
# House Price Dispersion in Boom-Bust Cycles: Evidence from Tokyo

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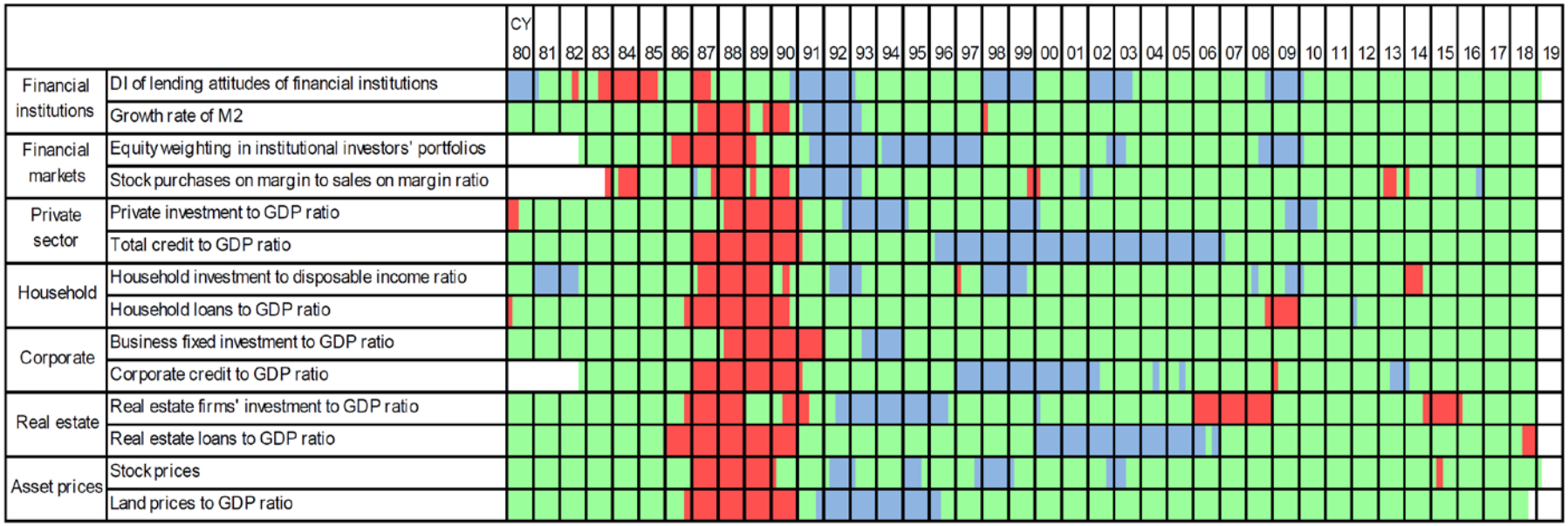
# Heatmap (Financial Activity Indexes)

## *Financial System Report*, BOJ, April 2019

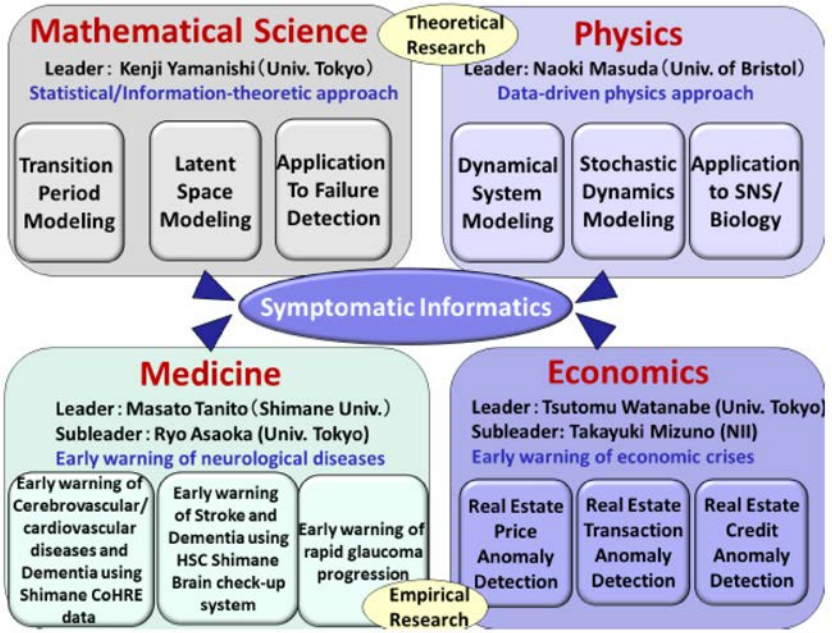
**Chart III-4-1: Heat map**




Note: The latest data for the DI of lending attitudes of financial institutions and stock prices are as at the January-March quarter of 2019. The latest data for the land prices to GDP ratio are as at the July-September quarter of 2018. The latest data for the other indicators are as at the October-December quarter of 2018.

