to a shift in the Dutch climate.

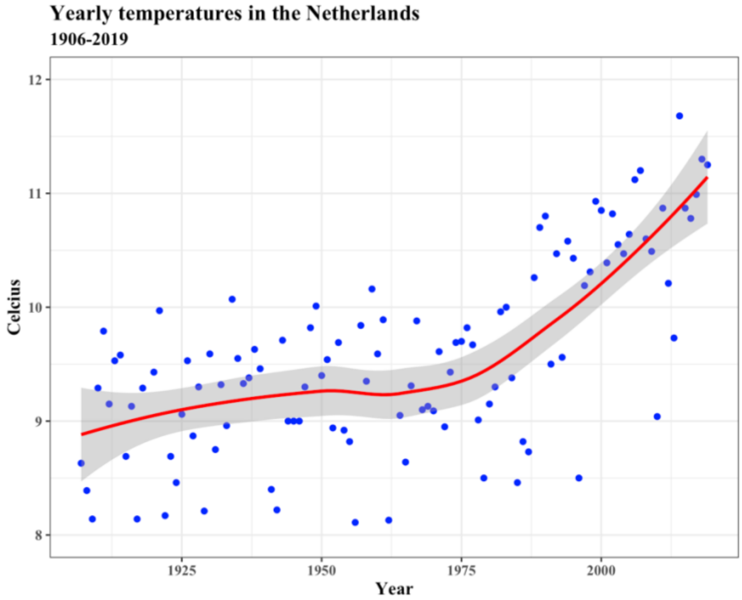
First, regarding drought, the Royal Netherlands Meteorological Institute (KNMI), published that 2018 was among the top 5 percent driest years in history and was similar to the record year of 1976. Figure 3 below shows this clear lack of precipitation in 2018. The precipitation deficit as of April 21th 2020 shows an alarming trend of drought values above the record year of 1976.

Figure 3: Precipitation deficit in the Netherlands, current and historical (KNMI, 2020b)

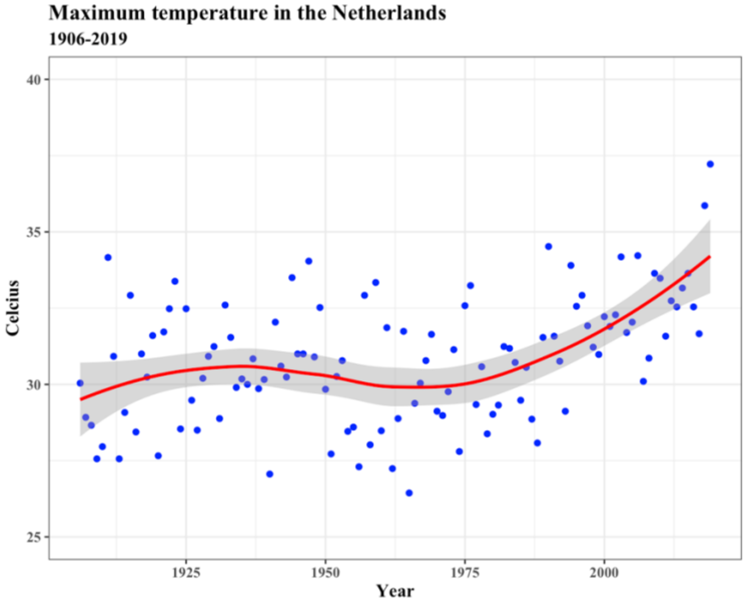


Next to increased drought, annual average temperatures have risen too as presented in *Figure 4a*. The red trend line shows that the average temperature in the Netherlands has increased with 2 degrees Celsius from 1906 to 2019. Related to the 30-30-30 rule, *Figure 4b* shows an upward trend regarding the maximum annual temperature in the Netherlands with increasingly more observations above the 30 degrees Celsius mark.

Figure 4: Yearly (a) average (b) maximum temperatures in the Netherlands over the period 1906-2019



(a)



(b)

Finally, Pryor and Barthelmie (2010) study the predicted wind speeds in Northern Europe to estimate the potential of wind energy. However, they conclude on no detectable change in wind speed. On another note, an increase in the occurrence rate and severity of heavy storms is expected in Europe following global warming models. The KNMI (2018a) states: "At the end of this century, Europe can be hit with a *Sandy* on a yearly basis.".

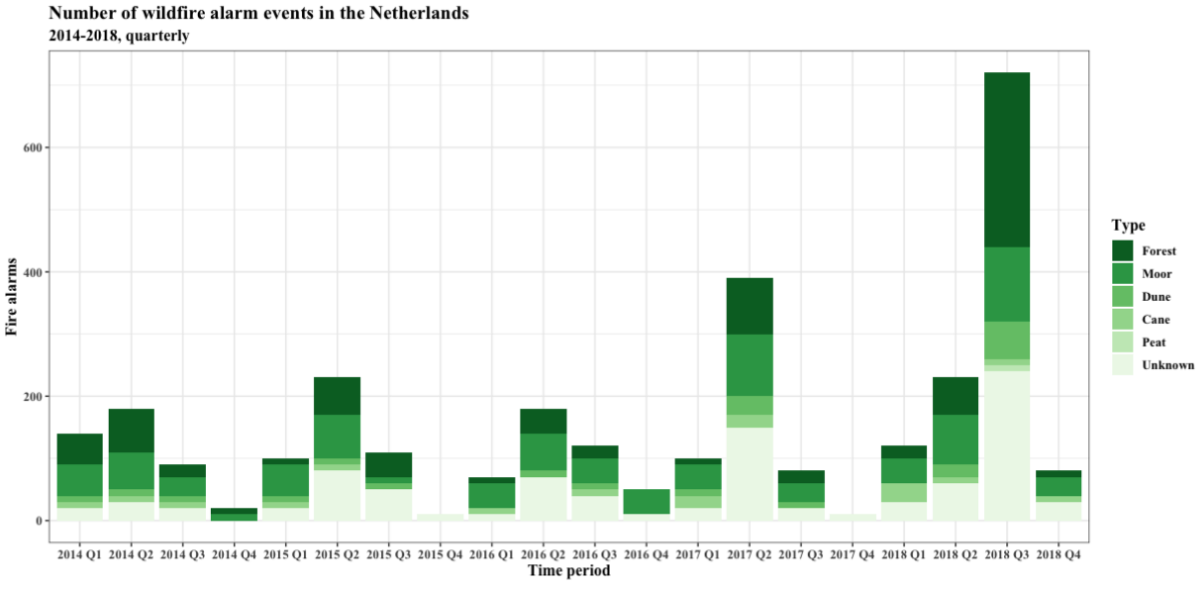
Thus, following the 30-30-30 rule, the increased drought and heat allow us to assume that wildfire events in the Netherlands will become more likely in the future. This conclusion is in line with academic literature which will be discussed in section 3.2.

2.4 Wildfire events in the Netherlands

Wildfires are a regular phenomenon in the Netherlands, however most of the fires are too small to catch the eye of the media and inhabitants. Still, once in a while a larger uncontrollable fire event takes place. Older events are the wildfires close to ‘t Harde (1970), near Arnhem on Rozendaalse Veld (1976), and near Kootwijk (1995). The fire on Rozendaalse Veld was previously considered to be the largest wildfire in the history of the Netherlands, burning more than 400 hectares of natural areas. The large fire in the Deurnese Peel in April 2020 took over the number one spot by burning 800 hectares, covering 80% of that natural area. Other recent examples include the fires in the dunes near Bergen and Schoorl (2009, 2010, and 2011), in Fochterloërveen in Drente (2011), and in the Strabrechtse Heide in Noord-Brabant (2010). The analysis in this paper will focus on the fire in the Strabrechtse in 2010. More information on the data of this fire is provided in section 4.

Related to the earlier observation that 2018 was among the top driest years in Dutch history, the number of wildfire alarm events doubled over 2018 compared to the year before. *Figure 5* shows that forest and heather fires had the largest jump. Along with this increase in alarm events, fire fighter response times went up, further endangering the control of wildfires

Figure 5: Wildfire alarm events in the Netherlands (CBS, 2019)



3. Climate Change and Risks

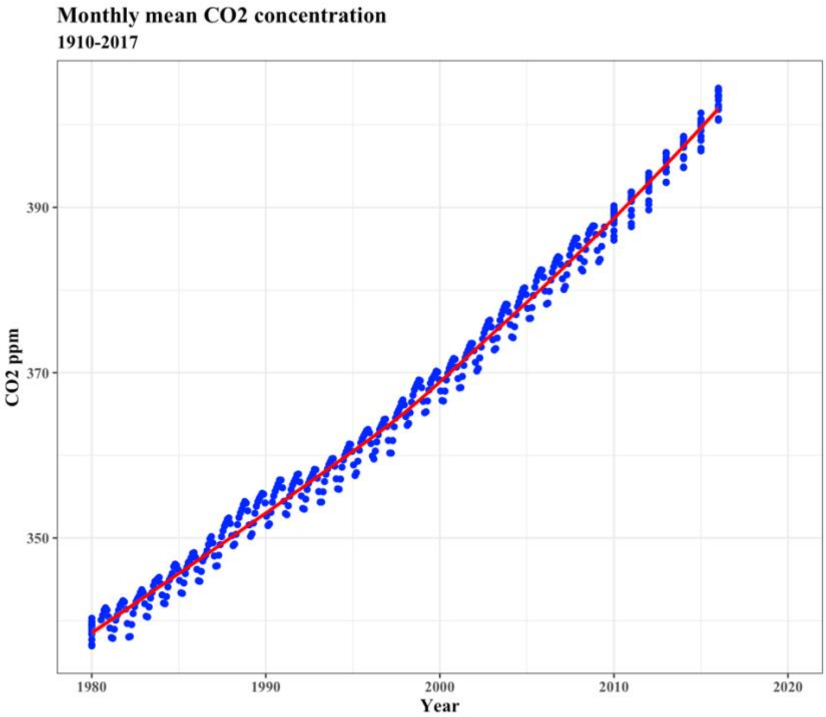
The previous section gave an overview of the increasing risks regarding wildfires in the Netherlands. This section will connect these risks to climate change by analysing the connection between emissions, global warming, and climate hazards. Moreover, the relation between climate change and real estate is further developed by studying other hazards such as flood risk and storm risk.

