Master Thesis Real Estate Studies:

Shaking up the Market: Assessing the Effects of Earthquakes on Real Estate Prices in Groningen

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Abstract

This master's thesis examines the impact of earthquakes on property transaction prices in Groningen from 2009 to 2018. The focus is on analysing the relationship between transaction prices, peak ground velocity (PGV), timing of transactions, property characteristics, and buyer origin. The findings shed light on several key aspects of the local housing market. The study reveals a significant negative relationship between cumulative PGV and transaction prices, supporting the hypothesis that an increase in PGV leads to a decrease in property prices. These findings are consistent with previous studies on the decline in property values following natural disasters. Furthermore, the analysis of transaction timing indicates that property prices were significantly higher before 2012, the year in which the Huizinge earthquake occurred. In the years following the earthquake, prices either decreased or remained stable. However, from 2016 onwards, property prices began to increase again relative to 2012. It is important to note that these results primarily reflect general housing market conditions rather than a direct causal relationship between earthquakes and property prices. This research demonstrates that the effect of PGV on house prices is not highly dependent on the specific time period under consideration. Additionally, the study explores the influence of property characteristics, such as location in Groningen, property type, floor space and size of the lot, on transaction prices. Overall, this thesis contributes to a deeper understanding of the factors influencing property prices in Groningen and provides valuable insights into the impact of earthquakes on the local housing market.

Keywords: homebuying, transaction prices, earthquakes, Groningen

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1 Introduction

1.1 Motivation

In 1959, the largest gas field in Europe was found in the village of Slochteren, Groningen. An overview of the exact production locations and the location of the gas field in Groningen are shown in green in figure 1. The Gas extraction took place from this gas field in the northern part of Groningen from 1963 (KNMI, 2022a). For the Netherlands, this gas extraction has contributed to the economy within the country and to the energy supply, but this has also had negative externalities (Voort & Vanclay, 2015). The main negative consequence of this being the earthquakes in the gas extraction area (De Kam & Idsardi, 2014). Natural disasters, including earthquakes can result in a substantial decline in property values within affected regions (Naoi et al., 2009; Ewing et al., 2007; Daniel et al., 2018; Sheldon & Zhan, 2019). According to KNMI, (2022a), there have been more than 1,000 earthquakes in Groningen since the beginning of gas extraction, and there were still 12 earthquakes in 2022 with a magnitude of 1.5 or higher caused by the extraction of gas. It was unknown for a long time that these earthquakes were caused because by gas extraction until the most famous earthquake, called the "Huizinge quake", occurred on August 16 in 2012. This was in the municipality of Eemsdelta. This earthquake had a magnitude of 3.6 on the Richter scale, making it the strongest earthquake to date (KNMI, 2022b). Prior to the Huizinge Quake, there was no scientific understanding of the connection between gas extraction and earthquakes (Goossens, 2017). This event served as a wake-up call and brought attention to the issue of earthquakes caused by gas extraction (Helweg, 2018). After this earthquake, the area received extensive attention in the news and media. As a result, the earthquake problem became nationally known. Furthermore, it became known that there could be more and possibly more powerful quakes. With this news, several negative impacts arose within the earthquake risk area. Examples include building damage, health issues, fear and reduced house prices (Voort & Vanclay, 2015). Because of this, houses in the earthquake area are less easy to sell and are for sale longer compared to similar areas (CBS, 2016). Partly because of aforementioned reasons, people from outside the earthquake area are reluctant to buy a house in the area and many residents of the area want to move out of it (Heeres, 2017). This exacerbated the already existing population shrinkage in the area (Bijker et al., 2012). As a result of the abovementioned consequences, the government has taken multiple measurements to reduce the risk and impact of the earthquakes. This is to reduce population shrinkage in the region. Compensation for the affected homeowners is an example of such measurement. However, relationship between the transaction prices of property, the cumulative peak ground velocity (earthquake damage), the timing of the transaction and moving distance is not yet fully understood. Because of this, this research focuses on the timing of the transaction of a property, the characteristics of these people and houses and whether they differ across different areas depending on the level of earthquake risk in Groningen. With the timing, it is interesting to look after the years before the earthquake problem became nationally known, i.e., before the Huizinge quake in 2012 and after there were active measures and compensations in place, i.e., the year 2018 and further. With the characteristics of people, it is interesting to see whether the moving distance influences the transaction price . For example, someone from outside the northern provinces of the Netherlands may have less knowledge and/or experience of the earthquakes than someone from the north itself and therefore pay a different price for a property.

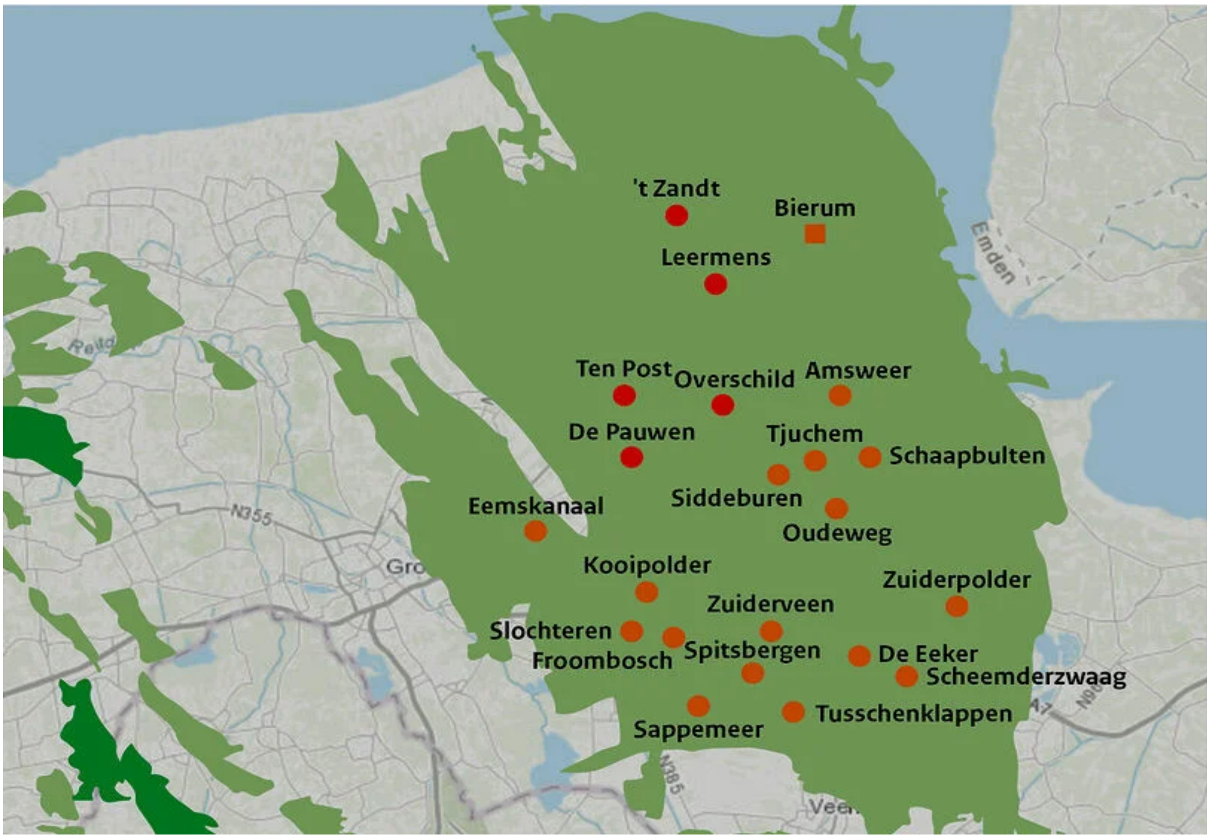

Figure 1: Overview map of location of production sites on the Groningen gas field (Source: https://gasuitgronigen.jouwweb.nl/productielocaties)

