"Real Estate and Climate: A Comprehensive Analysis of Weather's Influence on Property Values"

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ABSTRACT

While practical and logistical factors are frequently the deciding factors when choosing a place to reside, studying the impact of weather, and investigating possible relationships between weather, gross rents, and housing prices offers an intriguing perspective which can provide valuable insights into the dynamics of real estate markets. This study investigates relationships between climate and housing prices, analyzing differences between rental and owner-occupied markets. The study reveals homeowners are willing to pay more for homes in areas with higher January precipitation, indicating they place a premium on this specific climate condition. Cooling and heating degree days show negative correlation with housing prices and rents, validating the assumption that most people prefer to avoid temperature extremes. The increased sensitivity among homeowners, compared to renters, points to a more intricate connection between weather factors and the housing decisions of buyers versus renters. In summary, weather significantly impacts housing markets, with homebuyers showing greater willingness to pay for preferred climate conditions.

Keywords: climate, heat index, wind-chill, precipitation, owner-occupied & rental housing, United States of America

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PREFACE

This thesis, titled "Real Estate and Climate: A Comprehensive Analysis of Weather's Influence on Property Values", marks a significant milestone in my academic career within the real estate studies field. An extensive investigation is conducted within this thesis due to the growing academic interest in the complex relationship between housing prices and climate. Housing prices are a major economic factor that impacts people's lives. Understanding how they are affected by climate change is important for policymaking, urban planning, and preparing for the future. Housing may be influenced by factors such as increased insurance costs, the need for retrofitting or resilient infrastructure, and the overall desirability of living in certain areas. To solve these problems, proactive urban planning and policy development are required. For communities to lessen the effects of climate change on housing markets, they must adjust and implement sustainable practices. This could entail putting in place green infrastructure, creating zoning laws that take climate change risks into account, and advocating for energy-efficient building standards. The main goal of this study is to understand the complex relationship between different climates and housing costs for both owner-occupied and rental properties in various US geographic regions. During this thesis, I have thoroughly reviewed a large body of prior research and researched several datasets. By using strong statistical techniques, my goal is to reveal, and add to a better understanding of, the complex dynamics affecting the housing market.

I would like to express my profound gratitude to my supervisor, Dr. Xiaolong Liu, whose feedback, knowledge, and support have been vital in determining the direction and quality of this study, and therefore I truly appreciate it. In addition, I would like to express my appreciation to the University of Groningen, as well as my fellow students who have helped and supported me while I have been investigating the relationship between climate and real estate. Lastly, I would like to thank the scientific community for the ground-breaking work which served as the foundation for this thesis. Therefore, my goal is for this study to make a significant contribution to the body of knowledge already in existence. With an emphasis on the implications for owner-occupied and rental housing in the United States of America, this thesis seeks to provide deep insights into the complex relationship between climate and housing prices. I would be very delighted if this work will act as a springboard for more investigation and thought-provoking policy debates, helping to create more sustainable urban environments.

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Chapter 1: Introduction

1.1 Motivation

For centuries, people have been fascinated by the relationship between weather and human emotions, with anecdotal evidence indicating that sunny days tend to bring smiles, whereas gloomy weather can cast a shadow over our moods. When looking for a house to buy, or rent, the climate would for most people not be the first thing that comes to their mind. According to Rehdanz (2006), based on economic theory, perfectly mobile individuals locate where they can maximize their net benefits. Because individuals are drawn to areas that provide favored combinations of amenities, these areas should have both compensating house price and income differentials. Moreover, perceived weather differences across locales may influence migration patterns and future housing demand (Rehdanz, 2006). In reality home buyers prefer a house that is close to a school, close to a main street, and close to their place of employment (Mang, Zainal, & Radzuan, 2018). The location of the hospital and the shopping center is also taken into account, just as being near athletic facilities and a hospital (Mang, Zainal, & Radzuan, 2018).

While practical and logistical factors are frequently the deciding factors when choosing a place to reside, studying the impact of weather and investigating possible relationships between weather, gross rents, and housing prices offers an intriguing perspective which can provide valuable insights into the dynamics of real estate markets. For example, the capitalization of extreme temperatures for gross rents and house values has received little attention (Gourley, 2021). In this thesis this is addressed by researching the influence of atypical temperatures, as assessed by cooling and heating degree days, on housing prices. Additionally, precipitation is also included, making this one of the first works to establish a relationship between two key climate change characteristics (temperature and precipitation) and the potential difference in its influence on house values and gross rents. Comparing rental price sensitivities to owner-occupied valuations can indicate market failures around climate (dis)amenities. Quantifying these complex dynamics is thus an important area of housing research with implications spanning economics, policy, finance, and environmental planning. For the private sector, both consumers and enterprises, such information will assist consumers make cost-effective climate change adaptation decisions, while producers can use it to make cost-effective investment decisions (Koirala & Bohara, 2019).

1.2 Academic relevance

Throughout the years, within the scientific community there has been a substantial demand to understand how external (neighborhood) and internal (dwelling unit structure) aspects of residential quality affect market value and rental prices (Wilkinson, 1973; Karpavičiūtė, 2017). The link between environmental elements and housing prices has already been examined in several scientific studies. Such studies include for example: meteorological patterns (Gourley, 2021; Semenenko & Yoo, 2019), seasonal variations (Voltes-Dorta & Sánchez-Medina, 2020), proximity to natural amenities (White & Leefers, 2007), consequences of climate change (Union of Concerned Scientists, 2018; Sayce, Clayton, Devaney & van de Wetering, 2022), consequences of drought (Hardie, Narayan & Gardner, 2001; Li, Guo, Kun & Chen, 2019), impact of heat stress (Chiag & Feng, 2022), and extreme weather occurrences (Livy, 2017).

The scope of prior research regarding the influence of climate amenities on house values and gross rents has previously focused on the United States (Koirala & Bahara, 2013), Chile (Hernandez, Luna & Madeira, 2022) and Great-Britain (Rehdanz, 2006) or states within the United States of America such as Colorado (Gourley 2021), and California (Issler et al. 2019). According to Koirala & Bohara (2013) studies on preferences for climate amenities have not been significantly large enough. By expanding the sample to the whole of the US it encompasses a diverse array of houses in various climates, as property markets in locations with agreeable weather conditions, like San Diego, might exhibit different responses to unfavorable weather compared to areas with harsher climates, such as Buffalo (Gourley, 2021). Furthermore, there is no such research which includes both gross rents and house values. Researchers can account for different market segments, such as owner-occupied and rental housing, by including both rent and house value. This is important because the factors influencing house values and rents vary greatly between these segments (Des Rosiers & Therault, 2008).

The research aim of this study is to find out what individuals who rent or own the house that they live in are willing to pay extra for climate amenities. To estimate this one weather variable with respect to precipitation, wind-chill and heat-index is chosen from the literature. By researching more than one climate variable for gross rents and house values this research adds valuable information to the current body of scientific research. This research then seizes the opportunity to improve our understanding of how climate affects house values and gross rents differently. This is a valuable addition to the current body of scientific literature.

1.3 Research problem statement:

This study's objective is to methodically investigate and measure the relationship between precipitation, heat index, and wind-chill—three meteorological variables—and housing prices in the form of house value and gross rent in the United States of America. The following is the central research question, which is then accompanied by two sub-questions:

Central Research Question: What is the relationship between weather, in the form of heat index, chill index, and precipitation, and housing prices in the United States of America?

Sub-Question 1: What is the influence of weather conditions on the value of owner-occupied housing in the United States of America?

Sub-Question 2: What is the influence of weather conditions on the gross rents of rental housing in the United States of America?