3.1 Introduction to Climate Change

Originating from the early 1990s, the United Nations (UN) established the goal that the greenhouse gas (GHG) emissions in the atmosphere should be limited to prevent anthropogenic climate change. Anthropogenic climate change is defined as human-induced temperature increases and climate change resulting from human industry and agriculture. This section is an important starting point for the discussion of this paper, as different climate pathways predict more pessimistic or more optimistic circumstances regarding climate change and natural hazards.

Before discussing specific treaties and the negative current trends of GHG emissions, it is important to introduce the basics of greenhouse gases. The world's atmosphere consists for 78% of Nitrogen (N), 21% of Oxygen (O), and 0.9% of Argon (Ar). The remaining air surrounding the Earth consists of gases such as Carbon Dioxide (CO_2), Helium (He), Methane (CH_4), and Neon (Ne), among others. These greenhouse gasses are necessary to a certain extent as they keep the global temperature at 15 degrees Celsius on average. The molecules inside the GHGs absorb electromagnetic radiation, e.g. natural reflected sunlight, and emit heat as a result. Without these gases, the Earth would constantly be below the freezing point, so their presence is required to some extent. Yet, it makes intuitive sense that increasing GHGs would result in more reemission of heat, thus leading to higher temperatures on our planet. Even though Carbon Dioxide fills only a small percentage of the Earth's atmosphere, an increase in its concentration has serious effects. *Figure 6* below shows the increasing fraction of Carbon Dioxide in part per million (ppm). Additionally, atmospheric methane concentrations have risen by a factor of 2.5 from pre-industrial levels (1881-1910), also contributing to the warming of the Earth.

Figure 6: CO2 in dry air at NOAA's Muana Loa Observatory on Hawaii in ppm



In 1992, the first signatures were collected for an international environmental treaty called the United Nations Framework Convention on Climate Change (UNFCCC). Its objective was to stabilize atmospheric GHG emissions. However, there were no legal limitations and binding obligations presented until the establishment of the Kyoto protocol in 1997. In 2010, warming limits of 2 degrees Celsius above pre-industrial levels were presented during the UNFCCC conference. The more commonly known Paris Agreement from 2016 sets the target to 1.5-2 degrees Celsius. There are multiple scenarios for climate projections, the idea behind these climate scenarios and their connection to the topic of this paper will be worked out in sections 7.1 and 7.2 in the discussion.

3.2 Climate Change and Natural Hazard Risk

Climate change and increasing temperatures are inevitable. Natural hazards such as tropical storms, wildfires, floods, are heat waves were not uncommon in the past. Yet, the current question is whether increasing climate change, outlined in the previous section, influences the occurrence rate of these natural hazards.

Starting with wildfire events, on average research concludes on a positive relation between climate change and the risk of wildfires (Jones et al., 2020). Krikken et al. (2019) study the increase in wildfire events in Sweden in 2018. Following the +2˚C trend, risk for fire events increases two times, which is mainly attributable to higher recent temperatures in Sweden. Studies performed in the U.S. find similar results (Liu, Goodrick, and Stanturf, 2013). Wang et al. (2015) look at Canada and conclude on future climate change increasing active fire spread potential. Williams et al. (2019) show a link between anthropogenic climate change and increased wildfire activity in California through more drought as a result of warming. It is estimated that an additional 4.2 million hectares of forest fire area was caused by anthropogenic climate change. In the absence of such human-caused change, the expected forest fire area would be halved (Abatzoglou and Williams, 2016). Also, colder geographical locations such as Western Canada and Northern US show a rise in wildfire events as a result of melting snow and a longer period of moisture deficit in spring and summer (de Groot et al., 2013; Westerling, 2016).

Other climate risks seem to be affected by GHG emissions to a similar extent where Sippel et al. (2016) provide a multimethod analysis showing an increase in both the frequency and intensity of short-term heat waves in Europe. Vautard et al. (2019) research the human-induced effect on wind storms in Europe, but find no significant influence using past data. Nevertheless, using simulations, they find that global warming could lead to a 0% - 20% increase in the probability of extreme winds in Europe until 2050. The limitations of such a prediction model reduce the credibility of projections of future storms. Van der Wiel et al. (2017) show a positive relation between climate change and flood-induced extreme precipitation. Through simulations on the central US Gulf Coast, the authors conclude that the probability of extreme rain has become more likely to occur in 2016 compared to 1900. Following global climate models, anthropogenic climate change has increased the probability of 3-day extreme precipitation by a factor of 1.4.

3.3 Climate Risks and Real Estate

The previous sections established the relationship between GHG emissions, climate change, and natural hazards. This section outlines the connection of these climate risks to real estate. We have seen multiple wildfires across the globe with large impacts on nature and infrastructure. The 2018 *Attica Wildfires* in Greece destroyed or damaged over 1,000 buildings, killing 102 inhabitants. The 2019-20 Australian wildfire season destroyed over 9,000 buildings and is estimated to have killed more than 1 billion animals. The *Camp Fire* in California was the most destructive and most expensive natural hazard in 2018, destroying a total of 18,804 properties. The value impact of destroyed properties is usually published in the media and can be estimated using regular valuation data. However, the value impact on nearby properties which are not directly affected by the fire has low media coverage. The introduction of this paper already provided an overview of the current academic literature on the effect of wildfires on such real estate. *Table 1* shows a summary of some of the available literature in this field. In general, most studies find a negative price effect using events and samples in the US. Even though there are many fire events in other regions such as Australia, Portugal, and Greece, literature on the fire risk effect in these regions is still scarce. Moreover, despite the increasing drought and fire risk, this paper is the first to study the effect of wildfire risk in the Netherlands.

Table 1: Literature on wildfire risk and real estate

Author(s)	Year	Main Findings
PwC	2001	Price decrease of 3-11%
Huggett	2003	Short-lived price drop after 1 year
Loomis	2004	Price decrease of 15-16% after 5 years
Donovan et al.	2007	Fire risk data offsets availability of amenity data
Kiel & Matheson	2008	Price decrease of 21.9%
Mueller & Loomis	2009	Price decrease which is larger after second fire
Stetler et al.	2010	Price decrease for homes with a burn scar view
Hanssen & Naughton	2013	Price increase of 19% for large fires within 100m
Rossi & Byrne	2016	No significant price effect
Tanner & Garnache	2017	Price decrease for homes within 20km buffer
Garnache & Guilfoos	2018	Price decrease of 4.5% if burn scar view

Similar to the discussion on wildfire and real estate, literature on other climate risks that impact infrastructure is a trend in current research. Li (2009) studies temperature data from the Hong Kong Observatory and property transactions to indicate their negative and significant relationship. Daily temperature volatility is also inversely related to direct real estate returns (Semenenko and Yoo, 2019). Global warming is connected to snow quality by Butsic et al. (2011) who find reduced prices for ski resort assets as a result of higher temperatures.

Flood risk exposure, measured after the event of Hurricane Sandy, increases risk premiums for commercial properties exposed to, but not damaged by, the natural hazard (Eichholtz, Steiner, and Yönder, 2019; Ortega and Taspinar, 2016). The authors conclude that the price change is not a temporary drop, but a longer trend which incorporates more general waterfront flood risks. Bernstein et al. (2018) document a similar discount in exposed residential properties, while Murfin and Spiegel (2020) conclude on an insensitive relation for coastal properties and flood risk. Votsis and Perrels (2016) study the effect of public disclosure of flood risk on housing prices. They observe a negative relation between communicated risk through risk maps and coastal dwellings in three cities in Finland. This suggest that disclosures on less obvious risk could have wider potential for asset value calculations. Still, apart from price effects, American homeowners in coastal areas have taken limited action to mitigate the increasing risk of storms and flooding (Javeline and Kijewski-Correa, 2019).

