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# The effect of land subsidence on real estate values

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**Abstract.** Land subsidence in the Netherlands, mainly occurring in its western and northern peat and clay soils, causes significant damage to houses and infrastructure, estimated at EUR 17 billion until 2050, through differential settlement of shallow foundations, negative skin friction and fungal decay of timber piles. Various studies and reports both in The Netherlands and abroad have addressed the potential economic impacts of subsidence on houses: yet, these studies lack spatially detailed data and instead rely on generic assumptions on expected damage restoration costs. By using a hedonic pricing model, this study examines the impact of subsidence on housing prices in the Dutch cities of Rotterdam and Gouda. In contrast to earlier studies, subsidence and its impact on property values are examined at house level. We test for the effect of subsidence with data related to (i) general (uniform) subsidence (mm $yr^{-1}$), (ii) differential subsidence of a building and (iii) subsidence of the surrounding area in relation to the house. Results show that uniform subsidence has the largest impact on property values with approximately −6 %, while “differential” and “surrounding” subsidence show respectively −2 % and no effect. These results could prove useful to policymakers, homeowners and housing corporations by generating a better understanding of the impact of subsidence on property values and subsequently to create awareness and spur investments in measures to mitigate damage. It should be noted that these results are specific to the research area are therefore not immediately scalable to other cities as local conditions differ.

## 1 Introduction

Land subsidence is a substantial problem affecting many cities worldwide. It potentially causes damage to houses, businesses, agriculture and public infrastructure (Reddish and Whittaker, 2012). These consequences are observed in the Netherlands, which is prone to land subsidence due to artificial drainage of clay and peat soils, which leads to clay settlement and peat oxidation (Nieuwenhuis and Schokking, 1997; Schothorst, 1977). Especially in urban areas subsidence rates can vary over space due to a heterogeneous subsurface and loading by man-made structures such as buildings and infrastructure (Zeitoun and Wakshal, 2013). Subsidence in the Netherlands is estimated to cause around EUR 20 billion in damage up until 2050, of which at least EUR 17 billion in expected repair costs of structural damage – e.g. restoring foundations, cracked walls, sloping floors – to buildings (Van den Born et al., 2016). This restoration costs approach does not fully represent socio-economic impact, as individual preferences such as risk aversion are not accounted for.

### 1.1 Valuing subsidence risk in housing market

An approach that better reflects such individual preferences is the revealed preference approach “hedonic pricing”, as e.g. used by Yoo and Perring (2017) to assess the effect of subsidence on house transactions in Phoenix, Arizona, and to assess the impact of earthquake risks in Groningen (Koster and Van Ommeren, 2015). This method takes all aspects which influence a buyer’s decision into account by using the actual transaction prices. Yoo and Perring (2017) find that houses located in a subsiding area were valued 9.9 % less on average. This study evaluates subsidence on a large scale – local subsidence patterns and differences in foundation are not included. In the Dutch housing market, awareness of real estate damage due to subsidence has recently increased, among other things due to the spike in damage reports in the dry summer of 2018 (Vereniging voor het Bouw- en Woningtoezicht, 2019).

### 1.2 Study scope

Where previous hedonic pricing studies have assessed subsidence effects on a larger spatial scale, this study investigates the economic effects of land subsidence on the housing market at the building level. We apply the hedonic pricing method to assess the impact of subsidence on the property market in two Dutch cities – both known to be affected by subsidence and with a building-level settlement data available: Rotterdam and Gouda. We expect results could prove useful to policymakers, homeowners and housing corporations by generating a better understanding of the impact of subsidence on property values and subsequently to create awareness and spur investments in measures to mitigate damage.

## 2 Methodology

This study uses the hedonic pricing method. The hedonic pricing model regards real estate property as a heterogeneous good comprised of many characteristics: the total value of a house is considered a function of the values of individual characteristics, such as physical building characteristics, neighborhood characteristics, and environmental characteristics (Freeman, 1979). In our study, the variable "subsistence rate" is one of the environmental characteristics. Hedonic pricing theory assumes that home buyers are perfectly informed on all variables, and thus take subsidence into consideration when purchasing a house by adjusting their bid price accordingly. On subsidence risk there is often limited information available, so buyers are unlikely to be perfectly informed. The results will tell if buyers take subsidence into consideration, based on data available to them. To assess the effect of subsidence on property values, we distinguish three different types of subsidence: (i) uniform subsidence of the house – based on data on "absolute" subsidence rate of the building, (ii) differential subsidence – based on data on differential (uneven) settlement of the building, and (iii) subsidence of the buildings' surroundings. The latter includes subsidence of e.g. sidewalks, yards and streets, which is expected to lead to problems with e.g. damaged utility pipes especially with 'fixed' adjacent houses on (concrete) foundation piles. We expect that all types have a negative effect on the property value, with differential subsidence being the most detrimental. In the end we are interested in the marginal value buyers place on the presence of subsidence in their prospective house. The marginal value entails how much home buyers are willing to pay less for an additional unit of subsidence (e.g. 1 mm extra per year).

