

Time-Varying Determinants of Long-Run House Prices

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Working paper

Het doel van dit paper is om, vanuit wetenschappelijk perspectief, meer inzicht te verschaffen in de determinanten van woningprijzen en hoe deze zijn veranderd over tijd.

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Time-Varying Determinants of Long-Run House Prices

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Abstract

The determinants of house prices change over time. This paper documents these changes using long-run historical data from Amsterdam from the year 1825 onwards. Because many houses in Amsterdam have survived until this day, we can construct a long-run repeat sales index and examine its determinants. We find that in the early beginnings of our transactions dataset population growth, construction costs and new housing supply are the most important determinants of house price dynamics. After 1900 income starts to play a role and, with the development of the mortgage market, interest rates as well. Directly after World War II population and investment in housing are key determinants of house prices, which likely reflects the baby boom generation and post-war reconstruction plans. Our results imply that the determinants of house prices are not fixed but change over time and reflect the economic state of affairs in each different era.

KEYWORDS: house prices; long-run determinants; cointegration. **JEL-codes:** N9, R31, C32.

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1 Introduction

In Europe, housing accounts for 40% - 60% of total household wealth and it is roughly 20% for the average household in the United States (Statistics Netherlands and US Bureau of Economic Analysis and Statistics, respectively). It should, therefore, not come as a surprise that economists and policy makers are highly interested in the fundamental determinants of house prices.

Between the mid-1980s and 2008 real house prices more or less doubled in most industrialized countries (De Wit et al., 2013). From a historical perspective, however, this is a relatively new phenomenon. Figure 1, for example, shows historical real log house price indices for the US, UK, France, and the Netherlands. Annual real house price appreciation is close to zero, or in some cases even declining (France), during most of the 20^{th} century. Total real house price appreciation (averaged across the four countries) between 1900 and 1985 is 20% (on average 0.23% per year) while real house price appreciation for the period 1985 — 2010 is five times as large, about 107% (on average 7.15% per year). To understand these different growth rates, it is essential to understand how the fundamental determinants of house prices, and their impact, have changed over time.

This paper examines the time-varying determinants of long-run, historical, house prices. We use almost 200 years of house price data (1825–2012) from Amsterdam, the Netherlands. We focus on seven major determinant of house prices: housing supply, construction costs, Gross Domestic Product (GDP) per capita, the opportunity cost of capital (interest rates), labor force, unemployment, and population growth. We use a rolling (window) error correction model (R-ECM) with changing covariates to examine the cointegrating relationships between house prices and its determinant and show how these relationships have changed over time. Even though it is widely acknowledged that house price determinants differ across markets, this study examines the changes in house price determinants in a single housing market over a long period of time.

We find that the long-run cointegrating relationships change over time. Population growth, construction costs and housing supply were the main drivers of house prices in the 19^{th} century. Our results show that the cointegrating relationships changed from more construction cost driven to more income and - especially in the end of the sample - interest rate driven variables. Mortgage market innovations and financial liberalization allowed financial intermediaries to advance higher levels of credit to consumers from the 1970s onwards (Fernandez-Corugedo and Muellbauer, 2006). Conjoined with declining interest rates this resulted in more affordable housing and subsequent increases in house prices. Moreover, the size of the effects are also time varying. For example, the effect of GDP on house prices was substantial lower during the period 1900 — 1970 than in the period 1970 — 2012. Finally,



Figure 1: Log real house price indices for a selection of countries, 1900 – 2012.

Notes: The indices start at 1900, except for the UK which starts at 1952. The base year is 1963. The index for the US is taken from Freddie Mac (for the period 1975 – 2014) and is augmented by the historic data from Robert Shiller. The UK data is taken from Nationwide and for France from CGEDD. The house price data for France goes back to 1936. House price data from Paris was used to extend this time series. House prices for the Netherlands are based on our own calculations (see Section 2). Both the UK and UK indices are based on the 'standard' Case and Shiller (1987) repeat sales methodology. The French price index is based on (weighted) median sales prices. For the Netherlands, see Appendix A.2.

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we find that directly after World War II population growth and investment in housing are the main drivers of house prices. This likely reflects the baby boom generation and post-war reconstruction plans. Population also had a large impact on house prices in Amsterdam during the 1970s. This is mainly due to the large scale deurbanisation taking place in that time period.¹

Even though we are not the first to analyse changing patterns in long-run house price time series (most notably see, Ambrose et al., 2013; Ngene et al., 2014), we are the first to use additional data to analyse which fundamental house price determinants are important in which era.² This helps us to address several important questions about house price dynamics. First, our results can explain some of the discrepancies in the literature about the determinants of house prices. A stylized example is the study by Englund and Ioannides (1997) versus that of Adams and Füss (2010). Both use the same OECD database and both regress house prices on a proxy for economic activity and interest rates for 15 OECD countries. However, the effect of interest rates on house prices according to Adams and Füss (2010) is a multitude of that found by Englund and Ioannides (1997). This can be explained by the fact that the study of Englund and Ioannides (1997) uses data from 1970 — 1992 and the study of Adams and Füss (2010) is based on a different time period, 1975 — 2009. Generally speaking, during the 1970s and 1980s the loan-to-value caps were a lot stricter and access to credit was relatively limited. Thus, it should come as no surprise that the effect of interest rates on house prices was lower in the pre-1990s era.

Second, ignoring changing cointegrating relationships of house prices over time can very easily result in house price increases to be incorrectly interpreted as a bubble (Ngene et al., 2014). In the literature it is quite standard to measure bubbles using an error correction approach. Whenever prices are above (below) equilibrium houses are overvalued (undervalued). However, the equilibrium relation (and thus the deviation from it) depends on which variables are included. In fact, a number of academic studies conducted in the early 2000s suggested that the U.S. housing market was experiencing the characteristics of a house price bubble (see Ambrose et al., 2013). However, Case and Shiller (2003) compared U.S. house price growth with income growth since 1985 and concluded that income growth could explain nearly all of the house price increase for over 40 states. In addition, McCarthy and Peach (2004) found little evidence supporting a bubble in the U.S. housing market after adjusting

¹It were actually the babyboomers who had families by that time that left Amsterdam for more open / green areas directly neighboring Amsterdam.

