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Chapter 5

The Effect of Depreciation on House Prices

Abstract[1]

In this Chapter we introduce a hedonic price model which enables us to disentangle the value of a property into the value of land and the value of structure. For given reconstruction costs our model gives a good approximation of the impact of physical deterioration, functional obsolescence and vintage effects on the structure and the impact of time on sale (external obsolescence) on the land value simultaneously. Our findings show that maintenance has a substantial impact on the rate of physical deterioration. After 50 years of not or barely maintaining a home a typical structure has lost around 43% of its value. In contrast, maintaining a home very well results in virtually no physical deterioration in the long run.

5.1 Introduction

As of 2011 housing capital accounts for 35% of the total capital stock in the US and almost 60% of household wealth in the Netherlands (US Bureau of Economic Analysis and Statistics Netherlands respectively). However, as all tangible assets do, housing loses its value as it ages. Also, widely publicized measures for house price appreciation overstate the capital gain from homeownership, because they do not take into account the cost of maintaining a home (Harding, Rosenthal, and Sirmans 2007). Therefore, knowing the pattern of depreciation and the effect of maintenance becomes important for tax policies and for national income and wealth accounting alike (Leigh 1980; Smith 2004).

Depreciation is defined as *"to be the decline in asset values (or shadow price) due to ageing"* (Malpezzi, Ozanne, and Thibodeau 1987; Shilling, Sirmans, and Dombrow 1991), suggesting that if depreciation is sufficiently large houses will actually decrease in value. However, this definition leaves room for three types of categories within depreciation: Physical deterioration, functional and external obsolescence.

[1]This chapter is based on Francke and Van de Minne (2015).

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Physical deterioration is the simple wear and tear on the structure and all its components. Evolution in technologies (building quality) and tastes also affect preferences for residential living. This can make a home *functionally obsolete* (Lusht 2001) or at least less valuable.[2] An example could be an unappealing floor plan or a kitchen without sufficient space to add modern day appliances. The main difference between physical deterioration and functional obsolescence is that physical deterioration affects the actual structure, whereas functional obsolescence affects the amount of housing services provided by the structure. As a result functional obsolescence does *not need* to occur (Conijn 1995), whereas (as with all physical assets) deterioration will always be present (Wilhelmsson 2008). Also, *maintenance* activities benefit the owner by slowing the rate of physical deterioration. Some maintenance decisions may even allow the value of property to go up (Knight and Sirmans 1996; Arnott and Braid 1997). However, maintenance is never sufficient to cure the effects of functional obsolescence.[3] The final component of depreciation is *external obsolescence* (Knight and Sirmans 1996; Lusht 2001). This encompasses changes, not to the property itself, but to the area surrounding the property (such as changes in traffic volume). Apart from depreciation it is important to distinguish the *vintage effect*: a preference for specific structure characteristics. These characteristics often correlate with the construction period. The vintage effect may even offset the negative effect of physical deterioration on the structure value (Wilhelmsson 2008).[4]

The main contribution of this study is that we introduce a model which gives a good approximation of the effect of all age effects (physical deterioration 'net' of maintenance, functional and external obsolescence and vintage effects) on house prices simultaneously. This benefits us in many ways. Most importantly, we show that the rate at which a home deteriorates is heavily dependent on the level of maintenance. Before describing the model we first list the most common problems in traditional hedonic models with respect to measuring depreciation.

Firstly, key variables in the field of depreciation are *perfectly collinear*: time of sale, construction year and age (McKenzie 2006; Coulson and McMillen 2008).[5] Time of sale represents the general market conditions which is reflected in land value (Bourassa et al. 2011). Time of sale also impacts structure values due to changes in reconstruction costs, such as labor and material costs. Age is a measure of the physical deterioration of the structure (Malpezzi, Ozanne, and Thibodeau 1987). Construction year measures the separate impact of functional obsoles-

[2] In some cases functional obsolescence is also referred to as ageing, for example Conijn (1995) and Bostic, Longhofer, and Redfearn (2007).

[3] Although in reality, some maintenance decisions actually will cure at least some function obsolescence. When households decide to maintain a home, they will likely take this opportunity to alter their home to better suit their current tastes (think of wall papers).

[4] Vintage effects have impact on property prices, because replacing and changing structure characteristics is time consuming and even in some cases impossible. Structures with all the desirable characteristics in place will therefore be perceived by buyers as having higher appreciation potential, since the buyers demand a premium for the risk and time involved in changing the characteristics (if even possible).

[5] Time of sale = age + construction year.

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cence[6] as well as vintage effects (Wilhelmsson 2008). Even worse, since changes in tastes for residential living changes over time, both functional obsolescence and vintage effects are time varying. A common strategy to circumvent the multicollinearity issue in traditional hedonic models is by omitting one of the variables. However, this strategy has the caveat that it biases (upward or downward) the age estimate for physical deterioration. For example, if older homes are appreciated more for its distinct architecture one would get a positive age estimate if the vintage effect is not taken into account. Another option is to impose some structure on the functional form for the variables age, construction year and time of sale. However, the choice of the functional form is arbitrary and the results for all age effects (physical deterioration 'net' of maintenance, functional and external obsolescence and vintage effects) heavily depend on the chosen functional form.

Secondly, assuming the property is a composite of land and structure value and the land value is positive, regressing age – again as proxy for physical deterioration – on the property value will *always* bias the estimate downward. The size of the bias depends on the fraction of structure value to total property value. The precision of the estimated age parameters also suffers if the study is carried out over multiple regions and over a large time-span, as the structure value as fraction of total property value can vary substantially over space and time (Bostic, Longhofer, and Redfearn 2007; Davis and Heathcote 2007; Davis and Palumbo 2008; Bourassa et al. 2011; Sirmans and Slade 2011).

Both problems can be circumvented by realizing that age and construction year only impact structure value, and time of sale only land value, the last conditional on known reconstruction costs over time.[7] This approach enables us to simultaneously estimate the impact of physical deterioration (age), the joint impact of functional obsolescence and vintage effects (construction year) on structure value, and the effect of time of sale on land value.

In this Chapter we disentangle house prices into land and structure values in a nonlinear hedonic price model from transactions of houses including land. The structure value is equal to the *given* reconstruction costs minus the *estimated* depreciation, corrected for the effects of maintenance. Using reconstruction costs as basis for structure values is quite common in literature (see for example Bourassa et al. 2011, Davis and Heathcote 2007, Davis and Palumbo 2008 and Diewert, De Haan, and Hendriks 2015). Due to severe zoning restrictions (which are quite common in most industrialized countries), there is no option value in structures (i.e.

[6] As Stahl (1985) noted, the supply of housing services a structure provides barely changes after construction.

[7] The theory behind this framework is that land and structure components are unique goods and therefore their prices respond differently to demand and supply side variables (see, Bostic, Longhofer, and Redfearn 2007; Davis and Heathcote 2007; Davis and Palumbo 2008; Bourassa et al. 2011, among others). On the demand side structures can be seen as capital input for housing production, whereas land capitalizes the market value of local amenities such as infrastructure and accessibility to employment and facilities. Although there will always be delivery lags and, to some extend, imperfect foresight of agents (Harter-Dreiman 2004), structures are relatively easily reproducible on the supply side. On the other hand, (desirable) land is by definition *not* reproducible. The direct consequence is that, contrary to the value of the structure, the value of the land is subject to demand factors, such as income, interest rates and demographics (Bourassa et al. 2011).

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the current structure is the optimal structure). The law of one price now dictates that in order to reproduce the cash flow generated by the property (imputed rent in the case of the owner-occupied market) one must purchase the land and *reproduce the structure* minus any accumulated depreciation. The land value is further disentangled into the value of the footprint of the structure and the value of the yard, because of their completely different uses. The value of the footprint is expressed as a function of its size, house type, time of sale and location. The yard value is expressed as a function of its size, time of sale and location. In case reconstruction costs are known – an assumption that is not unrealistic in practice – we are able to estimate the impact of depreciation on the structure value and the impact of time of sale on the total land value. We estimate our model on an extensive and reliable micro dataset, made available to us by the Dutch Association of Real Estate Brokers and Real Estate Experts (NVM), covering the period of 2000 up to 2012 for the region 's-Hertogenbosch in the Netherlands.

There are two major assumption we need to make for the model to work. The *first* assumption is that in case of small sample periods the functional obsolescence and vintage effect (construction year) on house prices is time-invariant. When looking at small sample periods only, the change in preferences for living could not have changed *that* much over the analysed period. Still, we need to acknowledge that the effect of functional obsolescence and vintage are in fact time-varying. As a result, part of the function obsolescence and vintage effects are likely to be 'caught' by the time of sale dummies.

The *second* assumption is that there is no (redevelopment) option value on land ownership (or conversely there is no economic obsolescence). This is in contrast with the more recent perspective of the interaction between structure and land values. From this perspective, the value of land ownership (distinct from ownership of a built structure) derives purely from the development or redevelopment option value that such ownership entails (Geltner et al. 2014).[8] As the current structure moves away from its highest and best use (HBU) over time, the redevelopment option on land ownership will grow. Thus, it becomes near impossible to disentangle the value of the structure with the value of the land, since demolition is the exercise of a *call option* on the new building, with the strike price being the construction cost plus demolition cost plus the opportunity cost of the preexisting building and it is the *location* which affects the value of the call option. In case of the Netherlands (where our analysis will take place) we are comfortable making the assumption that there is no (substantial) redevelopment option, since it is mainly legislation that depicts what structures should look like due to severe zoning restrictions (Andrews, Sánchez, and Johansson 2011; Sanchez and Johansson 2011), so the 'optimal structure' is equal to the current structure at all times. This is buttressed by the extreme low number of demolished structures in the Netherlands.[9]

[8] Note that this is consistent with the 'real options' model of land value as a development option (see, Yamazaki 2001, Titman 1985, Clapp, Lindenthal, and Eichholtz 2010 and Clapp, Bardos, and Wong 2012, for example) .

[9] Other assumptions concerning the real option theory do not hold in real estate markets as well, such as the assumptions on liquidity, arbitrage opportunity and zero transaction costs (Chang and Chen 2011).

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Our findings show that the total effect of physical deterioration of structures over time differ significantly between a well maintained and a poorly maintained structure. The flexible specification of the age function also empirically verifies that year-to-year physical deterioration decreases with the age of the structure, in line with the findings of Cannaday and Sunderman (1986) and Goodman and Thibodeau (1995). Barely maintaining a home results in a 1.6% annual physical deterioration for the first 15 years, 0.9% annually for the first 30 years and 0.9% annually for the first 50 years. Maintaining a home very well results in almost no physical deterioration.

By comparing the footprint, yard and structure price indices we find that the average rate of return is lowest for the structure and highest for the footprint. The volatility is highest for the yard index, followed by the footprint and structure index. Worthy of note, the structure, footprint and yard price indices are barely correlated.

The setup of this paper is as follows: Chapter 5.2 provides a literature review on depreciation and disentangling land and structure values. Chapter 5.3 provides a detailed description of the empirical model. Chapter 5.4 describes the dataset used and provides descriptive statistics. Chapter 5.5 discusses the estimation results and, finally, Chapter 5.6 concludes.

5.2 Literature Review

Using the age and construction year of a property as a proxy for its depreciation in a hedonic framework is quite common in housing, as well as non-housing models (Wilhelmsson 2008). It is also quite common to use the construction year of the structure as a measure for the combined effect of functional obsolescence and vintage, by claiming that structure characteristics are usually highly correlated with the year they were built in (Coulson and McMillen 2008; Wilhelmsson 2008). The way households appreciate properties from a certain vintage, changes over time. Papers in which maintenance data is available usually analyse the level of maintenance in combination with the age of the property to find the physical deterioration 'net' of maintenance (Harding, Rosenthal, and Sirmans 2007). In the remainder of this Chapter we will describe the results of previous papers in the field of depreciation and try to answer the question why different papers find various depreciation rates.

Malpezzi, Ozanne, and Thibodeau (1987) conducted a survey on depreciation models based on literature prior to 1987. From the 12 selected studies only one study (Leigh 1980) did not use a hedonic model with age as proxy for physical deterioration on the right-hand side and transaction prices on the left-hand side. The estimated annual depreciation rates in these studies varied significantly between 0.38% and 2.40%. Malpezzi, Ozanne, and Thibodeau (1987) concluded that the variations in the reported results were due to differences in the definition of depreciation, differences in the models and data used and the conditions of the (local) real estate market at the time of the study. By using the same hedonic model and data for 59

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metropolitan areas in the US Malpezzi, Ozanne, and Thibodeau (1987) showed that physical deterioration – which was modeled by age, age^2 and age^3 in a hedonic framework – varies spatially. Table 5.1 shows the average age effect for several studies.

Building quality and climate differ over space. Therefore, the rate at which homes deteriorate can differ spatially as well. However, if we look in more detail at the different age coefficients Malpezzi, Ozanne, and Thibodeau (1987) estimate per metropolitan area, we see that in some regions age has a positive effect on house prices. Similarly, Rubin (1993) and Chang and Chen (2011) estimate a positive age coefficient in one or more regions in a hedonic framework. In general we can say that these studies (together with Shilling, Sirmans, and Dombrow 1991; Smith 2004; Sirmans et al. 2006) find a very small effect of age on property value.

The difference between the studies mentioned above and the other studies in Table 5.1 is that they incorporate neither construction year nor maintenance as control variables, or use low quality maintenance data alone in the regression. The most obvious reason to omit the construction year is to circumvent the multicollinearity problem between transaction year, construction year and age. The most plausible reason to omit the maintenance effect is a lack of available maintenance data.

Omitting maintenance from the regression biases the age effect downward for obvious reasons. Omitting the level of maintenance will also induce age-related heteroskedasticity (Goodman and Thibodeau 1995). The reason is that the variance of the price will increase with the age of the property, as the condition of the house (renovated, maintained or completely run down) is likely to vary more.

Shilling, Sirmans, and Dombrow (1991), Knight and Sirmans (1996), and Bourassa et al. (2011) claim that vintage and maintenance *can* be omitted if only relatively newly constructed homes (Age $\leq$ 20 years) are considered. Even though this solves the aforementioned identification issue, the question is to what extent these assumptions hold and what the (short-run) age estimate says about long-run physical deterioration. Wilhelmsson (2008) argues the construction year can be omitted, again to circumvent the multicollinearity problem, as long as age is entered in a nonlinear (in this case quadratic) form. In this setup age measures the combined effect of physical deterioration, vintage effects and functional obsolescence. However, this strategy has two drawbacks. Firstly, this makes it impossible to disentangle the effects of physical deterioration, functional obsolescence and vintage. Secondly, previous studies have shown that the vintage effect should be entered in a more flexible (less rigid) way (Goodman and Thibodeau 1995).

Two papers (Harding, Rosenthal, and Sirmans 2007; Coulson and McMillen 2008) do actually include the variables age, construction year and time of sale, using two completely different strategies. Firstly, Harding, Rosenthal, and Sirmans (2007) modify the standard Case and Shiller (1987) repeat sales index by taking the time-varying variables age and maintenance into account. Assuming that the characteristics (and subsequent shadow prices) of a structure do

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Table 5.1: Summary of the depreciation literature.

Author(s)	Age	NLAge	CY	Time	Maint.	L & S	Comments
Malpezzi, Ozanne, and Thibodeau (1987)	−1.00%	✓	X	✓/X	X	X	Time variable is entered as trend. Meta analysis. Some regressions have positive age estimate. Also Age^3. Micro data (AHS).
Shilling, Sirmans, and Dombrow (1991)	−1.18%	✓	X*	✓/X	X	X	Only new builds.* Time variable is entered as trend. Age is entered piecewise constant. (Small) micro data.
Rubin (1993)	−0.25%	X	X	X	✓/X	X	Some regressions have positive age estimate. Meta analysis. Characteristics are as assessed by the owner-occupiers themselves. 1 regression has a positive age estimate. Micro data (AHS).
Goodman and Thibodeau (1995)	−1.46%	✓	X	✓	X	X	Only transactions from 2 years. Also Age^2, Age^3 and Age^4 in separate regression. Micro data on single-family homes in Dallas, US.
Knight and Sirmans (1996)	−1.89%	✓	X*	✓	✓	X	Only new builds.* Unreliable database. (Small) micro data.

NLAge is Non-Linear Age specification, CY is construction year (vintage), Maint. is level of maintenance, L & S stands for whether or not the authors separate land and structure values, AHS stands for Annual Household Survey and N/A is not available. In case of a meta analysis the age effect is the average beta coefficient, in case of multiple regressions or piecewise constant age specification (Shilling, Sirmans, and Dombrow 1991) the most representative beta coefficient is presented.

* Because these authors only look at new builds they assume there is no vintage effect and that no maintenance has been done as of yet. On average the oldest structures in these papers are 20 years.

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Author(s)	Age	NLAge	CY	Time	Maint.	L & S	Comments
Smith (2004)	−1.11%	✓	X*	✓	✓/X	✓/X	The assessed land values are assumed to be constant over time. Assessed land values for one year only. Author interacts time of sale and location with age. Only (linear) vintage effect for properties built before 1930.* Maintenance level for one year only and assessed area-wide. Land specific variables regressed on structure value.
Sirmans et al. (2006)	−0.89%	X	X	✓/X	X	X	Time variable is entered as trend. Meta analysis. Multiple data sources.
Harding, Rosenthal, and Sirmans (2007)	−2.50%	✓	✓/X**	✓	✓	X	Repeat Sales Model.** Age is entered on a logarithmic scale. Micro data (AHS).
Wilhelmsson (2008)	−1.18%	✓	X	X	✓	X	The derivative of the age function is 0 at 23 years. Separate indoor and outdoor maintenance. Micro data on Stockholm, Sweden.
Coulson and McMillen (2008)	−1.65%	✓	✓	✓	X	X	Also Age^3 and Age^4. Also a semi-parametric approach as (McKenzie 2006) proposed. Micro data on the city of Chicago.
Chang and Chen (2011)	−0.46%	X	X	✓	✓/X	✓	Characteristics are as assessed by the owner-occupiers themselves. 2 of the 6 regressions have positive age estimate. Meta analysis. Micro data (AHS).