The corporate sector is supporting the discussion on climate risks and real estate through collaborations between insurance firms, investment funds, and geographical data-mapping start-ups. The Urban Land Institute (ULI), together with real estate investment fund Heitman LLC, published a strategy and risk report on the real threat that climate change presents to real estate investing (2019). Their report connects physical risk, such as catastrophes, to a decrease in both the liquidity and value of buildings. Moreover, transitional risk, can change the risk perception of specific living areas thereby influencing individual asset values negatively. After interviewing professionals in the field of investment management and the insurance sector, the authors find that the majority of the industry players have not adapted their insurance premiums or coverage to higher apparent climate risk. A team from PGGM Private Real Estate partnered with risk solution provider Munich Re to identify the location of portfolio risk (2020). By connecting hazard risk scores with PGGM's portfolio weights of assets, this Dutch pension fund is able to map and adjust its investments to be more protected against physical asset damage. Similar portfolio assessment will be widely available in the near future with data providers such as Four Twenty Seven and GeoPhy releasing products that map climate exposure of real estate investment trusts (REITs). According to their analysis, 35 percent of global REITs properties are exposed to climate hazards, with inland flood risk portraying as the largest risk (2018).

4. Data

The dataset of this paper consists of housing information from the Dutch Realtors Association (NVM), wildfire information from the Dutch National Georegister, and natural amenity information from the Natuurnetwerk Nederland (NNN).

4.1 Housing

The Dutch Realtors Association stores data on Dutch housing transactions representing around 75% of the market. The dataset contains transaction prices, sales date, location specifics, and a large array of house and neighbourhood characteristics on more than 2.5 million observations. In the analysis of this paper, data from 2000 until 2017 will be used covering the province of

Noord-Brabant. This province is chosen based on the high amount of natural areas, wildfire risk locations, and historical wildfire occurrences in the area. As discussed in the introduction, the largest wildfire in the history of the Netherlands took place in the Deurnsche Peel in April 2020, which is at the border between the provinces of Noord-Brabant and Limburg. Another large fire event was the wildfire on July 2nd, 2010 in the Strabrechtse Heide, located to the south-east of the city of Eindhoven. This event will be used to perform an event study and test for a direct effect of wildfire risk in the surrounding areas. The housing location characteristics are provided using 6-digit zip codes. However, spatial analysis requires coordinates information, therefore the zip codes are geocoded to longitude and latitude values using online tools. *Figure A1* in the Appendix shows a map of the property transactions between 2000-2017 in Noord-Brabant.

After cleaning the data set, 186,685 housing transactions remain at use for the hedonic model explained in section 5. This cleaning is done by first reducing the largest outliers, the bottom and top 1% of the observations in terms of transaction price are removed. This approach is similar to other studies using the same NVM data set like Aydin, Eichholtz, Kok, and Langen (2018). Next, the summary statistics of every single variable are analysed and plotted to spot left-over outliers and remove them from the data set. For example, observations with more than 15 rooms, 10 toilets, 5 floors, and a living area greater than 400 square metres are removed to reduce skewness and create normally distributed variables. Additionally, variables with similar traits are removed after studying correlation plots like in *Figure A2*. On the left, different 'space' variables have high correlations, thus the 'm2' variable is only added to the hedonic model. On the other hand, the right plot shows a medium to high correlation between the number of toilets and bathrooms. Removing the '#toilets' variable from the model is unlikely to alter our final results. Finally, dummy variables are formed for categorical variables. *Table A1* of the appendix shows the different variables and dummies with their corresponding mean values.

4.2 Wildfire risk

Wildfire risk data is obtained from the website of the National Georegister of the Netherlands. The map in *Figure A6a* in the appendix shows the risk areas for wildfires in the province of Noord-Brabant. The original grid cells from the *Risico Investarisatie Natuurbranden* (RIN) by Nexpri are taken and extended with grid cells that include areas which are under development by the provincial green fund. This RIN is an effort by the Netherlands Fire Service (Brandweer NL), the Institute of Physical Safety (IFV), and provincial planning departments to map the wildfire risk areas in the Netherlands. The underlying risk is defined as: "the chance that an existing fire will turn into an uncontrollable fire". So, the data from RIN gives us exactly what was described in section 2 of this paper on wildfire types and risk. More specifically, the data from RIN takes into account the 30-30-30 rule by including uncontrollability factors such as wind, heat, and drought. These risk locations are publicly available and can be viewed by anyone on risicokaart.nl.

Property-specific wildfire risk is determined through the following steps. First, RIN areas and housing coordinates are plotted on one map using overlay functionalities in Geographic Information Systems (GIS) software. Second, buffer areas of different sizes are added to the original shape file from the RIN. Finally, observations located within the area of each spatial buffer are identified. *Table 2* shows that 11,753 housing observations are located within the risk areas, 14,701 observations are located within a 100m buffer, and 26,931 observations are located within a 500 metres range from the closest risk area, etc..

To perform an event study, data is used from the fire in the natural area *Strabrechtse Heide* in the province of Noord-Brabant which broke out on July 2nd, 2010. This natural heathland covers around 1500 ha and is located in the municipalities of Heeze-Leende, Someren, and Geldrop-Mierlo. The area is also part of the Natura2000 nature protection network and mainly consists of heather and forest. The fire started in the summer after several weeks of intense heat and drought. The fire burned 220 ha, covering nearly 15 percent of the total area. Relating to *Figure 1* from section 3, the fire quickly turned into a crown fire and remained uncontrollable for a while. Hundreds of firefighters from surrounding municipalities and provinces spend a week extinguishing the fire. Moreover, a hundred Dutch Defence forces were deployed to assist in fighting the fire. A Cougar helicopter was even brought in to drop buckets of 2500L water (IOOV, 2011). This fire was widely covered in the media in the Netherlands and became a point of discussion in the Dutch Parliament. Ministers questioned the preparedness of the safety departments in each province and initiated a thorough research by the Ministry of Justice and Security. Consequently, this research led to innovations in the Risico Index Natuurbranden (RIN) used in the analysis of this paper. All in all, the size, duration, media coverage, and the political aftermath of this fire make it a significant event in the Dutch wildfire history.

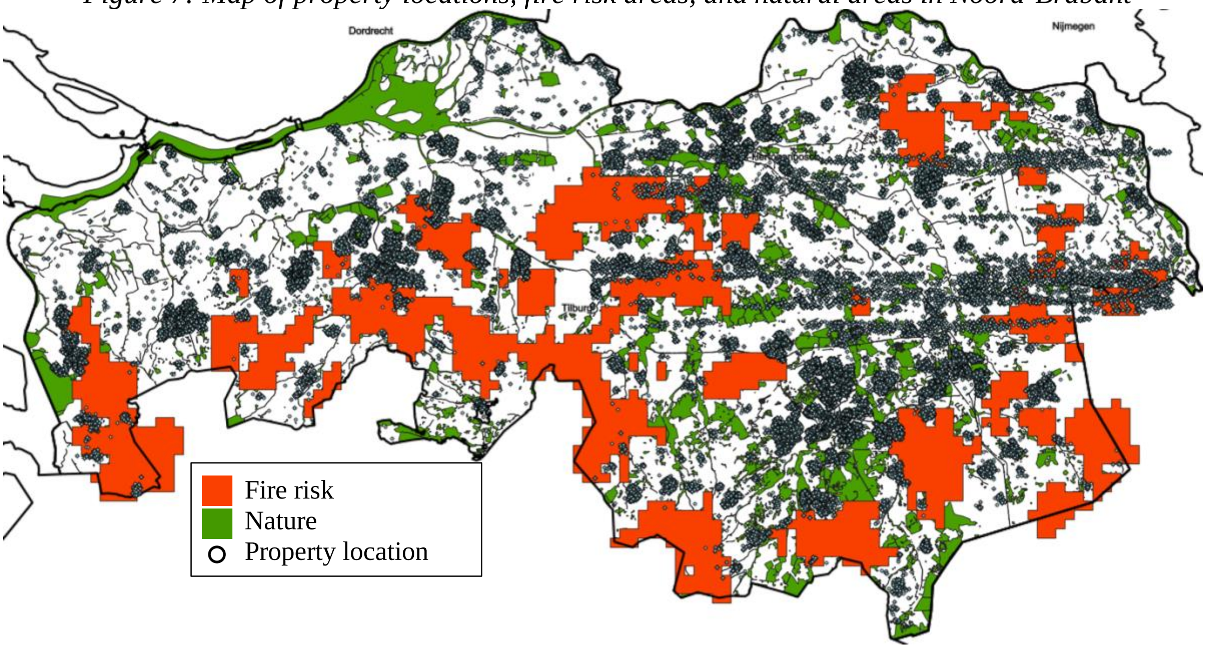
4.3 Natural amenities

Data on natural amenities are retrieved from the website of the province of Noord-Brabant. The downloadable information on the *Nature Network* includes a very detailed and wide array of natural area types. From the 49 different natural area types, the following are most common: dry & wet forests, riverbank forests, agricultural land acting as natural areas, peat forests, hornbeam forests, and dry heather. *Figure A6b* displays these natural areas in Noord-Brabant. Property-specific amenity exposure is calculated in a similar way to the above-mentioned property-specific wildfire risk. *Table 2* displays the amount observations in each natural area buffer. *Figure 7* below shows the data points and areas from all three data sources in one map.