²Both Ambrose et al. (2013) and Ngene et al. (2014) do not look directly at which variables affect house prices before and after a break. More specifically, Ambrose et al. (2013) explore the rent-price ratio on the same Herengracht as the yardstick for fundamental valuation for two sub-periods (1650 – 1915 and 1916 – 2005) and Ngene et al. (2014) analyse structural breaks in long memory or fractional integration using an ARFIMA model between 1991 and 2014 in the US. Ambrose et al. (2013) assume that interest rates and rents 'capture' all fundamentals such as economic development, demographics, wars, etc.

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housing prices to account for the effects of interest rate changes. In our study, we will cope with such issues by allowing the cointegrating relationships to change over time.

The remainder of this paper is structured as follows. Section 2 provides a discussion on the historical context of the Amsterdam housing market and Section 3 describes the data used in this study. Section 4 contains the methodology to examine the time-varying determinants of house prices. In Section 5 we report the results and Section 6 concludes.

2 House prices and the historical context of the Amsterdam housing market

To examine the long-run determinants of house prices, we start with constructing a price index for the Amsterdam housing market. We are not particularly interested in individual transaction prices, but in the price developments over time and the macro-economic determinants that can explain those changes. We used two sources to construct the long-run house price index. For the period 1825 - 1972 we exploit the same data as is used by Eichholtz (1997). The dataset covers all transactions of dwellings on the Herengracht from 1628 to 1972 (see Appendix A.1).

The Herengracht is one of the central canals in Amsterdam that was constructed between 1585 and 1660. By 1680, most of the canal lots were developed. The population and radius of Amsterdam grew only slowly in our analyzed period, and during most of this time the Herengracht remained a mix of residential properties and offices (Geltner et al., 2014). Only in the beginning and in the mid of the 20th century did Amsterdam see a sudden expansion of its metropolitan area size.³ One particular complication with this type of historical data is that at some periods in time there are not many or even no sales (see Appendix A.1). In addition, it may also take a long period of time between transactions of the same house. This is something we explicitly have to take into account when constructing the house price index.

Since most of the dwellings on the Herengracht have survived until this day, we can use a repeat sales approach to construct a 'constant quality' house price index. As is typical for repeat sales models, our method does not control for capital expenditures (including large scale renovations) and depreciation, resulting in a under- or overestimation of the price index, respectively (Harding et al., 2007). Especially in our case, with almost 200 years of data, many structures will have been altered completely. However, the most important

 $^{^{3}}$ In the 1930s an extensive construction plan ('plan Zuid') was executed and supervised by the famous Dutch architect Berlage. After the Second World War, and with help of the Marshall-plan, Amsterdam expended to both the West and East.

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characteristics of the properties remain the same: Location, land size and property type.⁴ Moreover, pairs with an (absolute) average return of 50% per year were omitted from the data. These 'abnormal' returns are probably caused by large scale changes to the property between sales.⁵ Also, in our specific application, we will only look at 30-year windows (see Section 4). The effect of (occasional) renovations on a house price index is less over 30-year windows than over the entire 200 years. Therefore, we expect that the repeat sales index will still be a good approximation of house price appreciation even in the long-run and we will use the index as basis for our analysis.

For this research, we have used a structural time series approach to estimate a local linear trend (i.e. house price index) model using the repeat sales methodology described by Francke (2010), instead of the more standard dummy variable approach (as made popular by Bailey et al., 1963). This approach has the following benefits. Firstly, the model is tailor made for thin markets and is able to cope with the often large time between sales (which can be decades in our case). Secondly, because we estimate a stochastic (local linear) trend to construct a house price index, the resulting price index should be less sensitive to (short-run) outliers and more sensitive to macro-economic (long-run) shocks. A detailed description of the construction of the house price index is available in Appendix A.2 and A.3.

Figure 2 contains the estimated real (log) price index from 1825 until 1973.⁶ We have extended the price index for the period 1973 – 2012 by using the Herengracht Index (HGI) as published on the website of Eichholtz.⁷ This index is based on a more traditional, Case and Shiller (1987), Repeat Sales methodology as described in Eichholtz (1997). The price index used in the analysis is deflated using the Consumer Price Index (CPI) which is directly available from the website of Statistics Netherlands. The CPI is the only deflator available to us for the entire time period.

Some of the explanatory variables in this research will be Amsterdam specific. Other explanatory variables, like GDP per capita, and unemployment rates, are on a (Dutch) aggregate level since this data is not available to us for Amsterdam for such a long time period. We are comfortable making the assumption that these macro variables will still affect

⁴Especially in large cities (like Amsterdam), it is known that the location is an important price determinant as the land value takes up a large proportion of the total house price value (Glaeser et al., 2008).

⁵An alternative approach can be found in Goetzmann and Spiegel (1995). The model by Goetzmann and Spiegel (1995) is an extension of the model by Case and Shiller (1987). Around the time of sale they expect that households who either sell or buy the property will make improvements to the structure and surroundings. This causes an increase in the value of the property which is independent of time. Therefore, they propose to add a non-temporal return to the model at the time of sale.

 $^{^{6}}$ We have estimated the price index using data starting from the 17^{th} century onwards to increase the accuracy of our estimates. The analysis in the remainder of this study, however, is based on the price index from 1825 onwards since the explanatory macro factors are only available as of 1825.

⁷We did not have access to the underlying micro data for this time period. Alternatively, we also used data from the Dutch Association of Real Estate Brokers and Real Estate Experts (NVM) as robustness check. However, the results and conclusions remain the same.



Figure 2: Log real house price index (1825 - 2012) and its sources.

Notes: Price index of the Herengracht (HGI) is based on the Herengracht micro data before 1977, using the Bayesian Repeat Sales model described in Appendix A.2 and A.3. After 1977 we use the HGI as publicized on the website of Eichholtz.