1.2 Academic relevance

Examining the relationship between transaction prices and varying levels of earthquakes holds significant academic significance. This research contributes to a comprehensive understanding of the diverse factors that influence the transaction prices in areas prone to protentional earthquake risks. The findings of this study may particularly interest policymakers who are concerned with effectively managing housing stock in such vulnerable regions. This research is of particular importance in the context of Groningen due to the existing population shrinkage experienced in many of the rural areas. Given this shrinkage, it becomes crucial to investigate whether this trend differs significantly in areas exposed to earthquake risks. By understanding and recognizing such patterns, this can be anticipated upon in policy making and negative consequences can be mitigated.

Academically, this research provides new insights into the complex relationship between earthquake risk, property characteristics and people's origins. Research has been done on motivations for people to leave the earthquake risk area or conversely to go there. However, this was mostly at one point in time or for one municipality. Bijker et al. (2012) find that people move towards the less popular rural areas in the North of the Netherlands because of the rural idyll, for friends and family or because of certain characteristics of the houses and the environment. In contrast, people who currently live in the rural areas like to leave these areas due to the earthquake risk, especially elder people or people who have personal experiences with the earthquakes (Jansen et al., 2017). This is mainly because they have a feeling of uncertainty and feel unsafe (Stroebe et al., 2019). When trying to sell their house, the sellers are unable to rent or buy elsewhere because of a decrease in the value of their current home (De Kam & Mey, 2017). Negative consequences like this cause both short-term and long-term social and economic impacts for people living in the area (Voort & Vanclay, 2015). Other examples of the negative effects of the earthquakes include damage to properties and the additional lower value of the property, if not repaired; fear of earthquakes in the future; a decrease of quality of life in the region because of feeling of insecurity (Koster & van Ommeren, 2015). However, a research gap still exists as there has been no explicit academic examination of the impacts of earthquakes over the years for different regions in Groningen. As mentioned in the introduction, there may be a change in pattern as measures were taken or when earthquakes were less frequent or less severe for some time, for example. The extent to which the abovementioned factors influence transaction prices of properties and how they differ between earthquake risk regions in Groningen needs to be examined.

1.3 Research problem statement

This research aims *to examine the impact of earthquakes, the timing of the transaction and the moving distance of the buyer on the transaction prices of properties in Groningen.* This study will not only look at the people who bought the house or the property itself, but both factors will be examined. Furthermore, this study will be including the factor of time. For instance, data can be looked at before the earthquakes were commonly known within the Netherlands, but also the years before or after. Another factor of time could be before and after the time that measures have been taken to protect homeowners in the earthquake area. All these factors are taken into account to create a understanding of the possible influence of earthquakes on the transaction prices in Groningen. To investigate this, the following sub-questions have been formulated to guide the research process:

- RQ1: What does theory describe about the relationship between natural disasters and transaction prices?
- RQ2: What is the relation between the cumulative PGV of a property, the timing of the transaction, the origin of the buyer and the characteristics of the property bought in the earthquake risk area of Groningen?
- RQ3: How does the cumulative PGV of a property, the timing of the transaction, the origin of the buyer and the characteristics of the property vary with the intensity of the earthquakes in Groningen?

Research question 1 will be answered by analysing already existing literature and theories. Research question 2 and 3 will be answered with the land register transactions dataset 2009-2018 provided by George De Kam and updated by Sarah Mawhorter. This dataset contains all residential property transactions from 2009 to 2018 in Groningen. In total, there are 51,191 number of records. To strengthen the answers to the research questions, a dataset provided by George de Kam with all earthquakes and impacts will be used.

2 Theoretical framework

2.1 Natural disasters and housing prices

Much research has been done on the relationship between natural disasters and housing prices. For example, Ewing et al. (2007) find an association between wind-disaster prone areas and housing prices. They find that wind-disaster-prone areas are affected by the risk of tornados and hurricanes, resulting in lower housing prices. Somewhat the same results occur for the risk of flooding (Daniel et al., 2009). Floods generally cause a significant damage to properties, which results to lower prices paid for properties in a flood-risk area (Bui et al., 2022). Other natural disasters, such as wildfires, can also affect the housing prices (Kiel & Matheson, 2018). Sheldon and Zhan (2019) show that the risk of wildfires, and natural disasters in general, can affect the demand for properties in an area that is at risk. This study finds that the properties who are in the high-risk area had significant lower prices compared to those who were in a lower risk area. Finally, Naoi et al. (2009) show that housing prices after an earthquake are much lower than before an earthquake. Natural disaster can affect housing prices through various channels, including the expected owner costs, risk of homeownership and changes in rental prices (Dillon-Merrill et al., 2018). However, the impact of the natural disaster on the housing prices may differ depending on the location of the property and the type of disaster (Bui et al., 2022). For example, induced earthquakes can have a significant impact on housing prices, however this impact can vary depending on the location, the intensity and scale of the earthquake (Duran & Elhorst, 2023). These are all studies on natural disasters and their impacts on a large research area. What is unknown is whether more localized natural disasters caused by human activity, such as the earthquakes in Groningen, have a different impact.

Bosker et al. (2016) find that the earthquakes in Groningen have a significant influence on the decline in property values in Groningen. Of all the municipalities within the earthquake area, it is the municipality of Loppersum (currently Eemsdelta) that has been affected the most (Voort & Vanclay, 2015). Koster and Van Ommeren (2015) identify three main effects of the earthquakes. These effects are: damage to properties and the additional lower value of the property, if not repaired; fear of earthquakes in the future; a decrease of quality of life in the region because of feeling of insecurity (Koster & van Ommeren, 2015). These negative consequences are both short-term and long-term economic and social impacts, influencing the house prices and the current residents (Voort & Vanclay, 2015). These impacts were most evident after the Huizinge quake. After this quake, house prices were significantly lower than before this quake (Koster & van Ommeren, 2015). However, the exact influence of the earthquakes on the transaction prices over the years for different earthquake risk regions is still unknown.