Table 2: Number of observations per fire and nature distance buffer

	Number of observations	
	Fire	Nature
Within	11,753	6,148
100 metres	14,701	20,177
500 metres	26,931	100,137
1000 metres	49,367	156,706

Figure 7: Map of property locations, fire risk areas, and natural areas in Noord-Brabant



5. Methodology

5.1 Hedonic pricing models

Rosen (1974) first proposed the idea of a hedonic relation where the value of an object is related to its individual characteristics. This relation is commonly used in real estate valuation:

$$Value = f(P, G, E) \quad (1)$$

where P relates to property specific, G to geographic, and E to environmental characteristics. In line with previous research on natural hazard risk (Eichholtz et al., 2019; Stetler et al., 2010), the analysis of this paper will include a similar hedonic pricing model. The data on housing characteristics, wildfire risk locations, and natural amenities are used as hedonics, whereas the property transaction price acts as the dependent variable. We first estimate the following regression:

$$Price_{i,t} = \beta_0 + \beta_1 \boldsymbol{Hedonics}_{i,t} + \gamma_t + \delta_z + u_{i,t} \quad (2)$$

where $Price_{i,t}$ is a variable on the natural logarithm of the transaction price for property *i* at time *t*. This indicates that a specific property can transfer ownership multiple times during the period 2000-2017. β_0 is a constant. $\boldsymbol{Hedonics}_{i,t}$ is a matrix of covariates including the variables and dummies from the NVM dataset (see *Table A1* for descriptive statistics). γ_t and δ_z are year- and zip code-fixed effects, respectively. $u_{i,t}$ is the residual. Fixed effects are added to the unbalanced panel regression of individual housing prices to control for omitted variable bias.

Next, we extent regression (2) by adding variables representing the wildfire risk a specific property is exposed to. As described in section 4, buffers are formed around risk areas using different distances. Buffer variables are added to regression (3) below where properties are given a value of 1 if they are located within that specific distance buffer:

$$Price_{i,t} = \beta_0 + \beta_1 \boldsymbol{Hedonics}_{i,t} + \beta_2 \boldsymbol{Fire} + \gamma_t + \delta_z + u_{i,t} \quad (3)$$

where $\boldsymbol{Fire}$ is dummy for fire distance. Four regressions are run where we move from a broad buffer of 1000m to 500m, 100m, and eventually use a dummy for observations sharing coordinate information with fire risk areas. This approach is similar to the study from Aydin, Eichholtz, Kok, and Langen (2018).

From the fire triangle introduced in section 2, trees and other vegetation can act as fuel for fires. Thus, we would expect fires to occur more frequently in natural areas. Similarly, Loomis (2004) states that high hazard risk areas are positively correlated to locations with high natural amenity values. This observation is key for the analysis of wildfire risk literature as fire and nature variables can have opposite effects. More specifically, it is expected that fire proximity has a negative effect on property values. Whereas Dombrow et al. (2000) find that houses located closer to the tree cover have higher prices. To test this effect identified by Dombrow et al., we run the following regression:

$$Price_{i,t} = \beta_0 + \beta_1 \boldsymbol{Hedonics}_{i,t} + \beta_2 \boldsymbol{Nature} + \gamma_t + \delta_z + u_{i,t} \tag{4}$$

where $\boldsymbol{Nature}$ is a dummy for nature distance. Comparable distance buffers to the $\boldsymbol{Fire}$ variable are used to correctly capture this natural amenity effect.

Finally, regression (3) and (4) are combined to determine the interplay between the wildfire risk distance and the natural amenity distance of a certain property. Without the $\boldsymbol{Nature}$ variable, a bias could be present where wildfire risk areas carry positive amenity value through the presence of forests. If this bias is not controlled for, the results of this analysis are not robust. Thus, similar to studies by Stetler et al. (2010) and Hansen et al. (2014), the regression below controls for this bias by adding dummy distance variables to natural amenities from Natuurnetwerk Nederland, as discussed in section 4:

$$Price_{i,t} = \beta_0 + \beta_1 \boldsymbol{Hedonics}_{i,t} + \beta_2 \boldsymbol{Fire} + \beta_3 \boldsymbol{Nature} + \gamma_t + \delta_z + u_{i,t} \tag{5}$$

5.2 Event study

To test the effect of a large fire on the risk perception of local homeowners, the earlier described fire event in the Strabrechtse Heide is used in the following hedonic regression analysis:

$$\begin{aligned} Price_{i,t} = \beta_0 + \beta_1 \boldsymbol{Hedonics}_{i,t} + \beta_2 \boldsymbol{Fire} + \beta_3 \boldsymbol{Nature} + \beta_4 \boldsymbol{Post} + \beta_5 \boldsymbol{Post} * \boldsymbol{Fire} \\ + \beta_6 \boldsymbol{Post} * \boldsymbol{Nature} + \gamma_t + \delta_z + u_{i,t} \end{aligned} \tag{6}$$

where $\boldsymbol{Post}$ is a dummy variable for properties sold after July 2nd, 2010. $\boldsymbol{Post} * \boldsymbol{Fire}$ is added to determine the price effect in fire prone areas after the large wildfire in the province. $\boldsymbol{Post} * \boldsymbol{Nature}$ is added to determine the price effect in natural areas after the large wildfire in the province. This regression can be applied to specific areas within the province of Noord-Brabant. By forming a sample of property transactions within the three municipalities that Strabrechtse Heide is located in, it is possible to review whether effects are more intense there. Noteworthy, findings on this topic are easier to interpret when comparing them to similar natural areas that did not experience a large local fire. Therefore, a similar analysis is applied to the natural area *Maashorst* located in the municipalities of Oss, Landerd, Bernheze, and Uden. The similarities in size and vegetation, compared to Strabrechtse Heide, make this area suitable for such an analysis.

The above hedonic event study can be extended by studying annual fire effects during the 'post' period. From this analysis we can study how long it takes for prices to incorporate, if any, wildfire risk effects. Huggett (2003) find that this effect is short-lived and takes place one year after the fire, whereas Loomis (2004) observes the largest price effect after 5 years.

6. Results

This section will present the findings of the data and regression analysis described in the methodology section above. All of the regressions are performed with zip code- and year-fixed effects. The results on the full list of NVM variables for equation (2) can be found in *Table A1* in the Appendix. The signs of the variables and dummies are intuitive and in line with previous hedonic research. The main focus of this paper is on the effects of fire and nature distance variables described in the upcoming paragraphs.

6.1 The hedonic pricing model

Table 3 presents the regression results on the price effect of wildfire risk and natural area distance proposed in equations (3), (4), and (5). The results are based on the 186,685 property transactions in Noord-Brabant. From column (1) it is evident that there is a positive and highly significant price effect when a property is located within a 1000 metre buffer from the risk area. When decreasing the size of this buffer, we also observe a positive effect for properties located within the fire risk areas. More specifically, observations that share coordinates with designated fire risk locations have a 0.8% price premium.

One possible explanation for this positive house price effect can be the positive natural amenity premium observed in column (2). The results in this column show a positive and highly significant price effect between 0.4% and 1.2% for properties located closer to or within natural areas. This premium makes intuitive sense and is in line with the findings from Dombrow et al. (2000).

Most importantly, column (3) combines fire and nature distances and shows that there is still a positive and significant effect on property prices of 0.6% for observations located within a fire risk area across Noord-Brabant. The coefficients and p-values of the results from columns (1) and (2) are slightly reduced, indicating a small interplay between the distance variables where the positive amenity value of nature is lower when taking fire risk into account. However, this difference is insignificant.

Table 3: Fire and nature distance effects

	Property Transaction Price		
	(1) Fire	(2) Nature	(3) Fire, Nature
Within Fire	0.008***		0.006**
Fire: 100 metres	-0.003		-0.003
Fire: 500 metres	-0.004*		-0.004*
Fire: 1000 metres	0.009***		0.009***
Within Nature		0.012***	0.011***
Nature: 100 metres		0.004***	0.004***
Nature: 500 metres		-0.001	-0.001
Nature: 1000 metres		-0.003***	-0.003***
Constant	Yes	Yes	Yes
Year-Fixed Effects	Yes	Yes	Yes
Zip Code-Fixed Effects	Yes	Yes	Yes
Observations	186,685	186,685	186,685
Adj. R-squared	0.695	0.695	0.695

Statistical significance is indicated as follows: *$p<0.1$; **$p<0.05$; ***$p<0.01$

6.2 Event study analysis

The hedonic analysis presented above, shows the relation between distance variables and the transaction price over the full period from 2000 until 2017. Thus, in that analysis, interesting shocks and events are averaged out and become unidentifiable. *Table 4* presents the results from equation (6) where we study the price effect after the large fire in the Strabrechtse Heide area in 2010. In addition to the results for the Noord-Brabant sample, columns (2) and (3) are added to study the price effect in the areas of Strabrechtse Heide and Maashorst, respectively.

First, for the area of Noord-Brabant all transaction prices from July 2010 to the end of 2017 were significantly lower than the prices from 2000 until June 2010. Again, we observe a small natural amenity effect with premia between 0.8% and 1.4%. There are some significant values for the ‘post-fire’ and ‘post-nature’ interaction variables, however there is no notable trend or pattern which allows us to draw a significant conclusion. Therefore, we can say that the fire event in Strabrechtse Heide did not have a significant effect on property prices located in fire risk areas in the province of Noord-Brabant.

Second, unlike the entire province, in the area of Strabrechtse Heide there is no general price difference between pre and post fire periods. Interestingly, properties closer to or within fire risk areas in Strabrechtse Heide have a significantly higher price. This premium ranges from 5.4% to 13.9%. The treatment variable 'post-fire' shows no significant results. So, homeowners in the local area of the Strabrechtse Heide did not change their fire risk perception after the fire event.