NLAge is nonlinear Age specification, CY is construction year (vintage), Maint. is level of maintenance, L & S stands for whether or not the authors separate land and structure values, AHS stands for Annual Household Survey and N/A is not available. In case of a meta analysis the age effect is the average beta coefficient, in case of multiple regressions the most representative beta coefficient is presented.

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not change over time, the construction year should be omitted from the regression. The unfortunate outcome is that in this framework one cannot measure the joint effect of functional obsolescence and vintage. Subsequently, Harding, Rosenthal, and Sirmans (2007) *force* an arbitrary nonlinear (log) transformation on age to avoid perfect collinearity with the annual house price index. The estimate of ln(Age) is -0.14, which results in an annual physical deterioration of about 2% for the first 20 years (of total property value).

In contrast to the heavily restricted specification of the age effect in the model of Harding, Rosenthal, and Sirmans (2007), Coulson and McMillen (2008) employ a more flexible approach, as proposed by McKenzie (2006) to estimate the age, construction year and time of sale effect simultaneously.[10] The multicollinearity is solved by assuming that some neighbouring parameters in the age, construction year and time of sale effect $(\beta_j - \beta_{j-1})$ are equal to a known constant (which in practice is set to 0). The big caveat with this approach is that the final estimates are sensitive to the parameters that are assumed to be equal and that many alternative restrictions on neighboring parameters may be considered (corresponding to the age, construction year and time of sale variables).

Coulson and McMillen (2008) estimate that the effect of age on property values is actually positive after the structure hit the age of 43 years. This is very likely to be a maintenance effect (the authors do not include level of maintenance in their model, see Table 5.1), since they include construction years to counteract the vintage (and functional obsolescence) effect.

Finally, the separability of land and structure values should be taken into account when estimating the depreciation effects (Chinloy 1980; Smith 2004). Physical deterioration and functional obsolescence (as well as vintage) only affect the structure value of the property and not the land value. As stated in Chapter 5.1 ignoring this will bias the age effect downward. As shown in Table 5.1 only two studies (Smith 2004; Chang and Chen 2011) considered this in their analysis.

In the case of Smith (2004) assessed land prices are subtracted from property prices to end up with structure values. However, these assessed values are only available to the author for one year (1996). The author makes the unrealistic assumption (see Bostic, Longhofer, and Redfearn 2007; Davis and Heathcote 2007; Davis and Palumbo 2008; Bourassa et al. 2011) that land values are constant over time in real terms in order to determine land values of properties in other years than 1996. This influences some key results. For example, Smith (2004) interacts time of sale with age and concludes that the age effect decreased between 1993 and 2000. This could, however, be explained be realizing that land values increased at a higher rate than structure values over this period.

In summary, one could say that in order to find the net physical deterioration of structures (with age as its proxy) in a hedonic framework one should control for maintenance, construc-

[10] By comparison, the authors also employ a more standard hedonic model where they force a nonlinear structure on age as Harding, Rosenthal, and Sirmans (2007) did. However, here we only discuss their nonparametric approach (McKenzie 2006).

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tion year (as proxy for vintage and functional obsolescence) and time of sale. It has also been argued that physical deterioration and construction year should be attributed specifically to the structure value of the property. Omitting maintenance and not separating the property value into land and structure components will bias the age coefficient downward, and omitting the construction years will bias the age coefficient either upward or downward. A summary of the key variables is given in Table 5.2.

Table 5.2: Summary of proxy variables for construction costs, depreciation and vintage effects.

Proxy variable	Structure	Land
Time of sale	- Changes in construction costs	- Changes in land prices. (External obsolescence (D))
Age & Maintenance	- Physical deterioration (D)	
Construction period	- Functional obsolescence (D) - Vintage effects	

D = part of depreciation.

5.3 Model

In this Chapter we provide econometric model specifications. We start with a 'base-line' model in Chapter 5.3.1. This is a traditional hedonic model in which we do not make the distinction between land and structure components. In Chapter 5.3.2 we provide the model in which we *do* decompose the transaction price into structure and land value. Chapter 5.3.3 discusses assumptions and some limitations to this model. The findings of both models will be compared in Chapter 5.5.

5.3.1 Base-line Specification

In this Chapter we provide the base-line specification. It is a traditional hedonic model with log house prices ($\ln P$) on the left hand side and house characteristics on the right hand side. This basic specification is in line with most of the models presented in Table 5.1, and is given by:

$$\begin{aligned}\ln P_{it} =&(d_{it}^{M} \times A_{it})\beta_1^{Age} + (d_{it}^{M} \times A_{it}^2)\beta_2^{Age} + \\ & d_{it}^{Time}\beta^{Time} + d_{it}^{CY}\beta^{CY} + x_{it}'\phi + \varepsilon_{it}.\end{aligned} \tag{5.1}$$

The subscripts $i = 1, \ldots, N$ and $t = 1, \ldots, T$ denote an individual property and time, where N is the number of observations and T is the number of time periods. The variable P is transaction price and A is age. The row vectors d_{it}^{M}, d_{it}^{CY}, and d_{it}^{Time} contain dummy variables

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for the accumulative level of maintenance up to time of sale, construction years and time of sale[11] and have the corresponding coefficient vectors β^{Age}, β^{CY} and β^{Time}.

Age (A) is used to measure the rate of physical deterioration. In case the renovation year is available in the data, it is better to define age as the difference between time of sale and year of renovation (Lusht 2001). This means that we will likely get a conservative estimate of the rate of physical deterioration. However this is a data issue and not so much a model issue. We argued that (only) physical deterioration can be retarded by maintenance (M) activity, thus age is interacted with maintenance. Even though this assumption is made by several papers (Wilhelmsson 2008), there are real life examples which indicate that some maintenance activities also affects functional obsolescence. If households for example need to replace the 'old' heating system, they will probably not replicate the system as it was, but upgrade to a system which better reflects current tastes and preferences. In this regard there is also a semantic discussion on what the difference is between 'regular' maintenance and renovations. As with the age parameter, not having renovation data is unfortunate when estimating functional obsolescence. Thus, the construction estimates will probably be an underestimation as well, especially when considering older properties. Both vintage effects and functional obsolescence are dependent on construction year (or renovation year in case of functional obsolescence), although the concepts are different. By using construction year as only explanatory variable it is not possible to distinguish between vintage effects and functional obsolescence. Time of sale ($Time$) represents the general market conditions.

Because time of sale, construction year and age are perfectly collinear we either have to omit one of these variables, or force a structure on the functional form on at least one of these variables. We choose to force both a linear and a quadratic function on age, because this is commonly practised in literature (Goodman and Thibodeau 1995).[12]

The vector x_{it} contains all other (control) variables of interest, such as location dummies, floor size and land size, with corresponding coefficient vector ϕ. These variables will be discussed in more detail in Chapter 5.3.2.

The error term ε is assumed to be normally and independently distributed with fixed variance σ^2. In contrast to Diewert, De Haan, and Hendriks (2015), we use the natural logarithm of the transaction price, instead of the transaction price itself, for two reasons. First, the resulting residuals are closer to normality. Second, it makes more sense to minimize the relative difference between model value and transaction price, as opposed to the difference itself. The first can be done approximately by using the natural logarithm of the transaction price as the dependent variable. The model is estimated by ordinary least squares.

[11] Obviously one category for the row vectors of dummy variables should be omitted to avoid the dummy trap.
[12] In case of the linear specification the age square term must be omitted from Eq. (5.1).

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5.3.2 Model for Structure and Land Values

In this Chapter we provide the model in which we decompose the transaction price in structure and land value. The age and construction year effects are attributed specifically to the structure value. In its simplest form the model is provided by:

$$\ln(P_{it}) = \ln(S_{it} + L_{it}) + \varepsilon_{it} \tag{5.2}$$

$$S_{it} = C_{it} \times \exp(D_{it}), \tag{5.3}$$

$$L_{it} = IL_{it} + G_{it}, \tag{5.4}$$

where S is the value of the structure, L is the value of the land, C is the (re)construction value, and $\exp(D) - 1 \approx D$ is the percentage impact of physical deterioration, functional obsolescence and vintage effects on the value of the structure. By taking the exponent of D we assume that the value of the structure cannot be lower than 0.[13] It is assumed that the value of the yard (G) and the value of the footprint (IL) add up to the value of the (total) land (L).

The individual components of Eqs. (5.2) – (5.4) are specified as follows:

$$C_{it} = \mathrm{FS}_{it}^{\gamma} \times c_{ref,t} \times d_{it}^{Dem}, \tag{5.5}$$

$$D_{it} = \underbrace{(d_{it}^{M} \times d_{it}^{A})\beta^{Age}}_{\text{physical deterioration}} + \underbrace{d_{it}^{CY}\beta^{CY}}_{\text{vintage}}, \tag{5.6}$$

$$\begin{aligned} IL_{it} = {} & \mu_{t_0}^{IL} \times (\mathrm{ILS}_{it}^{s} + \mathrm{ILS}_{it}^{l}\alpha_l) \times (1 + d_{it}^{\mathrm{Time}}\beta^{\mathrm{Time}}) \\ & \times (1 + d_{it}^{\mathrm{LOC}}\beta^{\mathrm{LOC}}) \times (1 + d_{it}^{\mathrm{PT}}\beta^{\mathrm{PT}}), \end{aligned} \tag{5.7}$$

$$\begin{aligned} G_{it} = {} & \mu_{t_0}^{G} \times (\mathrm{GS}_{it}^{s} + \mathrm{GS}_{it}^{l}\delta_l) \times (1 + d_{it}^{\mathrm{Time}}\lambda^{\mathrm{Time}}) \\ & \times (1 + d_{it}^{\mathrm{LOC}}\lambda^{\mathrm{LOC}}). \end{aligned} \tag{5.8}$$

Eq. (5.5) represents the (re-)construction cost (C). The (re-)construction value per square meter is based on a reference property. It depends on structure type (for example, single family homes, apartments, etc.), time (t) and region, and is denoted by c_{ref}. FS is the floor size. For $\gamma = 1$ the construction costs are proportional to the floor size, for $\gamma < (>)1$, the construction costs are less (more) than proportional to the floor size. The parameter γ will be estimated from the data. Dummy variable d_{it}^{Dem} is 0 in case the property is bought to be demolished and 1 otherwise. This effectively corrects for the right censoring of the age data. However, in our case we do not observe which properties are bought to be demolished. In addition, homes are barely demolished in the Netherlands. According to *Statistics Netherlands* less than 100 homes were 'extracted' after 1988. This number also includes homes that were burned down or

[13] One can think of real world situations in which the structure value is actually lower than 0. The most straightforward example is the case in which the cost of demolishing the structure is more than the actual value of the structure itself. However, in reality this rarely happens since structures are usually demolished a considerable time before the structure value hits 0, see Bokhari and Geltner (2014).

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multiple homes that were converted to (for example) one home. Thus, for this application, we fix d_{it}^{Dem} at 1.

Eq. (5.6) represents the impact of physical deterioration and vintage effects on the construction value (D). In the base-line model we had to force a structure on the functional form of age to circumvent perfect collinearity with time of sale and construction year. However, disentangling house prices into structure values and land values solves the identification problem in itself. The rate of physical deterioration should be estimated with as little structure on the age parameter as possible (Cannaday and Sunderman 1986; Goodman and Thibodeau 1995). Therefore, age is entered in Eq. (5.6) by dummy variables (d_{it}^{Age}). As in the base-line model age is interacted with maintenance. The joint effect of functional obsolescence and vintage is captured by construction year dummy variables (d_{it}^{CY}).

To avoid the dummy trap the most recent construction year, age = 0 and 'good' maintenance level should be omitted, since these omitted categories represent the reconstruction value best.[14] It is also preferred that the construction year cohort reference group overlaps the time of sale period. Otherwise, you could find a vintage effect on newly constructed homes. Furthermore, note that including time of sale in Eg. (5.6) – in case changes in reconstruction cost over time are unknown and need to be estimated – would lead to unidentifiable coefficients. [15]

The value of footprint IL in Eq. (5.7) depends on the size of the footprint (ILS), time of sale (d_{it}^{Time}), location (d_{it}^{LOC}) and property type (d_{it}^{PT}). The value of the yard G in Eq. (5.8) depends on the size of the yard, time of sale and location.

We expect that the marginal price per square meter of land decreases when the size of the land increases (Lusht 2001), irrespective of the use of the land. We model this by entering the land size as a linear spline. We first split both land sizes in small and large. In case of the footprint this would look like: $ILS = ILS^s + ILS^l$. In our case the difference between small and large is 75m^2. For example, in case the footprint size is 200m^2, then ILS^s is 75m^2 and ILS^l is 125m^2. The same knot is used for the split in yard size: $GS = GS^s + GS^l$.

Location (LOC) captures all kinds of location-specific amenities, which influence demand. It also – together with time of sale – controls for external obsolescence. We model location as dummy variables for four digit ZIP codes. Time of sale captures general market conditions and external obsolescence, and is modelled by dummy variables for the year of sale.

Zoning restrictions also restrict the property type (PT) allowed on the footprint. This will likely result in differences in value for the footprint (because of local availability or affordability of each property type, for example). We model property type as dummy variables as well.

The coefficient $\mu_{t_0}^{IL}$ ($\mu_{t_0}^{G}$) gives the price per square meter for the footprint IL (yard G) for

[14] Theory predicts that the housing services provided by a newly constructed structure is proportional to the value of the structure (Conijn 1995).

[15] In case the reconstruction values are not a good approximation of the structure value, due to option value and economic obsolescence, one could replace $c_{ref,t}$ with a coefficient χ_t and subsequently estimate it from the data (on a disaggregate level as possible). The big issue here is that χ also depends on time of sale and is thus not identifiable. In this case a structure needs to forced on χ_t. However, this is out of the scope of this research.

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the reference home in period t_0. The coefficient β^{Time} (λ^{Time}) gives the percentage of land price changes over time for the footprint (yard). The coefficient β^{LOC} (λ^{LOC}) gives the percentage premium or discount of the prices per square meter relative to the reference location for the footprint (yard). The coefficient α_l (δ_l) provides the relative prices of large land sizes compared to small land sizes for the footprint (yard). Finally, the coefficient β^{PT} gives the percentage premium or discount of the price for a certain property type relative to the reference property type for the footprint.

The model is nonlinear in its parameters and is estimated by nonlinear least squares.

5.3.3 Further Model Assumptions and Limitations

In Section 5.1 we introduced two major assumptions: (1) Functional obsolescence is time-invariant in short sample periods and (2) there is no redevelopment option value on land in case of the Netherlands. This Section reviews some smaller assumptions we make.

The first is that physical deterioration is uniform across structures. Obviously, a home built with low quality materials (or by a low quality contractor) will have a different rate of physical deterioration than a home built with high quality materials (or by a high quality contractor). However, we do not have data on the quality of the structure. Moreover, there is a possibility that building quality is correlated with the construction year. In this case, the vintage / functional obsolescence effect we find could actually be a physical deterioration effect. Even though we cannot completely rule out this possibility we should mention that one of the oldest still existing laws in the Netherlands is the Housing Act (in Dutch: *Woningwet*), which was introduced in 1902. The main purpose of this law is to guarantee a relatively high quality of newly constructed dwellings.[16]

Depreciation and vintage can vary with location (Malpezzi, Ozanne, and Thibodeau 1987; Smith 2004). For example, homes built near the ocean will deteriorate relativity quickly and 1930s homes will be valued differently (i.e. vintage) between New York and Miami. Since, in our application we will only look at a single region with relative a small number of dwellings the second assumption is that the parameters for physical deterioration and vintage are fixed within this region.

Furthermore, older structures tend to filter down to families of lower economic status (Rosenthal 2008), thus lowering land prices (Glaeser and Gyourko 2005). This last argument introduces the notion of endogeneity between structure value and level of maintenance, because the lower income households have fewer means to maintain their homes (Harding, Rosenthal, and Sirmans 2007)[17]. However, the endogeneity of house prices and maintenance is a smaller issue

[16] The quality of the structure can also be correlated with location. More specifically, we expect higher structural quality at better locations. In Chapter 5.5 we introduce a robustness check which allows for higher structure values at more expensive locations.

[17] This self-reinforcing decline is punctuated by increases in demand as obsolete and dilapidated structures are demolished and replaced by new structures attractive to higher income families (Rosenthal 2008).

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in the Netherlands since the way the mortgage market is designed in the Netherlands excludes households with low incomes or low wealth from the owner-occupier market (Schilder 2012). Thus, the third assumption is the level of maintenance is exogenous to house prices.

Still, as mentioned before, one major issue with our data is that we do not observe the year of renovation. Even though dwellings are hardly demolished, and the main characteristics of dwellings remain fixed (due to legislation) in the Netherlands, many (smaller scale) characteristics still alter during major renovations. This will bias the age estimates downwards. However, note that this is a data issue and not a issue of the model. In case the date of renovation is observed, one should take the renovation year to measure functional obsolescence and take the age of a property from year of renovation to measure physical deterioration.