A study by Stroebe et al. (2016) shows that there is an increase of health problems and a decrease of safety experience among residents of the earthquake risk area in Groningen. In this negative consequence, uncertainty about the future is the main reason people feel unsafe and bothered (Stroebe et al., 2019). This strengthens the desire to leave the area and can therefore lead to a lower transaction price of the property. This problem is especially prevalent among residents with multiple damages to their property. Mentioning here that policy in most cases has not been able to remedy this problem. Trust in, for example, NAM (Dutch petroleum company) and Centrum Veilig Wonen (Centrum safe housing) is therefore low. This trust is the lowest among people who have experienced damage because of the quakes (Stroebe et al. 2016). CVW was established in 2014 to take responsibility for repairing damage as a result of earthquakes. Until 2020, you could go to CVW to strengthen your building or home or to get support if you got damage as a result of an earthquake (CVW, 2023). A similar body is Institute for Mining Damage Groningen (IMG). This institution was created in 2018 because of the aforementioned low trust. In early 2018, the independent body Temporary Commission on Mining Damage Groningen (TCMG) was established to ensure that damage settlements would be faster and more efficient. This body continued as IMG in 2020 (IMG, 2022). Until

March 2022, the IMG has assigned approximately 1.25 billion euros in damages caused by the earthquakes to properties. Adding to this is the 404 million euros in compensation from NAM for physical damages. (IMG, 2022). However, these compensation measures only affect the first two named consequences by Koster and Van Ommeren (2015). The feeling of uncertainty and insecurity about the future and possible stronger quakes remains prevalent and this makes life for people in the earthquake risk area insecure in multiple aspects (Stroebe et al. 2019). This negative perception of their current living situation might influence transaction prices in the future.

In addition to the abovementioned social consequences, there are also several economic consequences. The earthquakes cause physical damage to properties. These damages include leaks, cracks in walls, etc. (Voort & Vanclay, 2015). Natural disasters, such as earthquakes, have a significant and long-lasting impact on the economic well-being of affected communities (Boustan et al., 2020). Several studies have been done research on the price change of homes with regards to earthquakes. Francke & Lee (2014) find that houses from the earthquake area do not have lower prices due to direct damage, but rather that price increases in the area lag behind compared to similar regions nearby. This while De Kam (2016) show that there is definitely a decrease in value in the earthquake area. This can amount to as high as a 10.9 percent decrease in the municipality of Loppersum (De Kam, 2016). Houses in the earthquake area are less easy to sell and are for sale longer compared to similar areas (CBS, 2016). Buyers are generally less eager to move to the earthquake area and this creates a longer time until finding a buyer. In addition, in many cases, sellers are unwilling to drop the price since the house is already under water (De Kam & Mey, 2017). The earthquakes have had a significant impact on the functioning of the housing market in the earthquake risk region, with house prices dropping (Boelhouwer & Van der Heijden, 2018). However, these problems with sales cannot be blamed entirely on the earthquakes, since they could also be related to population decline (De Kam & Mey, 2017). Thus, a decrease in prices comes on the one hand due to earthquakes, but on the other hand due to the overall reduced attractiveness of the region (Voort & Vanclay, 2015). However, from the mentioned researches, it has been clearly demonstrated that natural disasters, including earthquakes, have a negative impact on the transaction price of properties.

2.2 Migration to rural earthquake areas

Several research has been done on homebuying in the less-popular rural earthquake areas in Groningen. According to Bijker et al. (2012) people move towards these areas in the North of the Netherlands because of the rural idyll, to live closer to friends and family, the low prices of the houses and because of the characteristics of the houses and the environment. This appreciation of residential property is one of the factors that makes people value their living environment more. Nevertheless, there is still significant shrinkage in many rural areas of the Netherlands, with accompanying negative consequences (Venhorst & Haarsten, 2010). Bijker et al. (2012) divides the northern Netherlands into 3 different types of rural areas based on house prices: popular, average and less popular rural areas. Figure 2 shows that there are nine municipalities in total within the popular category. Furthermore, it can be seen that in the earthquake risk area a very large portion of municipalities fall under the category of the less popular rural areas of the northern provinces of the Netherlands.

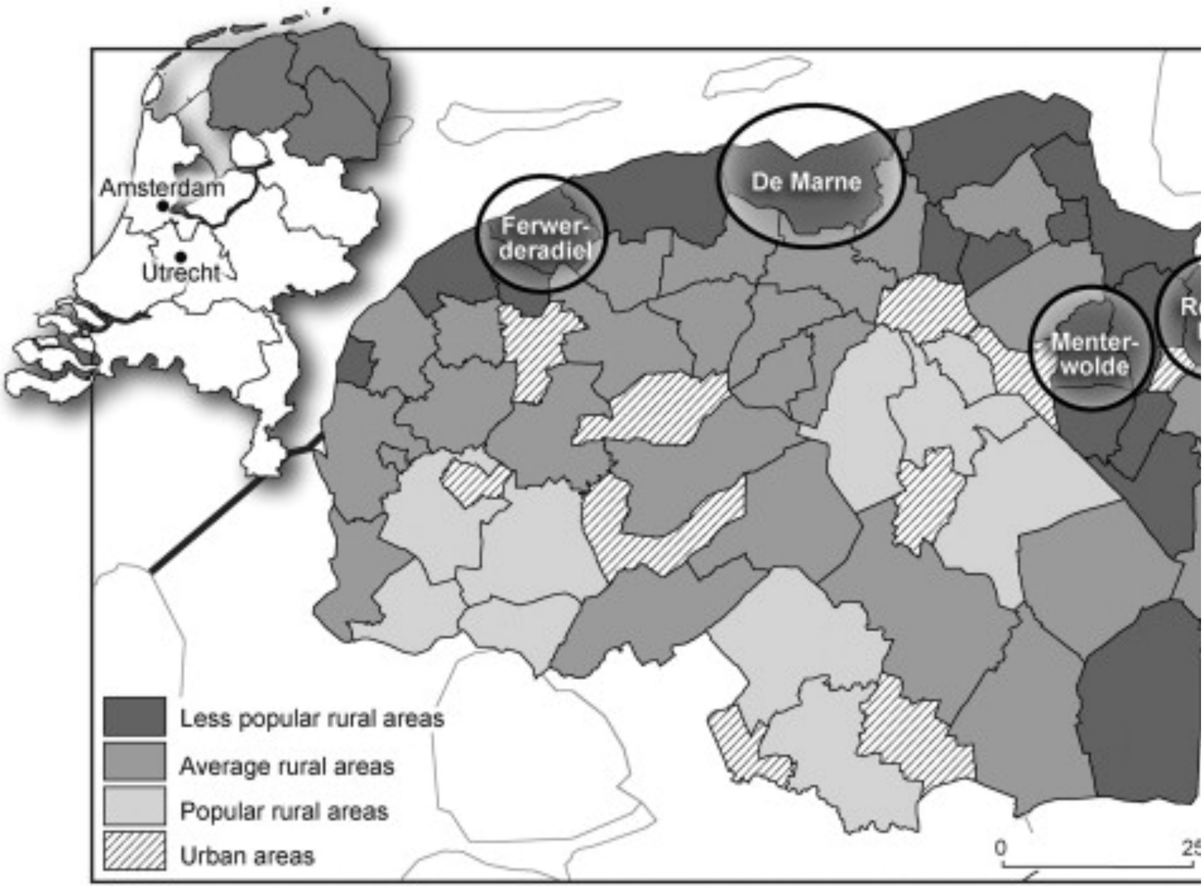

Figure 2: Three types of rural areas in the northern Netherlands (source: Bijker et al., 2012)

When looking at the motives for migration to rural areas in the Netherlands, three main motives can be identified: residential, household and work or education motives (Van Dam et al., 2002). Movers to less popular rural areas are mostly young and, in many cases, they already lived in the rural areas in the north of the Netherlands (Bijker et al.,2012). People who move to rural areas often give as a main reason the rural idyllic, such as quietness and space. These reasons are named more often than, for example, housing characteristics (Steenbekkers et al., 2008). In general, one can say that the people who leave for the less popular rural areas are those with high education, low income and are working most of the times (Bijker et al., 2012). This combined with the young age could refer to starters in the housing market who have just graduated. This contradicts the image that mainly older people live in and move to rural areas (Steenbekkers et al., 2006). When older people move, they are more likely to move rural areas, but this is a small proportion overall. For those people who left for rural areas, the availability of a house or a specific type of house, such as detached, was the main reason of choice for leaving here (Steenbekkers et al., 2008). Regarding the desire to leave the earthquake risk area, personal experiences with earthquakes play a significant role (Jansen et al., 2017). Thus, suggesting that experience with earthquakes decrease the desire to live in the earthquake risk area. Therefore, it is possible that people from within the earthquake risk region have a different level of sensitivity to earthquake risk compared to those from further away. This difference in perception could significantly impact the transaction prices of properties in the region.