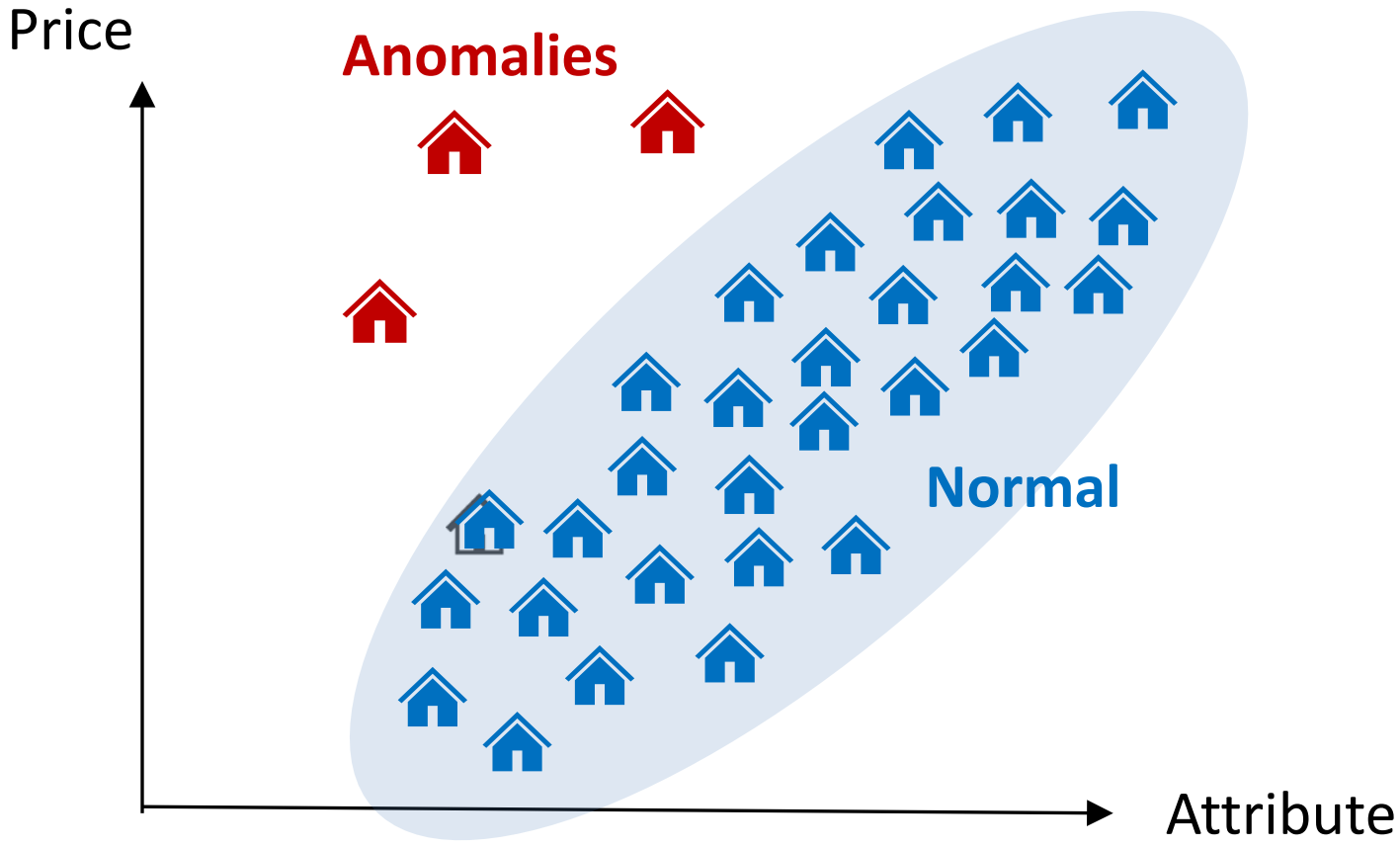
Source: Bloomberg; Cabinet Office, "National accounts"; Japan Real Estate Institute, "Urban land price index"; Ministry of Finance, "Financial statements statistics of corporations by industry"; Tokyo Stock Exchange, "Outstanding margin trading, etc."; BOJ, "Flow of funds accounts," "Loans and bills discounted by sector," "Money stock," "*Tankan*."

# Application of anomaly detection techniques to real estate markets




1. **Anomalies in real estate prices**
   - Especially anomalies in the cross-sectional distribution of real estate prices
2. Anomalies in real estate transactions
3. Anomalies in real estate credit

# Anomaly Detection




- Supervised vs. Unsupervised
- What is “Normal”?

# Heterogeneity in house prices

- A new look at house price dynamics
  - **Not time series but cross-section:** Case and Mayer (1996); Guerrieri et al (2013)
  - **Not mean but higher moments:** McMillen (2008); Sinai (2012); Van Nieuwerburgh and Weill (2010); Gyourko et al (2013); Deng et al (2012); Villar (2015); Zhang (2018); Andersson et al (2003); Blackwell (2018)
  - **Not across cities but within-city:** Case and Mayer (1996); Ferreira and Gyourko (2012, 2017); Glaeser et al (2012); Lyons (2015); Waltl (2016); Zhu (2018); Bogin et al (2018)

McMillen (J of Urban Economics, 2008)