Given the caveats (and mitigating circumstances) separating property values in land and structure values is still assumed to be a good working assumption. It should also be noted that none of the existing models are successful in circumventing all of the critiques described above.

5.4 Data and Descriptive Statistics

We estimate our model on the region of 's-Hertogenbosch in the Netherlands. Figure 5.1 provides a map of the distribution of the different regions within the Netherlands. Note that the largest city in the region of 's-Hertogenbosch (with a population of 150,000) is the city with the same name. Except for the relatively large city of 's-Hertogenbosch, the region also entails smaller cities (like Zaltbommel, population 28,000) and rural areas, making it a diverse area. The sales dataset is provided by the NVM, the largest brokers organization in the Netherlands; about 70% of all real estate brokers in the Netherlands is affiliated to the NVM. A total of 171 brokerage firms were active in the region of 's-Hertogenbosch in our sample period from 2000 up to 2012. On average they sold 55 houses during this period. In total, 56 brokerage firms were responsible for only 1 transaction. The most successful brokerage firm in terms of sales was responsible for 11.90% of the sales.[18]

For each house we observe the transaction price and the date of sale, that is the date of signing the preliminary sales contract. We also observe the house type (12 types), the construction year of the house, the number of floors, the total land size in square meters, the size of the yard in square meters, the maintenance level (9 categories varying from very poorly maintained to perfectly, separate numbers for inside and outside maintenance), the roof type (4 in total), parking facilities (4 types), and address.

The calculation of the construction costs is based on data from Bouwkostenkompas. It contains construction costs for 58 reference homes and eight types of extensions (including parking facilities) for the 12 different provinces in the Netherlands. By comparing the characteristics of the houses in the NVM database to the 58 reference homes we are able to calculate construc-

[18] These numbers were taken after the filters were applied, see below.

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Figure 5.1: Distribution of the NVM districts in the Netherlands.



The 's-Hertogenbosch region is 63. For your reference, 34 is Amsterdam.

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tion costs of individual houses. However, the data obtained from Bouwkostenkompas are only available for 2011. In order to calculate the construction costs in preceding years we backtrack to the year of sale, using the (non-constant quality) construction costs index provided by the national statistical agency, Statistics Netherlands.[19] The different data sources are summarized in Table 5.3.

Table 5.3: Overview of the data and sources.

Source	Data	Years
NVM	Sale and house characteristics	1985 – 2012
Calcsoft	Construction costs per m^2 for 60 reference homes in 2011	2011
Statistics Netherlands	Construction cost index	1906 - 2013

Since we do not observe land sizes (let alone yard sizes) for apartments in the data, we are forced to omit apartments from the analysis. The remaining house types are terraced, semi-detached and detached homes. Due to data limitations we can match the NVM transactions to the construction cost database for transactions in 2000 and upward; for transactions prior to 2000 essential data on, for example, type of roof is missing. Other filters have been applied as well. For example, houses with extreme transaction prices or lot sizes and newly constructed homes are omitted. [20] After applying the data filters 9,331 observations are available.

Subsequently, a few data transformations are made. Age is calculated by subtracting the construction year from the year of sale. The size of the footprint is calculated by subtracting the size of the yard from the total land size.

For maintenance 18 categories are available, 9 for both inside and outside maintenance, potentially resulting in 81 different combinations. However, the interior and exterior maintenance figures are highly correlated, and some categories have a very low incidence. Therefore, we reduce the number of maintenance categories to 3, based on the total of interior and exterior maintenance, varying from 'poorly to mediocre maintained' (denoted category -1) to 'well maintained' (denoted category $+1$). Reducing the number of maintenance categories also reduces potential bias in the brokers' reported view of maintenance. More details on definitions and coverage can be found in Table 5.4.

The level of maintenance in our analysis is as assessed by the individual sales brokers. Even though there are no specific guidelines for assessing the level of maintenance, the individual

[19] Obviously an index on the most disaggregate level is advised. However, in the case of the Netherlands, national level data will suffice, because distances in the Netherlands are small. With roughly 12,000 square miles the Netherlands is comparable in size to a relatively small state in the US like Massachusetts (10,555 sq mi).

[20] We omit newly constructed homes, since land prices in the Netherlands for new construction are usually pre-determined by municipalities and are thus not market prices in itself. Also, since construction can take a year or more, the prices of the properties when finished, might not be representative of the same properties when the contracts were signed.

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Table 5.4: Summary of the maintenance variable.

Level	Description	Criteria	N. observation	%
-1	Bad to mediocre	$M < 13$	740	7.9%
0	Normal	$13 \leq M < 16$	7,264	77.8%
1	Very good	$M \geq 16$	1,327	14.2%
Total			9,331	100.0%

M denotes the total of interior and exterior maintenance.

brokers affiliated to the NVM are supposed to take courses in engineering, which are provided by the NVM itself. The brokers have to redo these courses on a yearly basis in order to keep their NVM license. Thus, we assume that the building quality/maintenance is assessed uniformly by the different (171) brokerage firms active in 's-Hertogenbosch.

There is the question whether or not the age of the structure influences the way brokers assess the level of maintenance. If maintenance is measured in an absolute way, one expects that on average the older the property the lower the average maintenance. If it is measured relative to the age of the structure, one would expect that the average maintenance does not depend on age. Figure 5.2 shows the average maintenance level per construction year. If Figure 5.2 would be a flat line, it would be evident that brokers assess the level of maintenance relative to the age of the structure. In this case there would be an interaction effect between maintenance and age. However, Figure 5.2 reveals that, on average, older structures *are* assessed to be maintained less than newer structures. Still, we do now what the 'true' slope of Figure 5.2 would be if brokers truly assessed the level of maintenance in an absolute way. Thus, whether or not brokers asses the level of maintenance relative or absolute to age is more of an empirical question and we will keep the interaction between maintenance and age in the model.

Some details on terraced and (semi-) detached homes in the region 's-Hertogenbosch, from 2000 onwards, are given in Table 5.5. The frequencies of construction periods, house types, years of sale and zip codes can be found in Table 5.6.

Table 5.5 shows that the average floor size, footprint, yard size and transaction price per m^2 floor size are highest for detached houses, and lowest for terraced houses. Table 5.6 shows that terraced houses constitute 55% of the transactions and detached houses only 6%.

Since the age of the houses is the most important variable in this paper, we will look into it in more detail. First of all, neighborhoods tend to be developed in roughly the same time period (Clapp and Giaccotto 1998). This suggests that there should be more variation in the age of the housing stock throughout 's-Hertogenbosch than within the individual 4 digit zipcodes (Rosenthal 2008). To confirm that premise, we first measure the standard deviation of the age of the housing stock as of 2012, within each 4 digit zipcode (LOC). Secondly, we order the standard deviations per 4 digit zip code from lowest to highest. The percentiles presented in Table 5.8 are based on this ordering. As a comparison, the difference between the standard deviations of the individual 4 digit zip code and the entire region of 's-Hertogenbosch ($HERTOG$)

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Table 5.5: Some descriptive statistics for 's-Hertogenbosch, 2000 - 2012.

		Total	Terraced	Semi-detached	Detached
Number of observations		9,331	5,095	3,659	577
Transaction price	mean	€261,672	€215,654	€297,614	€440,095
	std. dev	€88,684	€51,062	€68,570	€125,084
	min	€90,000	€99,832	€90,000	€142,500
	max	€1,200,000	€680,000	€837,500	€1,200,000
Transaction price per m^2 floor size	mean	€1,961	€1,782	€2,127	€2,497
	std. dev	€571	€433	€391	€1,378
	min	€876	€876	€1,144	€1,332
	max	€4,492	€4,492	€4,442	€3,933
Reconstruction costs	mean	€180,257	€139,221	€216,615	€312,056
	std. dev	€65,951	€31,142	€45,941	€88,200
	min	€13,252	€13,252	€63,182	€33,763
	max	€691,514	€438,332	€530,402	€691,514
Reconstruction costs per m^2 floor size	mean	€1,328	€1,136	€1,533	€1,722
	std. dev	€268	€138	€148	€330
	min	€850	€850	€1,028	€939
	max	€3,376	€2,465	€2,032	€3,376
Floor size in m^2	mean	134	122	142	183
	std. dev	31	20	29	50
	min	10	12	45	10
	max	450	265	350	450
Footprint in m^2	mean	127	88	158	278
	std. dev	69	26	50	112
	min	10	10	24	10
	max	590	511	564	590
Yard in m^2	mean	98	61	126	241
	std. dev	92	34	95	179
	min	1	1	1	16
	max	1,500	1,400	1,400	1,500
Maintenance	mean	1.063	1.027	1.092	1.196
	std. dev	0.466	0.454	0.464	0.548
	min	0.000	0.000	0.000	0.000
	max	2.000	2.000	2.000	2.000
Age in years	mean	29	31	27	25
	std. dev	19	19	19	20
	min	1	1	1	1
	max	106	106	105	98
Number of rooms	mean	4.895	4.740	5.022	5.458
	std. dev	0.975	0.860	0.999	1.380
	min	1.000	1.000	1.000	2.000
	max	14.000	14.000	12.000	14.000

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Table 5.6: Frequencies on construction period, house type, and year of sale.

	N. obs	Frequency
Construction Period		
1906-1930	237	2.5%
1931-1944	521	5.6%
1945-1959	554	5.9%
1960-1970	1,768	18.9%
1971-1980	2,019	21.6%
1981-1990	1,919	20.6%
1991-2000	1,991	21.3%
After 2000 (*R*)	322	3.5%
House type		
Terraced (*R*)	5095	54.6%
Semi-detached	3659	39.2%
Detached	577	6.2%
Year of sale		
2000 (*R*)	643	6.9%
2001	682	7.3%
2002	761	8.2%
2003	796	8.5%
2004	868	9.3%
2005	926	9.9%
2006	907	9.7%
2007	929	10.0%
2008	709	7.6%
2009	522	5.6%
2010	539	5.8%
2011	495	5.3%
2012	554	5.9%

R = reference group.

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Table 5.7: Frequencies for zip codes in 's-Hertogenbosch.

ZIP-code	N. obs	Frequency	ZIP-code	N. obs	Frequency
5076	49	0.5%	5268	49	0.5%
5211	75	0.8%	5271	384	4.1%
5212	259	2.8%	5272	92	1.0%
5213	188	2.0%	5275	85	0.9%
5215	179	1.9%	5281	161	1.7%
5216	114	1.2%	5282	166	1.8%
5221	158	1.7%	5283	561	6.0%
5223	122	1.3%	5291	33	0.4%
5224	316	3.4%	5293	10	0.1%
5231	246	2.6%	5296	34	0.4%
5232	26	0.3%	5298	90	1.0%
5233	240	2.6%	5301	477	5.1%
5235	310	3.3%	5302	108	1.2%
5236	338	3.6%	5305	17	0.2%
5237 (*R*)	768	8.2%	5306	27	0.3%
5241	196	2.1%	5308	32	0.3%
5242	135	1.4%	5311	28	0.3%
5243	87	0.9%	5313	10	0.1%
5244	91	1.0%	5314	34	0.4%
5246	243	2.6%	5321	125	1.3%
5247	162	1.7%	5324	53	0.6%
5248	53	0.6%	5325	8	0.1%
5251	316	3.4%	5327	18	0.2%
5252	102	1.1%	5328	53	0.6%
5253	34	0.4%	5331	76	0.8%
5254	26	0.3%	5334	12	0.1%
5256	137	1.5%	5335	11	0.1%
5258	293	3.1%	5481	267	2.9%
5261	136	1.5%	5482	297	3.2%
5262	481	5.2%	6624	20	0.2%
5263	113	1.2%			

R = reference group.

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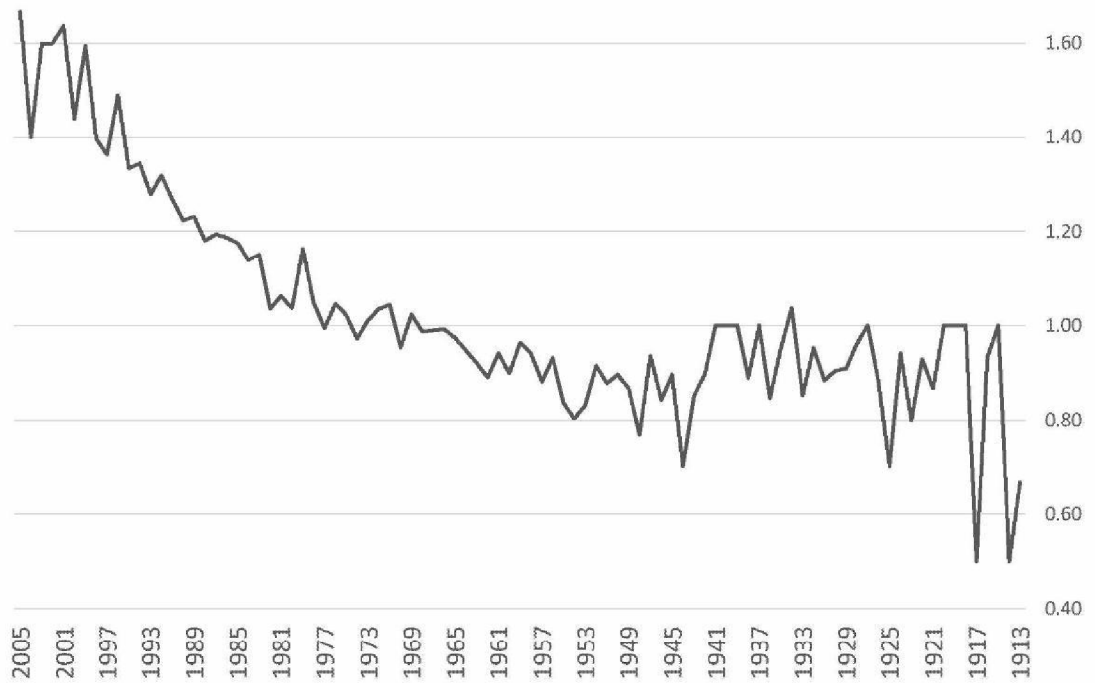
Figure 5.2: Average maintenance level per construction year.



is reported as well. Rosenthal (2008) argues that maintenance is also correlated with 4 digit zip codes. Therefore, we carry out the exact same analysis for level of maintenance as well. Finally, Figure 5.3 shows the construction year distribution within the different maintenance categories.

Table 5.8: Standard deviation of age and maintenance of the housing stock in 2012.

	σ^{Age}		σ^{M}	
Percentiles	Within 4 digit zipcode	Difference between 4 digit zipcode and 's-Hertogenbosch	Within 4 digit zipcode	Difference between 4 digit zipcode and 's-Hertogenbosch
10	4.77	-14.38	0.346	-0.122
25	10.94	-8.20	0.405	-0.063
50	14.91	-4.23	0.464	-0.005
75	19.41	0.27	0.502	0.034
90	23.57	4.43	0.564	0.096

The average age of the housing stock in 2012 was 33 years.

Table 5.8 confirms that homes within a given 4 digit zip code tend to have more similar construction years compared to the total region. Only at the 7th decile is $\sigma^{Age}_{LOC} \geq \sigma^{Age}_{HERTOG}$. On the other hand, the level of maintenance does seem to be more equally distributed over the 4 digit zip codes. Already around the median it holds that $\sigma^{M}_{LOC} \geq \sigma^{M}_{HERTOG}$. In Figure 5.3 we see that the number of homes built before the 1960s is relatively sparse. Still, there

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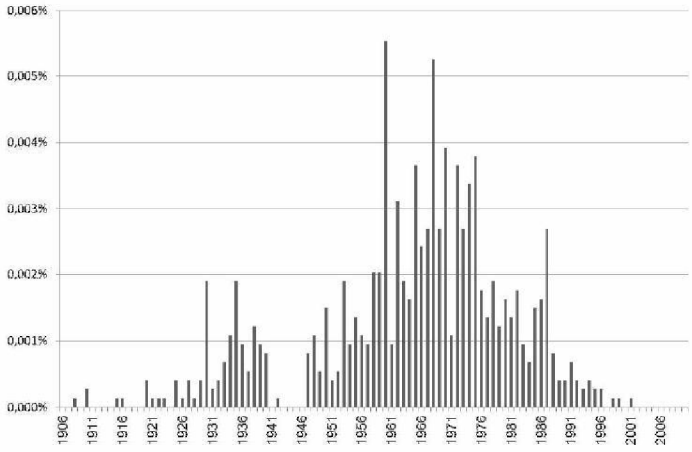
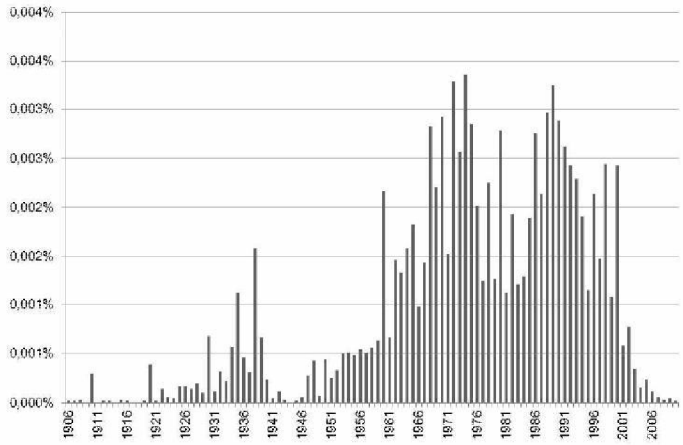
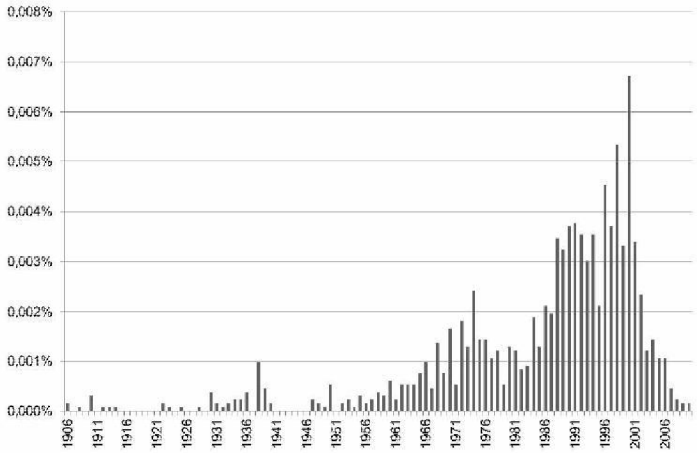
Figure 5.3: Distribution of construction years per maintenance category.



