Muth’s model of the housing market

MARK VAN DUIJN AND JAN ROUWENDAL

What is Muth's model?

Housing is characterized by substantial heterogeneity

- All units are different, if only by their exact location
- This complicates the application of standard tools of applied economic analysis
  - Which typically assume homogeneous commodities

Muth's proposed to treat housing as a standard homogeneous commodity

- 'Housing services' a scalar indicator of housing quality
  - Which is interpreted as a quantity of services consumed by the occupant of the house
- Available in arbitrary amounts at a constant price per unit on the housing market
- This approach became standard in economic analysis of the housing market in the 1970s and 1980s
- Is still often implicitly present in economist's thinking about this market

The present paper

Tests the validity of Muth's model

- Formal testing of the model has never been attempted before
- Although there is much casual evidence that calls into question the validity of Muth's model

What is the empirical content of Muth's model?

- A constant price per unit of housing services
  - That is: housing expenditure can be written as $P = \Pi H$
  - P: value (sales price) of the house, Π: unit price, H: number of housing services
  - The value of the house is proportional to its quality
  - The price ratio of two houses of given qualities must be the same in every market
  - $\frac{P_1}{P_2} = \frac{H_1}{H_2}$ for any value of Π
  - This is testable if we can measure quality independent of price

Relationship with price indices

Muth's model suggests that there is a single housing price characterizing the housing market

Hedonic and repeat sales indices measure this price Π

$P = \Pi H$, hence $\ln P = \ln \Pi + \ln H$

Quality/housing services is a function of characteristics: $\ln H = \sum_k \beta_k X_k + \xi$

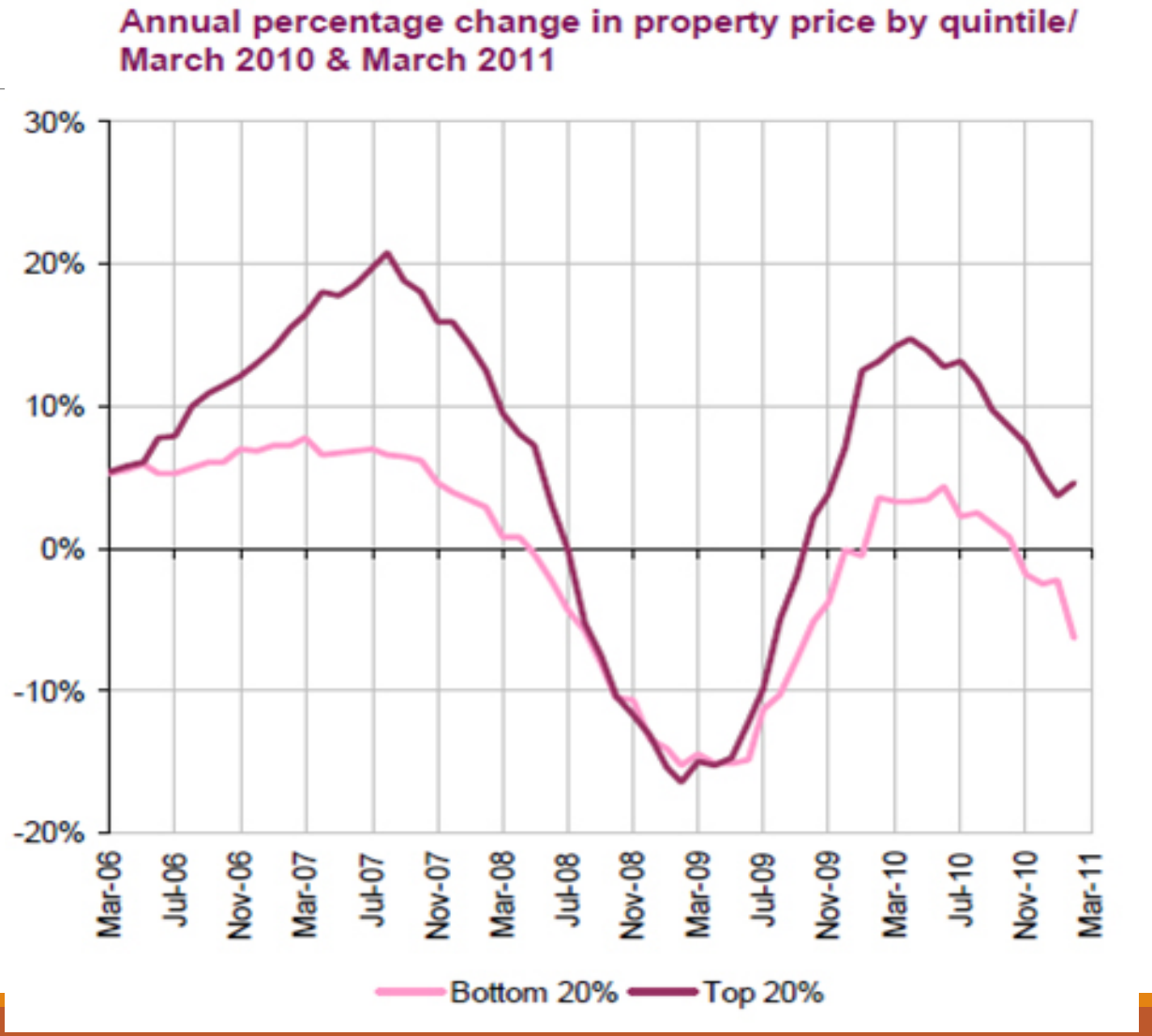
Estimating the equation for different geographical and/or temporal markets$m$ results in estimates of a unit price Π_m for each market