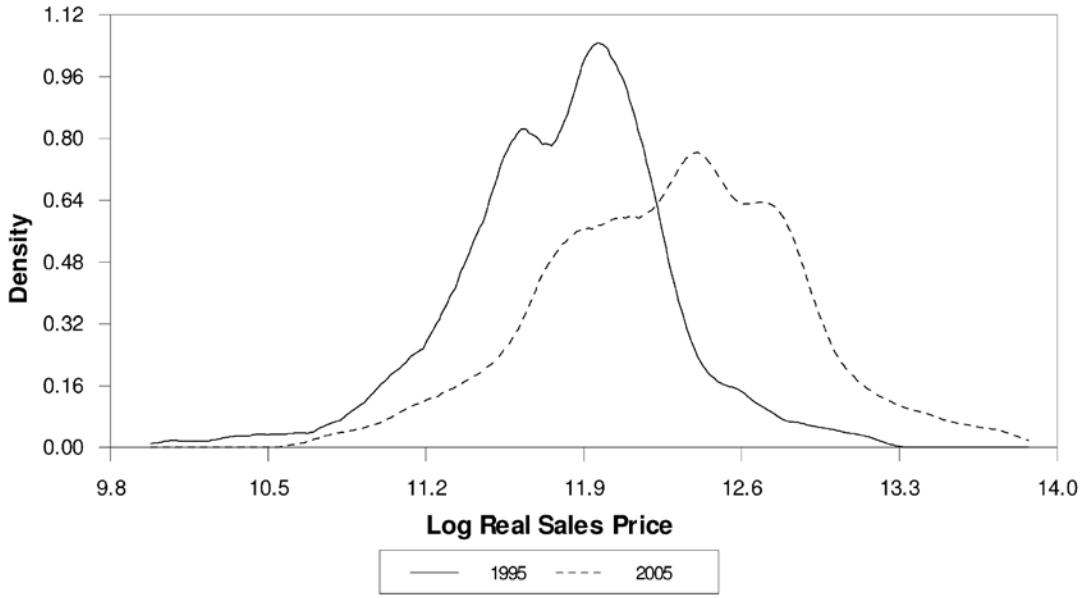



**Fig. 1.** Kernel density estimates for log of real sales price.

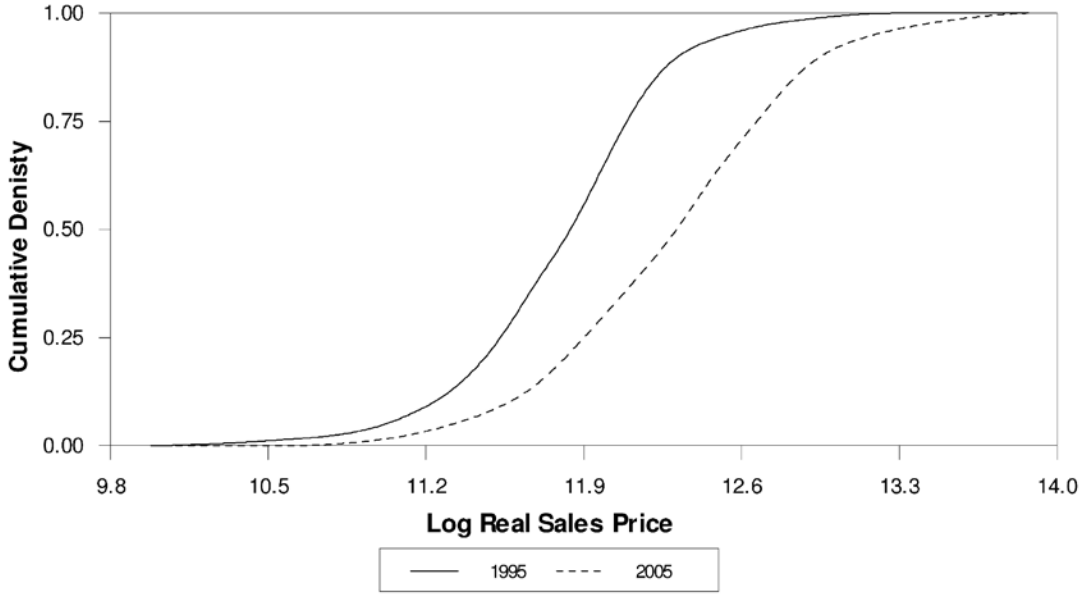
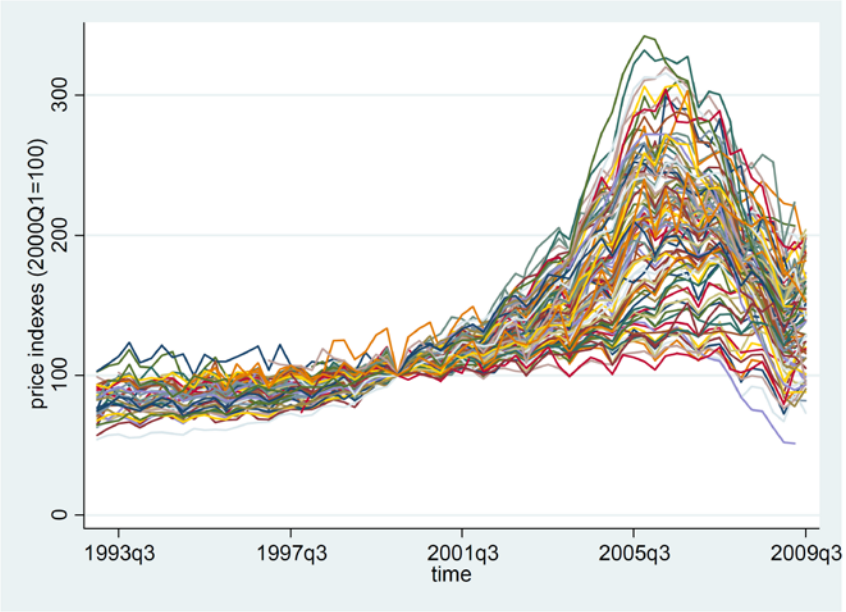


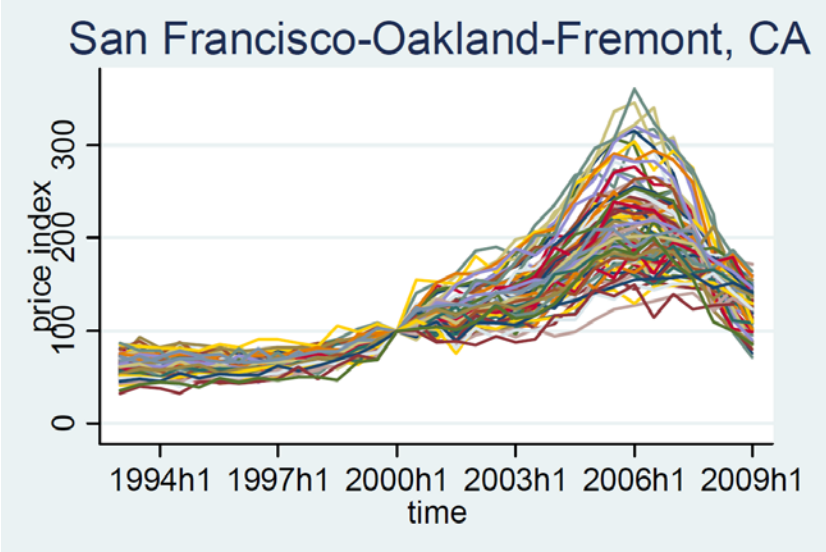

**Fig. 2.** Estimated cumulative density function for log of real sales price.

# Heterogeneity in house prices

- Heterogeneity in house prices in boom-bust cycles
  - Ferreira and Gyourko (2012, 2017); Sinai (2012); Glaeser et al (2012); Gyourko et al (2013); Lyons (2015); Zhang (2018)
  - **The recent US housing boom cannot be interpreted as a single, national event**, as different markets began to boom across a decade-long period from the mid-1990s to the mid-2000s (Ferreira and Gyourko 2012, 2017).

Figure 3: Individual Metropolitan Area Hedonic House Price Indexes by Quarter




Ferreira and Gyourko (2017)

# Assignment models of housing markets

- Previous papers in macroeconomics typically study an economy with a homogeneous housing capital good, where households choose different quantities of that good at a common per-unit price. Those studies do not tell anything about the cross-section of house prices.

- Assignment models of housing markets (Landvoigt et al 2015, Piazzesi and Schneider 2016, Määttänen and Terviö 2014, Rios-Rull and Sanchez-Marcos 2008)

  - A house is a bundle of units. Different houses consist of different sets of units (Rosen 1974). Each household buys one house and obtains a flow of housing services from it.

  - Equilibrium prices are determined so that households with high (low) demand for housing services are assigned to high (low) quality houses. The distribution of equilibrium prices across houses is determined by the distribution of qualities across houses and the distribution of characteristics across households.

  - The assumption of no costless unbundling implies limits to arbitrage in housing markets (Rosen 1974, Landvoigt et al 2015, Piazzesi and Schneider 2016).