2.3 Conceptual model & hypotheses

To create a clear, comprehensible representation of the problem statement and the literature, the following conceptual model is created. Showing different factors that contribute to the transaction price in the different earthquake risk areas in Groningen. The conceptual model is shown in Figure 3.

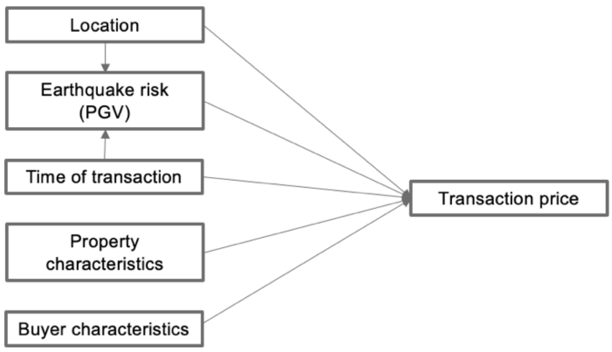

Figure 3: Conceptual model, by author

As described before, this research aims to investigate both the characteristics of the properties and the people that are bought in Groningen in relation with earthquakes, but also aims to include the factor time. These factors together determine the transaction price of a property.

Furthermore, based on the literature, this research conducts the following hypotheses:

- Hypothesis 1: The more cumulative earthquake peak ground velocity to a property, the lower the transaction price of that property.

- Hypothesis 2: Transaction prices of properties will vary across the following different earthquake-related periods: the years before the Huizinge quake, after the Huizinge quake and when active measures were taken.
- Hypothesis 3: The knowledge and/or experience with earthquakes influences property prices differently for local and non-local buyers, with non-local buyers paying more for homes than local residents.

3 Data & Methodology

This research aims to investigate the relation between transaction prices of properties and the impact of earthquakes in Groningen. The key dependent variable for this research is the purchase price of properties. As mentioned earlier, data from the land register transactions between 2009 and 2018 is used (N=51,191). Furthermore, a dataset with the number of earthquakes per year and cumulative peak ground velocity (PGV) in cm/s since the start of the earthquakes in 1992 on houses is used (N= 346,588). Both datasets are merged based on their PHT (ZIP code, house number and addition). After merging the data, every duplicate variable, variable with a missing transaction date, missing moving distance or classified as "Unknown" is dropped. This because these variables are insufficient for this research. Furthermore, every variable where the seller is not a natural person is dropped because this is not the target group. Finally, after looking at the descriptive statistics and histograms, the lowest 1 percent of the dataset regarding the purchase prices is dropped due to these variables being data errors. The outliers to the higher percentages were reviewed, but of these it was decided not to remove them because they are certainly not data errors. Thus, resulting in a dataset with 39,697 observations.

3.1 Measurements

3.1.1 Transaction measurements

As mentioned above, the key dependent variable is the purchase price of the properties in the province of Groningen. After looking into the data, it was concluded that the variable price was not normally distributed (see appendix A). Therefore, the natural logarithm of the purchase price has been taken. This variable is measured in euros and is from the time period 2009 until 2018. Another measurement about the transaction which is included is the transaction date. Both the month and the year of the transaction are included. The only measurement about the buyer of the property included is the moving distance in intervals of 100 kilometers of the buyer from the previous property to the newly bought property. This measurement is included due to the suggestion in the literature that someone who has less knowledge and/or experience with the earthquakes in Groningen is more likely to buy a house in the earthquake risk area.

There are also multiple property characteristics measurements in the dataset. The first one is the type of property. This variable indicates whether the property is an apartment, corner house, two under a roof, house in the middle of a row or a detached house. Furthermore, the floorspace is included. This is the amount of floorspace a property has in square meter. The same applies for the size of the lot. If the property did not have a lot, this was indicated as zero. Finally, the municipality of the property is included. This is, due to inconsistency in the data, converted into the 10 municipalities of Groningen established in 2021. This measurement is included to indicate where in the province of Groningen the property roughly is.

3.1.2 Earthquake measurements

To measure the earthquake risk for a certain property, up until the point of transaction, a variable has been created by the author. This has been taken from a dataset which contains the cumulative peak ground velocity (PGV) in cm/s since the start of the earthquakes in 1992 until 2021. Velocity is how fast a point on the ground is shaking as a result of an earthquake. Therefore, the peak ground velocity is the greatest speed of shaking recorded during an earthquake. The cumulative PGV has been taken up until the date of transaction. According to CBS (2016), houses in the research area are not for sale for more than 700 days. This is why it is decided to adopt a lag of 2 years compared to the start of the years available in the land register transactions data, which is 2009. Thus, resulting in cumulative PGV from 2007 until transaction date. In the earthquake data, there is a division in the year 2012: before the Huizinge quake and after this earthquake. This division is also implemented in this new variable. Furthermore, in the years 2015 and 2017, there was also a division between the first 6 months and the second half of the year. This division is also implemented in the new variable because it represents the results more accurately. From the total dataset, 20,477 variables had a cumulative PGV on transaction date higher than zero.

3.2 Statistical model

Following the description of the variables, the statistical equation for the regression analysis in this paper is as follows:

$$\text{LnY} = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + \beta_3\chi_3 + \beta_4\chi_4 + \beta_5\chi_5 + \beta_6\chi_6 + \beta_7\chi_7 + \varepsilon$$

Where $\mathrm{Ln}\Upsilon$ is the dependent variable, in this case the logarithm of the purchase price of the property. β_0 is the constant,. β_1, β_2, β_3, β_4, β_5, β_6, and β_7 are the regression coefficients, the estimated change of our dependent variable for a one-unit of change in each independent variable with all other independent variables constant. The independent variables χ_1, χ_2, χ_3, χ_4, χ_5, χ_6, and χ_7 in this research are the cumulative PGV in cm/s of the property bought, transaction date, moving distance of the buyer, municipality, type of property, floorspace and size of the lot respectively. These variables of interest were chosen based on the literature and the aim of this research. Finally, ε is the error term. For the analysis, different statistical analysis will be conducted and different models will be used, each incorporating additional variables. For this research, two statistical analyses were conducted. The first statistical model being a linear regression with the logarithm of price as the dependent variable. This statistical method is used to model the relationship between this dependent variable and several independent variables. The second statistical method which is used is the repeated sales method. This method is used to estimate the value of a property based on repeated sales in the data. For this second analysis, only the repeated sales in the earthquake area are used. As a result, the number of observations in this analysis is significantly lower compared to the linear regression. Based on a fixed effects of the address of the property, a change in price over the years will be examined. As mentioned, different models will also be used. The first model will only examine the relation between the cumulative PGV and the price. The second model will include the municipality of the property bought. Furthermore, the third model includes the transaction date of the property. Finally, model 4 will include the moving distance of the buyer. For all the models, the following control variables will be added: type of property, floorspace and size of the lot.