- This is fully consistent with Muth's model
- Also in repeat-sales applications (e.g. Case-Shiller)

Informal evidence of violations of the unit price property

For instance: evolution of house prices in the top and bottom quintile of UK house prices between 2006 and 2011

- The top quintile is much more volatile than the bottom quintile
- However, housing quality is not appropriately controlled for
  - The average quality per quintile may change over time



Nesting and testing Muth's model

We propose a generalized version of Muth's model

- That avoids the assumption of a constant unit price
- But maintains the concept of housing services

In the generalized version prices are a general increasing function of quality

- Proportionality is the special case associated with Muth's model

We measure quality on the basis of the *ranking* of the sales prices

- Which gives us an ordinal measure of quality

And use these estimates to test the unit price property

- Over time and over space

The model

We assume house prices are an increasing function of the number of housing services:

$P = F(H)$

Housing services are a function of housing characteristics: $\ln H = \sum_k \beta_k X_k + \xi$

Hence: $P = F(\sum_k \beta_k X_k + \xi)$

This is a 'transformation model'

- Such models have been studied by Ridder (1990), Horowitz (1996) and others
- A special feature here is that we want to apply the model to many markets
  - And the number of observations per market is relatively small
  - We define markets as postal code areas per quarter

Estimating housing quality

Our model implies that the ranking of prices reveals the ranking of qualities

$$P_i > P_j \left(\Leftrightarrow H_i > H_j\right) \Leftrightarrow \sum_k \beta_k X_{ik} + \xi_i > \sum_k \beta_k X_{jk} + \xi_j$$

We use this as a basis for estimating the β_ks

To make the model tractable, we assume the ξ_js are random draws from an extreme value type 1 distribution

- We estimate the variance

And apply the results of Beggs, Cardell and Hausman (1981) on the full ranking of a set of choice alternatives (rank-ordered logit model)

We set the coefficient for floor area equal to 1

This provides an ordinal measure of housing quality/housing services

- Any monotone transformation is an equally valid measure

Testing the unit price property

Muth's model implies: $\ln P_i = \alpha_{tm(i)} + \mu \widehat{H}_i + \varepsilon_i$

Where i refers to observations, tm to markets and $\widehat{H}_i$ is the predicted quality

Since we have an ordinal measure of quality we also estimate polynomial functions:

$$\ln P_i = \alpha_{tm(i)} + \mu_1 \widehat{H}_i + \mu_2 \widehat{H}_i^{\,2} + \cdots + \varepsilon_i$$

Muths model implies that cross-products of $\alpha_{tm(i)}$ and $\widehat{H}_i$ should have a coefficient 0. To test the model we therefore estimate specifications:

$$\ln P_i = \alpha_{tm(i)} + \left(\mu_1 \widehat{H}_i + \mu_2 \widehat{H}_i^{\,2} + \cdots\right) + \left(\gamma_1 \delta_{m=m^*} \widehat{H}_i + \gamma_2 \delta_{t=t^*} \widehat{H}_i\right) + \varepsilon_i$$

The model is rejected if $\gamma_1 \neq 0$ or $\gamma_2 \neq 0$.