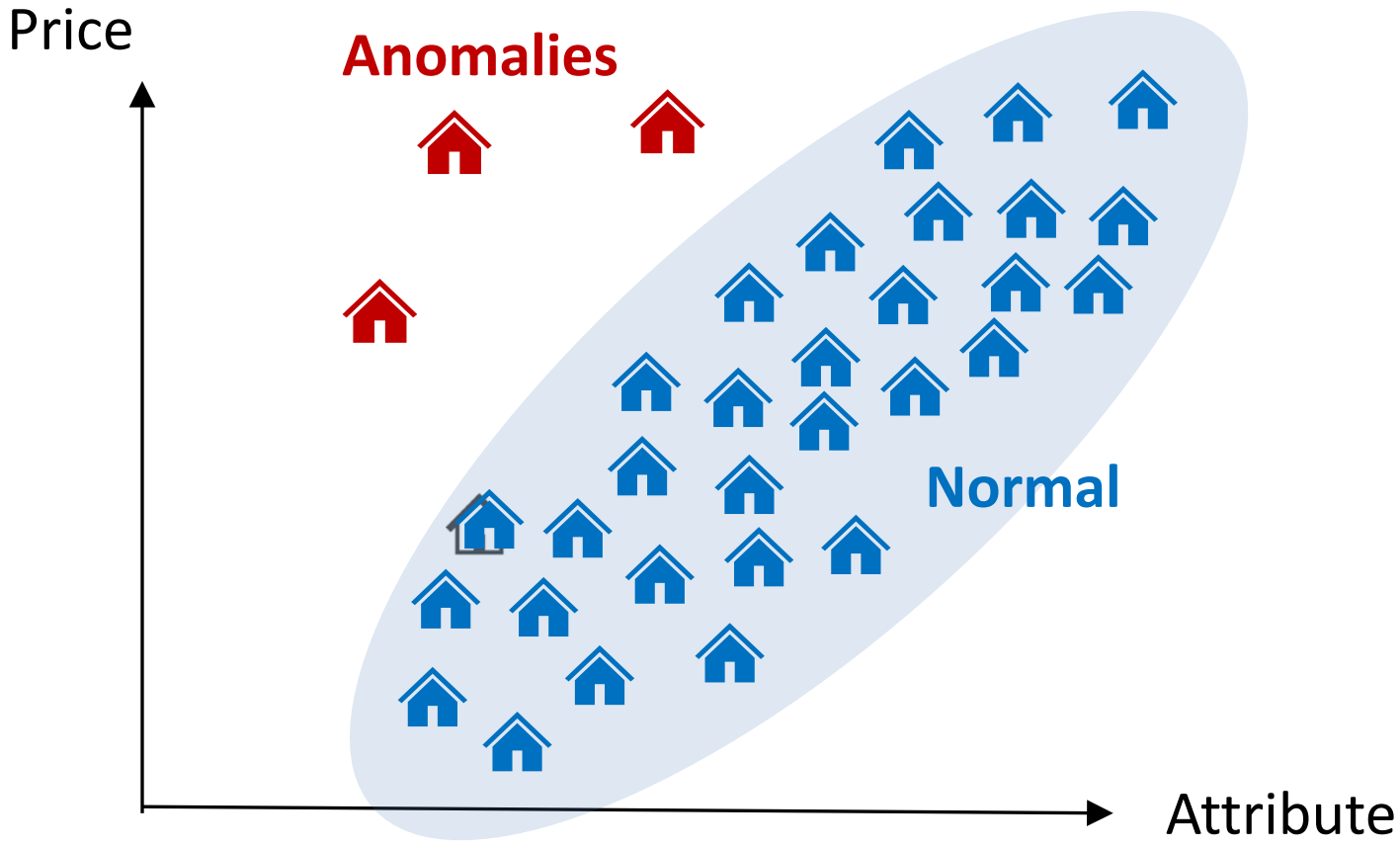
# What we do in this paper

- We propose a methodology to detect anomalies in real estate transactions
- We apply this methodology to real estate transaction data from Greater Tokyo Area
- We show that the cross-sectional distribution of house prices was close to a log-normal in most of the sample period, but deviated from it during the bubble years
- We ask why the cross-sectional distribution deviated from a log-normal during the bubble years

# Outline

- Methodology
  - Hedonic model
  - CLT
- Data
- Size-adjustment to house prices
- Submarket hypothesis
- Conclusion

# Anomaly Detection




- Supervised vs. Unsupervised
- What is “Normal”?

# Lognormal Distribution as Benchmark

**Lindeberg-Feller Central Limit Theorem**

Consider a hedonic model : $$\ln P_i = \sum_{k=1}^{K} x_{ik}$$

The price follows a lognormal distribution if $x_{ik}$ are independent from each other, and the following condition is satisfied.

$$\lim_{K\to\infty} \frac{\max_{k\leq K}\{s_k\}}{K\bar{s}_K} = 0$$

**Lindeberg's condition**

where $s_k^2$ is the variance of $x_{ik}$ and $\bar{s}_K^2 \equiv \frac{1}{K}\left(s_1^2 + s_2^2 + \cdots + s_K^2\right)$

A famous textbook example of the central limit theorem is the distribution of persons' height. The height distribution of, say, mature men of a certain age can be considered normal, because height can be seen as **the sum of many small and independent effects**. Similarly, the log house prices will be normally distributed if house prices are determined as **the sum of many small and independent effects**.

# Housing Attributes

$$\ln P_i = \sum_{k=1}^{K} x_{ik}$$

- We empirically show that the heterogeneity in house prices stems mainly from the size and the location. The variances of these two factors are very large relative to the variances of other factors, so that the Lindeberg's condition is violated.
- **The size of a house**
  - We construct size-adjusted prices, thereby eliminating the effect of house size on prices.
- **The location of a house**
  - We restrict price comparison to the neighborhood area, thereby eliminating the effect of location on prices.

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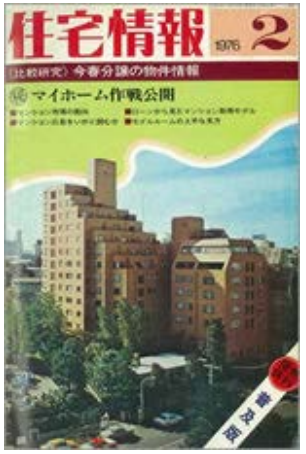
# Housing Information Weekly

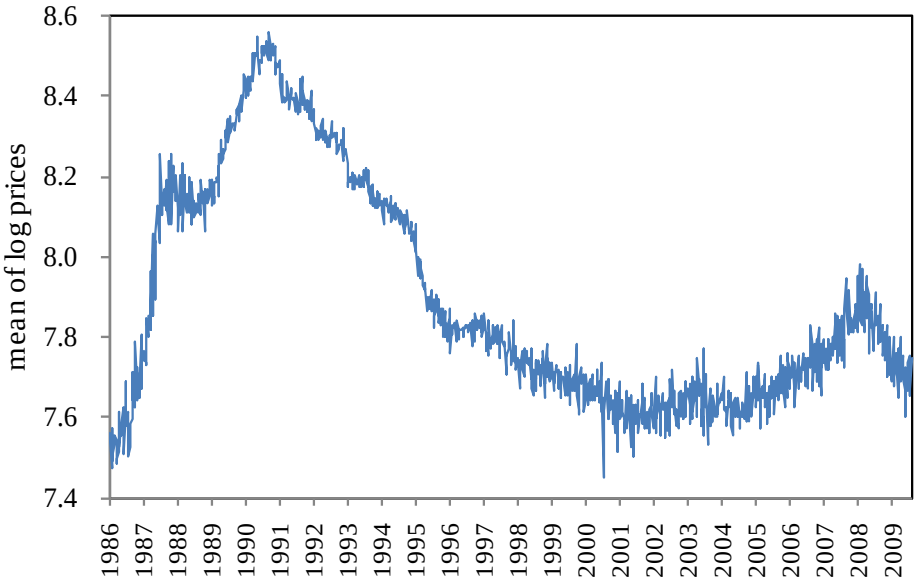
Real estate advertisement magazine published by RECRUIT CO. LTD