Third, general property prices in the area of Maashorst were comparable before and after the fire event. In contrast to Strabrechtse Heide, in Maashorst we observe a significant price discount for observations within 100m of a fire risk area. After the fire event this effect also takes into place for the larger buffers. Initially we also observe the natural amenity effect in Maashorst, however the fire occurrence eliminates this premium fully. Thus, it appears that the fire in a comparable natural area affected the premium of living within 100m from nature, but did not affect the discount of living 100m from a fire risk area.

To sum up, the results from *Table 4* seem to be location dependent. We see no fire premium or discount when studying the full province sample of Noord-Brabant. Also, the fire event did not have a significant impact on this scale. For Strabrechtse Heide we observe a premium for fire risk, whereas in Maashorst we observe a discount. The event had no significant effect on the Strabrechtse Heide area, but eliminated the natural amenity premium in Maashorst. A possible explanation for this finding is that homeowners in Maashorst expect a similar fire to take place in the future, while homeowners in Strabrechtse Heide believe there is a low probability of a second fire in their area. This line of reasoning is related to the article from Hansen and Naughton (2013) who state that locals might lower their risk perception of future fire reoccurrences.

Table 4: Impact of fire event on risk and natural amenity perception

	Property Transaction Price			
	1000 metres	500 metres	100 metres	Within
Noord-Brabant				
Fire	0.009***	-0.003	0.003	0.005
Nature	-0.003	0.003*	0.008***	0.014***
Post	-0.010***	-0.010***	-0.013***	-0.018***
*Post * Fire*	0.003*	0.004*	0.002	0.002
Post Nature*	0.008***	0.003**	-0.002	-0.008**
Observations	186,685	186,685	186,685	186,685
Adj. R-squared	0.695	0.695	0.695	0.695
Strabrechtse Heide				
Fire	0.014	0.071***	0.139***	0.054***
Nature	0.022	-0.006	0.026***	-0.006
Post	0.012	0.014	-0.008	-0.011
*Post * Fire*	0.001	-0.005	0.004	-0.008
Post Nature*	0.023	0.030***	-0.029**	-0.033
Observations	6,342	6,342	6,342	6,342
Adj. R-squared	0.721	0.723	0.722	0.721
Maashorst				
Fire	0.005	0.028	-0.038*	-0.143***
Nature	-0.013*	0.020***	0.024*	0.084***
Post	-0.015	-0.015	-0.013	-0.014
*Post * Fire*	-0.015**	-0.038***	-0.029	-0.047
Post Nature*	-0.001	-0.007	-0.025*	-0.096**
Observations	10,614	10,614	10,614	10,614
Adj. R-squared	0.702	0.701	0.701	0.701
Constant	Yes	Yes	Yes	Yes
Year-Fixed Effects	Yes	Yes	Yes	Yes
Zip Code-Fixed Effects	Yes	Yes	Yes	Yes

Statistical significance is indicated as follows: *p<0.1; **p<0.05; ***p<0.01

6.3 Annual post-fire analysis

The results from *Table 5* below give a more in depth picture of the price effects in the post fire event window for the Strabrechtse Heide area. The coefficients for the different distance buffers and years show no significant trend. This confirms the conclusion drawn in the previous section on the insignificance of the fire event on the risk perception of local homeowners.

Table 5: Annual impact of fire distance after event fire

	Property Transaction Price in Strabrechtse Heide area			
	1000 metres	500 metres	100 metres	Within
Fire Distance	-0.011	-0.016	0.008	0.049***
× *Year 1*	0.009	-0.018	0.099*	0.006
× *Year 2*	-0.044*	0.011	0.070	0.001
× *Year 3*	-0.024	-0.072***	0.045	0.026
× *Year 4*	0.026	0.006	0.071	0.013
× *Year 5*	0.024	-0.024	-0.019	-0.002
Nature Distance	0.006	-0.007	0.020**	-0.021
× *Year 1*	-0.026	0.028	0.002	-0.047
× *Year 2*	-0.025	0.044**	-0.023	-0.135
× *Year 3*	-0.053***	0.049***	0.022	-0.056
× *Year 4*	-0.007	0.019	-0.037	-0.037
× *Year 5*	-0.047***	0.032**	-0.004	-0.004
Constant	Yes	Yes	Yes	Yes
Year-Fixed Effects	Yes	Yes	Yes	Yes
Zip Code-Fixed Effects	Yes	Yes	Yes	Yes
Observations	6342	6342	6342	6342
Adj. R-squared	0.725	0.725	0.725	0.725

Statistical significance is indicated as follows: *p<0.1; **p<0.05; ***p<0.01.
Where Year 1 is a dummy for observation transacted in the period between July 2010 and July 2011, Year 2: July 2011-2012, etc.

6.4 Robustness

The hedonic regressions are based on unbalanced panel data and use fixed effects estimators to control for omitted variables. However, it is also possible to use random effects model. The Hausman test for panel data is applied to check whether the choice between fixed or random was correct. The test is significant at the 1% significance level and indeed points towards the preferred usage of the fixed effects model.

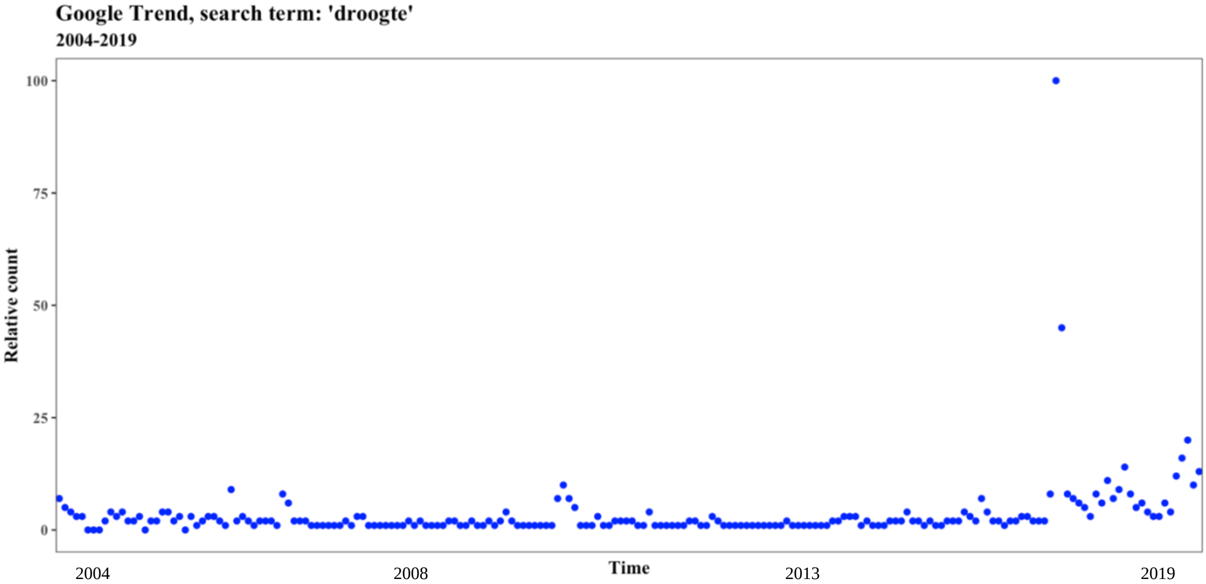
The analysis uses natural amenity data from the *Nature Network* which contains a large array of area types. Another common source of natural amenity data is the *Natura2000*. This is a large network of nature protection areas in the EU. Although both data sources share characteristics, not all nature areas in the Natura2000 are part of the Nature Network (CBS, PBL, RIVM, WUR, 2017). Consequently, the hedonic model is performed again using a natural amenity variable based on data from the Natura2000. The coefficients of the revised model do not differ significantly from the original, thus we can assume that the findings regarding the natural amenity premium are robust.

7. Discussion

7.1 Limitations

Section 2 and 3 of this paper discuss the past climate trends on a global and national scale. Awareness of the topics and data surrounding climate change has increased significantly over the past decade and the World Economic Forum (WEF) Risk Report (Franco, 2020) ranks climate change as the biggest global threat. This heightened risk perception adds to the relevance of this paper by informing the public on the importance of climate risks such as natural hazards. However, it also points to the first limitation where the used data and fire event may be outdated. *Figure A3* in the appendix (Franco, 2020) shows that back in 2010, environmental topics were not in the top 5 global risks. The main risk in terms of likelihood and impact was the asset price collapse. From 2011 onwards we see an increase in global risk perception towards GHG emissions and extreme weather. Moreover, *Figure 8* below shows the relative search count of the term "droogte" (drought) in the Netherlands. The graph shows a spike in 2018 and slight upward trend in recent years. Even though the fire in the Strabrechtse Heide had extensive media coverage, the lack of environmental risk awareness in 2010 may have limited the significance of the findings in this paper.

Figure 8: Relative search count for the term: 'droogte' in the Netherlands, 2004-2019



A second limitation of this paper is the limited extrapolating power of the regional results from Noord-Brabant to the Dutch national level. The province of Noord-Brabant was chosen due to its specific characteristics regarding natural areas, fire risk locations, and past fire events. However, these characteristics are less observable in the Randstad area around the larger cities such as Amsterdam, Rotterdam, and The Hague. *Figure A4* in the appendix shows the RIN map for the Netherlands where the large nature park the Veluwe, located in the province of Gelderland, acts as a big risk area. Yet, the limited amount of properties within the Veluwe makes it difficult to extrapolate this paper's results.