### 2.1 Statistical model

According to Cropper et al. (1988), ordinary least squares (OLS) statistical models are best used in hedonic price analyses in the presence of omitted variable bias (OVB), meaning that an unincluded variable affects the outcomes. Even though control variables are included in the regression, it cannot be ruled out that some OVB remains. Furthermore, a log-linear form of the OLS model is chosen, as this allows for easy interpretation of marginal effects and it performs best in recovering marginal effects under model misspecification (Cropper et al., 1988), an issue that often affects hedonic pricing models (Kagie and Wezel, 2007).

### 2.2 Site selection

Rotterdam and Gouda were selected as they both are known subsidence-affected areas and sufficiently detailed subsidence data was available. The city of Arnhem is used as a control area to test the model prior to including the subsidence variables. This city was chosen because of its good comparability to Rotterdam and Gouda in terms of average house values and it being much less affected by subsidence.

### 2.3 Model set-up

First, the model using data on Arnhem is used to test the model's performance without subsidence variables, so only the control variables are included. This models looks like this:

$$\ln(P_i) = \alpha + \beta \boldsymbol{X}_i + \boldsymbol{\varepsilon}_i . \tag{1}$$

The outcome of this model tells us if in an area without (or with very little) subsidence the variables have the effects that would be expected. $i = 1, \ldots, n$ denotes each housing transaction, $P_i$ is the selling price. The vector of control variables is denoted by $\boldsymbol{X}_i$ and $\boldsymbol{\varepsilon}_i$ represents the error term. The models that we are interested in, for Gouda and Rotterdam, includes the subsidence variables[1]:

$$\ln(P_i) = \alpha + \beta \mathrm{Su}_i + \gamma \mathrm{Sd}_i + \delta \mathrm{Ss}_i + \theta \boldsymbol{X}_i + \boldsymbol{\varepsilon}_i . \tag{2}$$

The subsidence variables uniform ($\mathrm{Su}_i$), differential ($\mathrm{Sd}_i$) and surrounding ($\mathrm{Ss}_i$) are included with annual thresholds of 3, 1, 3 mm respectively. The thresholds are set at the levels at which subsidence is expected to have a damaging effect. These levels are established based on expert knowledge (Don Zandbergen[2], personal communication, 16 May 2019). Subsequently, neighborhood spatial fixed effects are added. This means that only houses within the same neighborhood are compared. This means that relatively similar houses are

[1] This is the Gouda specification, $\mathrm{Sd}_i$ and $\mathrm{Ss}_i$ are omitted for Rotterdam.

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compared, but also takes away some of the variation as subsidence rates within neighborhoods might be more similar than between neighborhoods. This makes sense when looking at a phenomenon which shows so much local variability as subsidence. The regressions analyses are run for each city separately. This is done to account for regional market differences.

### 2.4 Data

To execute the hedonic pricing analysis, we used data on the selling price of houses, housing characteristics, neighborhood characteristics and the extent of subsidence at the building level. The subsidence data is based on InSAR technology and hasan error margin of 1 mm (SkyGeo, 2019). This data is not open source, but was kindly provided by the municipalities of Rotterdam and Gouda. For Rotterdam only uniform subsidence data was available. Micro-data on selling prices and housing characteristics was provided by the Dutch association of real estate brokers (NVM). Neighborhood control variables were obtained from Statistics Netherlands (CBS). Transactions between 1985–2018, 2009–2015 and 2016–2018 are used for Arnhem ($N = 40\,890$), Rotterdam ($N = 23\,116$) and Gouda ($N = 3033$) respectively. These are the periods for which data was available.

## 3 Results

This chapter discusses the results that were obtained from the regression analyses. It is divided into four sections: one for the results of each city and a subsequent sensitivity analysis of the outcomes.

In the test model for Arnhem with just the control variables, most coefficients show the sign that was expected. The size of the house, the house being a monument, having a garage and central heating all have a significant positive effect on the selling price. The year in which the sale took place also positively influences the prices. This makes sense, as property values in the Netherlands have shown a positive trend over the past 30 years. This test analysis shows that the model produces credible results.

Only the results obtained from the fixed effects analysis are presented and discussed, as these are deemed to be the most trustworthy given the local variability of land subsidence (as discussed in Sect. 2).

### 3.1 Rotterdam

For Rotterdam, the model shows a significant effect on property values of around −7 %, which gives reason to believe that uniform subsidence has a negative impact of uniform subsidence on property values in Rotterdam.