3.3 Descriptive statistics

Table 1 shows the general descriptive statistics for this research. Looking at the statistics, one can see that from the total of 39,697 observations the mean purchase price for the properties in this research is 188630.1 euros. This with a minimum of 53900 euros and a maximum of 2275000 euros. The moving distance of the people who bought a property in the research area is on average 16.15 kilometres. This with an average of 130.12 m2 floorspace for the property. The minimum floorspace being an apartment of 11 m2 and the maximum a detached house with a floorspace of 2941 m2. The average size of a lot is 573.72 m2. This with several houses having no lot and the maximum of almost 9.5 hectare.

Table 1: General descriptive statistics.

General descriptive statistics

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
Price	39,697	188630.1	101581.6	53900	2275000
Cum. PGV cm/s	39,697	0.37	0.88	0	11.64
Moving distance	39,697	16.15	38.15	0.002	317.36
Floorspace	39,697	130.12	78.66	11	2941
Size of the lot	39,697	573.72	1691.30	0	94913

Table 2 shows the descriptive statistics of the purchase prices per square meter floorspace in euros for properties across different municipalities in Groningen. It can be seen that the average purchase prices per square meter are the lowest in in Pekela and secondly Oldambt. The highest average prices are in the municipalities Groningen and Westerkwartier. This municipalities also have the highest maximum prices. This can be partly explained by the more urban structure of these municipalities. Finally, the municipality of Groningen is the only one which is above the pooled average.

Table 2: Descriptive statistics for price per square meter per municipality.

Descriptive statistics for price per square meter per municipality					
Municipality	Observations	Mean	Std. Dev.	Minimum	Maximum
Eemsdelta	2,795	1205.77	459.62	109.52	8400
Groningen	15,247	1843.75	675.68	75.93	27800
Het Hogeland	3,241	1299.10	424.94	38.78	5816.33
Midden-Groningen	3,711	1404.58	458.52	105.08	4032.26
Oldambt	2,791	1162.42	466.86	80.56	14318.18
Pekela	760	1077.98	399.58	90	2993.20
Stadskanaal	2,459	1428.41	433.21	217.67	4062.50
Veendam	2,234	1259.64	395.05	76.24	3780.58
Westerkwartier	4,624	1503.66	489.13	57.80	17138.89
Westerwolde	1,835	1418.05	633.78	82.99	5081.97
Total	39,697	1532.85	616.15	38.78	27800

Table 3 shows the cumulative PGV in cm/s on properties across the different municipalities between 2007 and 2018. it can be concluded that there are 4 municipalities in which no earthquakes occurred between 2007 and 2018: Pekela, Stadskanaal, Veendam and

Westerwolde. Furthermore, it can be concluded that there are properties in every municipality where no earthquake has occurred. The municipalities where the most earthquakes have occurred and therefore also has the highest cumulative PGV in cm/s is Eemsdelta.

Table 3: Descriptive statistics for cumulative PGV in cm/s

Descriptive statistics for cumulative PGV in cm/s					
Municipality	Observations	Mean	Std. Dev.	Minimum	Maximum
Eemsdelta	2,795	2.13	2.00	0	11.64
Groningen	15,247	0.23	0.37	0	5.02
Het Hogeland	3,241	0.89	1.04	0	6.29
Midden-Groningen	3,711	0.52	0.68	0	4.89
Oldambt	2,791	0.01	0.03	0	0.48
Pekela	760	0	0	0	0
Stadskanaal	2,459	0	0	0	0
Veendam	2,234	0	0	0	0
Westerkwartier	4,624	0.02	0.05	0	0.32
Westerwolde	1,835	0	0	0	0
Total	39,697	0.37	0.87	0	11.64

3.4 OLS assumptions

After conducting the linear regression, a 'regcheck' was performed in Stata to examine the fulfilment of all OLS assumptions. Based on this check, the following assumptions were found to be violated: heteroskedasticity problem, residuals are not normally distributed and functional form problem. To address the heteroskedasticity problem, the robust function was implemented in the relevant models. Regarding the other two issues mentioned, they were investigated and found to be caused by some of the independent variables being categorical variables. This resulting in the residuals not being normally distributed and the functional form problem.

4 Results and discussion

4.1 Linear regression

Table 4 presents the regression outputs for the pooled model. This means that in this regression, both properties with cumulative earthquake damage and houses without it are included. Therefore, these are all transactions in Groningen. Model 1 of this regression includes the cumulative peak ground velocity (PGV) that occurred on a property. Looking at the results of model 1, one can conclude that the variable cumulative PGV has a coefficient of -.036 ($p < .001$). This mentioned negative coefficient means that for every increase of 1 PGV in cm/s per property, the price of this house on average decreases by 3.5%. This is line with the findings of Naoi et al. (2019) that houses decrease significantly in value after an earthquake. It also corresponds to the findings of Bosket et al. (2016) and De Kam (2016), who find that there was a significant decrease in the values of homes in Groningen, due to earthquake damage to the property. This finding also supports the hypothesis that the transaction price of a property decreases with an increase of PGV. Furthermore, model 1 includes several control variables. These control variables are the type of property, the floorspace of the property and size of the lot. Looking at the coefficient of the type of property, one can conclude that a detached house is the most expensive type of property. This, because all the other four coefficients are significant and negative. Furthermore, the coefficients for floorspace and size of the lot are both significant and positive. For floorspace, the coefficient is .002 ($p < 0.001$). This implies that for every increase of one square meter of floorspace, the transaction price of the property increases with 0.2%[1]. The coefficient of the size of the lot is close to zero.

Model 2 includes the municipality of the property. The reference area for municipalities is Eemsdelta, chosen based on the descriptive statistics that indicate the highest cumulative PGV in this area. The largest difference in price relative to Eemsdelta is observed with the municipality Groningen, with a coefficient .488 ($p < 0.001$), indicating that the prices for comparable properties are 62.9% higher compared to Eemsdelta. For the municipalities Het Hogeland, Midden-Groningen, Stadskanaal, Veendam and Westerkwartier, all coefficients are significant and positive, thus indicating a higher average transaction price for properties in these municipalities. The coefficients for the municipalities Oldambt and Pekela are significant and negative. The only municipality that does not significantly differ from Eemsdelta is Westerwolde. Furthermore, as can be seen in the results of model 2, the coefficient of cumulative PGV has increased to -.013 ($p < 0.001$). These results align with the findings of Francke and Lee (2014) that prices in the rural areas of Groningen are lower. However, this cannot be solely attributed to the earthquakes. As Voort and Vanclay (2015) described, there is also an overall reduced attractiveness of these rural regions which contribute to the prices being lower compared to the urban areas in Groningen.