Amsterdam house prices, as the Dutch economy is heavily intertwined since the Renaissance (Geltner et al., 2014). In addition, in case of the construction costs and interest rates, there is no reason to believe that there is a (large) difference between the nationwide and Amsterdam specific time series. In that regard, it is also important to note that the Netherlands is comparable in terms of population and land size to a large Metropolitan Statistical Area (Dröes and Hassink, 2013). The Netherlands has a clear urban core (of which Amsterdam is part of) and a surrounding periphery, which accords with the definition of a MSA.⁸

3 Data and the determinants of house prices

In long-run equilibrium, new building developments are determined by production costs and the costs of land. When prices go up, because of an increase in demand and a temporary shortage of houses, there is an incentive to construct new houses (Francke et al., 2009). The supply of these houses will bring the house prices down to a new equilibrium (DiPasquale and Wheaton, 1994). Since we are interested in this long-run equilibrium, house prices should be examined by a macroeconomic housing model where supply and demand factors are both considered. In this study we focus on the following fundamental determinants of house prices: Housing supply, construction costs, Gross Domestic Product (GDP) per capita, the opportunity cost of capital, population growth, unemployment rate, and the working age population as percentage of total population. These variables are typical in studies which focus on explaining (long-run) house prices, see Table 1.⁹ Unfortunately, there are no time series on the (non-housing) wealth of households for the total studied time period in the Netherlands. The opportunity cost of capital is a combination of interest rates and user costs. In this Section, we discuss why these determinants are important, the different data sources that have been used, and the descriptive statistics.

Table 2 contains the data sources used in this paper. Most of the macro-economic factors are available from Statistics Netherlands (CBS). The interest rates, used to compute the opportunity cost of capital, are taken from the Dutch Association of Real Estate Brokers and Real Estate Experts (NVM) and Homer and Sylla (2005). As mentioned, house prices are obtained from Eichholtz (1997). House prices, construction costs, and GDP are index values. Housing supply is measured as the number of houses. The labor force share, the opportunity cost of capital, and employment are in percentages. Population is the total number of inhabitants in Amsterdam. Table 2 also contains a broad classification of the macro-economic factors into (housing) demand and supply factors (including their expected sign). Table 3

⁸The Netherlands is comparable in terms of population with large Metropolitan Statistical Areas (MSAs) such as the New York MSA and has the same GDP as the Los Angeles MSA.

⁹In this case *long-run* means the estimates of the long-run equation in error correction models. All studies mentioned in Table 1 used an error correction framework.

| | (I) | (II) | (III) | (IV) | (V) | (VI) | (VII) | (VIII) | (IX) |
|-----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|-------|--------------|--------------|
| Construction costs | | \checkmark | \checkmark | | | \checkmark | | \checkmark | |
| Housing or land supply | | \checkmark | \checkmark | \checkmark | \checkmark | | | | |
| GDP / income | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | \checkmark | ✓ | \checkmark | |
| Wealth | | \checkmark | | | \checkmark | | | | |
| Interest rates / User costs | \checkmark | \checkmark | | \checkmark | \checkmark | \checkmark | ✓ | \checkmark | \checkmark |
| Population | \checkmark | \checkmark | \checkmark | | \checkmark | \checkmark | | | |
| | | | | | | | | | |
| Country | US | UK/US | US | US | US | NL | NL | OECD | NL |
| Frequency | Y | Q | Y | Y | Y | \mathbf{Q} | Y | \mathbf{Q} | Υ |
| Sample start | 1979 | 1969 | 1979 | 1982 | 1981 | 1975 | 1965 | 1975 | 1650 |
| Sample end | 1996 | 1996 | 1995 | 2004 | 2003 | 2002 | 2009 | 2007 | 2005 |

Table 1: House price determinants according to a selected number of studies.

 $\mathbf{I} = \text{Malpezzi}$ (1999), $\mathbf{II} = \text{Meen}$ (2002), $\mathbf{III} = \text{Capozza et al.}$ (2002), $\mathbf{IV} = \text{McCarthy and Peach}$ (2004), \mathbf{V} = Verbruggen et al. (2005), VI = Gallin (2006), VII = Francke et al. (2009), VIII = Adams and Füss (2010). IX = Ambrose et al. (2013).

US = United States, NL = the Netherlands, UK = the United Kingdom, OECD = the countriesparticipating in the Organisation for Economic Co-operation and Development.

 $\mathbf{Y} =$ Yearly, $\mathbf{Q} =$ Quarterly.

and 4 reports the descriptive statistics of the macro-economic factors respectively in levels and in log first-differences (i.e. percentage differences). All time series (except population, housing supply, labor force and unemployment) are deflated using the CPI. The time series (figures) in log-levels are given in Appendix A.4. We will discuss the expected impact of the macro-economic factors on house prices in the remainder of this Section.

| Variable | Aggregation | Source | Unit | Type of | Expected |
|-----------------------------|-------------|-----------------------------|-------|-------------|-----------------------|
| | | | | determinant | sign |
| House price index | Amsterdam | Eichholtz (1997), CBS | index | | |
| Housing supply | Amsterdam | OIS | units | Supply | - |
| Construction costs | Ams./Neth. | CBS, Neha | index | Supply | + |
| GDP per capita | Netherlands | CBS | index | Demand | + |
| Labor-Force | Netherlands | CBS | % | Demand | + |
| Opp. cost of capital | Netherlands | NVM, Homer and Sylla (2005) | % | Dem./Sup. | -/+ |
| Unemployment | Netherlands | CBS | % | Demand | - |
| Population $(\times 1,000)$ | Amsterdam | OIS | total | Demand | + |
| _ 、 、 , | | | | | |
| Consumer Price index | Netherlands | CBS | index | | |

Table 2: Data sources: Macro-economic variables and house prices.

CBS = Statistics Netherlands, Neha = Dutch Historical Archives, OIS = Research, Information andStatistics, City of Amsterdam and NVM = the Dutch Association of Realtors.