### 3.2 Gouda

In Gouda, the model shows negative effects for uniform subsidence and differential subsidence. The effects are respectively −6 % and −2 %. Surrounding subsidence does not have a significant effect. This means that uniform subsidence shows the clearest negative effect on property values, while differential subsidence shows a smaller, but still negative, effect.

### 3.3 Sensitivity analysis

Although the subsidence thresholds (minimum subsidence rate) were carefully considered based on expert judgement, we test the results for different threshold values. Thresholds of 1, 2, 3 and 4 mm were tested for all subsidence variables.

In Rotterdam, the uniform subsidence coefficient becomes more negative with an increasing threshold, as to be expected: the more severe the subsidence, the larger the effect on the property value. In Gouda, the same trend is observed for uniform subsidence. Differential subsidence also shows a more negative effect when the threshold is increased. However, the 4 mm was not significant anymore. No trend was found for the variable surrounding subsidence.

## 4 Discussion

Using the threshold of 3 mm $\mathrm{yr}^{-1}$, the effect of uniform subsidence on property values is negative and significant. This is in line with the hypothesis that was posed for this effect. Uniform subsidence is found to have an effect of −7 % and −6 % in Rotterdam and Gouda respectively.

We expected differential subsidence to have a larger effect than uniform subsidence, as it has the potential to cause more structural damage. This is not reflected in the results for Gouda. Compared to the uniform subsidence effect in the fixed effects model, the differential subsidence threshold has a rather small effect of −2 % and is only slightly significant. A possible explanation for this might be the fact that there is a myriad of foundation problems in gouda, of which uniform subsidence is a better overarching proxy than differential settlement. The results of surrounding subsidence do not present a clear negative effect. The model shows an effect of zero. This points to the fact that house buyers do not typically consider negative effects of surrounding subsidence when buying a house – this is consistent with the relatively low awareness and long-term impact of this effect.

The exact size of the effects found in this study should not be emphasized too much, as the real impact could deviate. The information which buyers have about subsidence is limited and not everyone is likely to take subsidence into account. The negative and (mostly) significant coefficients do seem to persist across most of the different cities and subsidence types however, meaning that a negative effect of subsidence as a whole is likely realistic.

### 4.1 Comparison

The study results compare relatively well to the results of the hedonic pricing analysis of Yoo and Perring (2017). The authors find a decreased value of −9.9 % for houses located in a subsiding area. Compared to this, the (uniform subsidence) results of this study are more conservative at −6 % to −7 %. Other existing research is difficult to compare to this study, as both subsidence and house values are not measured at house level.

### 4.2 Study limitations and further research

Limitations of this study include the NVM sales data: it may be the case that houses suffering from subsidence damage are more difficult to sell, and are therefore underrepresented in the sample. Additionally, the selection of cities and study periods potentially limits the generalizability of this study. Future research with a larger database of settlement data and sales data would substantiate and strengthen the results. Furthermore, it would be interesting to see how effects will differ once information regarding subsidence damage (e.g. InSAR data) becomes more available. At present this data is often not freely accessible and home buyers not always aware of subsidence issues. To compare: information disclosure on wildfire risk in California led to a decrease in prices of those houses at risk (Donovan et al., 2007).

## 5 Conclusion

This study analyzed the effect of land subsidence on property values in Rotterdam and Gouda, the Netherlands, though a hedonic pricing analysis. We tested for three subsidence-related variables: uniform (proxy for overall subsidence of building), differential (proxy for uneven subsidence of building) and surrounding subsidence (house is fixed but adjacent area subsides). All three variables were expected to negatively affect property values, with the largest impact coming from differential subsidence, as this leads to most structural damage.

The fixed effects models for both Rotterdam and Gouda show a significant negative effect of uniform subsidence on property values of around −6 %. Differential subsidence is found to have a slightly significant negative effect of −2 %. The results indicate that surrounding subsidence has no effect.

Based on the outcomes, the total effect of land subsidence of property values is concluded to be negative. This study, is the first of its kind at this level of detail and sheds new light on the economic impact of land subsidence on the housing market. In a societal context, the results may be of interest to policymakers and other actors related to the housing market. Although difficult to compare to damage estimates based on restoration cost approach, this study provides further evidence that land subsidence negatively affects the built environment

**Data availability.** The datasets used for this article are unfortunately not publicly available. For the dataset owned by the Dutch Association of Real Estate Brokers (NVM), a non-disclosure agreement had to be signed. The same applies to the InSAR data obtained from the municipalities of Rotterdam and Gouda. This is sensitive data showing settlement of individual houses, which, if made public, could possibly influence future selling prices. Hence, the data was only provided conditional on confidentiality.

**Author contributions.** This article was written in collaboration with SK and OK. Both contributors played a vital role. SK conceptualized the research topic, methodology, provided resources, supervised the work and carried out editing and reviewing. OK contributed to the formal analysis, methodology, project administration, supervision, validation and carried out editing and reviewing.

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