Rehdanz (2006) states that measuring the value of climate to economic sectors as well as individuals provides useful information when developing a suitable abatement strategy. In case of future climate risks renters minimize nominal wealth exposure to housing prices but face more spending risk if they continue to consume housing in a market with correlated housing prices (Davidoff, 2006). The current body of scientific literature regarding the implicit pricing of climate amenities includes both research on house values and gross rents. For example, as the dependent variable in their research Koirala & Bohara (2019) used a logarithmic function of Gross Rents, while Hernandez et al. (2022) used a logarithmic function of the value of residential homes and agricultural properties. There has not yet been a study that looks at the difference in the influence that climate has on the pricing of rental housing versus owner-occupied housing. The goal to research differences between the influence of climate amenities on gross rents and house values stems from Bernstein, Asaf, Matthew Gustafson, & Ryan Lewis (2018) who estimate a discount in home prices of seven percent due to exposure to sea level rise. They found that this difference is more pronounced for non-owner-occupied properties, which they interpret as a reflection of increased sophistication of those individuals. It will be interesting to see if such a difference is also the case for the weather variables in this research.

Chapter 2: Theoretical background & hypotheses

2.1. Weather and the housing market

Economists have investigated a range of factors influencing property prices over time, such as features of individual properties and neighborhood facilities. Interestingly, the role of weather and climate in this context has often been understated. In recent times, more research has been done regarding the relationship between weather, climate, and real estate. Rose and Dolega (2022) investigated the way that weather affects the retail industry indirectly. Their results demonstrate that weather is an influential factor on consumer purchasing behaviors and plays a significant role in many aspects of retail sector decision making. Hereby directly influencing the returns shop owners will get from their shops. In the case of the residential real estate market, both rental- and owner-occupied housing prices are influenced by weather (Gourley, 2021).

It's evident that in the case of housing customers' decision-making is greatly influenced by environmental elements and when choosing a place to live people tend to be picky overall regarding the internal and external aspects of their new house. According to Greenstone and Greenstone (2005), people may avoid areas with poor environmental conditions out of concerns for their health and well-being, and they may be prepared to pay more to live in locations with better circumstances. A concrete example of this are climate risks which can pose as climate disamenities. For example, California faces increasing climate risk because climate change leads to more drought, which causes more wildfires. Such wildfires eventually lead to more foreclosures and mortgage defaults (Issler, Stanton, Vergara-Alert, & Wallace, 2019). Now more on the amenity or disamenity value of climate for house values and gross rents. People prefer a moderate climate for a variety of reasons, according to research. Higher mean temperatures in the coldest month increase happiness, while higher mean temperatures in the hottest month decrease it, according to Rehdanz & Maddison (2005). Moreover, Hernandez, Luna, & Madeira (2022) matched an administrative register of all the real estate properties' transactions in Chile between 2002 and 2020 with a high spatial resolution dataset of local temperatures and precipitation. Their statistical model considers climate variables such as maximum and minimum temperature in spring, summer, fall and winter and the amount of precipitation in spring, summer, fall and winter. The results show that higher precipitation in all seasons is associated with lower residential and agricultural property prices in Chile. Higher maximum temperatures during the Summer, Fall, and Winter seasons have a negative impact on residential house prices. According to Hernandez et al. (2022) the outcome of their statistical model is consistent with households' wish to avoid severely hot days.

Semenenko & Yoo (2019) examine the change in statistical properties of both average and maximum daily temperatures in their statistical model since climate change is primarily related to temperature increases over a substantial period of time. Semenko & Yoo (2019) their study focused on a list of 50 countries from around the world, and they found out that weather changes, specifically increased temperature volatility, negatively impact residential real estate prices between 2010-2017. Koirala et al. (2019) show that the positive effect of an increase in January temperatures and the negative effect of July temperature on housing rents reflect that the warmer January temperature is productive, while the warmer July temperature is unproductive for US firms. For short-term rental housing it appears that temporal weather affects prices more quickly than it does to owner-occupied housing prices. This is because poor weather conditions have a greater effect on the demand for short-term rental housing in the form of for example Airbnb (Voltes-Dorta, & Sánchez-Medina 2020). Liu (2018) states that gross rents seem to be more sensitive to haze compared to the prices of homes that are sold. Albouy, Graf, Kellogg & Wolff (2016) find that moderate temperatures about 65°F are most valued by American households because they allow for comfortable outdoor leisure, with satisfaction decreasing more rapidly with incremental warming versus cooling from that ideal range. Further investigation reveals that households have a specific aversion to marginal heat intensification, most likely due to health, sleep, and enjoyment consequences, although extreme cold or heat cause substantially less aggravated discomfort as people acclimate to more severe conditions. Nonetheless, Albouy et al. (2016) their main conclusion is that warming disproportionately erodes quality of life even when cold extremes are minimized, highlighting why climate change poses hazards through increased hot days that limit outdoor lifestyle and activities that Americans love.

2.2. Owner-occupied vs Rental Housing

The research aim of this study is to find out what individuals who rent or own the house that they live in are willing to pay extra for climate amenities. The majority of American families spend the most money on housing. This expense is a monthly rent payment to a landlord rather than a monthly mortgage payment to a lender for one-third of American households. Currently 44 million households are housed in the country's rental housing sector and compared to its homeowner counterparts, this industry serves a younger, less affluent, and more diverse racial clientele (Davidoff, 2006). A household deciding whether to buy or rent its accommodation must evaluate the risks associated with either tenure mode (Ortalo-Magne & Rady, 2002). Federal tax laws and municipal land use restrictions both show a continuous historical tendency in favor of homeowners in U.S. housing policy. Additionally, homeowners have the right to determine how the property is used, maintained, decorated, and eventually disposed of (Elsinga & Hoekstra, 2005), and the high cost of investing in the housing market affects how people consider other aspects of a property when making decisions than with for example renting (Gourley, 2019). Tenure choice and lengths of residence spells are determined by socioeconomic characteristics at the time the housing tenure decisions are made (Petkov, 2022).

There are a few fundamental theoretical reasons why owner-occupied and rental housing prices may respond to local conditions differently. Homeowners enjoy higher housing stability and a longer average stay. Individuals living in public housing, a type of rental property, often have less freedom to choose where they want to live. This difference is often because low-income households, the elderly, and people with disabilities tend to live in public housing (Petkov, 2022). Renters also commonly change residences. Due to the temporary nature of tenants, owners may prioritize weather readiness while renters may tolerate greater shortcomings (Cohen, 2021). The residential mobility process is also intimately related to opportunities households have in the housing market (Ioannides, 1987). For the young, the old, the disabled, those in highly mobile professions, and low wage working families, renting a house is typically the preferred tenure option (Collinson, 2009). According to Diaz (2006) moving rates are lower for homeowners and decrease with age. Among movers, roughly 53 percent report moving for reasons other than housing (new job, family reasons, natural disasters, etc.), so the climate people live in is not always tied to people's preferences. Furthermore, homeowners are more likely to carefully consider the maintenance expenses and investments required to meet extreme weather conditions such as heat, cold, or precipitation. Renters have a lower financial stake, which may indicate a willingness to tolerate greater risk or inadequate weather safeguards that homeowners may avoid (Gourley, 2021). Finally, homeowners may prioritize locations believed to be more "climate proofed" for long-term safety and stability. Conversely, renters focus more on immediate comfort and affordability if renting short-term rather than long-term implications of weather and climate hazards (Baldauf et al. 2018).

2.3. Housing Market Indicators

In this paragraph certain aspects which influence housing prices will be highlighted. In the third chapter more will be shared on this topic, as each specific control variable is highlighted in the operationalizing variables paragraph. Although the focus of this study is on the relationship between weather and housing prices, several housing market indicators also play a role in housing prices which have to be taken into account. Housing market indicators are critical tools for understanding market performance and making informed investment decisions. According to Cohen (2021) house prices are most commonly influenced by macroeconomic factors such as GDP, disposable income, and unemployment. Increased economic activity raises demand for space, and because housing stock cannot be changed in the short run, rents rise, resulting in higher housing prices. Higher housing prices make it more difficult for individuals to afford a home, particularly for low and moderate-income earners; as a result, fewer people can purchase homes, lowering homeownership rates (Davidoff, 2006). Lower housing prices, on the other hand, can make homeownership more affordable to a broader spectrum of people, leading to higher homeownership rates (Davidoff, 2006). Furthermore, home prices have a substantial negative correlation with housing vacancy rates (Igarashi, 1991). As property prices rise, demand for homes falls, perhaps leading to increasing vacancy rates. In contrast, as housing prices decline, housing demand rises, potentially resulting in reduced vacancy rates (Igarashi, 1991).