Real GDP per capita is seen as a proxy for economic activity and/or income (Englund and Ioannides, 1997). An increase in income is expected to have a positive effect on housing demand and, consequently, house prices. GDP has been increasing over time, on average, by 2.8 percent each year (see Table 4). Note that GDP is missing for the First and Second

| Variable | Mean | Std. Dev. | Min. | Max. | Skewn. | Kurt. | P-value |
|----------------------------------|--------|-----------|----------|----------|--------|-------|---------|
| House price index | 150.79 | 62.18 | 70.70 | 358.04 | 1.55 | 5.35 | 0.352 |
| Housing supply $(\times 1, 000)$ | 188.12 | 103.01 | 80.00 | 397.46 | 0.56 | 1.93 | 0.999 |
| Construction costs | 171.08 | 101.27 | 64.83 | 405.14 | 0.77 | 2.18 | 0.038 |
| GDP per capita | 6,257 | 11,888 | 97.00 | 45,569 | 2.07 | 6.20 | 0.579 |
| Labor-Force | 40.27% | 2.17% | 36.75% | 47.59% | 1.28 | 5.52 | 0.116 |
| Opp. cost of capital | 6.12% | 2.59% | 1.00% | 12.79% | 5.11 | 2.84 | 0.000 |
| Unemployment | 4.80% | 2.90% | 0.80% | 17.40% | 2.10 | 8.88 | 0.233 |
| Population $(\times 1, 000)$ | 556.54 | 237.81 | 192.33 | 872.43 | -0.30 | 1.49 | 0.707 |
| Consumer Price index | 693.89 | 953.05 | 96.00 | 4,572.00 | 1.68 | 4.44 | 0.939 |
| Number of observations | | | 187 | | | | |
| Sample period | | 1 | 825-2012 | | | | |

Table 3: Descriptive statistics (real, levels): Macro-economic variables and house prices.

Note. The reported P-values are the significance levels at which you can reject the null hypothesis of a unit root (Augmented Dickey Fuller test). All ADF tests were done with a constant and a trend. Critical values are taken from MacKinnon (2010). The test is conducted on the log of the variable.

The lag lengths differ per variable and are based on the Akaike Information Criterion.

| Table 4: | Descriptive statistics | (real, ln | ı first | differences) | : Mae | cro-economic | variables | and | house |
|----------|------------------------|-----------|---------|--------------|-------|--------------|-----------|-----|-------|
| prices. | | | | | | | | | |

| Variable | Mean | Std. Dev. | Min. | Max. | Skewn. | Kurt. | P-value |
|------------------------------|--------|-----------|---------|-------|--------|--------|---------|
| House prices | 0.006 | 0.070 | -0.365 | 0.258 | -0.492 | 7.358 | 0.000 |
| Housing supply | 0.009 | 0.011 | -0.020 | 0.080 | 1.510 | 11.717 | 0.002 |
| Construction costs | 0.006 | 0.067 | -0.338 | 0.278 | -0.254 | 7.732 | 0.000 |
| GDP per capita | 0.028 | 0.057 | -0.190 | 0.187 | -0.318 | 3.899 | 0.000 |
| Labor-Force | 0.001 | 0.006 | -0.017 | 0.022 | 0.528 | 4.780 | 0.324 |
| Opp. cost of capital | -0.005 | 0.284 | -0.847 | 0.999 | 0.142 | 5.066 | 0.000 |
| Unemployment | 0.001 | 0.207 | -1.211 | 0.606 | -0.813 | 9.969 | 0.000 |
| Population $(\times 1, 000)$ | 0.008 | 0.015 | -0.068 | 0.080 | -0.034 | 9.890 | 0.000 |
| | | | | | | | |
| Consumer Price index | 0.019 | 0.058 | -0.145 | 0.360 | 0.739 | 9.094 | 0.000 |
| Number of observations | | | 186 | | | | |
| Sample period | | 18 | 26-2012 | | | | |

Note. The reported P-values are the significance levels at which you can reject the null hypothesis of a unit root (Augmented Dickey Fuller test). All ADF tests were done with a constant and a trend. Critical values are taken from MacKinnon (2010).

The lag lengths differ per variable and are based on the Akaike Information Criterion.

World War periods (see Appendix A.4).

Population growth is another typical demand-side variable. Between 1825 and 1970 population of Amsterdam steadily grew from less than 200,000 to almost 870,000 inhabitants (see Table 3). If supply, at least in the short-run, is fixed due to the time it takes to construct buildings (Harter-Dreiman, 2004) or legislation and lack of available space (Hilber and Vermeulen, 2012), an increase in population is expected to have a positive effect on house prices. Between 1970 and 1985 the population of Amsterdam shrunk with almost 200,000 inhabitants due to large scale deurbanisation in that period. Glaeser and Gyourko (2005) found that population decline has a disproportionate effect on house prices, because the durability of housing means that it can take decades for negative urban shocks to be fully reflected in housing supply levels. During the 1990s and 2000s the population of Amsterdam grew to almost 800,000. Alternatively, working age population as percentage of total population might also have a positive effect on house prices (Case and Shiller, 2003). In essence, having a job is a precondition for owning a house. It typically, conjointly with income, determines house price dynamics (see also Chan, 2001). The working age is defined as the percentage of population aged between 20 and 65. The percentage working age population to total population during the period 1825–2012 has been between 36 to 47 percent (see Table 3). We only have data on the percentage working age population on a Dutch aggregate level.

Several studies also show that unemployment negatively affects house prices (see for example De Wit et al., 2013; Adams and Füss, 2010; Abraham and Hendershott, 1996). On average unemployment levels have been relatively low in the Netherlands (4.8%, see Table 3). However, in the 1930s - during the Great Depression - unemployment peaked at 17%.