Unobserved quality aspects

ξ_j is unobserved by the researcher, but observed by the sellers and buyers

Keeping it out could affect the results

There is some useful information:

- If the ranking of the imputed qualities $\widehat{H}_i$ differs from that of the prices, this must be due to unobserved quality aspects
- We look for the minimal correction needed to make the two rankings coincide
  - This cannot be determined uniquely, so we randomly choose a possibility

Making this correction does not affect the general conclusion, but it has an impact on the results

- In what follows we always present the results that make use of the correction

The data

Refer to Amsterdam in the period 1985-2013

We use postal code areas as geographical units (see map)

And quarters as our temporal units (see graph)

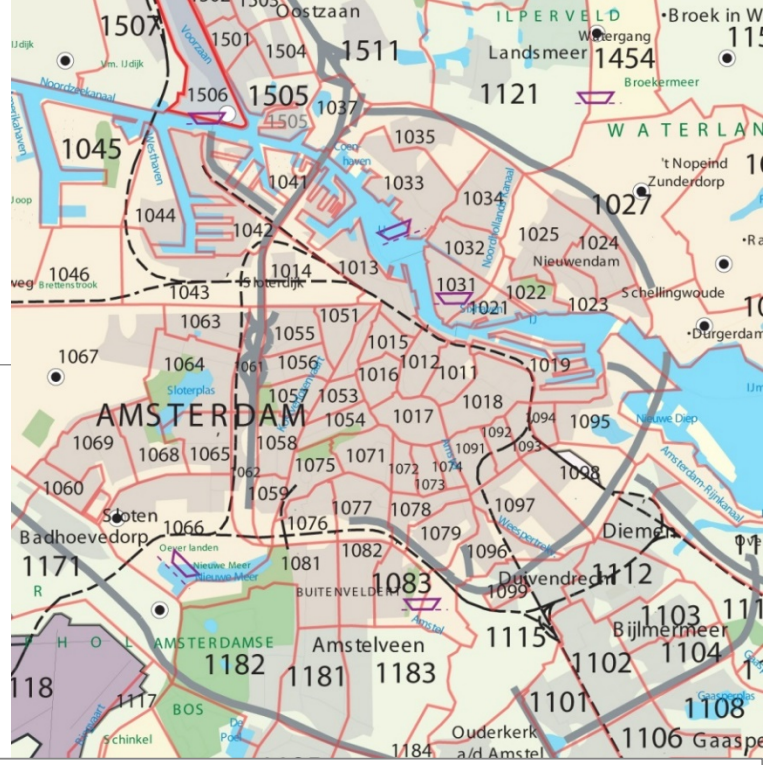
- Note that prices can change substantially in a single year

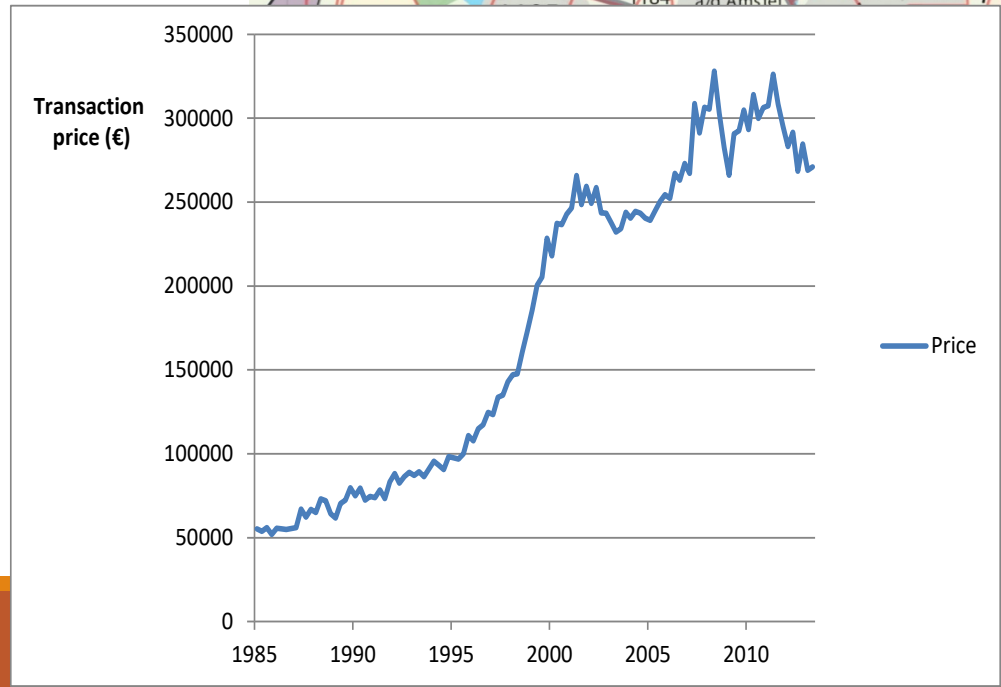
Markets are combinations of postal code areas and quarters