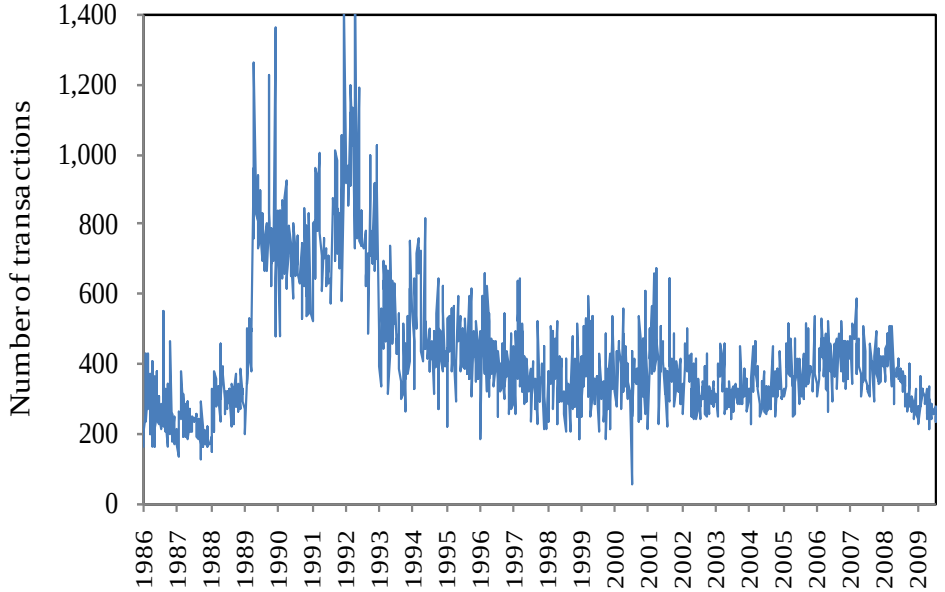

- Greater Tokyo Area
- Weekly data from 1986 to 2009 including the period of housing bubble in the late 1980s and its collapse in the first half of the 1990s
- **Condominiums: 724,416 listings**