The 5-year-annuity (nominal) mortgage interest rate, from 1973 onwards, is taken from the NVM. We use an index of the long-term Dutch government bond yields to proxy for the (mortgage) rates before this period (taken from Homer and Sylla, 2005). Subsequently, the real opportunity cost of capital is calculated by (see Williams, 2009)

$$OCC_t = (N_t - E[\Delta cpi_t]) + 2\%, \tag{1}$$

where N_t is the nominal rate and cpi_t the log of the CPI in year t. As is usual when computing the opportunity cost of capital we take the expected inflation instead of inflation itself, by using a simple (7-year) Moving Average filter. We add 2% to measure (imputed) rental returns minus maintenance expenditures and other costs. During the 19th century inflation was at times extreme. The time series of the opportunity cost of capital is very volatile (see Table 4). Only after the Second World War does the opportunity costs of capital seem to stabilize. We introduce a (lower bound) opportunity cost of capital cap of 1%, since we want to circumvent taking the log of a negative value and generally to filter out extreme values. This happened in 9 (consecutive) periods, with 5 of them being during the Second World War. The extremely low opportunity cost of capital in the 1970s is not surprising given the high inflation during this period (oil crises). The opportunity cost of capital can be interpreted as a demand and a supply-side factor. In particular, higher out-of-pocket costs (in case of increasing oppurtunity cost of capital) will decrease the demand for housing (especially relevant after the development of the mortgage market) resulting in decreasing house prices (Schilder, 2012). Alternatively, a higher interest rate may also have a negative effect on the ability of construction companies to obtain a loan, which decreases the supply of new housing and, consequently, increases house prices (DiPasquale and Wheaton, 1994; Capozza et al., 2002). The effect of the real interest rate is, therefore, mainly an empirical question.

The value of a property can be interpreted as the value of land plus the value of the structure (Bourassa et al., 2011). The construction cost of a property measures the replacement value of a structure and, therefore, is typically capitalized into house prices (see Case and Shiller, 1990; Davis and Palumbo, 2008). Furthermore, any given positive economic shock will be easier for an area to absorb if the housing stock can be increased at low cost. Therefore, we hypothesize that variables proxying for the cost of increasing the supply of housing should affect the time series properties of housing prices (Capozza et al., 2002). A construction cost index for the Netherlands from 1913 onwards is directly available from Statistics Netherlands. We used data from the Dutch Economic Historical Archives (in Dutch: 'Nederlandsch Economisch-Historisch Archief', abbreviated as Neha) as a basis to construct a measure for the construction costs index before 1913. The Neha reports the costs of all building materials in Amsterdam on a yearly basis from 1800 to 1913. Using the expert opinion of a Dutch architect specialized in 19th century buildings in Amsterdam we constructed a 'standard' home for this era. Next, the materials needed for this 'standard' home have been multiplied by the costs given by Neha. Based on the historic data from Statistics Netherlands, we assume that the material costs is constant at 70 percent of the total cost for new housing. For the remaining 30 percent, the costs are indexed by the national wage index (also obtained from Neha). Finally, the construction cost index is deflated by the CPI. The construction cost index quadrupled during our sample period (see Table 3). Also note the large increase in construction costs during World War I. This was mainly driven by the scarcity of (building) materials during this period.

Finally, we use Amsterdam specific housing supply to measure new housing construction. More specifically we use the number of housing units, both for the (social) rental and owneroccupied market in Amsterdam, made available to us by Research, Information and Statistics, City of Amsterdam (OIS) after 1908.¹⁰ Before 1900 the number of buildings are reported in

¹⁰There are many other potential measures of housing construction, such as the number of building permits

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the OIS data (multiple housing units can be in one building). We use an index of the number of buildings to proxy for the number of housing units before 1900. There is no data available on housing supply between 1900 and 1908 and for the first 10 years (1825 - 1835). In both instances we assume that during these periods there was no new construction.

During the 1930s the number of housing units sky-rocketed in Amsterdam. This reflects a change in policy view: Every labourer in Amsterdam should have a decent place to live. To this day, this is reflected in the substantial share of social housing in the Amsterdam (Van Ommeren and Koopman, 2011). We expect that new housing supply has a negative effect on house prices. Differences in supply elasticity have been argued to explain differences across US metropolitan statistical areas (MSAs) in house price levels and volatility (Green et al., 2005; Glaeser et al., 2008; Paciorek, 2013; Wheaton et al., 2014). In part, this may also reflect differences in regulation and space constraints (Hilber and Vermeulen, 2012). To the extent that those changes also occur over time, the size of the housing investment effect can change over time.

Housing literature generally treats both population and housing supply to be endogenous to house prices. Population and house prices are endogenous due to omitted variables which affect both prices and population (Saiz, 2007). House prices and supply are interlinked as they are jointly set in equilibrium (see Mayer and Somerville, 2000; Paciorek, 2013). In our case however, we use city center (Herengracht) house prices and Amsterdam level population and housing supply variables. The supply of houses on the Herengracht actually did not change *that much* over the analyzed period. As mentioned in Section 2, by 1680 most of the canal lots were already developed. The population of the city centre even decreased from almost 200,000 before the 1850s to less than 80,000 in 2012. Households moved to more modern and more spacious houses as new neighbourhoods were constructed. Thus, in our case population and supply can be considered (pre-)determined outside the model.¹¹

4 Model

The effect of the macro-economic determinants on house prices reflects both short-run fluctuations and long-run trends. These price dynamics can be captured by an error correction model (ECM), in which the dynamics are captured by a combination of current and past shocks and a gradual adjustment towards equilibrium. This model is based on the idea that the included time-series are, although non-stationary, cointegrated: Linear combinations of

issued (Hilber and Vermeulen, 2012; Paciorek, 2013) or new housing starts (Mayer and Somerville, 2000), however the actual housing supply is generally regarded as the most appropriate measure (Paciorek, 2013).

¹¹A Rolling Granger Causality test between the variables, revealed that house prices did not Granger-Cause both housing supply and population. In addition, our results indicate that housing supply and population are typically not in the same cointegrating equation, which is most likely due to multicolinearity.

the variables are stationary. These linear combinations can be interpreted as equilibrium relationships. Therefore, it should be no surprise that error correction models are a popular tool in analysing long-run house prices. Again, Table 1 contains a few examples of error correction models in housing literature. The standard error correction model is given by:

$$p_t = \beta + x_t' \delta + \varepsilon_t, \tag{2}$$

$$\Delta p_t = \sum_{k=0}^n \lambda_k \Delta p_{t-k} + \sum_{k=0}^n \Delta x'_{t-k} \theta_k + \alpha \left(p_{t-1} - p^*_{t-1} \right) + \eta_t, \tag{3}$$

where Eq. (2) represents the long-run equilibrium relation and Eq. (3) represents the shortrun relation. Variable p_t is the (log) house price index at time t, p^* are the fitted values of Eq. (2) and x is a vector of macro-economic covariates (i.e. population growth, housing supply, labor force, construction cost, unemployment, opportunity cost of capital, and GDP per capita). Parameter α , in the short-run relation (Eq. (3)), measures the degree of mean reversion and is estimated from the data. The series $(p_t - p_t^*)$ is also referred to as the error correction term. If the series $(p_t - p_t^*)$ is stationary, then $(p_t - p_t^*)$ is the co-integrating relation. In this study, we are especially interested in the parameters β and δ (the long-run cointegrating relationship) in Eq. (2). In the remainder of this Section we will discuss why the parameters β , δ , λ , θ and α are likely to be time-varying and how we model this.