Because consumers are drawn to areas that provide favored combinations of amenities, these areas should have offsetting house price and income differentials. If a family wants to have fewer rainy days or more hours of sunlight, it will have to acquire a house in such a region and possibly pay a premium for it (Rehdanz, 2006).

A home's worth is established by what prospective purchasers in the market are willing to pay for it, and it is influenced by criteria such as neighborhood comps, location, size, age, and condition. Green and Hendershott (1996) contend that house age is an important aspect to consider when analyzing housing prices. Because of the greater availability of modern amenities, superior construction processes, and changing consumer preferences, newer homes tend to have higher values (Green and Hendershott, 1996). As a result, it is anticipated that a neighborhood with a large proportion of newly built homes will result in greater values in the same region. While property values tend to climb over time, purchasing a home is not always a sure bet, and recessions and other natural calamities might result in reduced prices. These elements are regarded as contributory factors that may affect house prices in this study for all the aforementioned reasons. By including housing market indicators in an analysis, the accuracy, precision, and causal inference of the estimated connections are improved because they reduce the bias caused by omitted variables and isolate the precise effect of the important independent variable on the dependent variable. By incorporating these variables, researchers can account for additional potential influences on house prices and gain a more comprehensive understanding of the dynamics at work. Furthermore, this method allows for stronger, more reliable inferences to be drawn from the study's findings.

2.4 Hypotheses

To address the main research question of this thesis, hypotheses are formed from the aforementioned theory.

H0: There is no significant correlation between weather conditions and owner-occupied housing prices and rental property’s gross rents in the US with no regional variations.

H1: There is a significant correlation between weather conditions and owner-occupied housing prices and rental property’s gross rents in the US with regional variations.

The hypotheses have been described in simple, straightforward terms that lend themselves for statistical investigation. The null hypothesis holds that there is no significant correlation, whereas the alternative hypothesis holds that there is a significant correlation. Common meteorological measurements are used to operationalize weather conditions. Housing prices and gross rents are also well stated dependent variables. The hypothesis will be tested in a cross-sectional study that compares the effects of different meteorological factors, such as precipitation, wind chill, and heat index, on the prices of owner-occupied housing and the gross rents of rental housing, using linear regression models. The current body of scientific literature links mostly unfavorable weather conditions to decreases in housing prices, both for owner-occupied and rental properties (Hernandez, 2022; Koirala et al. 2019). The goal of this study is to find out the influence that climate has on the pricing of rental housing and owner-occupied housing. The premise in this is that there can be a different reaction to climate variables in gross rents compared to house value. This premise stems from the current body of scientific literature, as differences in the way gross rents and house values are influenced by certain (dis)amenities have occurred before. This has for example been the case in Bernstein et al. (2018). They interpret their findings in differences between gross rents and home values as a reflection of increased sophistication of individuals who rent. Due to several circumstances and differences in perception regarding the importance of certain amenities it is likely that among the influence of climate amenities a similar divergence exists among individuals who rent their house and individuals that own the house that they live in. In order to visualize this conceptual relationship a conceptual model has been created.

The conceptual model starts with the premise that various weather variables, namely precipitation, heat-index, and wind chill index related weather variables, are interconnected with housing markets in a direct way. Housing prices, both for owner-occupied and rental properties, serve as dependent variables. Precipitation, heat-index, and wind chill index related weather variables collectively represent the key independent variables. Additionally, the research will include control variables, such as population density, homeownership rates, vacant units, the unemployment rate, and the year of construction.

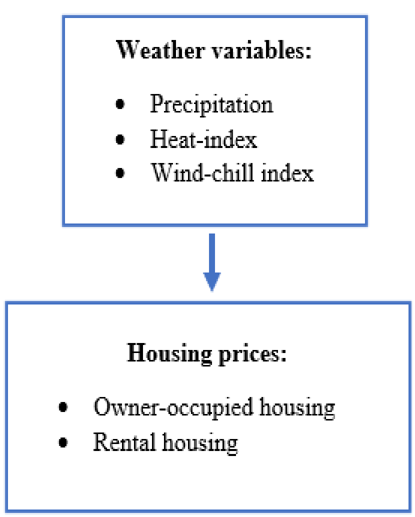

Figure 1: Conceptual model

Chapter 3: Data & Methodology

3.1. Dataset Background

The study investigates the relationship between weather and housing prices, both owner-occupied and rental housing, for the whole of the USA. This analysis uses data from two different datasets:

1. The Understanding America Study Contextual Data Resource (UAS-CDR): Weather Data, developed by Jennifer Ailshire, Kate Vavra-Musser, Emily Serman, and Sarah Mawhorter at the University of Southern California, with funding from the National Institute on Aging (U01AG054580-03S2). The data is available at the census tract level and covers the years 2009 through 2019 with annual, quarterly, and monthly averages provided. The primary function of census tracts is to provide a consistent set of geographic units for presenting statistical data. They are usually designed with relatively uniform populations ranging from 1,200 to 8,000 people. Regarding the meteorological data collection, please refer to https://gero.usc.edu/cbph/cdr or http://www.climatologylab.org/gridmet.html for additional information.

2. The U.S. Census Bureau (www.socialexplorer.com) provides, among other things, housing price data in the form of gross rent for rental housing and house value for owner-occupied housing through its Decennial Census and American Community Survey (ACS). The CDR offers Census data for 1990, 2000, and 2010 at the state, county, Core-Based Statistical Area (CBSA), and census tract levels of analysis, together with ACS data for 2005 through 2018. The dataset also provides socioeconomic and demographic information on the census tract levels. These are variables that may impact housing prices and will be used as control variables, including population density, homeownership rate, vacancy rate, unemployment and recent home construction.

To answer the sub-questions, a cross-sectional analysis will be done examining the association between weather and housing prices for owner-occupied and rental homes on the census tract level. The cross-sectional analysis will use a final dataset which includes dependent, independent and control variables from the weather and census datasets. From the US Census Bureau dataset, the 2016 dataset will be used as it is the most recent US Census Bureau dataset, I have access to. As mentioned earlier the Understanding America Study Contextual Data Resource (UAS-CDR): Weather Data will be used for the weather variables. In accordance with the US Census Bureau dataset the weather data will be taken as averages from over the years leading up to 2016, namely the 2012-2016 period.

3.2. Context

Heat index

The heat index is calculated using the National Weather Service (NWS) heat index equation. This equation uses temperature (ambient) and relative humidity to calculate heat index. It should be noted that there isn't a single, accurate calculation for the heat index; instead, there are numerous approximations, including the NWS equation. Heat index is expressed in degrees, just like temperature (more precisely, ambient temperature), but it is not the same as temperature. The heat index levels can be categorized according to how likely they are to have negative effects on human health. There are various index classifications with marginally distinct cutoff values. The NWS heat index level cutoff values listed below are used to define heat index levels:

Level	**Heat index values**	**Description**
Level 0	Heat index < 80	No hazard
Level 1	Heat index ≥ 80 and < 90	Caution
Level 2	Heat index ≥ 90 and < 103	Extreme caution
Level 3	Heat index ≥ 103 and < 125	Danger
Level 4	Heat index ≥ 125	Extreme danger

Table 1: Description of the five different heat-index levels

Wind Chill

Wind chill is calculated using an equation from the National Digital Forecast Database (NDFD). The wind chill equation is designed for use with temperature in degrees Fahrenheit and wind speed in miles per hour. Wind chill is given in units of degrees, like temperature, but should not be confused with ambient temperature. Wind chill values can be categorized according to the probability that a particular wind chill level can cause harmful effects on human health, particularly frostbite. There are various index classifications with marginally distinct wind chill cutoff values. The wind chill index levels, which define the CDR wind chill levels, are:

Level	**Wind chill index values**	**Description**
Level 0	Wind chill > 0	No risk
Level 1	Wind chill ≤ 0 and > -10	Low risk
Level 2	Wind chill ≤ -10 and > -28	Moderate risk
Level 3	Wind chill ≤ -28 and > -40	High risk - frostbite in 10 to 30 minutes
Level 4	Wind chill ≤ -40 and > -48	Very high risk - frostbite in 5 to 10 minutes
Level 5	Wind chill ≤ -48 and > -55	Severe risk - frostbite in 2 to 5 minutes
Level 6	Wind chill ≤ -55	Extreme risk - frostbite in < 2 minutes

Table 2: Description of the seven different wind chill levels

Precipitation

Measuring precipitation is crucial to comprehending and describing the monthly weather. They offer insightful information about the frequency and severity of precipitation occurrences during a given time. Here is some information on how measures of precipitation aid in our understanding of the monthly weather:

Frequency of Precipitation	This tells us how often measurable precipitation occurs during a month.
Percent of Precipitation Days	It represents the portion of days in a month with any precipitation.
Total Monthly Precipitation (in mm)	This is the cumulative amount of precipitation for the entire month.
Average Daily Precipitation (in mm)	This indicates the typical daily precipitation amount in the given month.

Table 3: Description of the four different precipitation variables

3.3. Operationalizing Variables

This thesis' research only uses one type of analysis: cross-sectional. This cross-sectional study will look at the predictive value of owner-occupied (median house value in inflation-adjusted 2018 dollars) and rental housing (median gross rent in inflation-adjusted 2018 dollars) housing in terms of favorable or unfavorable weather conditions at the census tract level. For both dependent variables the outliers below the 1st percentile and 99th percentile have been deleted. Furthermore, to capture market segments that are more representative of typical home values (median home prices in many markets now surpass $100,000) observations so this better reflects the current housing stock. Values less than this may be uncommon or of poor quality.

Aside from weather variables, a variety of other variables are likely to influence housing prices, for example, previous hedonic studies frequently included data on unemployment as an explanatory variable, treating a high rate of unemployment as a disamenity for which compensation is believed necessary for households residing in such areas (Rehdanz, 2006). Savva (2018) further confirms this by stating that the unemployment rate is negatively correlated with housing prices changes and that countries with high unemployment rates have lower demand for properties, therefore housing prices drop. Vacancy rates are also used as a control variable in hedonic models to account for the effect of vacant properties on property sale prices. According to Zabel (2016), vacancies have a significant impact on prices by signaling excess demand or supply conditions. Their impact varies depending on the market and time period, with prices responding more strongly when supply elasticity is low, or populations are declining. Year of construction is another control variable which will be used in the analysis. Bourassa, Hoesli, Vincent & Peng (2003) discovered that the relationship between house value and age creates a U-shaped curve, because many older houses can earn a premium due to their historic character and presence in specific neighborhoods. Typically, the house price fell by 0.04% when the age was increased by one unit. The fourth control variable that is used is population density. According to Miles (2012), the relationship between population density and housing prices is positive in high-density areas. In such densely populated areas, the rise in real estate prices is likely to outpace the rise in average income. De La Paz, Perez-Sanchez, García, & Perez-Sanchez, (2019) discovered a nonlinear quadratic relationship between housing prices and density, implying that density's effect on housing prices is not linear. The fifth and final control variable that is used in the analysis is the homeownership rate. Davidoff (2006) found that housing prices and homeownership rates are closely related. Financial assets are concentrated in the hands of homeowners because they are wealthier on average than renters. These homeowners' incomes converge positively with housing prices on average. The purpose of these control variables is to mitigate the bias caused by missing variables, isolate the impact of the primary independent variable, enhance the precision and accuracy of the model, and capture interactions and nonlinearities.

Having a large number of different climate variables available is generally advantageous for the fit of a regression analysis, but the large number of variables creates a problem of multicollinearity and complexity. Therefore, a decision has to be made regarding which independent variables to use for the analysis. The independent variables are chosen from the scientific literature related to the influence of climate and weather on housing prices and gross rents. The independent variables are calculated as an average from the years 2012 to 2016, and for each of the three weather variables (precipitation, heat-index, and wind-chill) one independent variable is chosen. The precipitation variable is average precipitation per day in January in 2012-2016 on the census tract level. This variable stems from Rehdanz (2006) her paper on hedonic pricing of climate change impacts to households in Great Britain. Rehdanz (2006) found out that household willingness to pay to avoid additional rainfall is significant, and reveals interesting regional differences based on existing January precipitation norms. Increased precipitation in January is viewed as a disamenity, with costs ranging from £4 to £9 (lowest value) and £12 to £14 (highest value) for one extra millimeter of rain each January. Specifically, areas that have historically higher average rainfall in January are willing to accept lower compensation for an extra millimeter of precipitation compared to drier regions.

This suggests households in traditionally wet winter climates have acclimatized more to rain and damp conditions during that time of year. As a result, an incremental rise may not disrupt life enjoyment or routines as much in high January rainfall locations. It will be interesting to see what discoveries can be made regarding average precipitation per day in January regarding gross rents and house values in the United States of America.

Wind chill and heat-index are the variables which will summarize temperature distributions. The use of these variables stems from Albouy et al. (2017) their statistical model in which they are using annual heating degree days (HDD) and cooling degree days (CDD) statistics which stand for a negative or positive difference between 65 °F and each day's mean temperature. The balance point represents the average daily outside temperature required for a home to maintain a comfortable interior temperature without using supplemental cooling or heating; thus, the mean daily deviation above or below this point represents cooling or heating degree days. Because individuals favor an average climate with not too much variance, these measurements of the amount of warmer and colder days than average can capture people's opinions of an area's temperature better than other measures (Graves, 1979).

Since Graves' (1979) research several studies have used a similar measure to explore the influence of cold and warm days on gross rents and house values. In this thesis the measure for cold days comes from Butsic, Hanek & Valletta (2011) their hedonic model in which they use the number of uncomfortably cold days, defined as days with a maximum temperature of 10 degrees Celsius (14 degrees Fahrenheit) or less, as a dependent variable. For this thesis a similar dependent variable is used in the form of the average number of days per year which are level 1 wind-chill (low risk for frostbite - wind chill ≤ 0 and > -10) to level 6 (extreme risk - frostbite in < 2 minutes - wind chill ≤ -55). According to Roshan, Mirkatouli, Shakoor & Mohammad-Nejad (2010) level one wind-chill is described as conditions for outdoor activities that are discomforting and you should wear warm clothes, (typically from 20°F and 20 miles per hour wind) and describe level six wind-chill as very dangerous: if body skin is not covered it will get frosted and the outdoor activity should be stopped and people should stay at home.

In this thesis CDD equals the average number of days per year which are level 1 heat-index (caution - heat index ≥ 80 and < 90) to level 4 heat-index (extreme danger - heat index ≥ 125), meaning days with a temperature higher than 80°F or 26°F. This variable originates from Brasington & Hite (2005) who used the number of cooling days in their climate variable to estimate the demand for environmental (dis)amenities.