(a) M(-1)



(b) M(0)



(c) M(+1)

The average age of the housing stock in M(−1) is 42 years, in M(0) 30 years and in M(+1) 19 years.

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is more than enough age variation within the maintenance groups, despite the fact that the construction year distribution is skewed to the right for well maintained homes and skewed to the left for poorly maintained homes.

5.5 Results

In this Chapter we present the estimation results. Because some of the frequencies of the joint distribution of age and level of maintenance are low (see Figure 5.3), we group the age into 5-year cohorts for the first 50 years (ending up with 10 groups of 5-year age cohorts) and 1 dummy for properties of age 50 and older. We also group the construction year cohorts in groups of 10 years on average to 'capture' the functional obsolescence and vintage effect. Note that this is a limitation of the data and that this grouping is not necessary if the data would allow for it.

The main results are presented in Table 5.9. The first column of Table 5.9 presents the results of the base-line model with the linear specification for age (denoted *Base A*). The base-line model with the quadratic specification of age is given in the second column of Table 5.9 (denoted *Base B*). The third column of Table 5.9 presents the results of the full model (which we will refer to as the *main model*), as given by Eq. (5.2). The fourth column of Table 5.9 displays the estimation results from the main model, in which location dummies have been omitted in order to check for possible correlation between construction year and location. This correlation could change the coefficient estimates (for construction year and age in particular) erratically. Finally, we expect higher unobserved structural quality at better locations, so the measurement error in replacement costs is possibly correlated with land price.[21] This could affect the coefficient estimates as well. The fifth column of Table 5.9, therefore, presents the estimation results of the main model with higher structural quality at better locations, using a 2-step approach.

In the first step we estimate the location values using the main model (third column of Table 5.9). We subsequently rank the location values from cheapest to most expensive and use the low (high) construction costs given in the Bouwkostenkompas data (in the main model we use average construction costs) to compute the 'new' reconstruction value of structures on the cheapest (most expensive) location. A straight-line between the low and high construction costs is used to determine the reconstruction value for structures on the other locations, based on their ranking.[22] In the second step we re-estimate the model, using the new reconstruction values for structures. Please note that if we would observe the quality of the structure in the

[21] Although it should be stressed - once more - that demolishing dwellings is highly unusual in the Netherlands. Thus, this correlation does not exist because highly valued locations are redeveloped with higher standards.

[22] We actually use a kinked line, because the average construction costs are not exactly in the middle of the high and low construction costs figures. Low construction costs are about 8% lower than average, whereas high construction costs are 12% higher than the average construction costs.

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data directly, this robustness check would not be necessary.

The age effect of the base-line models and the main model can be found in Figure 5.4. A price index for both land uses (estimated from the main model) and construction costs (from Statistics Netherlands) can be found in Figure 5.5.[23] The contribution of the individual components to total value is given in Figure 5.6 which is based on the main model as well. Total house price appreciation according to the main and base-line models is given in Figure 5.7. Finally mean returns, volatility of the returns and the correlations between the returns can be found in Table 5.10.[24]

We will discuss the results extensively in the remainder of this Chapter. Chapter 5.5.1 discusses the results for the structure variables and Chapter 5.5.2 discusses the results for the land variables.

5.5.1 Structure variables

The negative coefficients on age for all models (see Figure 5.4) indicate that structures tend to deteriorate with age, reducing the appreciation of the structure. All non-linear specifications of age result in homes deteriorating at a faster rate for the first 20 years. Analogously, maintaining a home decreases the effective age of a home considerably. However, it is evident that the rate of deterioration differs substantially between the base-line models and the main model. Part of this difference can easily be explained by realizing that the main model estimates the effect of age on the structure, whereas the base-line models estimate the effect of age on total property value. The average structure value is only 50% – 60% of the total value of the property (Figure 5.6). Indeed, the quadratic base-line model (Base B) 'underestimates' the physical deterioration and joint functional obsolescence and vintage effect by approximately 50% *on average*. However, the base-line model with the linear specification of age provides vastly different estimates.

In general, the linear base-line model (Base A) overestimates the joint effect of functional obsolescence and vintage and underestimates the effect of physical deterioration. This emphasizes that the results for all age effects (physical deterioration 'net' of maintenance, functional obsolescence and vintage) heavily depend on the chosen functional form. Other functional forms of age (like a log transformation of age, not presented) resulted in vastly different estimates for the construction year dummies as well.

The loss of value for a not or barely maintained structure, aged between 11 and 15 years, is almost three times as large for the main model compared (28%) to the quadratic base-line model (10%), and four times as large compared to the linear base-line model (7%). On the other hand, the loss of value for the same structure, aged between 46 and 50 years, is 'only' 1.5 times as large for the main model compared (43%) to the quadratic base-line model (28%), and

[23] For a full report on the age parameters see Table D2 in the Appendix. The coefficient estimates and t-values for time of sale can be found in the Appendix (Table D1) for all specifications.

[24] The estimates for the 4 digit zipcodes for both the yard and footprint are not presented here to conserve space, but are available upon request.

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Table 5.9: Estimation results.

Variable	(I) Base A	(II) Base B	(III) Main model	(IV) Robustness	(V) Robustness
FS(γ)	0.373	0.370	0.982	1.005	0.979
	(50.22)***	(50.17)***	(334.15)***	(347.11)***	(333.17)***
CY[1906,1930]	0.076	-0.014	0.069	0.072	0.064
	(2.54)**	(-0.51)	(1.67)*	(1.87)*	(1.56)
CY[1931,1944]	0.092	0.085	0.209	0.177	0.200
	(4.16)***	(3.86)***	(5.36)***	(4.75)***	(5.13)***
CY[1945,1959]	-0.071	-0.020	-0.035	-0.017	-0.036
	(-4.19)***	(-1.16)	(-1.00)	(-0.52)	(-1.04)
CY[1960,1970]	-0.142	-0.073	-0.147	-0.168	-0.151
	(-10.59)***	(-5.08)***	(-5.42)***	(-6.17)***	(-5.50)***
CY[1971,1980]	-0.114	-0.047	-0.116	-0.147	-0.119
	(-10.40)***	(-3.88)***	(-5.13)***	(-6.40)***	(-5.22)***
CY[1981,1990]	-0.103	-0.056	-0.101	-0.100	-0.104
	(-11.79)***	(-5.92)***	(-5.66)***	(-5.58)***	(-5.79)***
CY[1991,2000]	-0.062	-0.041	-0.073	-0.071	-0.074
	(-8.49)***	(-5.50)***	(-5.19)***	(-5.02)***	(-5.23)***
m^2 land ILS^s	0.245	0.247	€808	€698	€819
	(24.94)***	(21.59)***	(25.33)***	(18.90)***	(21.71)***
m^2 land GS^s	-0.011	-0.011	€328	€316	€334
	(-2.13)***	(-2.19)**	(7.52)***	(8.28)***	(7.63)***
ILS^l	-0.001	-0.001	0.152	0.152	0.150
	(-0.99)	(-0.86)	(17.09)***	(11.85)***	(16.95)***
GS^l	0.000	0.000	0.431	0.376	0.440
	(0.28)	(0.23)	(14.03)***	(10.76)***	(14.10)***
Semi-detached	0.113	0.111	-0.035	-0.125	-0.032
	(26.67)***	(26.35)***	(-3.23)***	(-8.35)***	(-2.97)***
Detached	0.270	0.266	0.193	0.126	0.196
	(36.31)***	(36.04)***	(7.65)***	(3.62)***	(7.71)***
N. of Rooms	0.083	0.087			
	(12.64)***	(13.32)***			
Parking-spot	0.010	0.010			
	(1.35)	(1.38)			
Carport	0.003	0.003			
	(0.59)	(0.58)			
Garage	0.029	0.030			
	(9.09)***	(9.34)***			
Separate L & S	No	No	Yes	Yes	Yes
Location dummies	Yes	Yes	Yes	No	Yes
Age specification	Linear	Quadratic	Dummies	Dummies	Dummies
2-step correction	No	No	No	No	Yes
R^2	0.860	0.867	0.866	0.810	0.865
RMSE	0.110	0.110	0.110	0.130	0.110
N	9,331	9,331	9,331	9,331	9,331

Note Coefficient (t statistic),*** sig. within 99% prob.,** sig. within 95% prob. and * sig. within 90% prob. The reference categories are: *After* 2000 for CY periods, *terraced* for house type, 5237 for location, 2000 for year of sale and *no parking place* for the parking variables.

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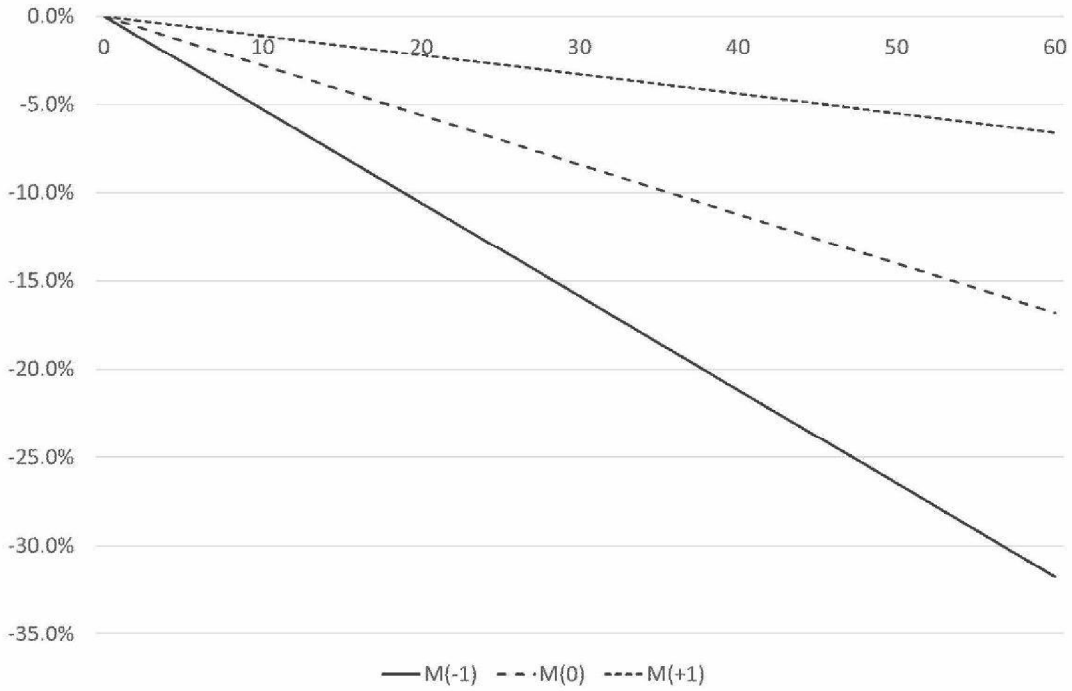
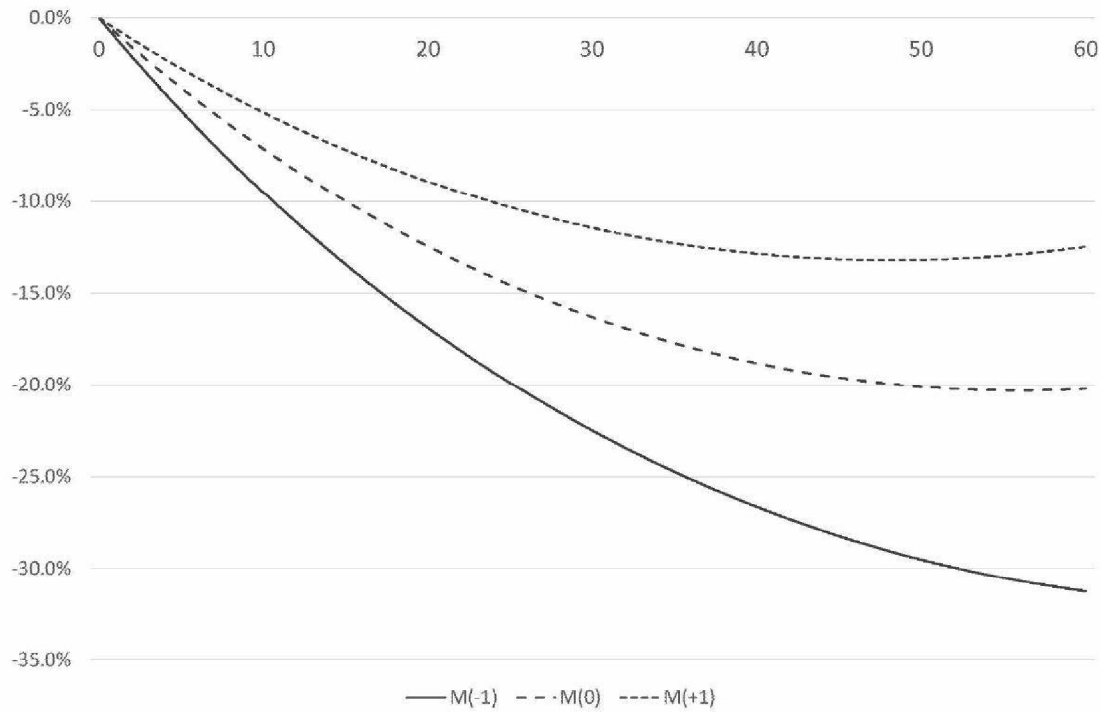
Figure 5.4: Physical deterioration.



(a) Linear base-line model (Base A). Total property loss in value (in%) due physical deterioration.



(b) Quadratic base-line model (Base B). Total property loss in value (in%) due physical deterioration.

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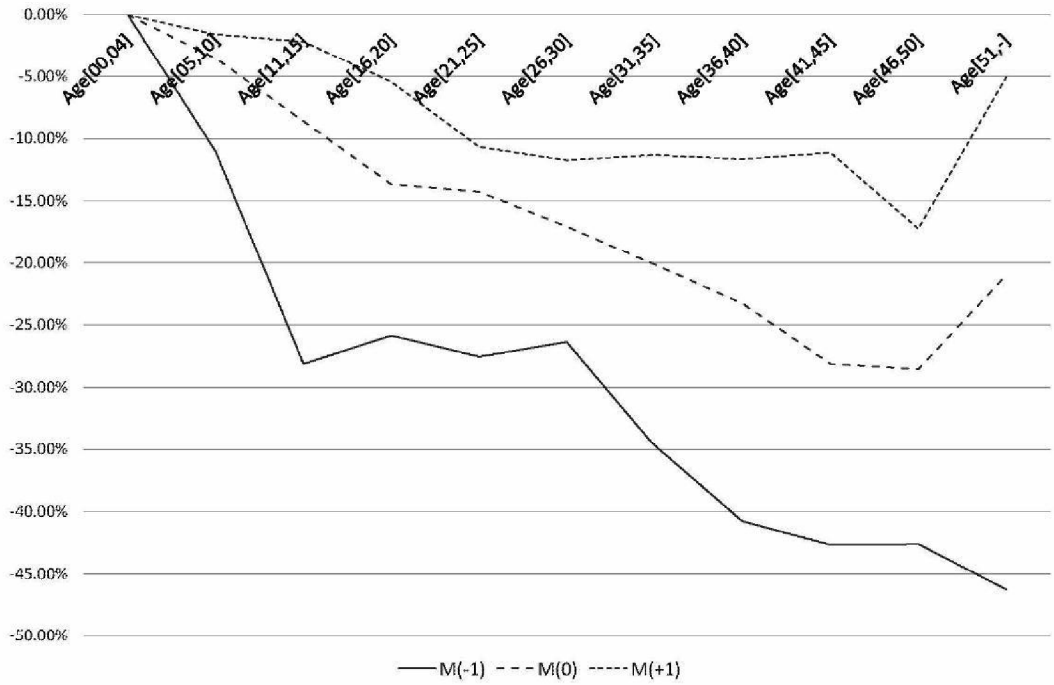
Figure 5.4: Age depreciation effect. *Continued*



(c) Main Model. Structure loss in value (in%) due physical deterioration.

Figure 5.5: Footprint, yard and structure price indices from 2000 (= 100) up to 2012 based on the main model.