  Single family houses: 1,602,918 listings

Mean of the cross-sectional distributions

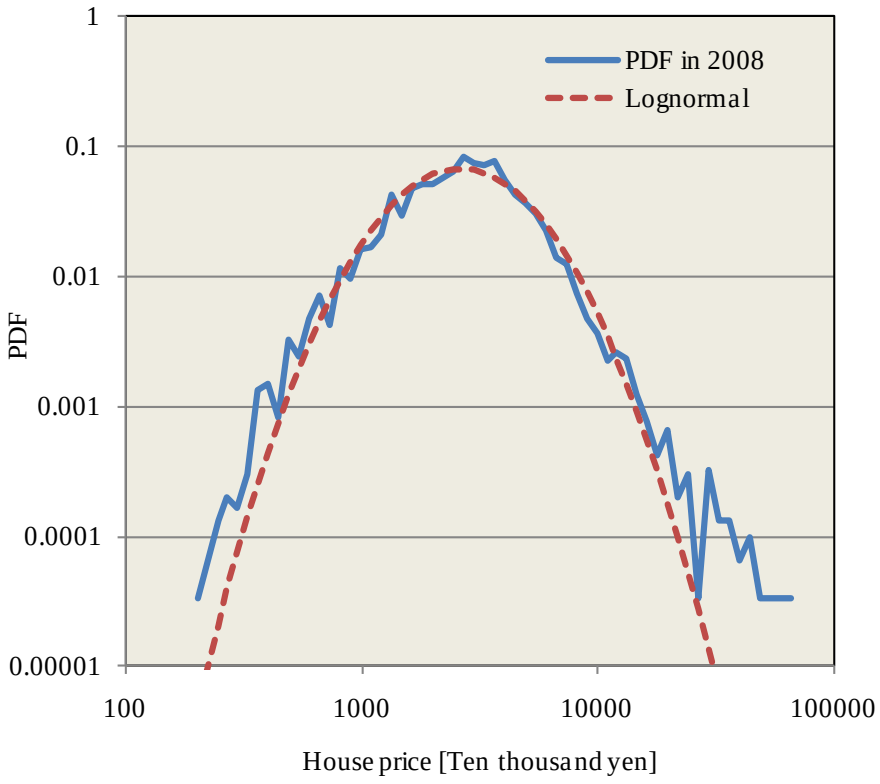



Number of weekly transactions

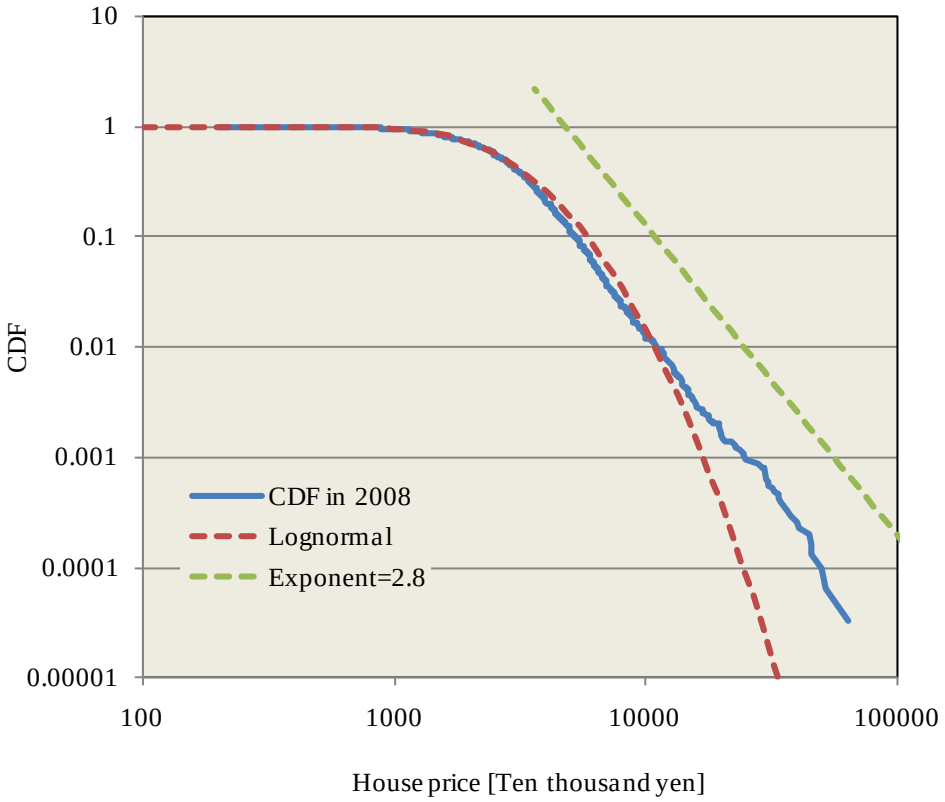


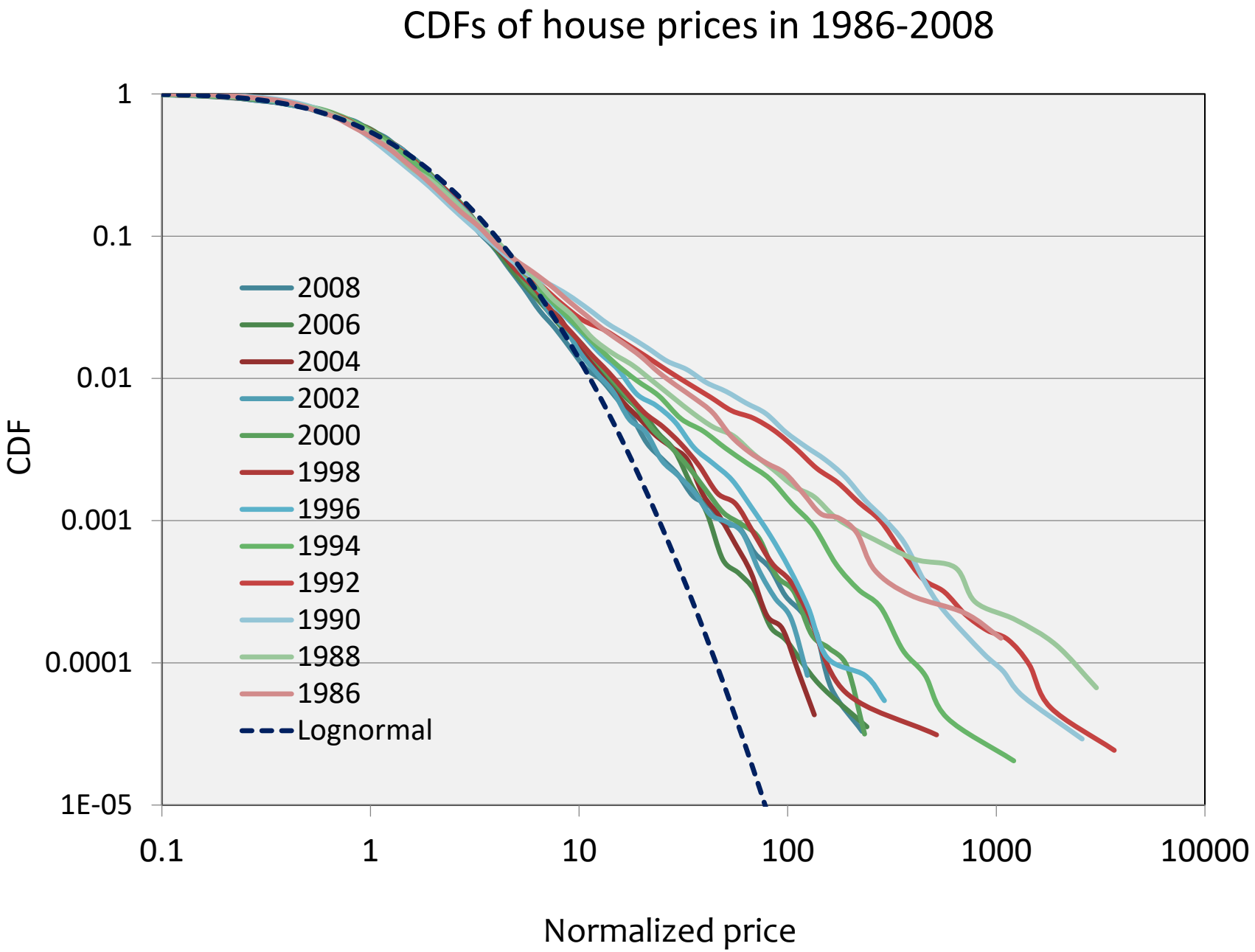
# PDF and CDF of original prices in 2008

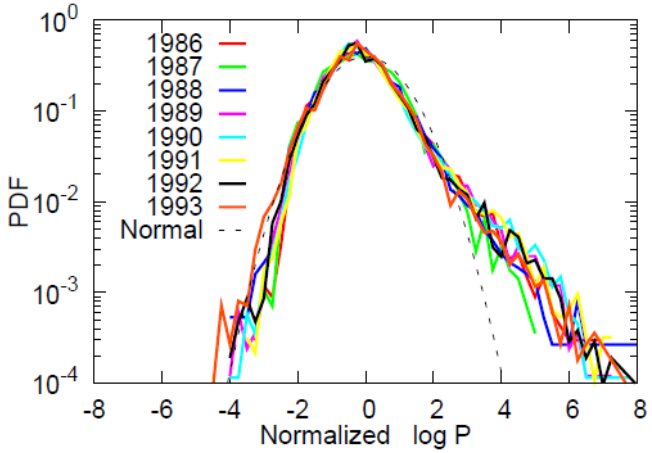
Prob Density Function

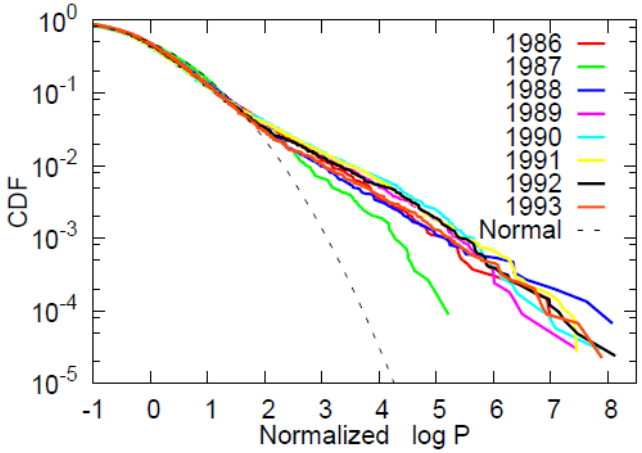



Counter Cumulative Distribution Fn




CDFs of house prices in 1986-2008
1
0.1
0.01
0.001
0.0001
1E-05
CDF
2008
2006
2004
2002
2000
1998
1996
1994
1992
1990
1988
1986
Lognormal
0.1
1
10
100
1000
10000
Normalized price