More than 100,000 observations

- Annual numbers increase over time

The data include a rich et of housing characteristics





Estimation of quality

We use the ranking of housing transactions per market

Two variants:

- i same variance of unobserved quality ξ_j in all postal code areas
- ii variance specific for postal code area with at least 10 observations in 1 quarter

Estimates do not differ much from those obtained with a conventional hedonic price function with market (= quarter x postal code) fixed effects

Size						
Ln(floor space) (m^2)	1	-		1	-	
Ln(lot size) (m^2)	0.0014	(.00035)	***	0.0011	(.00035)	***
Volume/floor area (m)	0.00043	(.00008)	***	0.00045	(.00008)	***
Rooms (#)	0.022	(.00045)	***	0.021	(.00051)	***
Type						
Detached house (ref: standard house)	0.38	(.0061)	***	0.38	(.0080)	***
Semidetached house (ref: standard house)	0.25	(.0094)	***	0.24	(.0090)	***
Corner house (ref: standard house)	0.066	(.0044)	***	0.053	(.0044)	***
Apartment (ref: standard house)	-0.070	(.0026)	***	-0.083	(.0029)	***
* Entrance at forecourt	-0.023	(.0021)	***	-0.022	(.0020)	***
* Entrance at gallery	-0.026	(.0026)	***	-0.024	(.0025)	***

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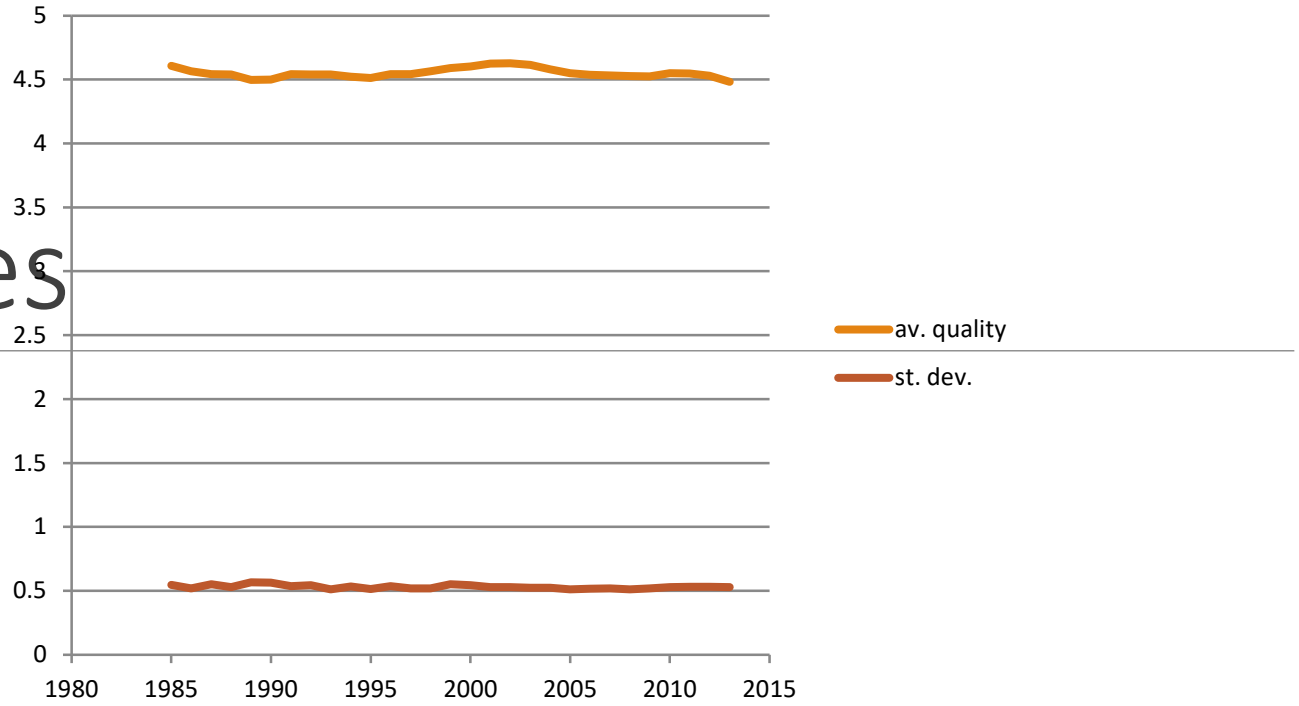
Construction period/age						
Built before 1905	-0.054	(.0035)	***	-0.044	(.0035)	***
Built 1906-1930	-0.073	(.0034)	***	-0.065	(.0033)	***
Built 1931-1944	-0.076	(.0039)	***	-0.069	(.0039)	***
Built 1945-1959	-0.22	(.046)	*	-0.22	(.0045)	***
Built 1960-1970	-0.30	(.0042)	**	-0.29	(.0041)	***
Built 1971-1980	-0.19	(.0048)	***	-0.20	(.0048)	***
Built 1981-1990	-0.15	(.0036)	***	-0.15	(.0035)	***
Built 1991-2000	-0.016	(.0033)	**	-0.014	(.0031)	***
Variance	0.180	(.00037)	***			
Postcode-specific variances	NO			YES		
Log likelihood	-168,403			-167,430		
Observations	101,408			101,408		