Table 4: Definition of variables included in the regression	
HOUSEVALUE	House value, inflation-adjusted 2018 dollars (median)
LOGHOUSEVALUE	Log of House value, inflation-adjusted 2018 dollars (median)
GROSSRENT	Gross rent, inflation-adjusted 2018 dollars (median)
LOGGROSSRENT	Log of Gross rent, inflation-adjusted 2018 dollars (median)
UNEMPLOYMENT	Unemployed in civilian labor force, aged 16+ (percent)
HOMEOWNERSHIP	Homeowners (percent)
POPDEN	Population density per square mile (percent)
VACANCY	Vacant housing units (units)
CONSTRUCTION	Housing units built 2010 or later (percent)
STATENAME	State in the United States of America
PRECJAN	Average precipitation per day in January 2012-2016 (mm)
HDD	Average annual heating degree days (wind-Chill level 1 to 6) (count)
CDD	Average annual cooling degree days (heat-index level 1 to 4) (count)

Table 5: Descriptive statistics of variables included in the regression				
VARIABLE NAME	MEAN	ST. DEV	MIN	MAX
HOUSEVALUE	287900.300	187980.500	100100	1187900
LOGHOUSEVALUE	12.402	0.558	11.514	13.988
GROSSRENT	1192.905	428.805	543.000	2912
LOGGROSSRENT	7.025	0.338	6.297	7.977
UNEMPLOYMENT	0.056	0.035	0	0.375
HOMEOWNERSHIP	0.642	0.222	0.011	0.989
POPDEN	6008.840	12031.120	0.546	263992.600
VACANCY	0.097	0.091	0	0.925
CONSTRUCTION	0.038	0.059	0	0.840
PRECJAN	2.119	1.110	0	14.149
CDD	119.797	59.760	0	306.141
HDD	147.833	70.754	0	355.364

Notes: Numbers are rounded to three decimals. The total observations over the whole of the United States of America is 52,355. The dependent variables are the log house value for the owner-occupied housing and the log gross rent for the rental housing. The key independent variables are PRECJAN, HDD & CDD.

3.4 Methodology

The first hypothesis relates to the cross-sectional analysis of the predictive value of owner-occupied housing and rental housing. To answer this a linear regression model is used to research the relationship between the dependent and independent variables. The independent variables are average precipitation per day in January in 2012-2016 (mm), average annual heating degree days in 2012-2016 (wind-Chill level 1 to 6), and average annual cooling degree days in 2012-2016 (heat-index level 1 to 4). The dependent variables consist of the log of house value for owner-occupied housings, and the log of gross rent for rental housings. Furthermore, based on the theoretical background, several housing market indicators could affect house value and rent; those indicators are added as control variables to the statistical model. Following the data cleaning, the statistical equation for the regression analysis in this paper is as follows:

$$\ln(Y_i) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \gamma_1 Z_{1i} + \gamma_2 Z_{2i} + \gamma_3 Z_{3i} + \gamma_4 Z_{4i} + \gamma_5 Z_{5i} + \delta_i + \epsilon_i$$

This equation is used in both owner-occupied and rental housing regression models by differentiating the dependent variable into house value for owner-occupied housing and gross rent for rental housing. To ensure this the models are broken down into two distinct regression models. Y represents the dependent variable (house value or gross rent) in natural logarithmic form. The X represents key independent variables which consist of three different variables, which are the following: X1 represents precipitation in the form of average precipitation per day in January in 2012-2016 (mm); X2 represents the heat index in the form of average number of annual heating degree days (wind-Chill level 1 to 6) in 2012-2016. X3 represents wind-chill in the form of average number of annual cooling degree days (heat-index level 1 to 4) in 2012-2016. α represents the constant or intercept; β represents the coefficient of the key independent variable; Matrix Z represents the housing market indicators as the control variables at a census tract level, including population density, homeownership, vacancy rate, unemployment, and recent house-built year (in 2010 or later).; i represents state fixed effect at a census tract level; δ represents the coefficient of state fixed effect; γ represents the coefficient of the control variables; and ε defines the error term.

Chapter 4. Results and Discussion

This chapter presents an empirical analysis examining the relationship between weather patterns and house values (model 1 & model 2) and gross rents (model 3 & model 4) at the census tract level in 2016. Initial linear regression models are estimated to assess the association between the three chosen weather variables and housing prices for both owner-occupied and rental housing units. Following the identification of potential linear relationships, regressions with robust standard errors are used to account for heteroskedasticity issues in housing data. Real estate transactions and prices frequently exhibit uneven volatility and diversity among market segments. When certain assumptions of traditional linear regression are not met, robust standard errors provide more precise estimates of the standard errors of the regression coefficients. They are especially helpful when dealing with real-world data that contains complications like heteroscedasticity, autocorrelation, outliers, and model misspecification. In the second and fourth regression model a location factor is added to the regression.

Table 6: Four models used for the estimation of both (log) house value and (log) gross rent				
	Model 1	**Model 2**	**Model 3**	**Model 4**
	log of house value	Log of house value	Log of gross rent	Log of gross rent
PRECJAN	0.0181*** (0.0017)	0.0769*** (0.0035)	0.0105*** (0.0011)	0.0299*** (0.0022)
CDD	-0.0052*** (0.0001)	-0.0028*** (0.0001)	-0.0018*** (0.0000)	-0.0009*** (0.0000)
HDD	-0.0048*** (0.0000)	-0.0036*** (0.0001)	-0.0025*** (0.0000)	-0.0020*** (0.0001)
POPDEN	0.0000*** (0.0000)	0.0000*** (0.0000)	0.0000*** (0.0000)	0.0000*** (0.0000)
UNEMPLOYMENT	-3.0247*** (0.0592)	-3.8983*** (0.0577)	-1.1394*** (0.0365)	-1.6235*** (0.0347)
HOMEOWNER	0.3102*** (0.0121)	0.3260*** (0.0106)	0.3808*** (0.0073)	0.3788*** (0.0064)
VACANCY	-0.2520*** (0.0296)	-0.0223 (0.0252)	-0.5675*** (0.0171)	-0.4639*** (0.0153)
CONSTRUCTION	0.8667*** (0.0308)	1.2144*** (0.0287)	0.5607*** (0.0216)	0.7822*** (0.0201)
_cons	13.5663*** (0.0165)	12.4978***(0.0270)	7.3930*** (0.0095)	6.8691*** (0.0175)
Location effects	No	Yes	No	Yes
N	52355	52355	52355	52355
R-squared	0.3546	0.5239	0.2673	0.4486
Standard errors in parentheses: * p<0.05, ** p<0.01, *** p<0.001				

The impact of PRECJAN (January precipitation), CDD (cooling degree days), and HDD (heating degree days) on housing values and rents is investigated in this study. The findings shed light on the distinct preferences of homeowners and renters, revealing intricate patterns in the housing market. The addition of a location factor is included in the second and forth model to account for unobserved or unmeasured characteristics that change by location, assisting in explaining regional variances in the data. The regression analysis found a significant positive link between January precipitation (PRECJAN) and both housing values and rents. Notably, the precipitation coefficient differs by a factor of two in favor of housing values. This suggests that homeowners are more willing to pay for homes in areas with higher January rainfall, indicating a potential premium for such climatic conditions. Renters also have a positive preference for additional January precipitation, albeit with a more moderate willingness to pay. This is intriguing because Rehdanz (2006) & Hernandez et al. (2022) both discovered something different. Rehdanz (2006) demonstrated that winter rainfall is often regarded as unfavorable due to issues such as floods, wetness, darkness, and cold. Rehdanz (2006) discovered that higher January rainfall of one millimeter per year is viewed as a disamenity that reduces house values by £4 to £14 depending on the amount. In contrast, our model discovered that increased January precipitation correlates to greater property prices. Hernandez et al. (2022) found a similar relationship between the amount of January precipitation and house values.