[1] Percentages are calculated using the formula: (exp(coefficient) – 1) * 100%

Model 3 also includes the year in which the property is transacted. The year 2012 has been chosen as the reference year due to the Huizinge quake that occurred in August of that year. This quake was selected because it was the strongest recorded quake in the Netherlands resulting from gas extraction until that point. Because of this, it had a significant societal impact nationwide. Furthermore, Koster and Van Ommeren (2015) find that the house prices in Groningen were significantly lower after the Huizinge quake. By having this reference year, one can see the impact of this quake in the years before and after. To observe the impact on of the earthquake on transaction prices, an interaction will be necessary. This concept will be further explained later in this paragraph.

The final model, model 4, includes the moving distance of the buyer. The moving distance of the buyer is also significant. The coefficient for moving distance is -.020 ($p < 0.001$). This implies that the transaction price of a property is 2.0% lower for every 100 kilometers of moving distance of the new buyer. This disproves the hypothesis that people moving from further away will pay more for homes. This research shows that people moving from further away actually pay less. Bijker et al. (2012) described that one of the reasons for people to move to the research area was to be closer to family or friends. Therefore, it is possible that someone from a greater distance pays less because they likely have different motivations, such as the lower housing prices in the area also described by Bijker et al. (2012). Looking at the final coefficients for model 4, one can see that the coefficient of cumulative PGV has decreased to -.021 ($p < 0.001$). This means that for every increase of 1 cumulative PGV per house, the price of the house, on average throughout Groningen, decreases by 2.1%.

Looking at the coefficients for the different years before the year of the Huizinge quake, one can see that these are .048 ($p < 0.001$), .047 ($p < 0.001$) and .048 ($p < 0.001$). This implies that in the years before this earthquake, properties in all of Groningen were respectively 4.9%, 4.8% and 4.9% more expensive than in 2012. Furthermore, the two years after the year of the Huizinge quake both have a negative significant coefficient: -.059 ($p < 0.001$) and -.035 ($p < 0.001$). This means that the properties in Groningen were 5.7% cheaper in 2013 and 3.4% cheaper in 2014 compared to 2012. From 2016 onwards, there is a significant increase in the price paid for the properties. This resulting in a coefficient of.037 ($p < 0.001$) in 2016, .098 ($p < 0.001$) in 2017 and .156 ($p < 0.001$) in 2018. This indicates that prices in 2016 were 3,8% higher than in 2012, in 2017 10.3% higher, and in 2018 they were 16.9% higher than in 2012. This supports the hypothesis that the transaction prices of properties differ in the time periods before and after the year of the Huizinge earthquake. It has been considered to convert the years into the time periods of this hypothesis. However, the results turned out to be quite similar and therefore it has been decided to take the years separately in order to create a clearer and broader understanding of the differences between the various years.

These abovementioned coefficients and percentages may suggest a potential correlation between the Huizinge quake and the transaction prices. However, it is important to note that they primarily reflect housing market conditions rather than a direct causal relationship. To determine whether there is a relationship between the cumulative PGV of a property and house prices over time, an interaction term between the variables was constructed. However, the results indicate that this interaction term is not statistically significant as a whole. This was the same when interacting with the time periods mentioned above instead of considering the years separately. This implies that the relationship between cumulative PGV and house prices does not significantly vary with time. In other words, the effect of PGV on house prices does not depend on the specific time period being considered. Therefore, it is not displayed in the regression output table. This result contrasts with what the literature described. As mentioned, Koster and Van Ommeren (2015) find that house prices in Groningen were significantly lower after the impact of the Huizinge quake. However, this result is not fully supported in this research. This research does find that the houses are indeed cheaper in the years following this earthquake, but it not directly related to the PGV. A possible explanation for this could be the that there was a strong sense of feeling unsafe and bothered after this earthquake, as described by Stroebe et al. (2019). However, it could also be attributed to general housing market conditions. This research supports the hypothesis that transaction prices of properties vary across different time periods: before the Huizinge quake, after the Huizinge quake, and in the years following the implementation of active measures. However, the findings of this study do not provide evidence specifically attributing these variations to the activities mentioned in the hypothesis. It is plausible that these fluctuations primarily reflect general housing market conditions.

Table 4: Regression output table: linear regression.

Regression output table								
Linear regression	Model 1		Model 2		Model 3		Model 4	
DV: Log. Price	Coef.	R. SE	Coef.	R. SE	Coef.	R. SE	Coef.	R. SE
Cum. PGV (cm/s)	-.036***	.002	-.013***	.003	-.020***	.002	-.021***	.003
Municipality (ref = Eemsdelta)								
Groningen			.488***	.009	.482***	.009	.482***	.009
Het Hogeland			.056***	.010	.051***	.010	.052***	.010
Midden-Groningen			.124***	.010	.113***	.010	.112***	.010
Oldambt			-.075***	.011	-.090***	.011	-.090***	.011

Pekela			-.158***	.015	-.176***	.015	-.175***	.015
Stadskanaal			.102***	.011	.085***	.012	.085***	.012
Veendam			.051***	.011	.034**	.012	.034**	.011
Westerkwartier			.238***	.010	.225***	.010	.224***	.010
Westerwolde			-.007	.013	-.021	.013	-.018	.013
Transaction year (ref = 2012)								
2009					.047***	.009	.048***	.009
2010					.046***	.009	.047***	.009
2011					.047***	.009	.048***	.009
2013					-.059***	.009	-.059***	.009
2014					-.035***	.009	-.035***	.009
2015					-.002	.008	-.002	.008
2016					.036***	.008	.037***	.008
2017					.097***	.008	.098***	.008
2018					.155***	.008	.156***	.008
Moving distance (100 km)							-.020***	.005
Type of property (ref = Detached)								
Apartment	-.211***	.012	-.502***	.013	-.504***	.013	-.504***	.013
Cornerhouse	-.142***	.009	-.272***	.009	-.272***	.009	-.274***	.009
Two under a roof	-.067***	.008	-.112***	.007	-.113***	.007	-.114***	.007
In the middle of a row	-.119***	.008	-.304***	.008	-.303***	.008	-304***	.008
Floorspace	.002***	.000	.002***	.000	.002***	.000	.002***	.000
Size of the lot	.000*	.000	.000**	.000	.000**	.000	.000**	.000
Constant	11.896***	.024	11.791***	.024	12.008***	.008	11.760***	.025
R^2	0.2008		0.3827		0.4027		0.4030	
* p < .05 ** p < .01 *** p < .001	Obs.39,697		Obs.39,697		Obs.39,697		Obs. 39,697	

4.2 Repeated sales

Table 5 presents the regression output for the repeated sales analysis. Only properties that were sold more than once were included in this regression, resulting in 9,720 observations within 4,664 groups. With the inclusion of property fixed effects, the results are as shown in Table 6. Several control variables were omitted due to the absence of any changes in the repeated sales. Examining the coefficient for cumulative PGV in model 1, one can conclude that the variable cumulative PGV has a coefficient of -.01289 ($p < .05$). This mentioned negative coefficient means that for every increase of 1 PGV in cm/s per property, the price of this house on average decreases by 1.3%. The difference in percentage may be because of less variation in properties and PGV compared to the previous research method. Still, this finding supports the literature, the hypothesis and the findings in the previous regression that an increase in PGV negatively impact the transaction prices of properties.