PDF
Normalized log P
1986
1987
1988
1989
1990
1991
1992
1993
Normal


CDF
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1987
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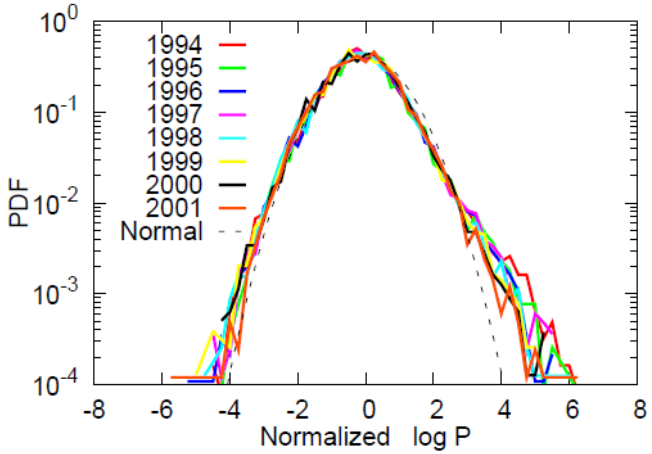
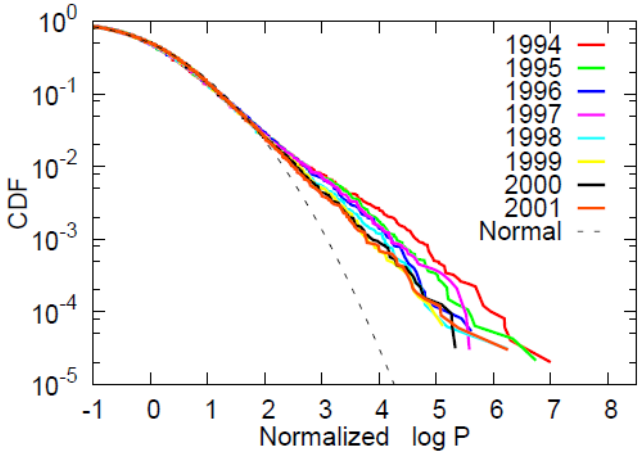

PDF
Normalized log P
1994
1995
1996
1997
1998
1999
2000
2001
Normal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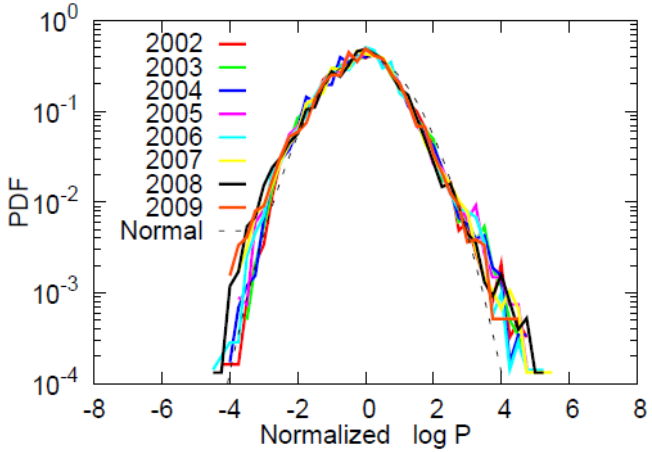
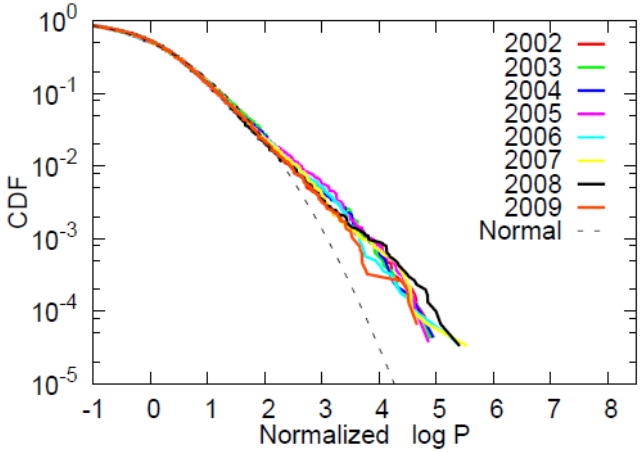

PDF
Normalized log P
2002
2003
2004
2005
2006
2007
2008
2009
Normal


CDF
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2002
2003
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2007
2008
2009
Normal

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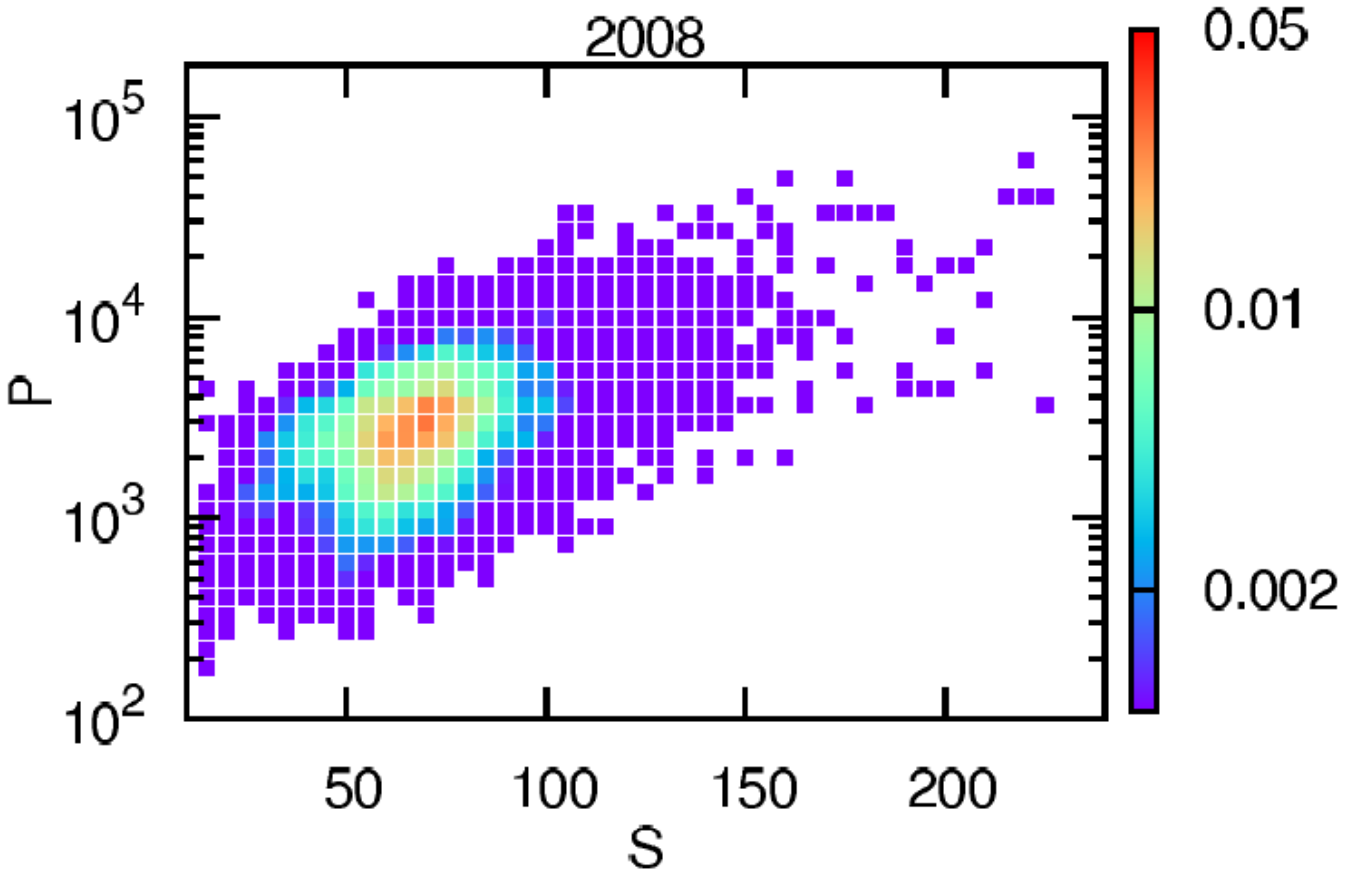
# Joint distribution of log price and house size