Cooling degree days (CDD) and heating degree days (HDD) have negative coefficients, indicating that warmer and colder weather has a negative impact on both housing values and rents. CDD, on the other hand, has a much larger negative impact on housing values, nearly three times that of rents. The effects of HDD, on the other hand, are roughly comparable between the two housing indicators. This implies that rising temperatures, particularly during the summer months, may have a disproportionate impact on property appeal and marketability, with homeowners exhibiting a marked aversion to rising temperatures. The findings regarding CDD & HDD are supported by the literature. These results are consistent with previous results showing that more extreme temperature days are not preferred. This is speculated to be this way since days with higher or lower than moderate temperatures increase residential electricity consumption, particularly during hotter than usual days (Hernandez et al. 2022). Butsic et al. (2011) also found a negative influence of the amount of -10°F (level 1 wind-chill or higher) days on real estate values. The Two-Stage Least Squares (2SLS) model and the Limited Information Maximum Likelihood (LIML) model from Brasington & Hite (2005) offer opposing views on the relationship between climate and housing prices. While the 2SLS model suggests that less CDD & HDD is associated with lower housing prices, the LIML models align with common sense, proposing that less CDD & HDD lead to higher real estate values. The assertion of the 2SLS model that improved climate correlates with lower housing prices defies conventional wisdom. This unexpected finding implies that areas with better weather conditions may see a decrease in housing demand, resulting in a drop in prices. Such a conclusion calls into question the commonly assumed positive correlation between pleasant climates and increased housing demand, which is often assumed to drive up prices. The LIML models from Brasington & Hite (2005), on the other hand, support a more intuitive viewpoint by indicating that a better climate is associated with higher housing prices. This is consistent with the widely held belief that pleasant weather makes a location more desirable for habitation, increasing competition for limited housing inventory. As demand increases in these climatically advantageous areas, both sale and rental prices rise, reinforcing the traditional understanding of the positive relationship between climate amenities and housing values. This is also in line with the findings from the research of this thesis.

Now more on the difference in prices between owner-occupied housing and rental housing, while renters have similar preferences, homeowners show a significantly higher sensitivity to January precipitation levels and the amount of heating degree and cooling degree days. This increased sensitivity among homeowners indicates a tighter link between weather-related factors and housing decisions. This is in accordance with Gourley (2019) who states that the high cost of investing in the housing market affects how people consider other aspects of a property when making decisions than, for example renting. Further research into the underlying causes of this discrepancy between owner-occupied and rental housing could reveal important insights into the dynamic interplay between homeownership and climatic circumstances.

Chapter 5: Conclusion & Recommendations

5.1. Conclusion

This study investigates the relationship between weather and housing prices in the United States of America for both owner-occupied and rental property. The main research question of this thesis was the following: *What is the relationship between weather, in the form of heat index, chill index, and precipitation, and housing prices in the United States of America?* After doing the literature review some interesting discoveries were made already. The existing literature on the relationship between climate conditions and real estate results demonstrates a significant disparity in climate's influence on home prices and gross rents. Scholars and researchers have given contradictory findings, demonstrating that the impact of climate on these two characteristics of the real estate market is not uniform. This disparity in results emphasizes the complexities of the factors influencing real estate markets and emphasizes the importance of considering multiple modeling approaches to fully understand the dynamics at work.

The primary goal of this research was to look into the impact of various weather conditions on the price of owner-occupied and rental housing in the United States. The goal was to find possible patterns or trends in these interactions, which might differ between the type of housing (owner-occupied or rental). The significance of the relationship between weather conditions and housing prices was assessed using statistical tests, delving into both the strength and direction of these connections. The findings from this research add to our understanding of weather preferences in the housing market, with implications for both homeowners and renters.

More January precipitation, according to our model, leads to higher housing prices for both owner-occupied and rental housing. This is a surprising finding given that Rehdanz demonstrated that winter rainfall is often regarded as unfavorable due to issues such as floods, wetness, darkness, and cold. As a result, our conclusion calls into question earlier notions that increased January rainfall lowers home values. This study's proven link between Cooling Degree Days (CDD) and Heating Degree Days (HDD) correlates perfectly with current literature, validating the assumption that people generally like to avoid different than moderate temperature situations. Recognizing that severe temperature days, whether hot or cold, are continuously evaluated negatively by homeowners highlights the importance of adaptive and climate-responsive housing solutions. This agreement with earlier studies strengthens the robustness of our findings and emphasizes the universality of the sensitivity to temperature extremes in affecting housing preferences.

To reach a definitive conclusion, in the research of this thesis it is discovered that, while renters have similar preferences, homeowners have a significantly higher sensitivity, particularly to January precipitation levels and the number of cooling degree days. This increased responsiveness among homeowners suggests a more complex relationship between weather-related factors and their housing choices. Furthermore, the research findings highlight the nuanced dynamics shaping housing preferences, revealing that homeowners are more sensitive to January precipitation levels and the number of cooling degree days. This increased responsiveness among homeowners suggests a multifaceted relationship between weather-related variables and the decisions they make about their homes. Further investigation into the underlying causes of this disparity between owner-occupied and rental housing could yield critical insights into the dynamic interplay between homeownership and climatic conditions.

5.2. Recommendations

There is still plenty we can investigate to better understand these disparities and properly map out the complex links between weather and housing costs. This type of study can be useful for projecting how rent prices will vary in the future, particularly for groups of people who may be more vulnerable to such changes. Future research could go beyond focus on identifying more variances in different regions within states to delve even further into this topic. Furthermore, there is a chance to investigate the precise relationships between temperature and housing expenses in greater depth and breadth. This could help us understand what factors truly influence rent costs and how they may evolve in the next few years. Regarding the relationship between housing prices and precipitation, the interesting finding occurred that, contrary to Rehdanz (2006), for both rental and owner-occupied housing increased January precipitation results in higher housing prices. It is important to look into why our models estimate this link differently than Rehdanz (2006). The key considerations are whether housing preferences for winter precipitation have changed since 2006, or if methodological flaws are causing the disparities in outcomes between research. Clearly, the influence of January rains on the property market may be more nuanced than previously imagined.