The moving distance of the buyer is not significant at a 95% confidence interval. However, this may be because of statistical power because of not having enough variation in properties. In contrast, some of the transaction years do show significance. The coefficients for the three years before the year of the Huizinge quake are all significant. Specifically, for the years 2009, 2010 and 2011 the coefficients are .05235 ($p < 0.001$), .04811 ($p < 0.001$) and .02951 ($p < 0.01$). This indicates that, during these years, the purchase price of the properties that were sold more than once were 5.4%, 4.9% and 3.0% higher compared to 2012. For the three years following the year of the Huizinge quake, the coefficients are negative, but only the year 2013 is statistically significant. For 2013, the coefficient is -.02904 ($p < 0.01$). This indicates that the purchase price of the properties that were sold more than once was 2.9% lower in 2013 compared to 2012. For the years 2016, 2017 and 2018, the coefficients are significant and positive. The coefficients for these years are .05419 ($p < 0.001$), .12862 ($p < 0.001$) and .19557 ($p < 0.001$) respectively. In percentage terms, this represents an increase of 5.6%, 13.7% and 21.6% respectively compared to 2012.

However, it is again important to note that these year coefficients primarily reflect broader housing conditions. Therefore, an interaction variable has been included to examine the relationship between the cumulative PGV of a property and the transaction year. Model 2 includes this interaction between the cumulative PGV and the transaction years. Upon examining the coefficients for this interaction, it can be concluded that only the years 2009 and 2010 are statistically significant. The coefficients for these years are .08711 ($p < 0.05$) and .07584 ($p < 0.05$). This indicates that the properties that were sold again in Groningen were 9.1% more expensive in 2009 and 7.9% more expensive in 2010 compared to the year 2012 when considering the interaction between the transaction year and the cumulative PGV of a property. This finding is not in line with the already existing literature, since they find that house prices in Groningen were significantly lower after august 2012 due to the impact of the Huizinge earthquake (Koster & van Ommeren, 2015; Bosker et al., 2016; Voort & Vanclay, 2015). The relationship implied by the literature between earthquake damage and the timing of the transaction, such as the Huizinge quake, turns out to be less significant in this study. This has been observed in both the linear regression and the repeated sales method. Therefore, this research does not find evidence to support the suggested relationship between the timing of the transaction and earthquakes. However, this research does find evidence for the negative relationship between natural disasters and transaction prices of properties.

Table 5: Regression output table: repeated sales.

Regression output table		
Repeated sales	Model 1	Model 2

DV: Log. Price	Coef.	Robust S.E.	Coef.	Robust S.E.
Cum. PGV (cm/s)	-.01289*	.00609	.01464	.01908
Transaction year (ref = 2012)				
2009	.05235***	.00847	.04912***	.00887
2010	.04811***	.00880	.04479***	.00914
2011	.02951**	.00885	.02716**	.00929
2013	-.02904**	.01013	-.04356***	.01111
2014	-.01014	.00869	-.01286	.00937
2015	-.00415	.00862	-.01398	.00926
2016	.05419***	.00800	.05071***	.00815
2017	.12862***	.00771	.12065***	.00815
2018	.19557***	.00799	.19319***	.00845
Transaction year (ref = 2012) x Cum. PGV (cm/s)				
2009			.08711*	.03410
2010			.07584*	.02931
2011			.03136	.03232
2013			.02688	.01527
2014			-.01050	.01526
2015			.00721	.01673
2016			-.00881	.01328
2017			.00094	.01337
2018			-.01380	.01413
Moving distance (100 km)	.00617	.00520	.00676	.00520
Constant	11.903***	.00621	11.898***	.00701
R^2	Within: 0.2646	Overall: 0.0283	Within: 0.2683	Overall: 0.0231
* p < .05 ** p < .01 *** p < .001	Obs.9,720	Groups.4,664	Obs.9,720	Groups.4,664

In order to visualize the results of the interaction more effectively, a graph depicting the price, the different time periods and cumulative PGV has been generated (see appendix B). The time periods considered in this graph are as follows: from 2009 until the Huizinge earthquake, from the Huizinge quake onwards until 2015 and from 2016 until 2018. Upon observing the graph, it is evident that for the first and the second time period, an increased housing prices occur for areas where earthquakes occur relative to those which are not. This occurrence can most likely be attributed to unobserved factors and therefore omitted variables. However, what is interesting to observe is that the increase in housing prices with PGV in the first time period was substantially greater than in the periods following the Huizinge quake. This finding supports the hypothesis that transaction prices differ across these different time periods.

4.3 Sensitivity analysis

After running the regressions, a sensitivity analysis has been conducted on the pooled model to test if there is a structural difference in the relationship between the purchase price of the properties, the cumulative PGV and the influence of moving distance across different periods. The pooled model has been chosen to include all observations possible. The dataset was split up in three different time sub-samples: from 2009 until the Huizinge quake (July 2012), from the Huizinge quake onwards (August 2012) until 2015 and from 2016 until 2018, when active measurements started to occur. The null hypothesis for the Chow F-test is that there is no structural difference between the restricted and unrestricted models. The formula used for this test can be found in the appendix. When looking at the result, it can be concluded that that the calculated Chow test statistic was greater than the critical F value with the desired level of significance of 0.05. Because of this, the null hypothesis cannot be rejected that there are no structural differences between the different models. Therefore, it is crucial to acknowledge that structural difference does indeed exist among the different sub-samples with distinct time periods. This factor has been taken into consideration when interpreting and analysing the results obtained from the regressions. A further investigation was undertaken to determine whether the dissimilarities observed were solely the variations in the models or if they extended to the relation between the cumulative PGV and the transaction prices. The analysis revealed that these dissimilarities were negligible and therefore it was determined that the results should be presented, analysed and interpreted as demonstrated in the preceding sections.

5 Conclusion

This master thesis aims to investigate the impact of earthquakes on the transaction prices of properties in Groningen. This was examined by looking at the relationship between the transaction price, peak ground velocity of a property, the timing of the transactions, characteristics of the properties and origin of the people. The research findings shed light on several key aspects.

This research mainly focused on the transaction prices of properties in Groningen and their relationship with earthquake-related factors. The results of the analysis revealed a significant negative relationship between the cumulative peak ground velocity (PGV) and the transaction price of properties. The hypothesis that an increase of PGV would decrease the transaction price of a property is supported by both research methods. Furthermore, these finding aligns with previous studies that reported a significant decrease in property values following natural disasters (Naoi et al., 2009; Ewing et al., 2007; Daniel et al., 2009; Bui et al., 2022; Kiel & Matheson, 2018; Sheldon & Zhan, 2019).

Furthermore, this study analysed the impact of the timing of the transaction on the property prices. The year 2012 was chosen as a reference year, since a significant earthquake known as the Huizinge quake occurred in this year. The findings of the analysis revealed that in the years before the Huizinge quake, property prices were significantly higher compared to 2012. In contrast, in the years following the year of this quake, prices decreased or did not significantly differ. From 2016 onwards, property prices showed a significant increase compared to 2012. These results supports the hypothesis that transaction prices of properties differ in the time periods before and after the Huizinge quake. However, it is important to note that these findings primarily reflect housing market conditions rather than a direct causal relationship between the earthquake(s) and property prices. To examine this relationship an interaction term was created between timing and PGV. The result from this was that the effect of PGV on house prices does mostly not depend on the specific time period being considered. This may support the literature that a feeling of unsafe and bothered influences the prices significantly (Stroebe et al., 2016). On the other hand, this research does not find evidence that the Huizinge quake significantly impacted the transaction prices in Groningen (Bosker et al., 2016; Koster & van Ommeren, 2015; Voort & Vanclay, 2015). The relationship implied by the literature between the Huizinge quake and transaction prices turns out to be less significant in this research.