The parameters are likely time-varying in the long-run because of (long) real estate cycles. The main reason for real estate cycles to occur is because developers tend to overbuilt if developers' future projection of demand (usually measured by macro-economic variables) is positive (Pyhrr et al., 1999). Especially delivery lags and illiquidity worsens the ability of developers to respond quickly to changes in demand. Too much supply suppresses prices (Mayer and Somerville, 2000) for a considerable time, until aggregate demand and supply are in equilibrium again. Unfortunately, literature in the field of real estate cycles is not unambiguous on the average length of a typical cycle. The 'average' real estate cycle is somewhere between 18 years (Rabinowitz, 1980) and 60 years (Kaiser, 1997).

A second reason why the parameters are likely to be time-varying relates to regime shifts. The change of, or shift in, political and economic regimes usually occurs when a smooth change in an internal process (feedback) or a single disturbance (external shocks) triggers a completely different system behaviour. Common examples in the real estate literature are changes in legislation and innovations in the construction or mortgage market (Fernandez-Corugedo and Muellbauer, 2006).

The challenge is to recognize when a cycle starts and ends, which variables are part of the cointegrating relationship, and when there has been a shift in regime. In practice this is very difficult to identify. A yearly rolling regression with changing combinations of covariates is attractive in this regard, because it allows us to estimate a series of parameters without imposing any particular structure on the way in which conditional covariates change over time (Rossi, 1996). To simplify the procedure we estimate the error correction model in a (rolling) 2-step Engle-Granger framework (Engle and Granger, 1987). Since we estimate the long-run equation (first step, Eq. (2)) separate from the short-run equation (second step, Eq. (3)) and because no lags are included in the long-run equation, the total number of possible combinations of covariates reduces considerably.¹² To simplify the procedure even further, we use the same variables in the short-run equation as we use in the long-run equation.

Consequently, the specification of the rolling error correction model becomes (Eqs. (4) - (5)):

$$p_t = \beta_r + x'_t(r)\delta_r + \varepsilon_t, \tag{4}$$

$$\Delta p_t = \lambda_r \Delta p_{t-1} + \Delta x'_t(r)\theta_r + \alpha_r \left(p_{t-1} - p^*_{t-1}\right) + \eta_t, \tag{5}$$

for $t = r, \ldots, r+n-1$ and $r = 1, \ldots, T-n+1$. The dependent and independent variables are of fixed length for any regression and represents the *n* periods (denoted *the window length*) immediately preceding period *t*. The function *r* reflects different combinations of covariates (one such combinations could be: Population and construction costs) per window. Thus, we get estimates for δ in every window for every combination of covariates *r*. This estimation procedure provides consistent estimates of the β and δ values - provided that *p* and *x* are cointegrating (Lütkepohl and Krätzig, 2004). In total the estimation and selection procedure consist of four steps.

Firstly, one important requirement is that the variables are integrated of order 1 (I(1)). If a variables is I(0) in a particular time window, the variable is excluded from the regression in that particular window (see Appendix A.5). Secondly, we regress all remaining combinations of covariates (r) in every window on house prices, using Eq. (4). We choose to fix the window length n at 30 years, as this is roughly the average length of a real estate cycle found in literate. For robustness, we also tried window lengths of 20, 25 and 40 years. However, the key results did not change. In addition, the number of cointegrating relationships was largest using 30 year windows.

In the third step we establish which combination of covariates (x_r) are cointegrated. The most important requirement is that the error correction term $(p_{t-1} - p_{t-1}^*)$ is stationary.

¹²Instead, estimating the R-ECM in a dynamic way, in an ADL framework or by the Johansen trace/eigenvalue test would acquire lags of the dependent and independent variables. The number of lags can be different for every variable. Different combinations of lag structures can result in different cointegrating relationships. This ammounts to an almost infinite number of possible relationships.

5 RESULTS

If multiple combinations of x are cointegrated in one window, the combination of variables which are cointegrated at the 1% level are reported in favor of the combination of variables which are cointegrated at the 5% level. If the degree of cointegration is similar for more than one combination of covariates in the same window, we look at the adjusted \mathbb{R}^2 . Another requirement is that the parameter estimates are at least significant at the 10% level. To account for the missing data for GDP per capita during the two war periods and, more in general, to estimate the effect of the wars on house prices a dummy for these periods is added to every regression in which one or both wars are within the window length.

In the fourth and final step, the model is re-estimated in first-differences, with the inclusion of the error correction term (lagged one period) estimated from the first step, see Eq. (5). Both (long- and short-run) models are estimated with OLS. In our application, we end up with 158 windows. Our 7 variables give a total of 127 possible combinations of covariates. Thus, we estimate more than 40,000 different models (total long-run *and* short-run regressions). The next Section summerizes our findings.

5 Results

In this section, we discuss the most important findings. The results are summarized in Table 5 and Figure 3. Table 5 reports the number of times a variable was part of a cointegrating relationship during certain time periods. The final column of Table 5 also gives the average coefficient estimate over the entire period in parenthesis. The main drivers of house prices in the 19th century were construction costs, housing supply and population. After 1900 the Gross Domestic Product per capita starts to play a role and after the 1970s interest rates as well. After World War II population and housing supply are key additional determinants of house prices.