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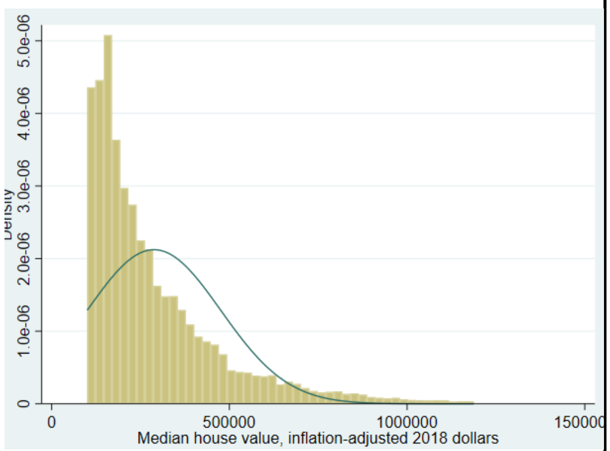
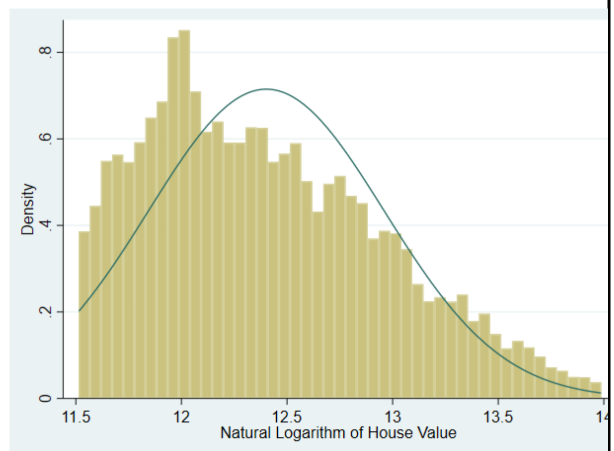
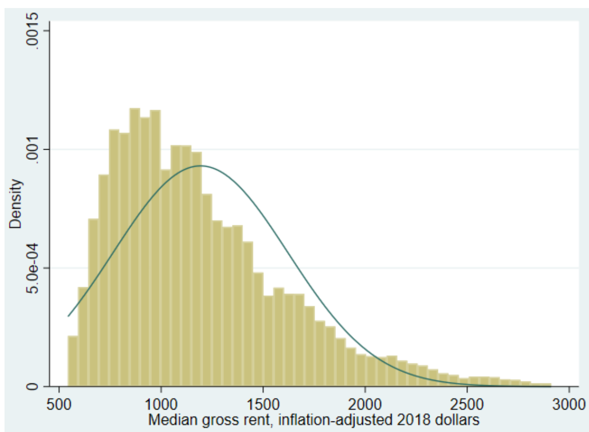
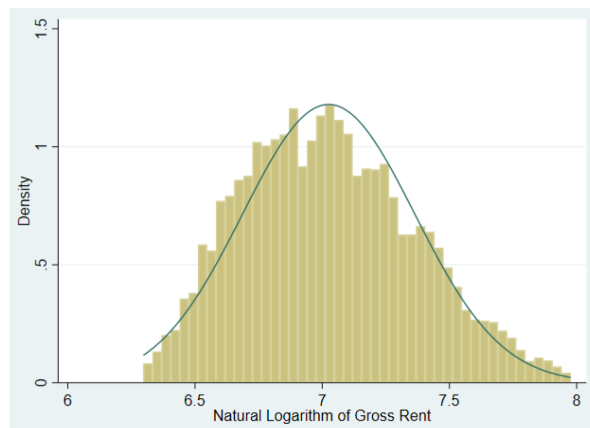
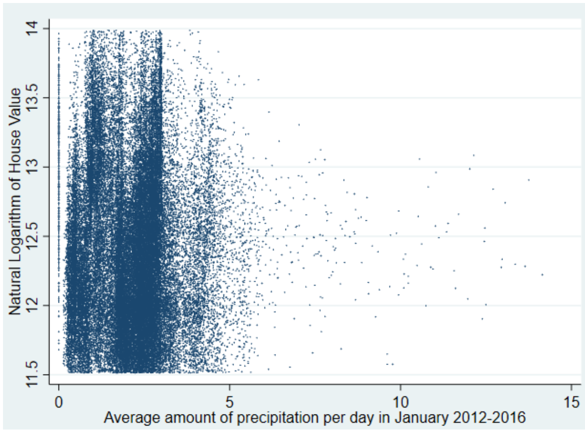
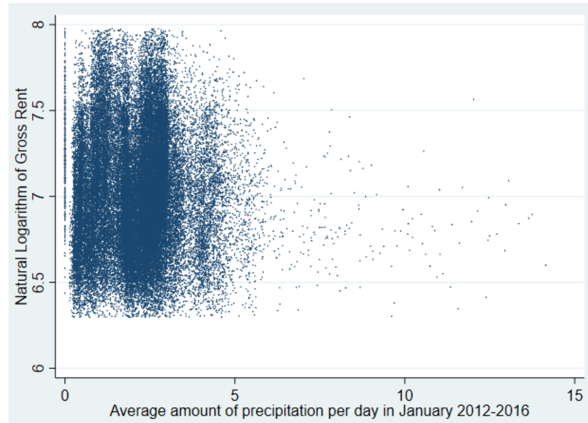
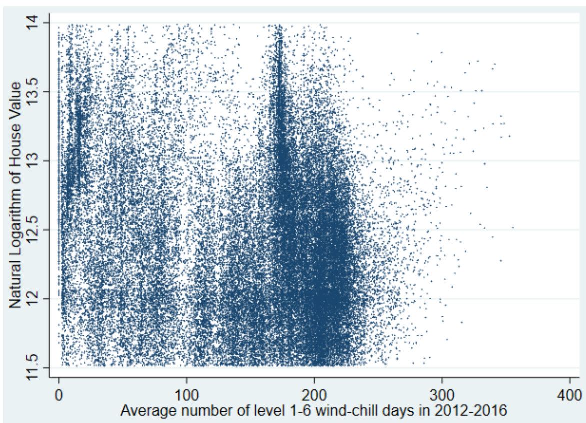
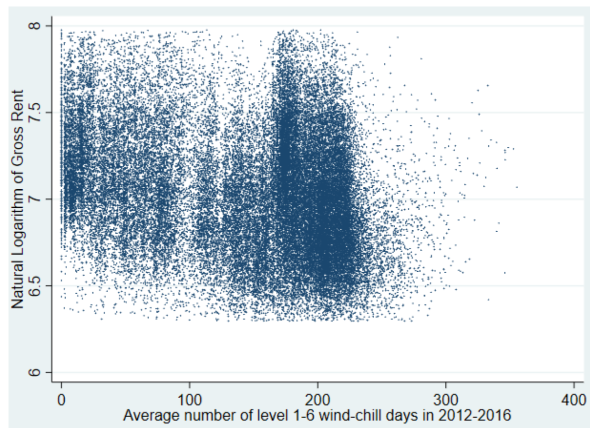
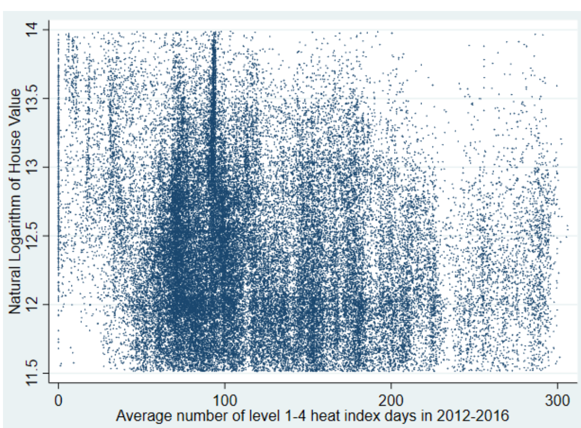
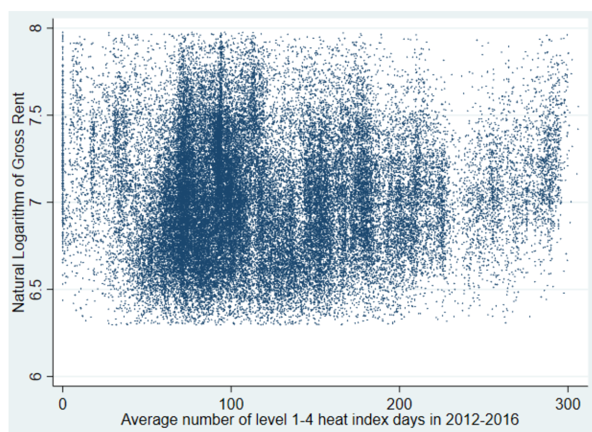
Appendix

Variable	Before Log transformation	After Log transformation
House value 2016		
Gross rent 2016		

Scatter plots

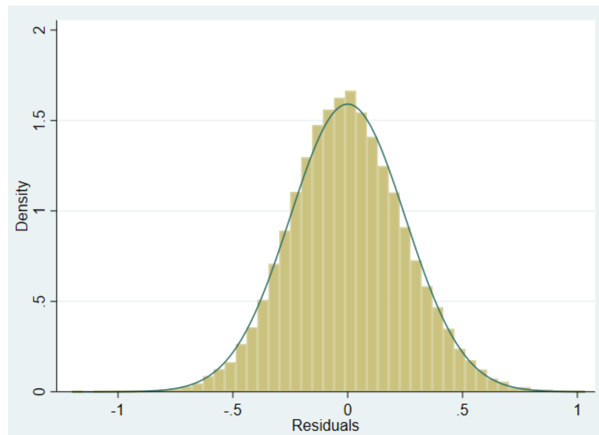
<table>
<tr><th></th><th>Log House value</th><th>Log Gross rent</th></tr>
<tr><td>PRECJAN</td><td>
</td><td>
</td></tr>
<tr><td>HDD</td><td>
</td><td>
</td></tr>
<tr><td>CDD</td><td>
</td><td>
</td></tr>
</table>