The moving distance was included because of the assumption that someone who has less knowledge and/or experience with the earthquakes in Groningen is more likely to buy a house in the earthquake risk area and therefore have a higher transaction price. For the moving distance, this research does not find evidence to support the hypothesis that people from further away pay more. In contrast, this research finds that people from further away actually pay less. We also do not find evidence for this finding in the repeated sales method. However, we are concerned that this may be because of statistical power because of not having enough variation in properties.

Moreover, this study examined the influence of the location (municipality) on transaction prices. The highest transaction prices were in the municipality of Groningen. This is most likely because of the urban characteristics of this municipality. In contrast, the lowest transaction prices were in the municipalities of Oldambt and Pekela.

While this research presents valuable insights, there are several limitations that should be considered. This study focused on exploring and examining relationships between several variables, but causality cannot be established. For example, there may be other unobserved factors that influence the relationships identified. Examples of these could be economic factors, general market fluctuations or policy changes. Such changes were not fully accounted for in the analysis. Another limitation is that this research was not always able to include as many control variables as would have been liked. This is because this was not available or not applicable to this research. Because of this, there is a risk of omitted variable bias. Furthermore, it could be that the PGV or the moving distance can be change very slightly in the time period researched. This makes it more difficult to interpret the outcome of such variables more difficult. Finally, this research fully relied on quantitative secondary data. Therefore, qualitative methods, such as interviews or surveys, were not included in this research. Such qualitative insights could have provided a deeper understanding of the relationships examined.

Further research could therefore address these limitations by adopting a mixed-methods approach. Additionally, future studies could explore whether similar findings emerge in the context of different natural disasters in different regions. Finally, investigating more recent data would be beneficial for future research. While this study focused on the time period from 2009 to 2018, it would be interesting to analyse data from years after 2018. This is particularly relevant as significant changes, such as active compensation policies for residents living in earthquake risk area, were implemented around this time. Examining the effects of such policies remains an important area for investigation.

In conclusion, this master thesis successfully investigated the impact of earthquakes on the transaction prices of properties in Groningen. By doing this, this thesis contributes to a deeper understanding of the different factors influencing property transaction prices in Groningen and provides further insights into the impacts of earthquakes on the local housing markets.

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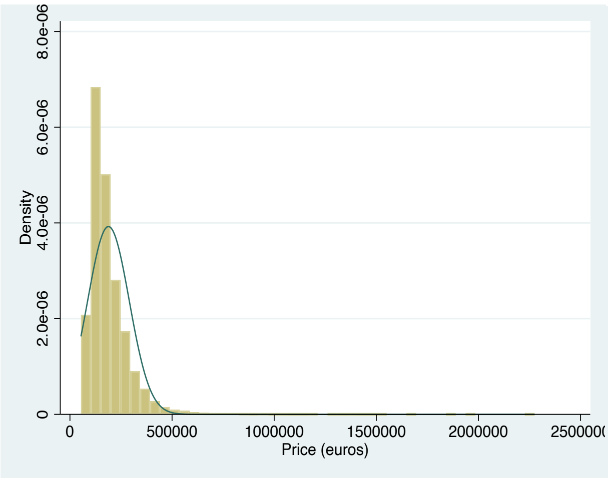
7 Appendix

Appendix A: Histograms of price variable



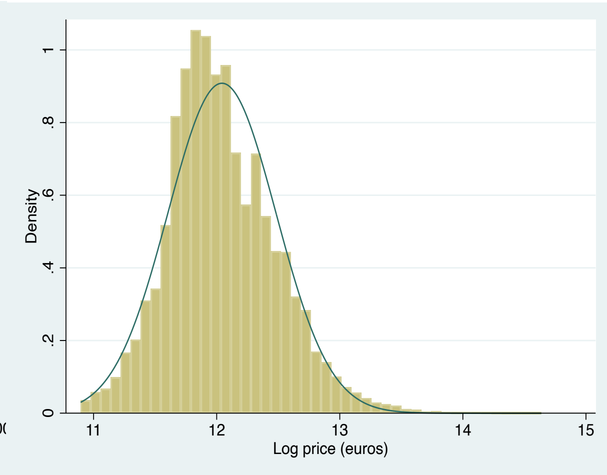
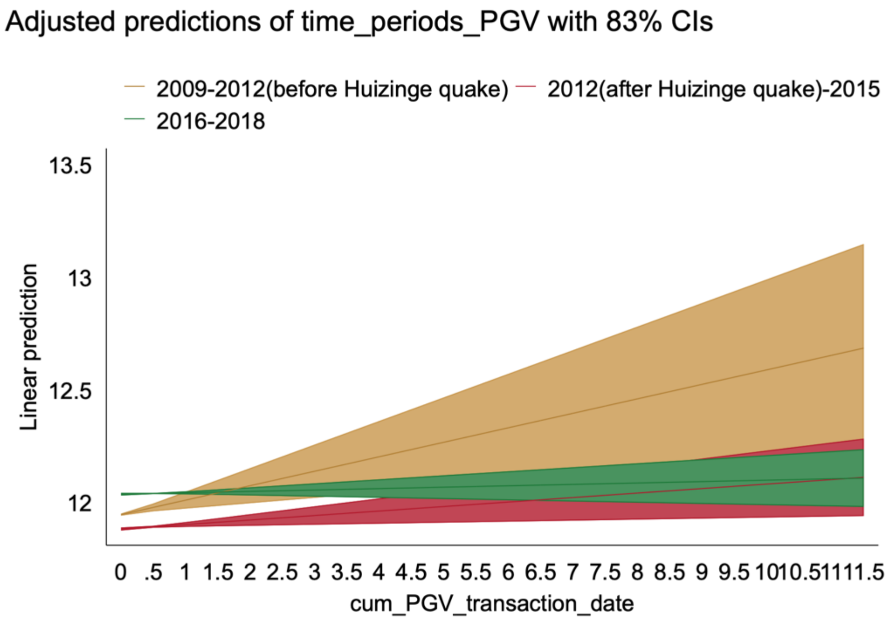


Figure: Histogram of purchase prices

figure: Histogram of log purchase prices

Appendix B: Interaction graph



Appendix C: Chow test

$$test\ statistic = \frac{RSS - (RSS_1 + RSS_2)}{RSS_1 + RSS_2} \times \frac{T - 2k}{k} \qquad (6.56)$$

where RSS = residual sum of squares for the whole sample;
RSS_1 = residual sum of squares for sub-sample 1;
RSS_2 = residual sum of squares for sub-sample 2;
T = number of observations;
$2k$ = number of regressors in the 'unrestricted' regression (as it comes in two parts), each including a constant; and
k = number of regressors in (each) 'unrestricted' regression, including a constant.