A third limitation of this paper is related to the fire risk data from the *Risico Index Natuurbranden* (RIN). The RIN shows risk area locations where an existing fire can become uncontrollable. So, it is important to note that this definition from the RIN does not include the probability that a fire will occur in the first place, but only covers factors that can increase the size of a fire. Additionally, the RIN distinguishes between multiple severity levels as some regions have a higher risk potential than others. However, these in-depth data are only published for fire brigades and safety institutions and was not available for the analysis performed in this paper. Thus, this paper assumes that the risk is equally high in every section of the RIN areas, leaving out interesting information.

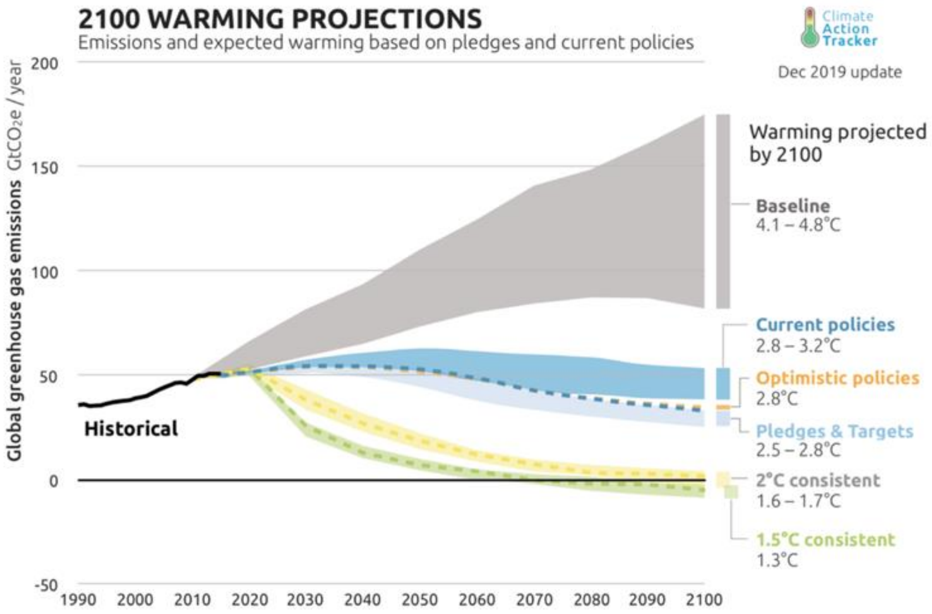
Fourth, the analysis is based on data from the NVM which only covers around 75% of the market. As the used sample excludes certain property transactions which are not member of NVM, the potential presence of selection bias acts as a limitation in this study.

Fifth, when performing the event study on a natural occurrence such as the fire in Strabrechtse Heide, researchers can also perform a difference-in-difference analysis. In that case, we would need comparable pre- and post-samples and a treatment and control group. A balance check between the means of the most important variables in this study shows that these would not be similar enough to provide robust results. When this is the case, it is common to create a matched sample by identifying observations with similar property traits in both samples. This matching method is beyond the scope and expertise of this paper and acts as one of the limitations of the performed analysis.

7.2 Future Research

By mentioning the limitation that the data and fire event can be outdated relative to the risk perception among the public, an obvious future research recommendation is to employ the described analysis in this paper on updated data 3 or 5 years from now. The fire in the Deurnsche Peel in April 2020 can act as a good fire event as it is currently the largest fire in the history of the Netherlands. In line with the climate trends discussed in this paper, more and larger fire events are likely to occur in the future, increasing the future research potential of this topic. This is dependent on the global response to climate change in the upcoming years. *Figure 9* shows the relation between global GHG emissions and warming projections for different policies and pledges. When we fail to follow targets and pledges to actively reduce annual emissions, temperatures are expected to rise, and coefficients of similar research are likely to show more significant values in the future.

Figure 9: GHG emissions and expected warming for different policies and targets (CAT, 2019)



Instead of using a single fire as the event in the analysis, it is also possible to study a cluster of fire events within a certain time period. When multiple fires occur, the risk perception is more likely to change compared to a single fire occurrence.

This paper uses the NVM dataset which only includes residential property transactions. An interesting extension is the analysis of wildfire risk on commercial property prices in the Netherlands. In relation to this, the effect of wildfire risk on portfolio performance is also an interesting future research step.

Another future research twist is to study the effect of natural hazards on rental prices instead of transaction prices. Similar research has been conducted in the field of sustainability and real estate (Eichholtz, Kok, & Quigley, 2013). This extension can determine whether a premium or discount in property values as a result of climate risks, is fully or partially reflected in rental prices.

In addition to wildfire risk, the Netherlands is greatly exposed to flood risk. This risk has been studied extensively and Bosker et al. (2019) find a 1% price discount for exposed properties. Mueller et al. (2018) are the first to combine the effect of fire and flood risk by studying house prices after the Schultz Fire and summer monsoon rains. When a wildfire is followed by heavy rain, the soil is less capable of storing the water and post-wildfire floods are likely to occur. The authors find significant losses in the local property market. A similar study can be of interest in the Netherlands.

Lastly, future research could use a difference-in-difference or matched sample approach to increase the robustness of its findings.

7.3 Implications

First, the results from this paper are relevant for housing associations and real estate investors in the Netherlands who own assets exposed to wildfire risk. As *Table 4* has shown, even though the current effect of wildfire risk is ambiguous, it is possible to incorporate fire risk variables in the asset valuation of Dutch real estate. The analysis and data from this paper can be a starting point for the implementation of natural hazards in the valuation process. Moreover, it is important that the topic of climate-related risks gets a place on the agenda and that housing associations and real estate investors take preventative actions to prevent future potential damage. In addition to adaption, it is also crucial to focus on mitigation measures such as isolation, solar, LED, etc. to limit energy consumption and GHG emissions in the real estate sector. Additionally, the defined risk areas from RIN can become an indicator in the location choice of new construction as the demand for sustainable and 'future-proof' housing is increasing (Teicher, 2018; Chegut, Eichholtz, & Kok, 2014).

Second, the topic of this paper has several implications for insurance companies who are *double-exposed* to climate change: (1) increased insurance claims and (2) potential portfolio investment losses. Collinge et al. (2020) from Robeco state: "Climate change is seen as a major challenge by many insurers, but they can be part of the solution". Possible solutions for insurance companies are to lower climate risk exposure in their investments and to add climate-related criteria in their insurance process. For instance, re-insurance firm Munich Re uses climate data to estimate asset losses from extreme weather by partnering with asset managers. Bachir et al. (2019) from Deloitte conclude that insurance firms need to improve their climate risk resilience by working with customers, regulators, and policy makers. The United Nations Environment Programme Finance Initiative (UNEP FI) Principles for Sustainable Insurance acts as a good starting point for insurance companies and many big firms have already committed to the current principles. The data and results of this paper show that there is an increasing risk and that insurance firms will be better off if they start adjusting as soon as possible. Note that this risk for insurance firms is also relevant for homeowners as they will potentially face rising insurance premia and additional non-insurable risks.

Third, the contents of this paper are aimed at increasing awareness among regulators and public policy makers in the Netherlands. Dutch Wildfire expert Cathelijne Stoof (2020) describes eight direct action points that need to be undertaken. Her points relate to more and better data, innovation, and knowledge creation and sharing. The Dutch government and safety officials should learn from best-practices abroad and prepare for a future where wildfire occurrences are more common. The findings of this paper are in line with this view and contribute to the risk awareness of policy officials. In addition to risk awareness, policy makers could also make use of the described methodology in this paper to obtain more insights on local climate risks.

Finally, the analysis performed in this paper can act as a starting point for other academics in the field of geospatial analysis, climate risks, and real estate valuation. The described hedonic models can be replicated using updated data and other climate risk variables such as drought indices, heavy rainfall measures, earthquake probabilities, or local heat stress maps. Moreover, the literature review of this paper provides future researchers in the same field with a complete and detailed overview of the relevant literature.

8. Conclusion

We examine whether homeowners in the Netherlands take wildfire risk into account when buying or selling residential properties. Property locations, wildfire risk data, and natural areas are mapped to identify fire and nature distance variables. A hedonic model is developed to test the effect of nearby located wildfire risk and natural areas on 186,685 property transactions in the province of Noord-Brabant over the period 2000-2017. An event study is added to check whether the risk perception of local homeowners in Strabrechtse Heide and Maashorst is affected by the large fire in the Strabrechtse Heide in July 2010.

This paper puts forward four important findings and takeaways. First, the number of wildfires in the Netherlands will increase in the future as a result of increasing drought, wind and heat. Second, properties located closer to natural areas observe a value premium. Third, there is no significant price effect when studying the full sample of Noord-Brabant. An analysis on smaller samples with observations in the Strabrechtse Heide and Maashorst, shows the presence of a price premium and discount, respectively. The fire event does not affect the risk perception in Noord-Brabant and Strabrechtse Heide. However, in Maashorst the natural amenity premium disappears after the fire, indicating that local homeowners expect a similar fire to take place in the future. Fourth, the climate risk perception among the public is still low as transaction prices in the sample are not affected by wildfire risk obtained from publicly available sources. This risk perception needs to increase as the Netherlands prepares for a future with more and larger wildfires.