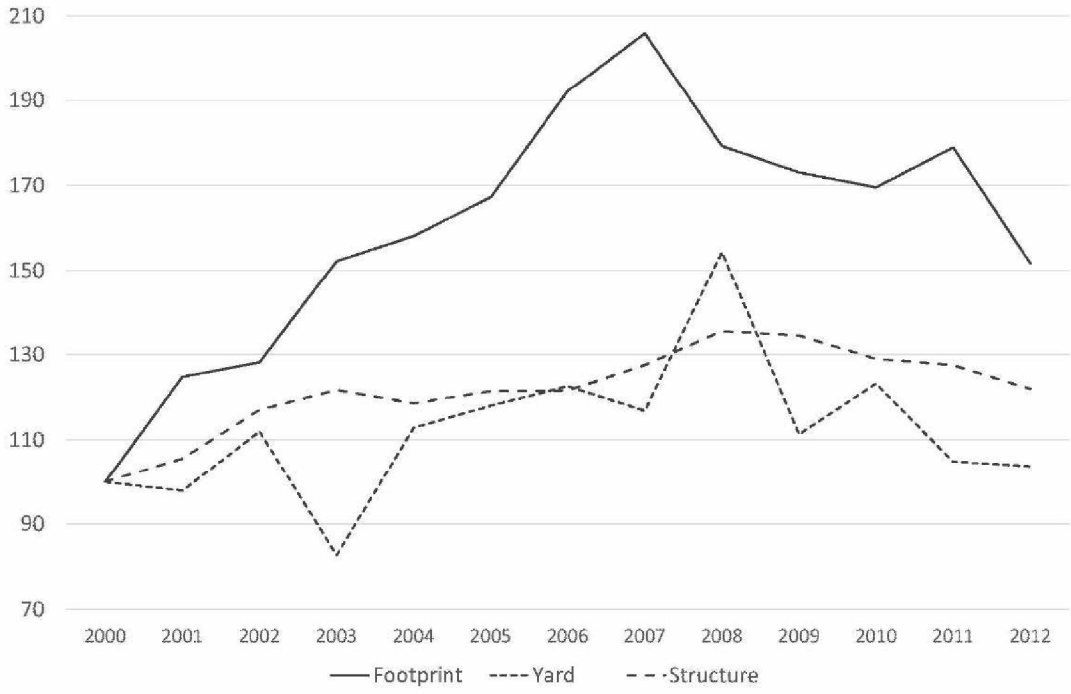


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Figure 5.6: Contribution of the individual components to total property value. Expressed as % of total property value.



The components are calculated as follows. First the value of each component calculated of all transactions as if they were sold in 2000 using the parameter estimates of the main model. Subsequently the components are multiplied by the indices in Figure 5.5. Also note that do not take into account the cost for site preparation or alternative use of the land. Thus, in reality the fraction of land value to total value is very likely to be lower.

Table 5.10: Statistics and correlation between the land and structure returns.

Mean returns and volatility		
returns	mean	std. dev.
Structure	1.77%	4.68%
Footprint	2.83%	11.28%
Yard	-1.53%	20.53%

Correlations		
	Structure	Footprint
Footprint	0.314	
Yard	0.080	-0.272

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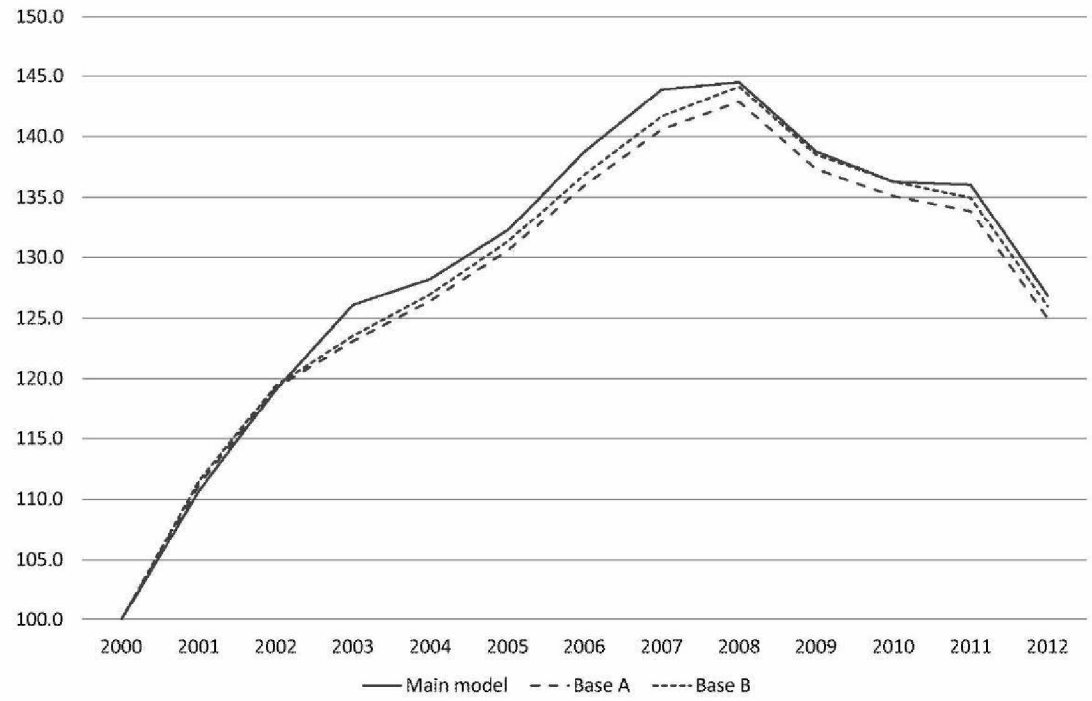
Figure 5.7: House price appreciation from 2000 up to 2012 based on the main model and the base-line specifications. The index value in 2000 is 100.



twice as large compared to the linear base-line model (23%). Obviously, homeowners maintain their homes to slow down the rate of decay. Maintaining a home well results in a loss of value of 28% after 50 years (or about 20% and 14% according to the quadratic and linear base-line specifications respectively). Maintaining a home very well results in virtually no physical deterioration in the long run.

The joint impact of vintage and functional obsolescence is quite large. The results (second column in Table 5.9) imply that, apart from the physical deterioration, homes built between 1931 and 1944 sell at a significant premium of 22% compared to new homes. Homes of this era are valued for a distinct (expressionistic) brick architecture, popularized by 'the Amsterdam School' in the 20s and 30s. Prices are lowest (-16%) for homes built between 1960 and 1970. The estimates of the quadratic base-line model for the joint effect of functional obsolescence and vintage are again only half of the estimates of the main model (which was expected considering that the land value is approximately 50% of total property value). Most signs and the ranking of the effects are the same. In most cases, the effect of construction year on prices is twice as large for the linear base-line model, compared to the quadratic base-line model. The ranking of the estimates has changed as well.

The explanatory power and total house price appreciation are comparable between the base-line models and the main model (Figure 5.7). However, this could be attributed to the fact that the percentage of structure value to the total property value is relatively stable in our

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application, see Figure 5.6. If this fraction would be volatile, this would affect the precision of the estimated age parameters for the base-line models, but not for the main model.

There does not seem to be an interaction between construction year and location. Leaving out the location dummies in the fourth column of Table 5.9 does not substantially change the coefficients for construction year and the signs remain the same. The age effect (Table D2) does seem to attenuate as the age of the structure increases. Column five of Table 5.9 reveals that the parameter estimates do not change erratically when the reconstruction values are corrected for land prices. This was expected, because the measurement error in replacement costs in the main model will be 'captured' by the land dummies. Thus, the indices, the *average* fraction of land value to total property value and parameter estimates (except for the land dummies), should not change that much. However, if the correction is not considered, on a property level the fraction of land value to total value is structurally over- or undervalued, depending on the location. Better quality data would benefit us greatly in this regard.

The parameter estimates for floor size, γ in Eq. (5.5), show that building costs are approximately proportional to floor size; the estimate is slightly lower than 1 for the main model. The base-line specifications estimate a 0.45% price increase for every 1% increase in floor size. Please note that the number of rooms is also entered in the base-line models. Omitting this variable from the regression increases the effect of floor size on house prices.

Structures have the lowest annual average return of all indices (1.8%). The correlation between the structure returns and the returns for the footprint and yard is relatively small (Table 5.10). This was expected, since construction is supplied elastically, hence, its costs do not vary greatly with demand, while land is in fixed supply and it residually captures almost all the longitudinal movement in property asset market values. The volatility of the structure returns is - indeed - almost half of the volatility of the footprint returns. Both figures are consistent with empirical work and theory of earlier research in land pricing (Bostic, Longhofer, and Redfearn 2007; Davis and Heathcote 2007; Davis and Palumbo 2008; Bourassa et al. 2011). Around 2003 the structure price index goes down, whereas the index of the footprint goes up. The correlation between the structure returns and the returns on the footprint is, therefore, even lower for the period after 2003, namely 0.11.

5.5.2 Land variables

The parameter estimates of the land variables for the main model in Table 5.9 show that, *ceteris paribus*, the square meter footprint price for detached housing is higher than the square meter prices of terraced and semi-detached housing. The square meter price of the footprint for semi-detached and terraced housing is roughly the same. The base-line specifications find a premium for semi-detached housing, but this can be attributed to a higher square meter reconstruction value for said type of housing (Table 5.5). Thus, that premium is part of the structure value and not the land value.

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It is expected that the marginal price per square meter land decreases when the size of the land increases, so $0 < \alpha_l < 1$ and $0 < \delta_l < 1$ in Eqs. (5.7) and (5.8). The estimated coefficient α_l is about 0.15, implying that every square meter footprint larger than $75m^2$ is approximately 15% of the price per m^2 for the first $75m^2$. The estimated coefficient δ_l is about 0.40, implying that every square meter yard after $75m^2$ is approximately 40% of the price per m^2 for the first $75m^2$. The value of the footprint is more than twice the value of the yard (€808 versus €328 for the reference home). The base-line specification estimates a 0.25% price increase for every 1% increase in footprint size for the first $75m^2$. The effect of the yard size and the splines (both footprint and yard) on house prices are negligible / non-significant, according to the base-line models.

The volatility of the yard returns is much larger than that of the footprint and structure returns (Table 5.10). Still, because of the relative low value of the yard, the price range per square meter yard for the reference home is only €250 – €460 between 2000 and 2012; a difference of €210. The range of the footprint square meter price, on the other hand, is approximately €800 – €1,600 between 2000 and 2012; a difference of €800. In other words, the high volatility of the yard returns hardly contributed to the total value of the property, see Figure 5.6 as well.

5.6 Concluding Remarks

The focus of this Chapter is the measurement of depreciation of houses. The main contribution is that we show that it *is possible* to simultaneously estimate age, construction year and time of sale, in a nonlinear hedonic price model, by attributing the age and construction year effects to the structure value and the time of sale effect to the land value. Physical deterioration is measured by age and maintenance level, functional obsolescence and vintage by construction year and external obsolescence by year of sale. Compared to traditional hedonic models our model (1) gives less biased estimates for physical deterioration and vintage, (2) is free of the multicollinearity issues between age, time of sale and construction year, without imposing any structure on the functional form of said variables and, (3) can easily be applied in markets in which the percentage of structure value to total property value is volatile.

The proposed model circumvents the typical problem of perfect collinearity between time of sale, age and construction year in hedonic price models, by making some appropriate assumptions: physical deterioration (age and maintenance), vintage and functional obsolescence (construction year) only affect the structure value and external obsolescence (time of sale) only the land value.

The proposed model explicitly assumes that land and structure values are additive. In the case of the Netherlands this is a plausible assumption. However, in regions with less rigid zoning restrictions it will be more important to use a proxy for option value and control for the

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endogenous effect of maintenance.

Using reliable data from a region in the Netherlands we show that maintaining a structure poorly results in an annual physical deterioration of more than 1.5% for the first 20 years and almost 1% for the first 50 years. Maintaining a home well reduces the effective age considerably. However, it shold be noted that our depreciation estimates are probably conservative due to missing renovation data.

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Chapter 6

Conclusion

In conclusion, this thesis outlines multiple important issues related to house price dynamics and its determinants. This dissertation focusses on changing determinants of house prices in the long-run (Chapter 2), the effect of credit conditions on house prices (Chapter 3), the effect of demographic growth and decline on house prices (Chapter 4) and finally the effect of depreciation on house prices (Chapter 5). Even though we limited ourselves to the housing market in the Netherlands, the findings might be relevant for other sectors in the real estate market or even any other market that is characterized by (heavy) supply constraints.

Chapter 2 examines the determinants of house prices using almost 200 years of data from the Amsterdam housing market. In total we focus on seven major determinant of house prices: housing supply, construction costs, income per capita (GDP), the opportunity cost of capital (interest rates), the percentage of working age population to total population, unemployment, and population growth. One main contribution of this study is that we allow for the determinants to be time-varying. Parameters are likely time-varying in the long-run because of (long) real estate cycles and (political and economic) regime shifts. A yearly rolling regression with changing combinations of covariates is used, because it allows us to estimate a series of parameter estimates without imposing any particular structure on the way in which conditional covariates change over time. Since the long-run time-series are non-stationary, the model is estimated using a rolling (Engle and Granger 2 step) error correction model. We fix the window length at 30 years as this is the average length of a real estate cycle according to literature and, in addition, because it resulted in the largest number of cointegrating relationships. The results imply that the determinants of house prices are, indeed, *not fixed* but change over time and reflect the economic state of affairs in each different era.

During the 19th century population growth, housing supply and construction costs are the main drivers of house prices in Amsterdam. At the start of the 20th century GDP per capita starts to play a role. After World War II there is a time period in which housing supply and population growth determine house prices. This reflects the post-war reconstruction efforts in the Netherlands and increases in housing demand as a result of the baby-boom generation and

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subsequent decrease in housing demand due to the large scale deurbanization of Amsterdam. Finally, from the 1970s onwards, income and interest rates (co-jointly with construction costs) start to have a large impact on house prices, most likely due to financial innovation and liberalization. During this time period financing a house through mortgage debt became more and more popular. It also signals the beginning of a remarkable period in time in which house prices start to increase rapidly in many countries (i.e. the 1990s).

In Chapter 3 we focus on the effects of the mortgage market on house prices in more detail for the period 1995 – 2012. We first introduce a new method to estimate a credit condition index (CCI). The CCI represents changes in the supply of credit over time, apart from changes in interest rates and income. It is estimated by an unobserved component in an error correction model in which the average amount of new provided mortgages per period is explained by the borrowing capacity (which is a function of variables like interest rates and household income) and additional control variables. By controlling mortgage lending for different demographic and economic variables the unobserved component should capture the credit conditions. The unobserved component itself is modelled as a local-linear trend (LLT), random walk (RW) and as linear splines (LS), resulting in three CCIs. The model has been estimated on data representing first time buyers (FTB). For FTB we can assume that the housing and non-housing wealth is essentially zero. This makes FTB more reliant on the supply of mortgage debt, as they do not have any liquid funds themselves. This reduces some demand side effects which could 'contaminate' the unobserved component.

In all models the credit conditions reveal a steady growth until 2009 with a small interruption in 2007, during the credit crunch. The increasing levels of mortgage lending can be attributed to more households taking an interest only mortgage and the growing popularity of the NHG product which made mortgages less risky investments from a bank's perspective. After 2010 however, there was a steady decline, probably mostly fuelled by more stringent liquidity ratios on banks (Basel accords), the 'de facto' abolishment of interest only type mortgages and lower LTV caps allowed by the Dutch government. In $2012.Q4$ the supply of credit is on the same level as it was during the period 2003 – 2004. The estimated CCI has a high correlation with the Bank Lending Survey, a quarterly survey in which banks are asked whether there is a tightening or relaxation of (mortgage) lending standards compared to the preceding period.

The CCI has subsequently been used as an explanatory variable in an error correction model for house prices representing not only FTB, but all households. The models have been estimated on quarterly data from 1995 to 2012. The CCI has explanatory power in the error correction model for house prices. In real terms house prices declined about 25% from 2009 to 2012. The estimation results show that about half of this decline can be attributed to a decline in the CCI.

The focus of Chapter 4 is the asymmetry between the effect of population growth and decline on housing prices taking into account local (municipalities) supply constraints in the Netherlands. This asymmetry arises in the first place, because of the durable nature of houses.

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Homes are built to last for decades if not centuries. The durability of housing means that it can take decades for negative urban shocks to be fully reflected in housing supply levels. This slow adaptation of existing stock during decreasing demand results in disproportionally large house price decreases. A city will start to decline when housing prices are below construction costs, because investments in housing will stop being feasible. When urban productivity falls, the most active members of the labor force will naturally flee; but durable housing ensures that their homes will then be occupied by those that are less connected to the labor market.

Demographic growth on the other hand has a more ambiguous effect on house prices, depending on the local supply constraints. When supply is unable to keep pace with demand shocks quickly and cheaply, more of the demand shocks carry through into prices. Usually, whenever a city grows, delivery lags and imperfect foresight of agents will enable housing price increases on the short-run, until a new long-run equilibrium is reached. However, in some instances supply will not even react to house prices in the long-run due to (local) supply constraints. These supply constraints can be caused by physical space constraints or by regulatory constraints. Physical space constraints refers to the scarcity of land (amount of developable land) and uneven topography (steep slopes etc.). The main regulatory constraints in the Netherlands are the zoning plans made on municipality level.

To estimate the effect of demographic decline and growth (taking into account supply constraints) we utilize a panel data set with 15 years of data on municipality level in the Netherlands. The data is differenced over the full 15 years, so we only capture long-run effects. Population change is entered in piecewise linear form to allow for differential effects in expanding versus declining municipalities. We subsequently interact population growth with a measure for local supply constraints (which we estimate from the data). To construct this index, we first regress house prices on new housing permits, using an IV approach. We rank order the municipalities from the most supply constraint to the municipality with the least supply constraints and subsequently group them in categories ranging from 'no supply constraints' to 'heavy supply constraints'.

Every 1% decrease in population results in a housing price decrease of 1.9%, *ceteris paribus*. In the most constraint markets a 1% increase in population results in a 0.4% price increase on average. Population growth barely (or even slightly negatively) affect house prices for the least constraint municipalities.