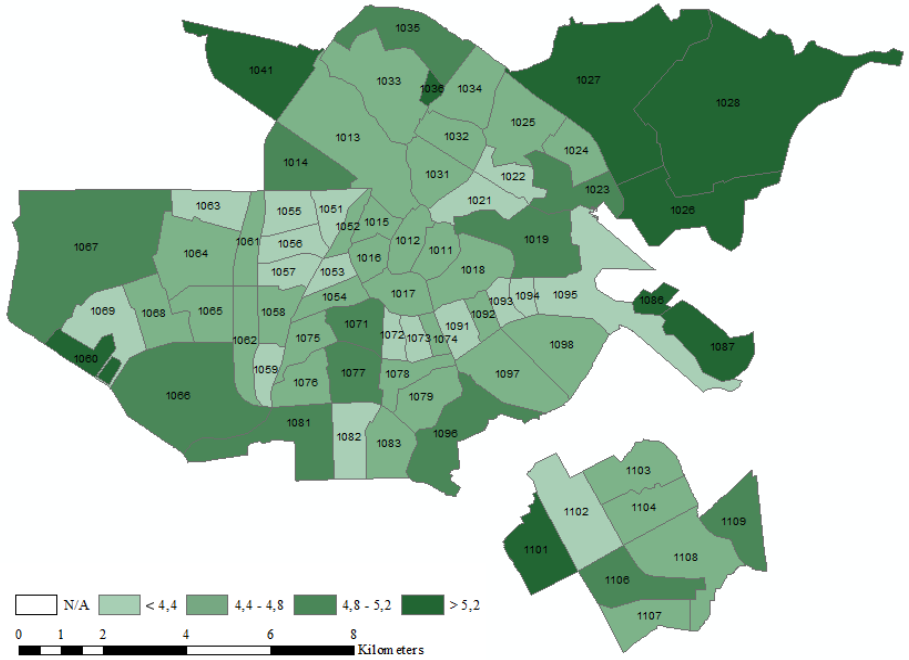
Quality estimates



Estimated quality and its variance are almost constant over time

Substantial spatial differences in average housing quality per neighborhood

- Highest quality in rural area in the north (e.g. refurbished farmhouses)
- Lowest quality in 19th century ring surrounding the canal belt



Testing the constant unit price

We tried polynomials in the imputed quality, taking into account all the information about ξ_j