Correlation matrix

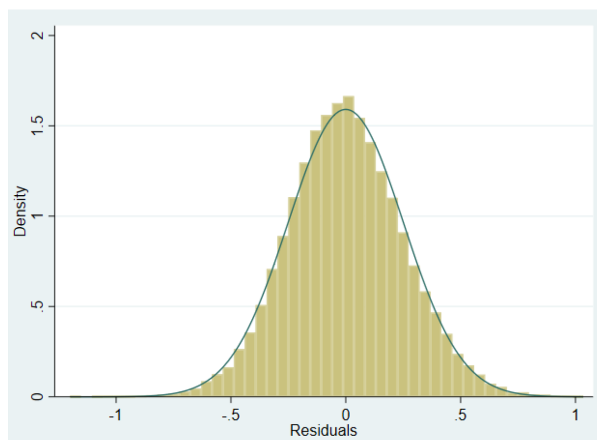
	hou~2016	loghou~6	gro~2016	loggro~6	pre~1216	cdd1216	hdd1216	pop~2016	une~2016	hom~2016	vac~2016	con~2016
houseva~2016	1.0000											
loghous~2016	0.9492	1.0000										
grossre~2016	0.6617	0.6933	1.0000									
loggros~2016	0.6467	0.7009	0.9789	1.0000								
precjan1216	-0.0226	-0.0163	-0.0143	-0.0070	1.0000							
cdd1216	-0.1803	-0.1806	-0.0107	0.0052	0.0480	1.0000						
hdd1216	-0.2094	-0.1963	-0.2471	-0.2618	0.0565	-0.6842	1.0000					
popden2016	0.3425	0.3226	0.1876	0.2066	0.0309	-0.0845	-0.0705	1.0000				
unemplo~2016	-0.1358	-0.1624	-0.1425	-0.1367	0.0257	0.0940	-0.1486	0.1327	1.0000			
homeown~2016	-0.0842	-0.0590	0.1106	0.0829	0.0423	-0.0201	0.1830	-0.4604	-0.3025	1.0000		
vacancy2016	-0.0839	-0.1190	-0.1929	-0.2043	0.1034	0.0992	-0.0359	-0.0634	0.1114	-0.0462	1.0000	
constru~2016	-0.0025	0.0313	0.0658	0.0702	0.0291	0.1317	-0.0371	-0.1142	-0.1077	0.0418	-0.0069	1.0000

Normal distribution of the residuals

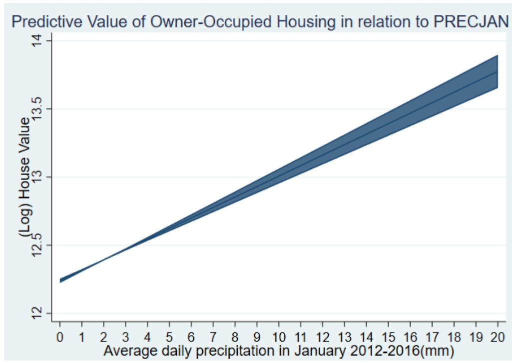
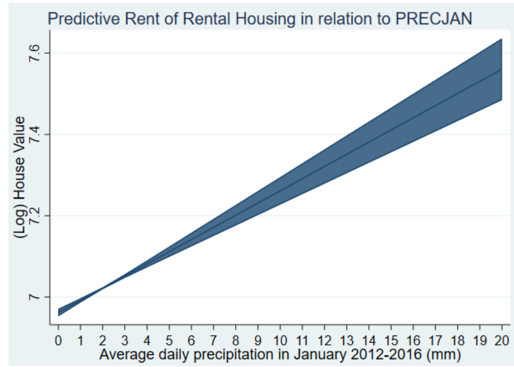
Log House Value



Log Gross Rent



Marginplots

<table>
<tr><td></td><td>Log House Value</td><td>Log Gross Rent</td></tr>
<tr><td>PRECJAN</td><td>
</td><td>
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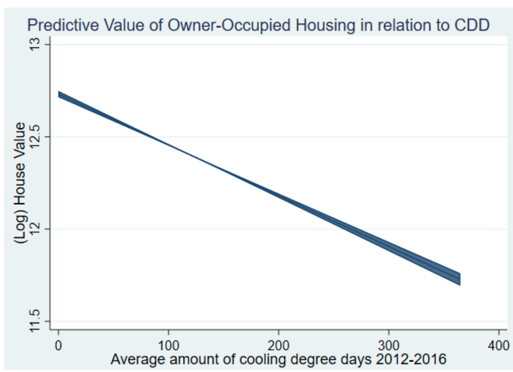
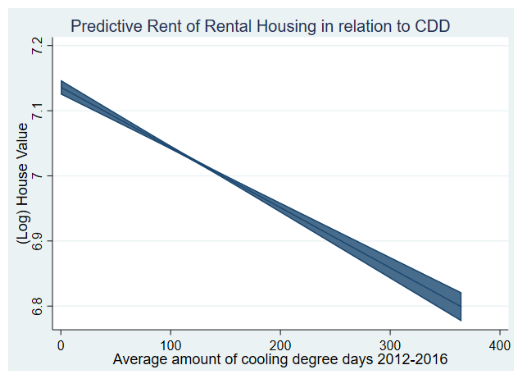
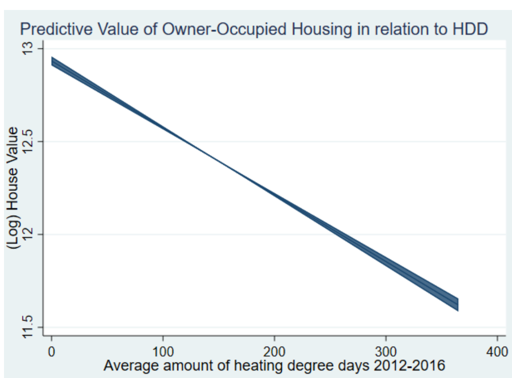
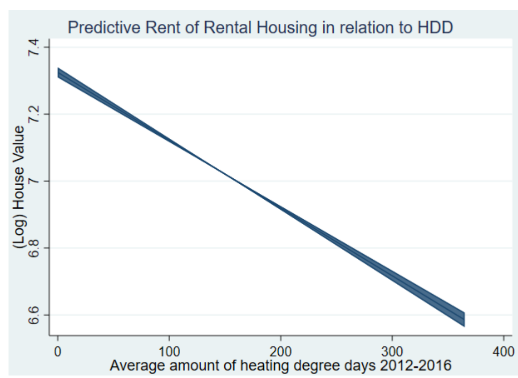
<tr><td>CDD</td><td>
</td><td>
</td></tr>
<tr><td>HDD</td><td>
</td><td>
</td></tr>
</table>

Heterogeneity test (VIF)

	Log House Value			Log Gross Rent		
VIF (Variance Inflation Factor)	Variable	VIF	1/VIF	Variable	VIF	1/VIF
	hdd1216	2.04	0.489086	hdd1216	2.04	0.489086
	cdd1216	2.04	0.491310	cdd1216	2.04	0.491310
	homeown~2016	1.42	0.703846	homeown~2016	1.42	0.703846
	popden2016	1.32	0.757293	popden2016	1.32	0.757293
	unemplo~2016	1.14	0.878305	unemplo~2016	1.14	0.878305
	constru~2016	1.05	0.955622	constru~2016	1.05	0.955622
	vacancy2016	1.04	0.959360	vacancy2016	1.04	0.959360
	precjan1216	1.04	0.965338	precjan1216	1.04	0.965338
	Mean VIF	1.39		Mean VIF	1.39	

NSW Heat index

NWS Heat Index — Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Classification	Heat Index	Effect on the body
Caution	80°F - 90°F	Fatigue possible with prolonged exposure and/or physical activity
Extreme Caution	90°F - 103°F	Heat stroke, heat cramps, or heat exhaustion possible with prolonged exposure and/or physical activity
Danger	103°F - 124°F	Heat cramps or heat exhaustion likely, and heat stroke possible with prolonged exposure and/or physical activity
Extreme Danger	125°F or higher	Heat stroke highly likely

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Wind Chill Chart

Temperature (°F)

Wind (mph)	Calm 40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Frostbite Times: 30 minutes | 10 minutes | 5 minutes

$$\text{Wind Chill } (°F) = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph) *Effective 11/01/01*

Figure 1: Wind chill temperature, problems, and required actions (Roshan et al. 2010)