In contrast to current literature on the relation between wildfires and real estate, this paper is the first to study this relation in the Netherlands. The findings of this paper are relevant for Dutch housing association, real estate investors, insurance firms, homeowners, policy makers and international academics. All in all, the wildfire risk perception among Dutch homeowners was minimal during the period 2000-2017, it is clear that current and future climate trends require a heightened climate risk perception.

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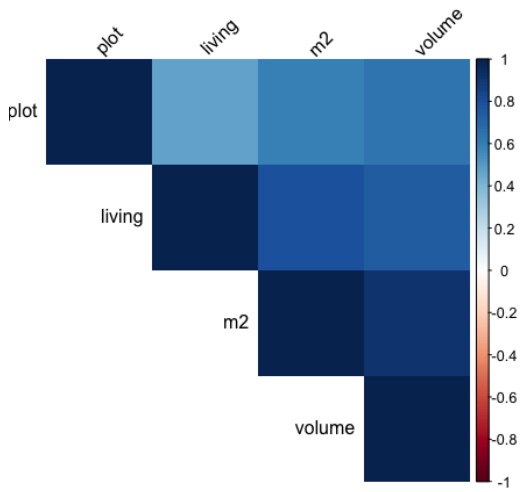
Appendix

Table A1: Variable descriptive statistics and output parameters equation (2)

Variable	Mean	Coeff var	Variable	Mean	Coeff var
Transaction Price (€)	249.411		D: Monument	0.002	0.079***
Size in m2 (log)	133.400	0.520***	D: Garden	0.834	-0.014***
Number of rooms	4.956	0.013***	D: Parking option	0.490	0.065***
Number of floors	2.786	-0.012***	D: Lift	0.004	-0.076***
Number of bathrooms	0.930	0.027***	D: Basement	0.036	0.038***
Construction period [1]			D: Attic	0.527	-0.005***
Construction 1500-1905	0.019	0.041***	D: Balcony	0.086	0.018***
Construction 1931-1944	0.063	0.039***	D: Roof terrace	0.056	0.011***
Construction 1945-1959	0.082	0.004*	*Heating type* [1]		
Construction 1960-1970	0.165	-0.004	D: AC/Solar	0.013	0.019*
Construction 1970-1980	0.199	0.034***	D: Gas/Coal	0.018	-0.103***
Construction 1980-1990	0.178	0.075***	D: Central heating	0.926	0.027***
Construction 1990-2000	0.1592	0.137***	*Location I*		
Construction 2001-later	0.074	0.182***	City centre	0.064	-0.001
House type [1]			On a quite road	0.470	0.007***
Corner house	0.167	-0.116***	On a busy road	0.028	-0.026***
Terraced house	0.040	-0.028***	*Location II*		
Row house	0.396	-0.164***	Free view	0.111	0.017***
Detached house	0.144	0.185***	Next to a forest	0.017	0.054***
			Next to water	0.025	0.043***
			Next to a park	0.033	0.030***
Constant	Yes				
Zip code-fixed effects	Yes				
Year-fixed effects	Yes				

Notes: Statistical significance is indicated as follows: *p<0.1; **p<0.05; ***p<0.01
D = Dummy, [1]Base values: Construction = Construction 1906-1930, House type = Semi-detached house, Heating = no heating.

Figure A1: Correlation plots between different 'space' and 'room' variables



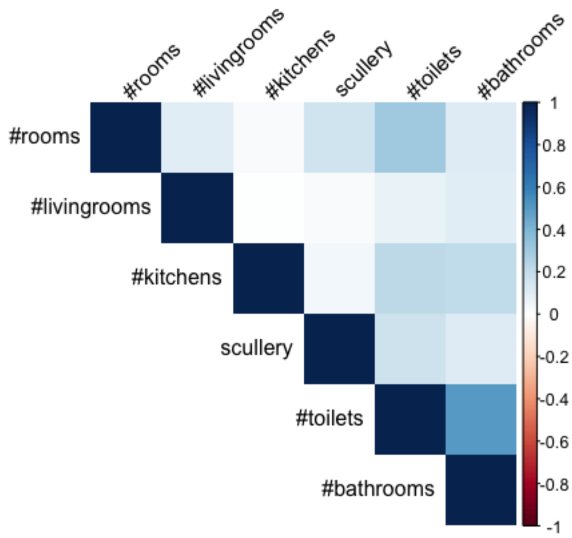


Figure A2: Geolocations of transacted properties between 2000-2017 in Noord-Brabant

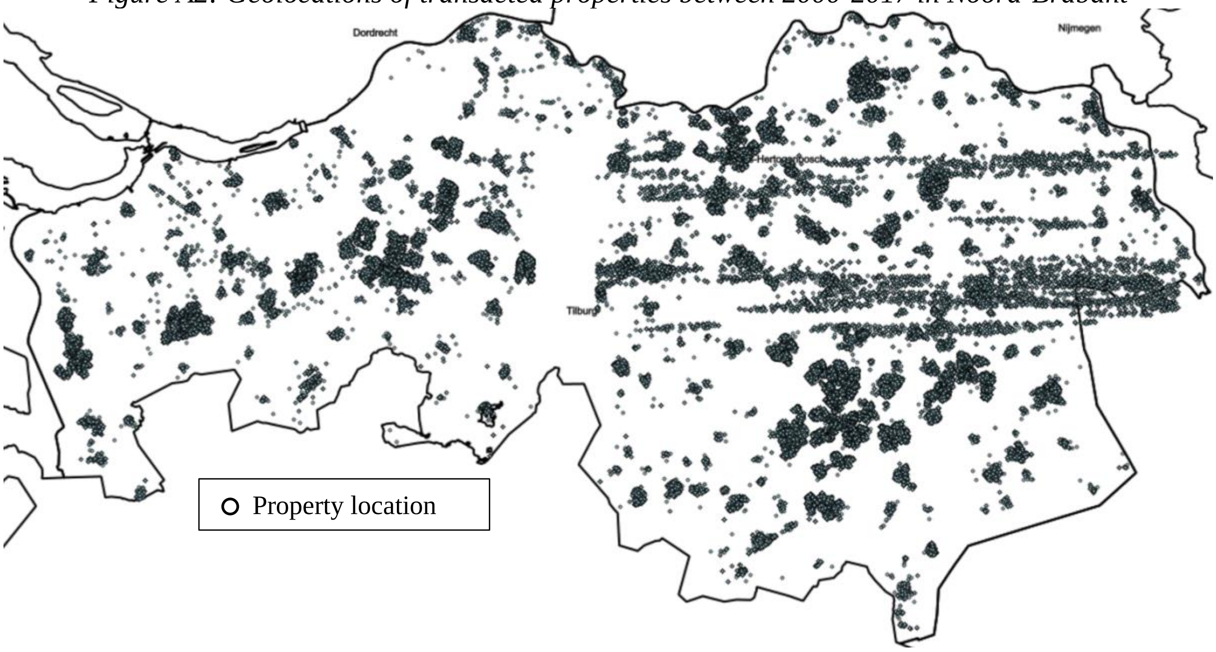


Figure A3: The evolving risk landscape, 2007-2020 (WEF, 2020)

Top 5 Global Risks in Terms of Likelihood

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Infrastructure breakdown	Blow up in asset prices	Asset price collapse	Asset price collapse	Storms and cyclones	Income disparity	Income disparity	Income disparity	Interstate conflict	Involuntary migration	Extreme weather	Extreme weather	Extreme weather	Extreme weather
2nd	Chronic diseases	Middle East instability	China economic slowdown	China economic slowdown	Flooding	Fiscal imbalances	Fiscal imbalances	Extreme weather	Extreme weather	Extreme weather	Involuntary migration	Natural disasters	Climate action failure	Climate action failure
3rd	Oil price shock	Failed and failing states	Chronic diseases	Chronic disease	Corruption	Greenhouse gas emissions	Greenhouse gas emissions	Unemployment	Failure of national governance	Climate action failure	Natural disasters	Cyberattacks	Natural disasters	Natural disasters
4th	China hard landing	Oil price shock	Global governance gaps	Fiscal crises	Biodiversity loss	Cyberattacks	Water crises	Climate action failure	State collapse or crisis	Interstate conflict	Terrorist attacks	Data fraud or theft	Data fraud or theft	Biodiversity loss
5th	Blow up in asset prices	Chronic diseases	Deglobalization (emerging)	Global governance gaps	Climate change	Water crises	Population ageing	Cyberattacks	Unemployment	Natural catastrophes	Data fraud or theft	Climate action failure	Cyberattacks	Human-made environmental disasters

Top 5 Global Risks in Terms of Impact

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
1st	Blow up in asset prices	Blow up in asset prices	Asset price collapse	Asset price collapse	Fiscal crises	Financial failure	Financial failure	Fiscal crises	Water crises	Climate action failure	Weapons of mass destruction	Weapons of mass destruction	Weapons of mass destruction	Climate action failure
2nd	Deglobalization	Deglobalization (developed)	Deglobalization (developed)	Deglobalization (developed)	Climate change	Water crises	Water crises	Climate action failure	Infectious diseases	Weapons of mass destruction	Extreme weather	Extreme weather	Climate action failure	Weapons of mass destruction
3rd	Interstate and civil wars	China hard landing	Oil and gas price spike	Oil price spikes	Geopolitical conflict	Food crises	Fiscal imbalances	Water crises	Weapons of mass destruction	Water crises	Water crises	Natural disasters	Extreme weather	Biodiversity loss
4th	Pandemics	Oil price shock	Chronic diseases	Chronic disease	Asset price collapse	Fiscal imbalances	Weapons of mass destruction	Unemployment	Interstate conflict	Involuntary migration	Natural disasters	Climate action failure	Water crises	Extreme weather
5th	Oil price shock	Pandemics	Fiscal crises	Fiscal crises	Energy price volatility	Energy price volatility	Climate action failure	Infrastructure breakdown	Climate action failure	Energy price shock	Climate action failure	Water crises	Natural disasters	Water crises

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Source: World Economic Forum 2007-2020, *Global Risks Reports*.
Note: Global risks may not be strictly comparable across years, as definitions and the set of global risks have evolved with new issues emerging on the 10-year horizon. For example, cyberattacks, income disparity and unemployment entered the set of global risks in 2012. Some global risks have been reclassified: water crises and income disparity were recategorized as societal risks in the 2015 and 2014 *Global Risks Reports*, respectively.