The focus of Chapter 5 is the measurement of depreciation of houses, where we define depreciation as *"to be the decline in asset values (or shadow price) due to ageing"*. Depreciation consists of three parts: (1) physical deterioration, (2) functional obsolescence and (3) external obsolescence. Physical deterioration is the simple wear and tear of the structure. Functional obsolescence is caused by the evolution in technologies (building quality) and preferences for residential living. External obsolescence encompasses changes, not to the property itself, but to the area surrounding the property. Apart from depreciation it is important to distinguish the vintage effect: a preference for specific structure characteristics. Physical deterioration can be

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retarded by maintenance activities. Functional obsolescence, on the other hand, is much more difficult (if even possible) to cure.

In this study we measure physical deterioration by the age of the structure, the joint effect of functional obsolescence and vintage by the construction year and the external obsolescence by the time of sale in a (non-linear) hedonic framework. We also interact the age of the property (as proxy for physical deterioration) with the level of maintenance. There are two difficulties regarding depreciation studies. Firstly, there is perfect collinearity between key variables: age, construction year and time of sale. Secondly, regressing age on the property value will always bias the estimate downward. The size of the bias depends on the fraction of structure value to total property value.

The proposed model circumvents these typical problems by making the following assumptions: physical deterioration (age and maintenance), vintage and functional obsolescence (construction year) only affect the structure value and external obsolescence (time of sale) only the land value. Another important assumption we make is that there is no (redevelopment) option value in structures in the Netherlands due to heavy zoning restrictions. The structure is a function of its reconstruction value, the structure size, the age (interacted with maintenance level) and the construction year of the structure. The land value is disentangled in a yard value and a footprint value. The land values are functions of the location, time of sale, size of the land and the property types allowed on the land.

The model is non-linear in its parameters and is therefore estimated with non-linear least squares. The NVM made the data available to us for a region in the Netherlands called 's-Hertogenbosch. After the filters were applied we were left with more than 9,000 individual transactions of homes between 2000 and 2012. Data on reconstruction values are obtained from the website of Bouwkostenkompas.

Our findings show that maintenance has a substantial impact on the rate of physical deterioration. After 50 years of not or barely maintaining a home a typical structure has lost around 43% of its value. In contrast, maintaining a home very well results in virtually no physical deterioration in the long run. The findings also suggest that land prices are more volatile than structure prices. Both indices are barely correlated, indicating that the market for structures and land are separate ones. Compared to traditional hedonic models our model (1) gives unbiased estimates for physical deterioration and vintage, (2) is free of the multicollinearity issues between age, time of sale and construction year, without imposing any structure on the functional form of said variables and, (3) can easily be applied in markets in which the percentage of structure value to total property value is volatile.

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Appendix A

Appendix for Chapter 2

A.1 Transaction Data Herengracht

Data description is provided in Tables A1 – A3 and Figure A.1.1. The descriptives are based on the data after filters were applied. If a home was converted to an office or if the home was combined with a neighboring home the sale was removed from the data.

After the filters were applied we end up with 580 different homes and about 3,000 transactions. Table A1 also reveals that the average time between repeat sales is 34 years. Most homes were sold 6 times in our data. One specific home was sold 17 times during the 350 year period (Table A2). The average number of transactions per year is approximately 10. However, in some years there are no transactions (see Figure A.1.1). Table A3 provides the yearly log nominal returns subdivided in different quantiles. The average yearly log nominal return is a little under 2%. The mode is lower with 0.05%.

Table A1: Descriptive statistics Herengracht data.

Description	
Number of transactions	3,416
Number of transactions (with at least two sales)	2,953
Number of different homes	580
Minimum year of sale	1628
Maximum year of sale	1972
Average years between repeat sales	34

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Figure A.1.1: Number of transactions per year, Herengracht data.

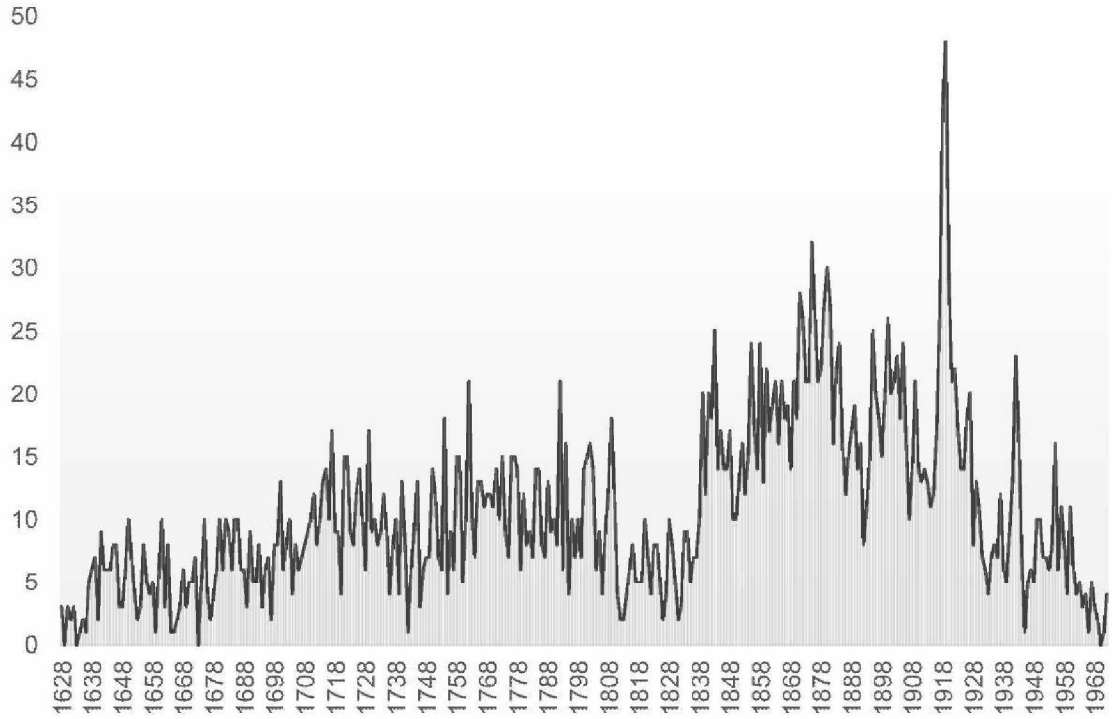

Table A2: Number of sales of the same property

Number of sales	Number of observations
2	66
3	54
4	62
5	68
6	95
7	61
8	55
9	41
10	24
11	16
12	12
13	5
14	4
15	2
17	1

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Table A3: Log nominal return statistics

Quantile	**Annual log nominal returns**
average	0.018
0.025	-0.052
0.05	-0.033
0.1	-0.019
0.5	0.005
0.9	0.059
0.95	0.104
0.975	0.185

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A.1.1 Constructing a House Price Index

The methodology to estimate the price index using the Herengracht data is described extensively in Francke (2010). Here we give a brief description of the model and some descriptive statistics of the data. The 'standard' Case and Shiller repeat sales is given by:

$$\ln\left(\frac{P_{i,t}}{P_{i,s}}\right) = \beta_t - \beta_s + \alpha_{i,t} + \epsilon_{i,t}, \qquad \epsilon_{i,t} \sim N(0, \sigma_\epsilon^2), \tag{A.1}$$

$$\alpha_{i,t+1} = \alpha_{i,t} + \eta_{i,t}, \qquad \eta_{i,t} \sim N(0, \sigma_\eta^2), \tag{A.2}$$

for $t = 1, \ldots, T$ and $i = 1, \ldots, M$, where T is the number of years and M is the number of houses. P are house prices sold at time t (sale) and s (buy), with $t > s$. Subscript i is for the individual properties. The coefficient β_t is the logarithm of the cumulative price index at time t. The random walk component (α) is the cumulative idiosyncratic drift of each property (Case and Shiller 1987), since the variance of the error term is related to the interval between time of sales.

In the repeat sales model it is typically assumed that the β_t's are fixed unknown parameters. In the methodology described by Francke (2010), it is assumed that β_t is a scalar stochastic trend process in the form of a local linear trend model, in which both the level and slope can vary over time. The local linear trend model is given by:

$$\beta_{t+1} = \beta_t + \kappa_t + \zeta_t, \qquad \zeta_t \sim N(0, \sigma_\zeta^2), \tag{A.3}$$

$$\kappa_{t+1} = \kappa_t + \xi_t, \qquad \xi_t \sim N(0, \sigma_\xi^2). \tag{A.4}$$

The local linear trend model 'in differences' is estimated with the Bayesian procedure described in Francke (2010), avoiding the somewhat more usual ad hoc two-step procedure. The model can be expressed as a linear regression model with a prior for β, induced by the local linear trend model. Estimates of parameters are obtained by maximizing the likelihood of the 'differenced' data.

A.1.2 Estimation Results

The results of the model are given in Table A4. The standard deviation (σ) is relatively high with approximately 30%. This could be because of the large average time of sale (34 years, Table A1). Taking into account the large average time between sales and the large variance in time between sales (Table A2), it is surprising to note that the standard deviation for the individual random walks (σ_η) is near 0. The price level of the next year is best explained by taking the price level of this year, with a standard deviation of 8.3% per year (σ_ζ), plus a drift. The drift of next year is best explained by taking the drift of this year plus a small standard deviation of 0.3% (σ_ξ).

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Table A4: Estimation results

	Estimate	**Log estimate**	**Std. error.**	**t-value**
σ	0.310	-1.171	0.015	84.28
σ_η	0.000	-10.471	1.688	6.20
σ_ζ	0.083	-2.492	0.162	15.39
σ_ξ	0.003	-5.936	2.325	2.55

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A.1.3 Long-run time series: Macro Determinants

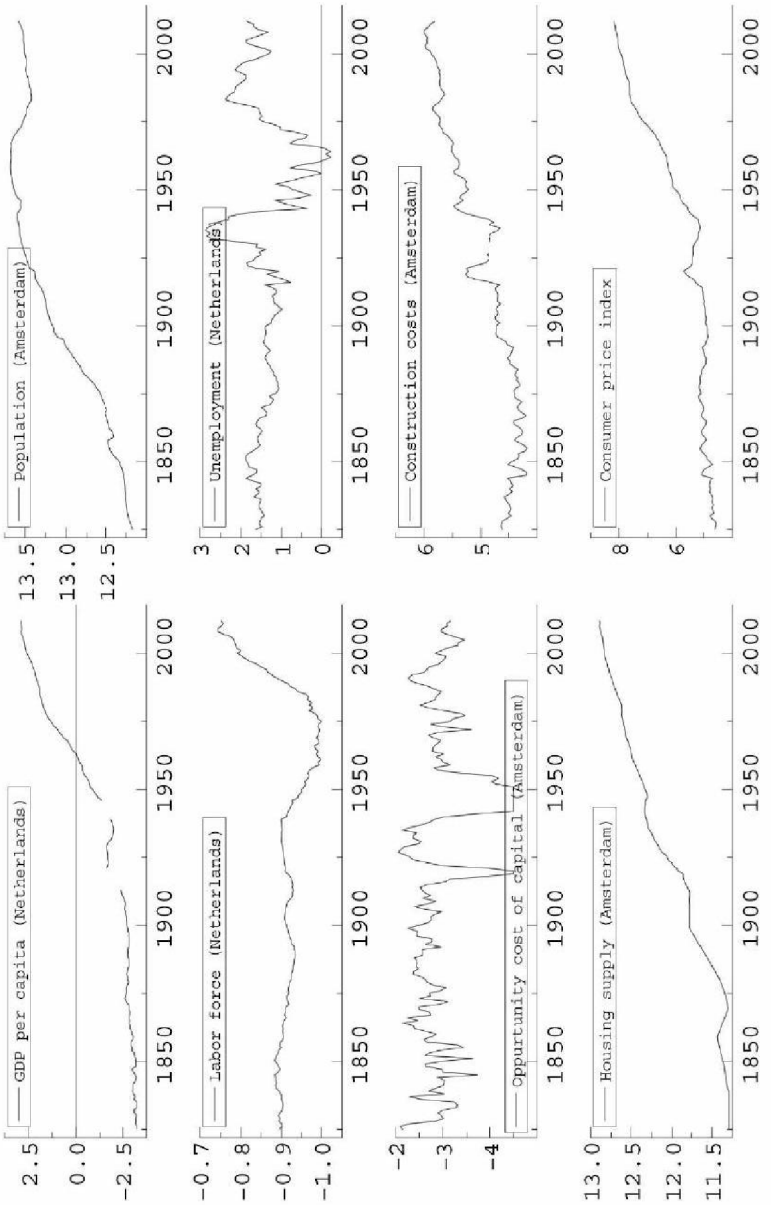

Figure A.1.2: Time series in Log levels.

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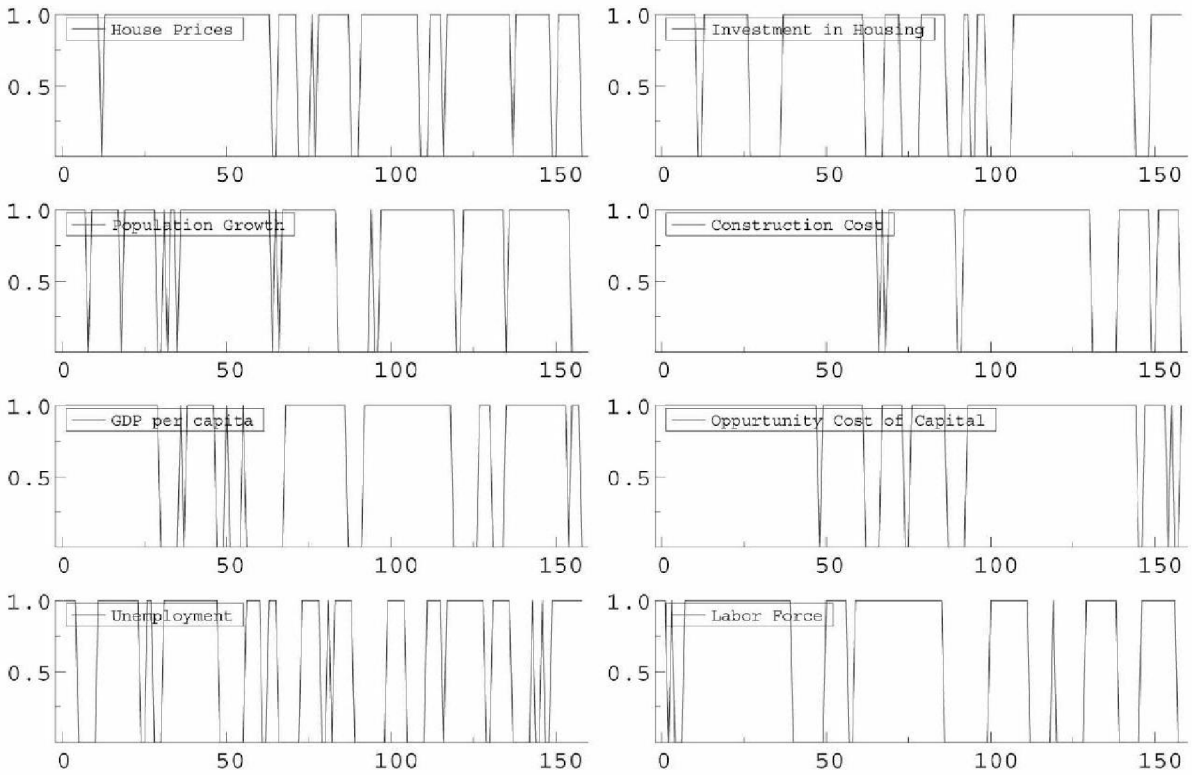
A.1.4 Order of Integration

Figure A.1.3: Order of integration of the variables.



Note. Order of integration: 1 means I(1), which is necessary for the R-ECM framework. We only use I(1) variables in the regressions. The x-axis is the number of years starting from 1825.

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Appendix B

Appendix for Chapter 3

B.1 Financial Liberation in the Netherlands

Table B1: Dating of financial liberalisation in the Netherlands.

Year	Event
1990	Change that allowed households to use a share of other household members' income as a basis for obtaining mortgage credit.
2001	The first restriction to the deductibility of mortgage payments on income was made in 2001. Here it was determined that after a period of 30 years, households were no longer entitled to deduct the interest payments.
2004	The so-called 'bijleenregeling' assumes that households use all their positive equity (if present) built up in their former property and use it to finance the new property in case of a move. If households decide to finance this amount through a mortgage anyway, this is no longer deductible.
2011	Banks themselves agreed (GHF) that at most 50% of the assessed value of the home may be financed through an interest-only mortgage.
2011	The maximum allowed LTV for new mortgages decreased from 110% to 106%. The main reason being the lowering of transfer tax from 6% to 2%.
2012	Maximum allowed LTV for new mortgages is lowered even further. From 2012 onwards the maximum allowed LTV is lowered with 1%-point until it is 100% in 2018.
2013	From 2013 the deductibility of interest payments on income is limited. Interest rate deductibility is applicable to annuity and linear mortgage products only.

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B.2 Granger Causality Tests

Table B2: Granger causality test ($1995.Q1 - 2012.Q4$, with 4 year lags), between house prices p and mortgage levels m for first time buyers.