In approximately 50% of all windows at least one cointegrating relationship was found. In most cases the number of variables in the cointegrating relationship is between 2 and 4 (including a constant), see Figure 3. The reason why we did not find a cointegrating relationship in in all periods could simply be explained by missing variables and measurement errors. However, it is important in this regard to realize that deviations from equilibrium do not adjust to the long-run equilibrium level as well when a housing market is in crisis. Indeed, both Hall et al. (1997) and later Nneji et al. (2013) found evidence for this using error correction Markov switching models for the UK and the US, respectively. The durable nature of housing and 'anchoring' of home-buyers are the main reasons explaining the absence of cointegration. More specifically, supply usually does not adjust negatively in considerable quantities (especially not in the short- or even long-run) in case demand for housing goes down (Glaeser and Gyourko, 2005). In addition, in time of crisis households tend to have too high reservation prices due to negative (home) equity or because of loss aversion (Genesove and Mayer, 1997, 2001). Periods of consequent crises seem to coincide with windows with low number of cointegrating relationships. For example, the least number of cointegrating relationships are in the period 1900 - 1945. During this period, the First World War (1910s), the Great Depression (1930s) and the Second World War (1940s) all affected the Dutch economy severely.¹³

| Variable | 1825 - 1900 | 1900 - 1945 | 1945 - 1970 | 1970 - 2012 | Total |
|--------------------------------------|-------------|-------------|-------------|-------------|--------------|
| | | | | | (Mean Coef.) |
| Housing supply | 12 | 5 | 1 | 11 | 29 (-1.48) |
| Construction costs | 11 | 1 | 1 | 4 | 17 (1.07) |
| GDP per capita | 3 | 5 | 3 | 16 | 27 (0.39) |
| Labor force | 3 | 3 | 1 | 0 | 7 (4.57) |
| Opp. cost of capital | 0 | 0 | 2 | 17 | 19 (-0.39) |
| Unemployment | 7 | 5 | 1 | 2 | 15 (-0.49) |
| Population | 8 | 3 | 2 | 9 | 22 (1.55) |
| Total | 44 | 22 | 11 | 59 | 136 |
| | | | | | |
| Number of regressions | 21 | 12 | 7 | 32 | 72 |
| Variables p. regression [*] | 3.1 | 2.8 | 2.6 | 2.8 | 2.9 |

Table 5: Number of times a variable is part of a cointegrating relationship per subperiod.

*A constant is included in this number. However, the war dummy is excluded from this number as it not used in the test for cointegration.

From Table 5 it is also evident that unemployment and labor force are not part of a cointegrating relationship in many windows. Even though these variables might not be as interesting from an economic perspective, we kept them included in the model as control variables.

In the remainder of this Section we are going to discuss the results in more detail. Section 5.1 contains the time-varying, long-run, estimates of the demand side factors, and Section 5.2 those of the supply side factors. In Section 5.3, the model diagnostics, the error correction term estimates (i.e. the adjustment parameter), and the impact of the war time period is discussed. For expositional reasons, the other short-run, second step, estimates are not reported.

5.1 Demand side determinants of house prices

Figure 4 shows the rolling window point-estimates of population on house prices and its effect on house prices. If an estimate is only statistically significant at the 10 percent significance

¹³Other examples of crises in the 20^{th} century are the Oil crisis in the 1970s and the dotcom and the Financial crisis in the beginning of the 21^{th} century. In the 19^{th} century the Belgian revolution (1830s) and two large crop failures (first one around 1850 and the second one at the end of the 19^{th} century due to cheap imports from the US) resulted in an economic crisis.



Figure 3: Number of variables within a cointegrating relationship.

level this is denoted by * (otherwise it is significant at the 5 percent level). The horizontal axis gives the time window for which the error correction model was estimated. The left vertical axis gives the value of the parameter estimate (marginal effect) and the right vertical axis gives the total (maximum) effect of population on house prices by multiplying the maximum population minus the minimum population in that window by the corresponding parameter coefficient.

The population variable is part of the cointegrating relationship in many of the rolling windows. Interestingly, population growth was mainly part of the cointegrating relationship in the 19^{th} century and during the 1970s. The effect of a one percent population increase has an average positive effect of about one to two percent on house prices. The total maximum effect is between 5% and 60%. There is a spike in the population effect in the windows starting in the beginning of the 1950s, probably due to the high birth rates (baby boomers) after the Second World War.

Figure 5 contains the estimates and total effect of the labor force on house prices. The effect of changes in the labor force is only part of the cointegrating relationship in seven windows and it is only highly statistically significant in four cases. Six of the seven successful windows are in the 19th century. A one percent increase in the working age population as percentage of the total population has a positive 2 to 7 percent effect on house prices. However, the min-max range of labor force has been relatively low per window. During the 19th century the increase (decrease) therefore only resulted in roughly 14% higher (lower) house prices.

In all cases a constant is included.



Figure 4: Effect of population growth.

Figure 5: Effect of labor force.



In Figure 6 the unemployment effects are depicted. Similarly to the effect of labor force, there are not many windows in which unemployment has a large effect on house prices. Especially before World War II, there seems to be some effect of unemployment. The total effect of a change in unemployment on house prices for this period is 28%.



Figure 6: Effect of unemployment.

The effect of GDP per capita and the opportunity cost of capital are presented in Figure 7 and Figure 8, respectively. There are two striking similarities between these figures. First, both variables are part of the same cointegrating relationship in many of the time windows. Second, the coefficient estimates increase in size especially from the 1970s onwards. Although house prices were affected by GDP per capita during most of the 20th century, the coefficient is relatively small, less than 0.2 percent after a one percent increase in GDP per capita in most cases, before the 1960s. During this period most houses were financed by the own savings of households. Instead, during the 1970s financial innovation and liberalization, combined with tax benefits on mortgage debt, made the use of mortgage debt more popular (Fernandez-Corugedo and Muellbauer, 2006) and, consequently, the impact of GDP on house prices increased. Interestingly, during the 1980s the Loan-to-Value cap increased to over 100%, a feature of the Dutch housing market which persists until this day (Andrews et al., 2011).