Figure A4: Map of the Netherlands showing fire risk areas (yellow is province of Noord-Brabant)

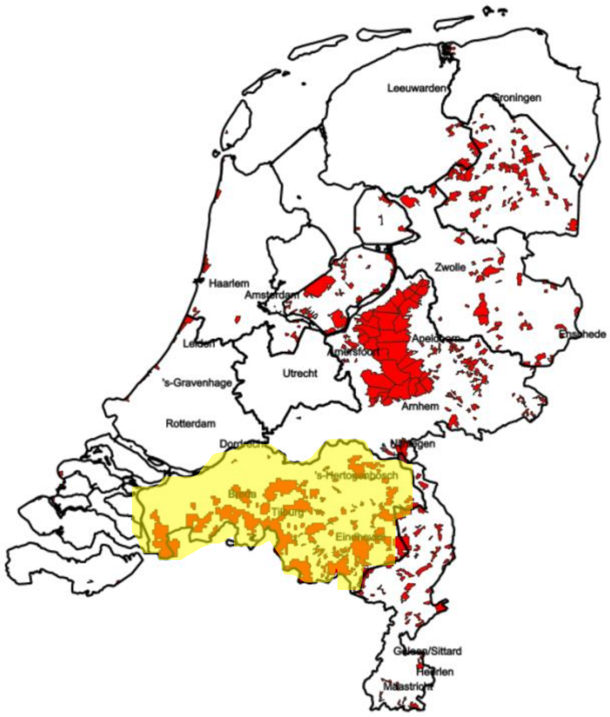


Figure A5: Annual average transaction price per distance buffer in Noord-Brabant

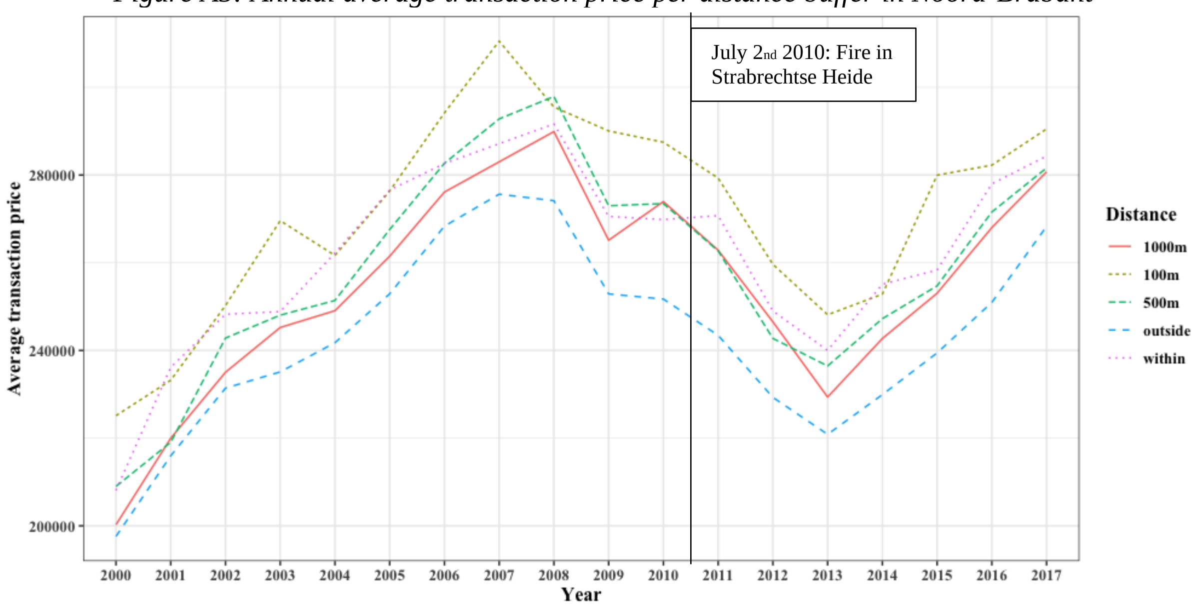
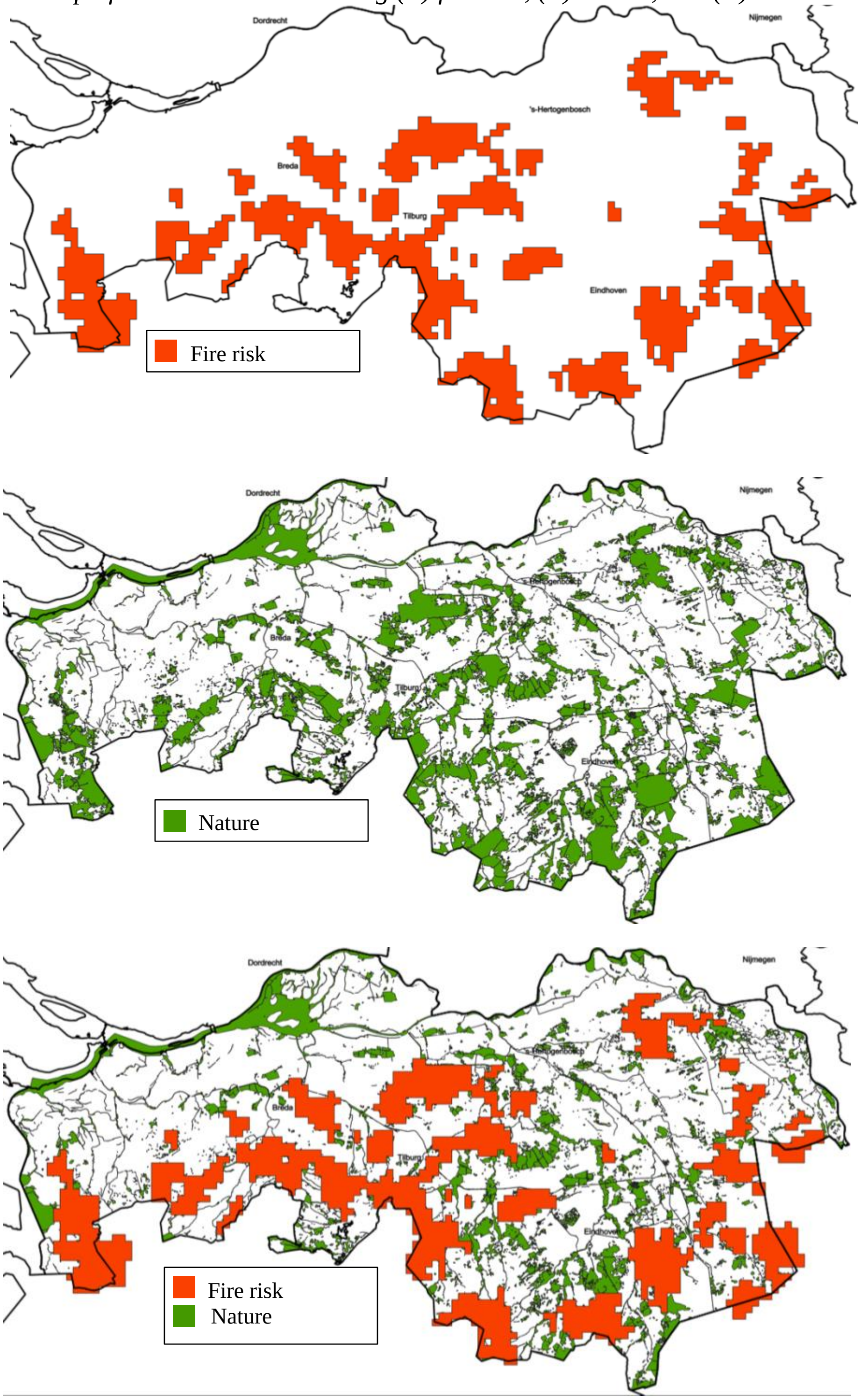


Figure A6: Map of Noord-Brabant showing (A) fire risk, (B) nature, and (C) both areas



(a)

(b)

(c)