Granger Causality		F-test	P-values
$p_{ftb,t}$	$\rightarrow m_{ftb,t}$	1.723	0.114
$m_{ftb,t}$	$\rightarrow p_{ftb,t}$	2.137	0.047
$\Delta p_{ftb,t}$	$\rightarrow \Delta m_{ftb,t}$	1.352	0.252
$\Delta m_{ftb,t}$	$\rightarrow \Delta p_{ftb,t}$	1.997	0.066
$\Delta p_{ftb,t}$	$\rightarrow m_{ftb,t}$	1.464	0.201
$m_{ftb,t}$	$\rightarrow \Delta p_{ftb,t}$	2.581	0.020
$p_{ftb,t}$	$\rightarrow \Delta m_{ftb,t}$	1.497	0.187
$\Delta m_{ftb,t}$	$\rightarrow p_{ftb,t}$	2.165	0.047

Table B3: Granger causality test ($1995.Q1 - 2012.Q4$, with 4 year lags), between house prices p and credit conditions cci (RW model) for all households.

Granger Causality		F-test	P-value
p_t	$\rightarrow cci_t$	1.367	0.302
cci_t	$\rightarrow p_t$	2.825	0.040
Δp_t	$\rightarrow \Delta cci_t$	0.768	0.706
Δcci_t	$\rightarrow \Delta p_t$	2.702	0.054
Δp_t	$\rightarrow cci_t$	0.897	0.602
cci_t	$\rightarrow \Delta p_t$	2.477	0.071
p_t	$\rightarrow \Delta cci_t$	0.689	0.771
Δcci_t	$\rightarrow p_t$	2.435	0.075

B.3 Test for Cointegration

Table B4: Tests for cointegration in CCI models

	ρ	critical value (k)	$\rho \leq k$
Model I	0.500	0.522	Yes
Model II	0.504	0.522	Yes
	ADF		$ADF \leq k$
Model III	-4.049	-3.967	Yes

Note. All critical values are obtained from (MacKinnon 2010). The critical values for the Unobserved Error Correction Models are computed by multiplying the standard deviation of ρ by the critical values, plus 1.

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B.4 Long-run time series Macro Determinants

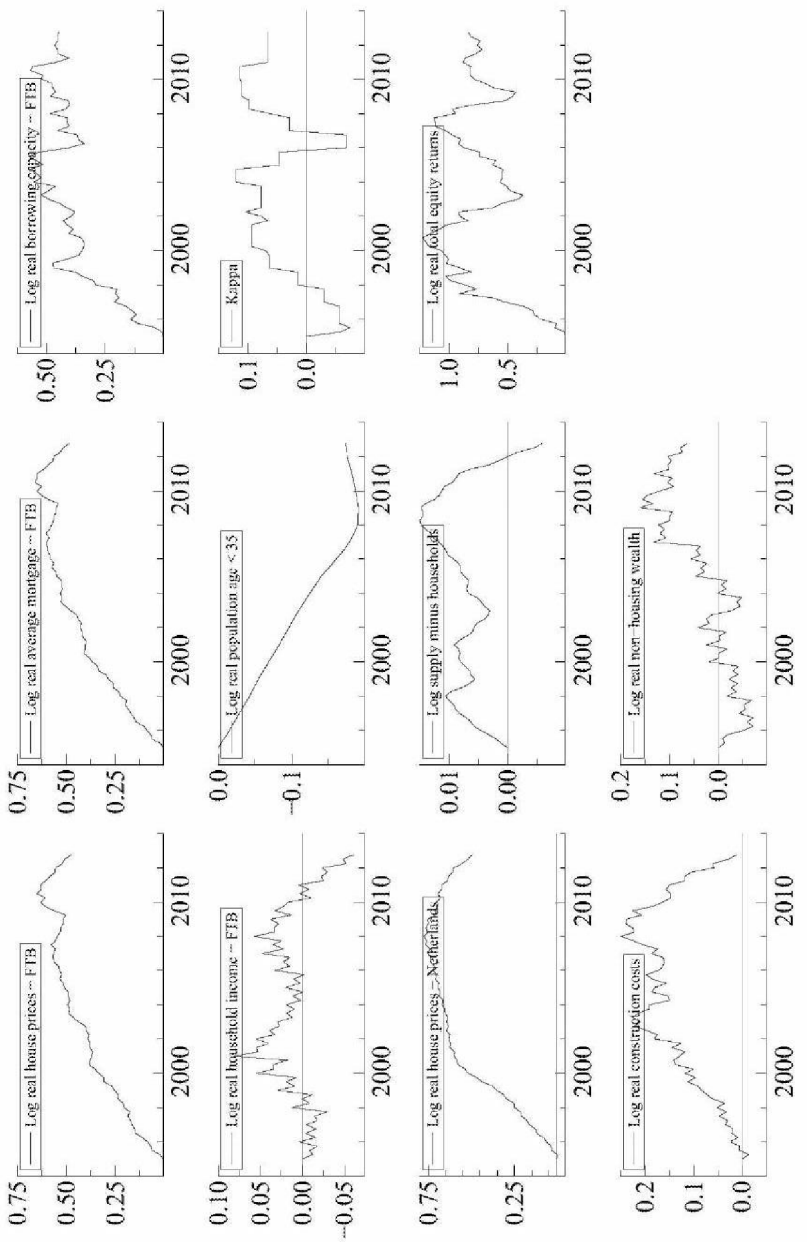

Figure B.4.1: Time series indices in log levels. 1995.Q1 = 0.

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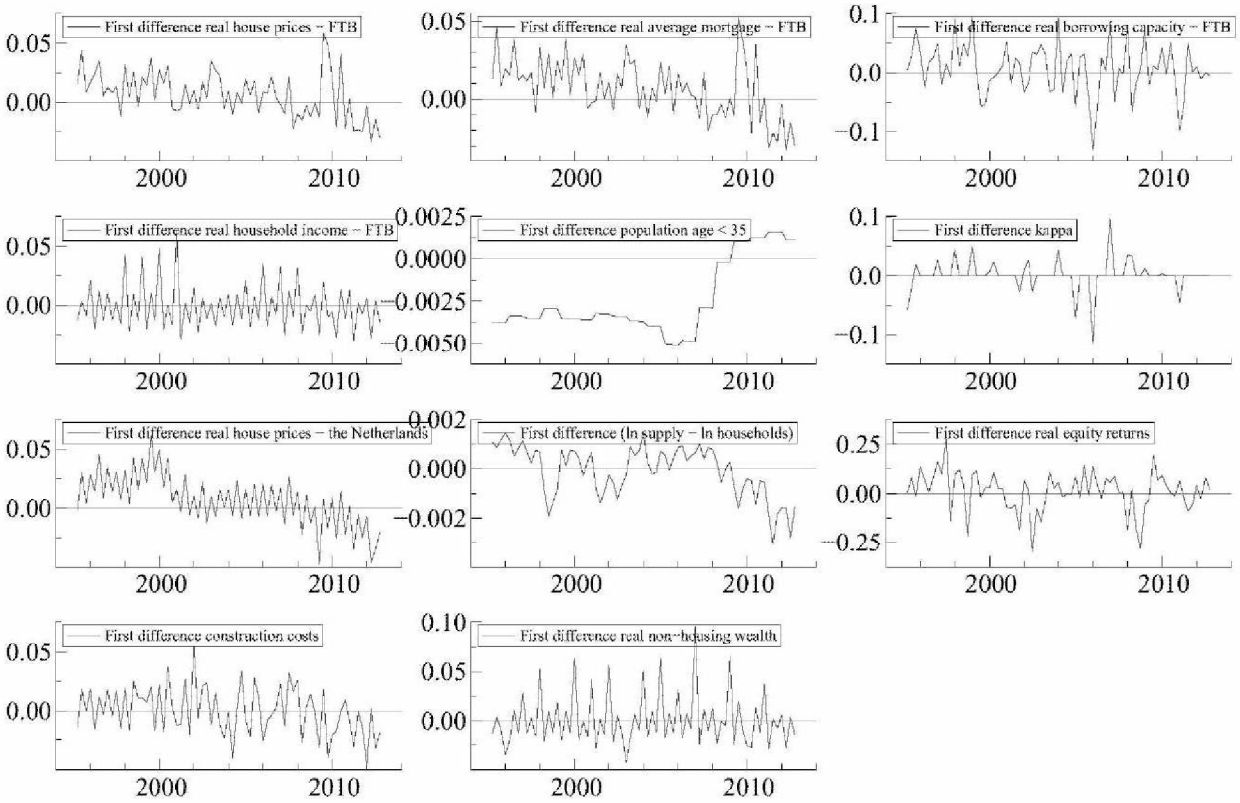
Figure B.4.2: Time series indices (*Continued*), First-differences.



Appendix C

Appendix for Chapter 4

C.1 Municipalities in the Netherlands

Table C1: List of absent municipalities

Aalten	Leidschendam-Voorburg
Bergeijk	Middelburg (Z)
Berkelland	Midden-Delfland
De Bilt	Moerdijk
Boxtel	Nieuwkoop
Breda	Nijmegen
Bronckhorst	Ommen
Coevorden	Oost Gelre
Cranendonck	Pijnacker-Nootdorp
Dinkelland	Rijswijk (ZH)
Echt-Susteren	Roermond
Emmen	Sittard-Geleen
Ferwerderadiel	Steenbergen
Geldrop-Mierlo	Tilburg
Goirle	Utrechtse Heuvelrug
s-Gravenhage	Waalwijk
Gulpen-Wittem	Woensdrecht
Heeze-Leende	De Wolden
Hof van Twente	Zundert
Horst aan de Maas	

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Figure C.1.1: Distribution of the municipalities in the Netherlands. End of 2009.

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C.2 Results and Descriptives of the Supply Equations

Table C2: Subdivision municipalities in three types, used for the 'simple' model. Period 1995 - 2009.

Housing Market	Variable	Average increase	N x Cases
	Growing municipalities		
Inelastic supply	Population	> 0.00% per year	86
	Housing stock	< 0.75% per year	
Medium elastic supply	Population	> 0.00% per year	171
	Housing stock	>= 0.75% and < 1.25% per year	
Elastic supply	Population	> 0.00% per year	87
	Housing stock	> 1.25% per year	
Subtotal			344
	Declining municipalities		
Inelastic supply	Population	< 0.0% per year	24
	Housing stock	< 0.50% per year	
Elastic supply	Population	< 0.0% per year	34
	Housing stock	>= 0.50% per year	
Subtotal			87
Total			402

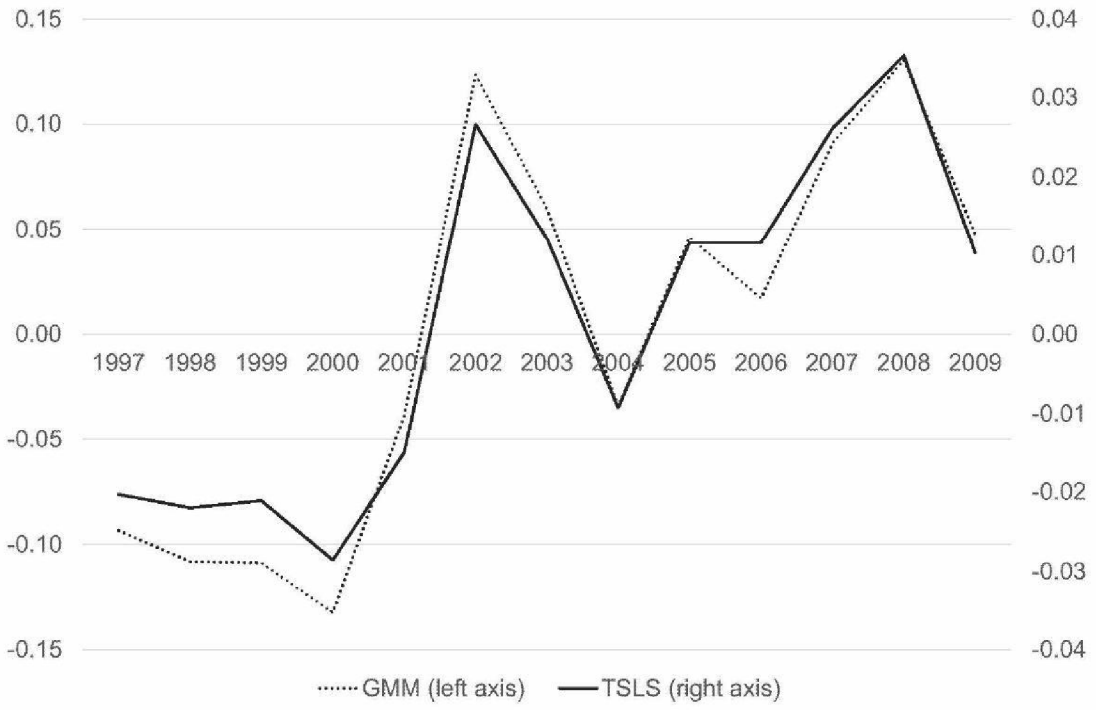

Figure C.2.2: Time fixed effects of the myopic and forward looking model.

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Table C3: Estimation results for the Myopic and Forward Looking models. The (log) ranking of the Location Fixed effects are entered in the main model.

Description	**Parameter**	**Myopic**	**Forward**
Log price	γ_1	0.007	
		(4.25)**	
Marginal cost of investment	γ_1		0.059
			(1.71)*
Density	γ_2	-0.001	-7.673
		(-3.07)***	(2.24)**
Method		TSLS	GMM
Location FE		Yes	Yes
Time FE		Yes	Yes
Adj. R^2		0.284	0.211
Sigma		0.010	0.088
N		5,625	5,625
P(J-stat)		0.766	0.680

Note. IV estimates of variants of Eq. (4.3) using linear projections onto *industry* and *age distribution* instruments, as described in the text. In both cases the instruments are appropriately uncorrelated with the error term. Unfortunately the density parameter is not significant in the myopic model. The probably reason is that overall housing stock changes is quite slow (only 1%). Heteroskedasticity-robust standard errors in parenthesis.

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C.3 Detailed description of the Variables

Detailed description of the variables as seen in Table 4.1:

- **B:** Someone belonging to the population living in a given area.
- **HH:** Group of people living in one accommodation who provide for their own housing and daily needs or whose housing and daily needs are provided for by others.
- **HS:** Number of people in a private household.
- **U:** Unemployment benefits are based on one of the following regulations: Unemployment insurance act (WW), Unemployment Provisions Act (WWV), State Group Regulation for unemployed Persons (RWW), Act on Income Provisions for Older or Partially Disabled Unemployed Persons (IOAW), Civil Service Redundancy Payment Scheme (WRO).
- **P:** Housing prices are based on data provided by the Land Registry Office (Kadaster) which are calculated by Ortec Finance (OF) by a repeat sales method.
- **K:** A housing unit indented to be lived in and that, from a building technical point of view, is meant to permanently function as a dwelling for households. It suffices all the criteria applicable to housing, except for a kitchen and toilet. However the housing unit must be in a building which compensates for these short comings.
- **A:** all measurements are in square kilometres. Included are area used for traffic (railways, roads, airport), buildings (housing, retail, catering, public, social cultural, business), semi-built (dump, wrecks repository, graveyard, mineral extraction site, building site, semi solidified other area), recreational (park, plantation, sports ground, allotment, recreation [short stay], tourism [long stay]). The sum of the square kilometres is multiplied by the highest density achieved in the Netherlands.
- **CC:** The construction cost index from 1995 onwards is based on analysed permits of all homes in the Netherlands. Price changes resulting from changes in quality have been eliminated as much as possible.
- **I:** All permits for houses or apartments on the owner-occupier market which are intended - from a building technical perspective - for permanent living by a single household.

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Appendix D

Appendix for Chapter 5

Table D1: Estimation results period dummies. Results are in log.

	House price				Footprint					
	(I)		(II)		(III)		(IV)		(V)	
	Base A		Base B		Main model		Robustness			
year	estimate	t-value	estimate	t-value	estimate	t-value	estimate	t-value	estimate	t-value
2001	0.106	17.556	0.108	18.163	0.222	5.109	0.140	1.871	0.230	5.200
2002	0.176	29.943	0.177	30.385	0.248	5.662	0.268	3.345	0.250	5.591
2003	0.208	35.554	0.211	36.393	0.420	8.882	0.341	4.065	0.416	8.668
2004	0.234	40.307	0.239	41.255	0.458	9.578	0.481	5.464	0.462	9.470
2005	0.267	45.684	0.272	46.853	0.514	10.443	0.536	5.977	0.524	10.401
2006	0.307	51.690	0.314	52.958	0.653	12.284	0.690	7.201	0.662	12.153
2007	0.341	56.500	0.349	57.906	0.723	13.017	0.703	7.282	0.735	12.945
2008	0.357	55.148	0.366	56.577	0.583	10.512	0.767	6.920	0.594	10.452
2009	0.317	45.003	0.326	46.364	0.548	9.788	0.461	4.607	0.551	9.678
2010	0.301	42.115	0.310	43.441	0.528	9.649	0.653	6.382	0.533	9.565
2011	0.292	39.361	0.300	40.612	0.582	10.453	0.640	6.290	0.598	10.495
2012	0.223	30.109	0.231	31.289	0.417	8.182	0.538	5.681	0.426	8.170
							Yard			
year					estimate	t-value	estimate	t-value	estimate	t-value
2001					-0.021	-0.245	0.202	1.173	-0.042	-0.493
2002					0.113	1.194	0.069	0.413	0.109	1.155
2003					-0.191	-2.398	0.048	0.282	-0.170	-2.108
2004					0.121	1.316	0.242	1.332	0.116	1.263
2005					0.166	1.753	0.219	1.228	0.145	1.545
2006					0.204	2.100	0.243	1.354	0.181	1.886
2007					0.156	1.587	0.278	1.521	0.126	1.297
2008					0.433	3.588	-0.009	-0.046	0.404	3.382
2009					0.108	1.008	0.229	1.082	0.096	0.904
2010					0.209	1.956	-0.047	-0.263	0.195	1.841
2011					0.048	0.474	-0.099	-0.570	0.008	0.084
2012					0.037	0.378	-0.254	-1.651	0.014	0.148

Table D2: Estimation results of the log age variables.