The amount of mortgage debt a household can borrow is not only determined by income but also by interest rates. It is, therefore, not surprising that both variables have jointly determined house prices after 1970. A one percent increase in GDP per capita had an effect on house prices between 0.2 and 1 percent. A percent decrease in the opportunity cost of capital (again the variable is in logs) has had a positive effect of 0.2 to almost 1 percent on house prices. Although we argued that the opportunity cost of capital can also be viewed as a supply-side factor affecting housing construction, our empirical estimates suggest that the demand side impacts are dominating. The total maximum effect of the opportunity costs of capital after 1970 is 60% on average.



Figure 7: Effect of GDP per capita.

5.2 Supply side Determinant of House Prices

Housing supply and construction costs are considered supply side determinants of house prices. Figure 9 shows the long-run coefficient estimates for the housing supply variable. The effect of a one percent increase in housing supply results in a 1.5% house price drop on average. Between 1830 and 1860 the coefficient of housing investment on house prices is relatively large, compared to the other periods. However, the min-max range of investment in housing during this period is low, which attenuates the effect of investment in housing on house prices. Interestingly, between the periods 1958–1988 and 1960–1990 there is a relatively large effect of housing investment on house prices. This likely reflects the post-war reconstruction of the Netherlands.



Figure 8: Effect of opportunity cost of capital.

Figure 9: Effect of housing supply.





Figure 10: Effect of construction costs.

The construction cost index is used to proxy for changes in structure values and for the rate at which constructors can add new housing supply to the market. Figure 10 shows the effect of construction costs on house prices. In most cases the elasticity is close to one. This suggest that house prices have mainly increased because the construction cost of houses increased. In a well-functioning market this is what one would expect. However, as mentioned earlier in Section 5.1, during most of this period population was also part of the cointegrating relationship. If housing markets would be efficient, however, supply should adjust immediately if prices increase and population should not have an effect on house prices. The maximum total effect of construction costs on house prices ranges between zero and 60 percent.

5.3 Model diagnostics, error correction, and the War Time period

This section discusses some remaining issues regarding model diagnostics, the adjustment parameter (α), and the effect of war on house prices. The upper left panel of Figure 11 presents the effect of the war time periods (World War I, World War II, we included a dummy in the rolling error correction model) on house prices. As mentioned, time series on GDP per capita are missing for this period. The Figure shows that the war time period had a negative effect on house prices of about zero to 54 percent. This is likely an underestimate

since the price index is only based on those houses that have actually been sold.

The adjusted R-squared of the estimated regression models are depicted in the upper right panel in Figure 11. The average adjusted R-squared is quite high, about 0.6, which is not uncommon to see with this kind of macro-economic data. There is quite some variation around the average. During the mid (end) of the 19th century, and at the end of our sample period, the adjusted R-squared is above 0.80.

Finally, the lower panel of Figure 11 presents the rolling point-estimates of the coefficient of the error correction term in the short-term model, α_r in Eq. (5). The average effect of the error correction term is 0.28. This suggests that shocks out of equilibrium are absorbed within 3.5 years. However, there is large variation in this adjustment parameter. For example, during the beginning of the 19th century and 20th century there are several periods were shocks out of equilibrium are corrected almost instantaneously. Instead, in some periods the parameter estimate is as low as 0.05. At that rate shocks out of equilibrium are only absorbed after 20 years.

6 Concluding remarks

This paper has examined the determinants of house prices using almost 200 years of data from the Amsterdam housing market, the Netherlands. The results show that at different points in time there are different key determinants of house prices (cointegrating relationships).

During the 19th century, population, housing supply, and construction costs are the main drivers of house price dynamics. At the start of the 20th century income starts to play a role. After World War II there are a few decades in which housing supply and population determine house prices. This reflects the post-war reconstruction efforts in the Netherlands and increases in housing demand as a result of the birth of the baby-boom generation and subsequent decrease in demand due to the adult baby-boomers leaving the city for greener and more spacious areas neighboring Amsterdam. Finally, from the 1970s onwards, income and interest rates start to have a large impact on house prices, most likely due to financial innovation and liberalization. Starting from the 1970s financing a house through mortgage debt became 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). Although the results in this paper are, to some extent, not surprising, this paper is one of the first to document such long-term changes.

The results in this paper can explain why in some instances the key determinant of house prices differ across studies, even if those studies focus on the same housing market, and it provides a more long-term perspective on the fundamentals of house prices. The rapid increase in house prices can, for example, easily be mistaken as a bubble if it is unclear what



Figure 11: Model diagnostics and the War dummy.

(c) Error Correction Term

the impact of different determinants are and how such determinants have changed over time. This paper has provided an analysis from the perspective of the Amsterdam/Dutch housing market. It would be interesting to see a similar analysis for other countries to examine to what extent the broad trends discussed in this study are generalizable across housing markets.

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A Appendix

A.1 Transaction Data Herengracht

Data description is provided in Tables A1 - A3 and Figure A.1. The descriptives are based on the data after filters are 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). 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%.



Figure A.1: Number of transactions per year, Herengracht data.

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

Table A1: Descriptive statistics 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 |

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 |

A.2 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:

$$\ln\left(\frac{P_{i,t}}{P_{i,s}}\right) = \beta_t - \beta_s + \alpha_{i,t} + \epsilon_{i,t}, \qquad \epsilon_{i,t} \sim N(0, \sigma_\epsilon^2), \qquad (6)$$

$$\alpha_{i,t+1} = \alpha_{i,t} + \eta_{i,t}, \qquad \qquad \eta_{i,t} \sim N(0, \sigma_{\eta}^2), \qquad (7)$$

for t = 1, ..., T and i = 1, ..., 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:

$$\beta_{t+1} = \beta_t + \kappa_t + \zeta_t, \qquad \qquad \zeta_t \sim N(0, \sigma_{\zeta}^2), \qquad (8)$$

$$\kappa_{t+1} = \kappa_t + \xi_t, \qquad \qquad \xi_t \sim N(0, \sigma_\xi^2). \tag{9}$$

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.3 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

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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}).

| | 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 |

Table A4: Estimation results



A.4 Long-run time series: Macro Determinants

Figure A.3: Order of integration of the variables.

A.5 Order of Integration





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