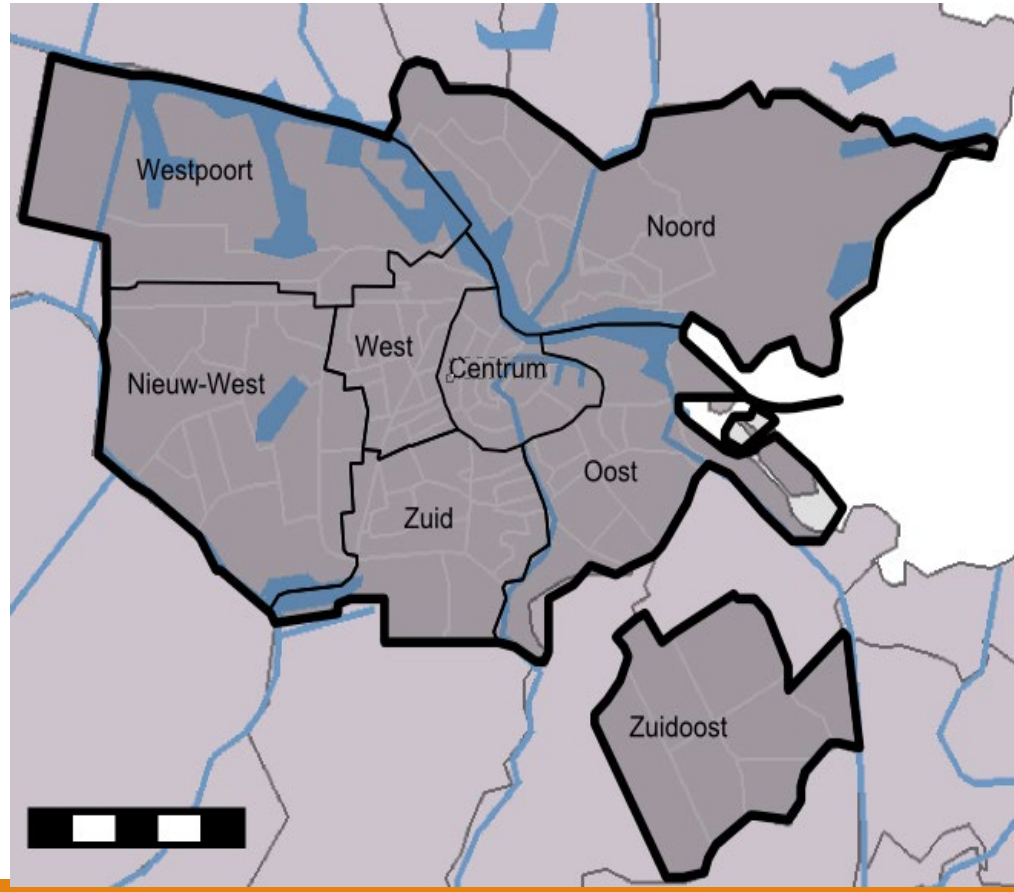
- Linear specification is the preferred one

Cross terms for geography

- (i) inside vs outside the ring * quality
  - ring=west, centrum, zuid, oost
- (ii) Centre + South vs rest * quality

Cross terms for time

- trend * quality
- $trend^2$ * quality



Testing the Muth model

	Linear	Ring	Ring + center	Trend	Trend + trend^2	Ring, center, trend, trend^2
$\widehat{H}$	0.72*** (.02)	0.75*** (.02)	0.70*** (.02)	0.79*** (.02)	0.98*** (.04)	0.92*** (.06)
$\widehat{H}$*outside ring		-0.12*** (.026)	-0.072** (.028)			-0.070** (.27)
$\widehat{H}$* (ce + so)			0.079*** (.028)			-0.073*** (.028)
$\widehat{H}$*trend				-0.0034** (.0013)	-0.030*** (.0047)	-0.026** (.0050)
$\widehat{H}$*trend^2					0.00079*** (.00011)	0.00068*** (.00011)
Quarter*postcode fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.91	0.91	0.91	0.91	0.91	0.91

Results

The Muth model is rejected by the geographical as well as the temporal cross products

- Column 2: Houses of the lowest quality ($\widehat{H}_i$=3) are 43% more expensive inside than outside the ring, but houses of high quality (($\widehat{H}_i$=7.3) are 140% more expensive inside the ring.
- Column 3: inside the ring the marginal price of quality /housing services is higher in Centre and South than n the other areas.
- Column 4: houses of higher quality have become somewhat cheaper relative to those of low quality over time
- Column 5 shows that there was initially a strong trend towards smaller price differences between high an low quality (half of the difference disappeared), but that it reversed around 2000
- Column 6: all cross products have significant coefficients when included simultaneously

Are the results due to changes in the quality index?