	(I) Base A		(II) Base B		(III) Main model		(IV) Robustness		(V) Robustness	
Variable	estimate	t-value	estimate	t-value	estimate	t-value	estimate	t-value	estimate	t-value
Age × M(-1)	-0.005	-16.45	-0.011	-18.138						
Age^2 × M(-1)			0.000	9.978						
Age × M(0)	-0.003	-9.03	-0.008	-15.450						
Age^2 × M(0)			0.000	12.489						
Age × M(+1)	-0.001	-3.36	-0.006	-10.267						
Age^2 × M(+1)			0.000	8.857						
Age[05,10]					-0.117	-1.79	-0.106	-1.55	-0.120	-1.82
Age[11,15]					-0.330	-5.59	-0.188	-3.47	-0.324	-5.64
Age[16,20]					-0.299	-6.46	-0.239	-5.19	-0.296	-6.41
Age[21,25]					-0.322	-7.65	-0.230	-5.65	-0.318	-7.62
Age[26,30]					-0.306	-8.51	-0.232	-6.48	-0.310	-8.52
Age[31,35]					-0.426	-11.65	-0.350	-9.63	-0.430	-11.61
Age[36,40]					-0.524	-12.70	-0.371	-9.56	-0.532	-12.72
Age[41,45]					-0.556	-12.62	-0.352	-8.78	-0.564	-12.66
Age[46,50]					-0.555	-10.87	-0.282	-6.46	-0.549	-10.84
Age[51,-]					-0.621	-13.84	-0.357	-8.92	-0.617	-13.83
Age[05,10] × M(-1)					-0.036	-2.75	-0.029	-2.13	-0.036	-2.68
Age[11,15] × M(-1)					-0.090	-6.01	-0.077	-5.06	-0.091	-6.02
Age[16,20] × M(-1)					-0.147	-8.57	-0.111	-6.47	-0.148	-8.59
Age[21,25] × M(-1)					-0.154	-7.95	-0.104	-5.38	-0.155	-7.95
Age[26,30] × M(-1)					-0.187	-8.63	-0.141	-6.46	-0.188	-8.64
Age[31,35] × M(-1)					-0.225	-9.52	-0.167	-7.00	-0.226	-9.49
Age[36,40] × M(-1)					-0.265	-10.10	-0.187	-7.12	-0.267	-10.11
Age[41,45] × M(-1)					-0.330	-11.02	-0.178	-6.09	-0.334	-11.07
Age[46,50] × M(-1)					-0.336	-9.78	-0.135	-4.18	-0.341	-9.91
Age[51,-] × M(-1)					-0.236	-6.32	-0.074	-2.10	-0.240	-6.44
Age[05,10] × M(+1)					-0.016	-1.02	-0.020	-1.22	-0.016	-1.06
Age[11,15] × M(+1)					-0.022	-1.20	-0.019	-1.01	-0.024	-1.29
Age[16,20] × M(+1)					-0.056	-2.45	-0.040	-1.67	-0.059	-2.56
Age[21,25] × M(+1)					-0.113	-3.92	-0.064	-2.20	-0.116	-4.03
Age[26,30] × M(+1)					-0.125	-3.99	-0.084	-2.61	-0.128	-4.07
Age[31,35] × M(+1)					-0.120	-3.82	-0.077	-2.38	-0.120	-3.79
Age[36,40] × M(+1)					-0.124	-3.13	-0.059	-1.48	-0.127	-3.21
Age[41,45] × M(+1)					-0.118	-2.58	-0.006	-0.14	-0.126	-2.76
Age[46,50] × M(+1)					-0.189	-3.10	-0.134	-2.21	-0.197	-3.22
Age[51,-] × M(+1)					-0.052	-1.21	0.036	0.87	-0.057	-1.32

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Samenvatting (Summary in Dutch)

Woningprijsdynamieken

Het effect van krediet, demografie en depreciatie

Vaak wordt het eigenwoningbezit gezien als een solide investering. De kredietcrisis en de daar op volgende woningprijsdalingen hebben echter laten zien dat het eigenwoningbezit ook risico's met zich meebrengt. Dit proefschrift bevat vier empirische onderzoeken met betrekking tot woningprijsdynamieken en woningprijsdeterminanten. Dit proefschrift analyseert veranderende woningprijsdeterminanten over de tijd heen (Hoofdstuk 2), het effect van 'kredietvoorwaarden' op woningprijzen (Hoofdstuk 3), het effect van bevolkingsgroei en krimp op woningprijzen (Hoofdstuk 4) en het laatste hoofdstuk behandelt de gevolgen van depreciatie op woningprijzen (Hoofdstuk 5). Al beperkt dit proefschrift zich tot de Nederlandse woningmarkt, de resultaten kunnen relevant zijn voor andere sectoren binnen de vastgoedmarkt of zelfs voor andere markten die gekenmerkt worden door aanbod dat slecht reageert op prijzen.

Hoofdstuk 2 bestudeert de determinanten van woningprijzen gebruik makende van 200 jaar aan (voornamelijk) Amsterdamse data. Zeven verschillende woningprijsdeterminanten worden behandeld: woningvoorraad, constructiekosten, bruto nationaal product (BNP) per capita, de (gecorrigeerde) hypotheekrente, beroepsbevolking als percentage van de gehele populatie, werkloosheid en bevolkingsgroei. Een belangrijk onderdeel van deze studie is dat de woningprijsdeterminanten tijds-variant verondersteld worden. Parameters moeten tijds-variant worden verondersteld vanwege (lange) vastgoedcycli en door veranderingen in (politieke en economische) regimes. Een jaar-op-jaar rollende regressie, met daarin alle mogelijke combinaties van woningprijsdeterminanten, is gebruikt om woningprijzen te analyseren. Het voordeel van zo'n model is dat er geen a priori structuur opgelegd wordt aan de manier waarop de woningprijsdeterminanten veranderen over de tijd heen. Aangezien de tijdreeksen niet-stationair zijn, wordt het model geschat in een foutencorrectieraamwerk. De lengte van het raam is vastgezet op 30 jaar, aangezien dit de gemiddelde lengte is van een vastgoedcyclus en omdat dit resulteert in het grootst aantal coïntegrerende relaties. De resultaten laten zien dat de woningprijsdeterminanten inderdaad veranderend zijn en dat deze de economische werkelijkheid van dat tijdperk weergeven.

Gedurende de 19^{e} eeuw zijn bevolkingsgroei, woningvoorraad en constructiekosten de hoofddeterminanten van woningprijzen. Aan het begin van de 20^{e} eeuw wordt het BNP per capita

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steeds belangrijker. Na de Tweede Wereldoorlog is er een korte periode waarin woningbouw-investeringen en bevolkingsgroei belangrijk zijn. Dit is een afspiegeling van de naoorlogse wederopbouw van Nederland en de groeiende vraag naar woonruimte door de geboorte van de babyboom-generatie. Na 1970 zijn BNP per capita en de hypotheekrente de belangrijkste woningprijsdeterminanten. Dit is op zijn beurt weer een afspiegeling van de eenvoudige toegang tot de hypotheekmarkt in deze periode. Deze bijzondere periode wordt (wereldwijd) tevens gekenmerkt door enorme woningprijsstijgingen.

In Hoofdstuk 3 testen we in meer detail wat het effect is van de hypotheekmarkt op woningprijzen voor de periode 1995 – 2012. Eerst construeren we een 'kredietvoorwaardenindex' (CCI). De CCI geeft het aanbod van krediet op de hypotheekmarkt weer, los van de rentestand en het inkomen van leners. De index wordt geschat als een niet-geobserveerde component in een foutencorrectiemodel waarin de gemiddeld verkregen hypotheek verklaard wordt aan de hand van variabelen als de leencapaciteit van huishoudens (berekend gebruik makende van de Nibud normen) en andere controle-variabelen. Het idee is dat als we woningprijzen verklaren aan de hand van economische en demografische variabelen, de overgebleven niet-geobserveerde component de CCI moet zijn. De niet-geobserveerde component is gemodelleerd als 'local linear trend', 'random walk' en als 'linear splines'. Het model wordt geschat op data voor starters. Het voordeel is dat starters geen eigen vermogen uit de vorige woning mee kunnen nemen en dat ze daardoor (bijna) in zijn geheel afhankelijk zijn van de banken. Hierdoor verdwijnen enkele vraagzijde factoren die de niet-geobserveerde component zouden kunnen vervuilen.

In alle modellen stijgt de CCI tot en met 2009, met een kleine interruptie tijdens de kredietcrisis in 2007 – 2008. Het feit dat steeds meer huishoudens een aflossingsvrije hypotheek namen en de groeiende populariteit van de Nationale Hypotheek Garantie zijn belangrijke verklaringen voor de stijging van het kredietaanbod op de hypotheekmarkt in deze periode. Echter, na 2010 zien we een sterke daling van het kredietaanbod op de hypotheekmarkt. De reden moet waarschijnlijk gezocht worden in de strengere kapitaaleisen voor banken, de afschaffing van aflossingsvrije hypotheekproducten en de strengere Loan-to-Value eisen, opgelegd door de overheid. Aan het einde van 2012 is het aanbod van krediet op de hypotheekmarkt ongeveer zo hoog als in 2003 – 2004. De geschatte CCI is hoog gecorreleerd met de 'Bank Lending Survey' (BLS). In de BLS wordt medewerkers van banken elk kwartaal gevraagd of zij denken dat de hypotheekverstrekking is verscherpt of juist is versoepeld ten opzichte van de vorige periode.

De CCI is vervolgens opgenomen in een foutencorrectiemodel waarin Nederlandse woningprijzen verklaard worden (niet specifiek voor starters) op kwartaalbasis tussen 1995 en 2012. De verklaringskracht van de foutencorrectiemodellen stijgt na het opnemen van de CCI. In reële termen zijn woningprijzen tussen 2009 en 2012 met 25 procent gedaald. Ongeveer de helft van deze woningprijsdalingen kunnen verklaard worden door de daling van de CCI.

Hoofdstuk 4 richt zich op het asymmetrische effect van bevolkingsgroei en krimp op woningprijzen, waarbij expliciet rekening gehouden wordt met het feit dat woningaanbod niet of nauwelijks meteen kan reageren op veranderingen in de vraag naar woonruimte. Door de

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duurzame aard van woningen – ze worden immers gebouwd met het idee tientallen jaren mee te gaan – duurt het zeer lang voordat het aanbod van woningen zich heeft aangepast aan de vraag in het geval van krimp (er wordt nauwelijks tot sloop overgegaan). Door deze vraaguitval zullen woningprijzen disproportioneel hard dalen. Een regio raakt in verval als woningprijzen lager zijn dan de herbouwwaarde van diezelfde woningen, aangezien investeringen dan geen economisch nut meer hebben. Op het moment dat een regio in verval raakt zullen huishoudens met het meeste 'menselijk kapitaal' als eerste verhuizen naar een andere regio. Huishoudens met een lager menselijk kapitaal zullen hun plaats innemen.

Woningprijzen reageren anders op demografische groei. Het effect van demografische groei op woningprijzen is namelijk sterk afhankelijk van hoe snel het aanbod van woningen reageert op de vraag. Als het aanbod niet kan inspelen op de vraag, dan zal de vraag zich vooral vertalen in hogere prijzen. Op de korte termijn zal er altijd enige discrepantie zitten tussen vraag en aanbod aangezien het ontwikkelen van woningen enige tijd in beslag neemt. Echter, het kan ook zo zijn dat het aanbod van woningen zich zelfs niet of nauwelijks aanpast op de lange termijn. Dit kan komen door een fysiek tekort aan ruimte of door regelgeving. Regelgeving in Nederland met betrekking op woonaanbod is vooral te vinden in de Wet Ruimtelijke Ordening. Het belangrijkste uitvoerende orgaan in de geanalyseerde periode is de gemeente met haar bestemmingsplannen.

Om het effect te schatten van demografische groei en krimp op woningprijzen gebruiken we een panel data set op gemeenteniveau voor de periode 1995 – 2009. De bevolkingsgroei of -krimp moet echter langdurig zijn wil die de woningprijzen structureel beïnvloeden. Om deze reden is er gekozen om te modelleren naar het langst mogelijke tijdsinterval: 15 jaar. Aangezien we vooral geïnteresseerd zijn in het asymmetrische effect van bevolkingsgroei en -krimp wordt de variabele bevolkingsmutatie opgesplitst in een variabele met bevolkingstoename en in een variabele met bevolkingsafname. De variabele met bevolkingstoename wordt bovendien verder opgesplitst in categorieën die aangeven hoe eenvoudig het aanbod zich kan aanpassen aan de vraag in desbetreffende gemeente. Om deze categorieën aan te maken verklaren we eerst woningprijsontwikkelingen aan de hand van het aantal nieuwbouwvergunningen. De categorieën zijn een ordening van gemeentes waarbij het aantal nieuwbouwvergunningen weinig reageert op woningprijzen tot en met gemeentes waar het aantal nieuwbouwvergunningen zeer goed reageert op woningprijzen.

Elke 1% bevolkingskrimp resulteert in 1,9% lagere woningprijzen. In de gemeentes waar het aanbod het minst reageert op vraag zullen prijzen met 0,4% stijgen bij elke procent bevolkingstoename. Bevolkingsgroei zal woningprijzen echter niet of nauwelijks beïnvloeden in gemeentes waar het aanbod zich relatief snel aanpast aan de vraag. Voorbeelden hiervan zijn de gemeentes Barendrecht, Houten en Almere.

Hoofdstuk 5 analyseert het effect van depreciatie op woningprijzen. Via depreciatie wordt rekening gehouden met het waardeverlies van de woning als gevolg van het feit dat de woning ouder wordt. Depreciatie bestaan uit drie onderdelen: (1) fysieke slijtage, (2) functionele

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veroudering en (3) externe veroudering. Fysieke slijtage is de slijtage van de opstal naarmate deze ouder wordt. Onder functionele veroudering verstaan we de vermindering van de door de woning geleverde woondiensten door de tijd heen. Externe veroudering is de waardeverandering van de grond, bijvoorbeeld omdat de lokale voorzieningen door de tijd heen kunnen veranderen. Daarbij zijn er ook nog zogenoemde 'vintage' of 'jaargang' effecten. Dit is een extra prijseffect (positief of negatief) op de opstal die enkel en alleen voorkomt omdat de woning in een bepaalde periode is gebouwd (denk in de breedste zin aan architecturale stijl). Fysieke slijtage kan tegengegaan worden door goed onderhoud te plegen. Functionele veroudering kan alleen tegengegaan worden door (grote) renovaties.

We gebruiken de leeftijd van de opstal om de fysieke slijtage te meten, het bouwjaar van de opstal om het gezamenlijke effect van de functionele veroudering en 'vintage' te meten en het verkoopjaar om de externe veroudering te meten in een (niet-lineair) hedonisch model. Daarbij kijken we specifiek naar het effect van fysieke slijtage (leeftijd) *per* onderhoudsniveau.

In het algemeen zijn er twee grote problemen bij studies over depreciatie. Ten eerste is er een identificatieprobleem tussen de belangrijkste variabelen: leeftijd, bouwjaar en verkoopjaar. Ten tweede zal men altijd een onderschatting vinden van de leeftijdseffecten op het moment dat de grondprijzen groter zijn dan nul. Ons model omzeilt deze problemen door ervan uit te gaan dat de fysieke slijtage (gemeten als leeftijd) en het gezamenlijke effect van fysieke veroudering en 'vintage' (gemeten als bouwjaar) alleen invloed hebben op de opstal. De externe veroudering (verkoopjaar) daarentegen heeft alleen invloed op de grondprijs. De enige input in het model is de herbouwwaarde van de opstal. De opstalwaarde is nu een functie van de herbouwwaarde van de opstal, de leeftijd en het bouwjaar van de opstal en de grootte (aantal vierkante meters) van de opstal. De grondwaarde wordt opgesplitst in tweeën: een waarde van de grond waar de woning op staat en een tuinwaarde. De waardes van de grond zijn functies van de locatie, grootte, verkooptijd en het type opstal dat op de grond staat.

De Nederlandsche Vereniging van Makelaars (NVM) heeft ons data geleverd van meer dan 9.000 woningtransacties in de regio 's-Hertogenbosch in de periode 2000 – 2012. Data over herbouwwaardes zijn verkregen van de website Bouwkostenkompas.

De resultaten laten zien dat de staat van onderhoud een belangrijke effect heeft op de fysieke slijtage van de opstal. Na 50 jaar van geen of nauwelijks onderhoud zal een opstal 43% in waarde zijn verminderd. Een goed onderhouden opstal zal daarentegen nauwelijks in waarde verminderen. De resultaten laten tevens zien dat grondprijzen een stuk volatieler zijn dan opstalprijzen. Daarbij zijn de grondprijzen- en opstalindex nauwelijks gecorreleerd. Vergeleken met traditionele hedonische modellen heeft het beschreven model drie voordelen. Ten eerste geeft ons model geen onderschatting van de leeftijdseffecten. Ten tweede is ons model niet gevoelig voor het eerdergenoemde identificatieprobleem. Als derde en laatste is de precisie van de leeftijdsschattingen niet gevoelig voor volatiele grondprijzen.

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