It is possible that the concept of quality changes over time

- For instance, private parking possibilities may become more valuable when public parking prices increase
  - Van Ommeren found no evidence for this
- Here we look at the impact of changes in the age of buildings
  - Depreciation tends to decrease the relative price of older buildings relative to new ones
  - Vintage effects may work in opposite direction and may be important in Amsterdam
    - The canal belt is World Heritage

We find indeed strong vintage effects

- Interaction of age and construction period gives strongly significant coefficients
  - Which are positive for construction before 1950, negative for later construction years

Table 4 Construction period and housing quality						
Variables	(1)			(2)		
Other characteristics	YES			YES		
Construction period/age						
Built before 1905	-0.044	(.0035)	***	-0.60	(.091)	***
* Year of sale – 1905				0.0056	(.00089)	***
Built 1906-1930	-0.065	(.0033)	***	-0.52	(.067)	***
* Year of sale – 1930				0.0061	(.00087)	***
Built 1931-1944	-0.069	(.0039)	***	-0.34	(.057)	***
* Year of sale – 1944				0.0046	(.00092)	***
Built 1945-1959	-0.22	(.0045)	***	-0.11	(.051)	*
* Year of sale – 1959				-0.0023	(.0011)	**
Built 1960-1970	-0.29	(.0041)	***	-0.086	(.0037)	**
* Year of sale – 1970				-0.0058	(.0010)	***
Built 1971-1980	-0.20	(.0048)	***	0.11	(.030)	***
* Year of sale – 1980				-0.013	(.0011)	***
Built 1981-1990	-0.15	(.0035)	***	0.066	(.017)	***
* Year of sale – 1990[1]				-0.014	(.00097)	***
Built 1991-2000				0.037	(.0077)	**
* Year of sale - 2000[1]				-0.0080	(.0011)	***
Postcode-specific variances	YES			YES		

Testing Muth's model

Now the quartic specification (4 degree polynomial) is preferred.

Muth's model is still rejected by significant coefficients for geographical as well as temporal cross-products

- Although the cross product with center and south is now only marginally significant

	Linear	Quartic	Ring, center, trend, trend^2	Ring, center, trend, trend^2
$\widehat{H}$	0.52*** (.016)	15.73*** (3.45)	0.88*** (.050)	14.23*** (2.38)
$\widehat{H}^2$		-5.15*** (1.19)		-4.47*** (0.82)
$\widehat{H}^3$		0.75*** (.18)		0.65*** (.12)
$\widehat{H}^4$		-0.040*** (.0096)		-0.034*** (.0069)
$\widehat{H}$*outside ring			-0.059** (.029)	-0.074*** (.026)
$\widehat{H}$*(center, south)			0.077** (.030)	0.051* (0.28)
$\widehat{H}$*trend			-0.040*** (.0045)	-0.042*** (.0043)
$\widehat{H}$*trend^2			0.00098*** (.00011)	0.0010*** (.0010)
Quarter*postcode Fixed effects	Yes	Yes	Yes	Yes
R^2	0.83	0.84	0.84	0.84

Interpretation

Is there an alternative for Muth's model?

We may consider houses as fixed bundles of characteristics, summarized in a number of housing services

- The stock of houses of a given quality is fixed

Households differing in income compete for these houses

The market equilibrium is a possibly non-linear price function $P = F(H)$

- The function is linear when the distribution of houses fits the income distribution
  - Demand densities correspond to supply densities for a given price per unit of quality
- But can be locally concave or convex if there is excess supply or demand, respectively
- Our findings may therefore be explained by demand pressure of high income households inside the ring, and renewed pressure of high income demand for the total area since 2000

Conclusion

Muth's model has set the standard for applied economic research on the housing market

- Despite the strong assumptions, there has been no formal testing of the model

Muth's model is rejected by the data

- Even with (quarter x postal code area) fixed effects there are substantial price movements that remain undetected by the conventional price indices

We present a methodology that allows for the construction of price indices that are conditional on quality / housing services

- And provide evidence that indices referring to high and low quality evolve differently over time

These findings can be interpreted by a model that considers the housing stock as fixed, while prices are determined by a competitive bidding process