House price
[10 thousand yen]




House size [square meters]

# Size-adjustment to house prices

We empirically show:

$$P_{it} \sim PL\left(\zeta_t\right) \tag{1}$$

$$S_i \sim Exp\left(\lambda_t\right) \tag{2}$$

This implies:

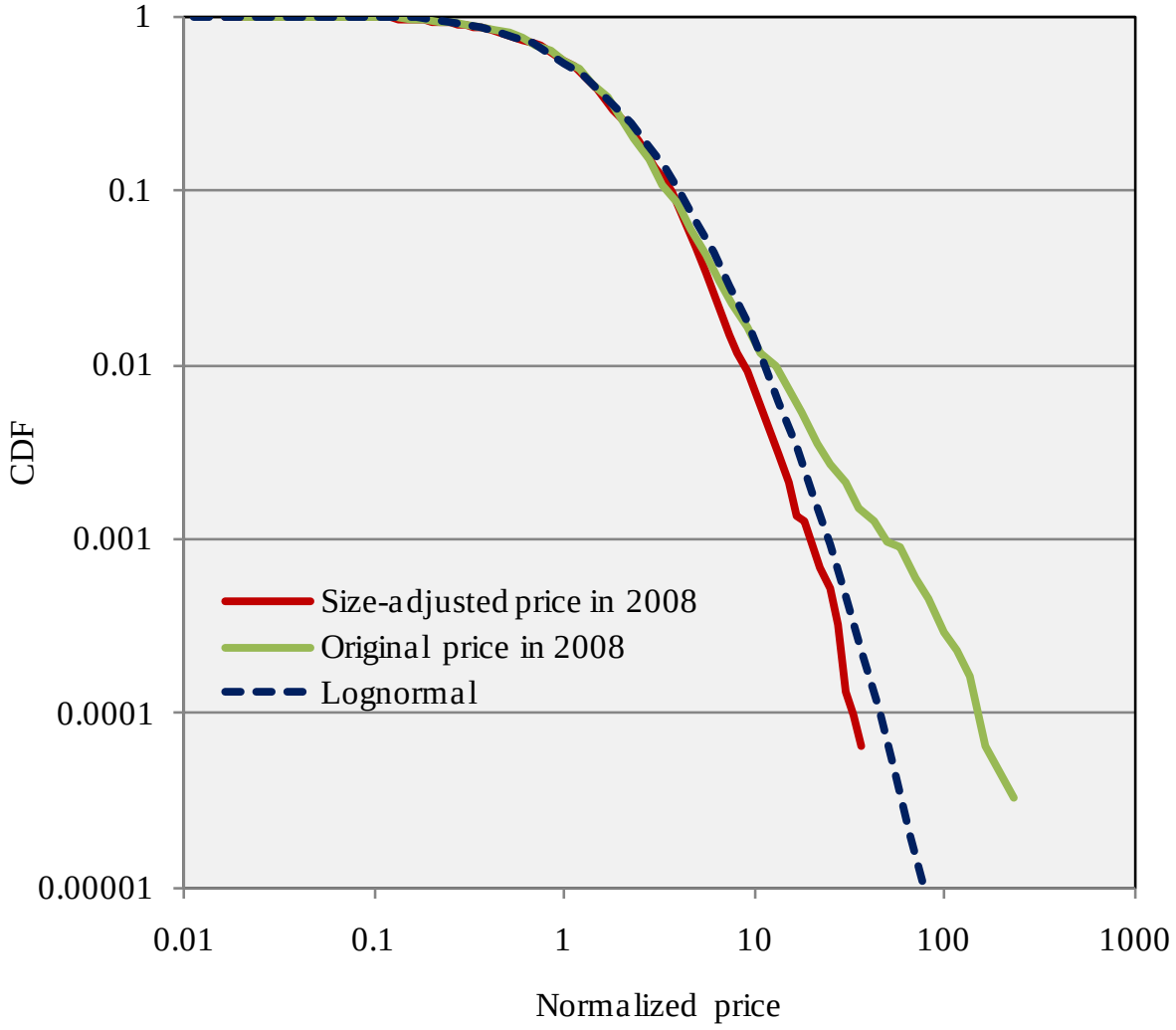
$$\ln P_{it} = \left(\frac{\lambda_t}{\zeta_t}\right) S_i + \epsilon_{it} \tag{3}$$

where $\epsilon_{it}$ is a Gaussian disturbance term.

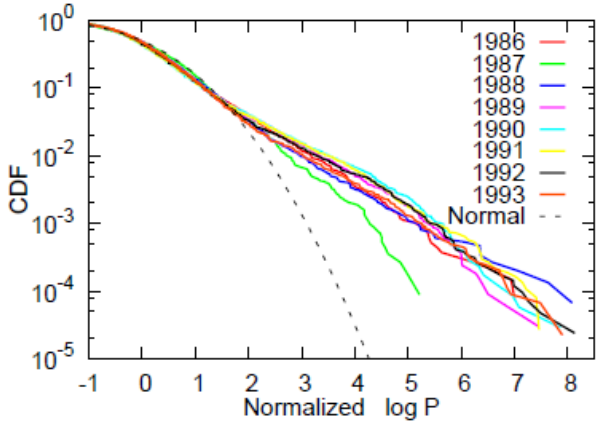
## Size-adjusted prices

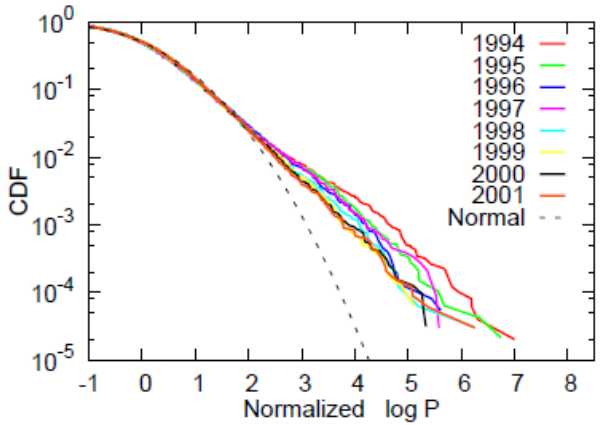
$$\tilde{P}_{it} \equiv \frac{P_{it}}{\exp\left[\left(\lambda_t/\zeta_t\right)S_i\right]} \sim LN$$

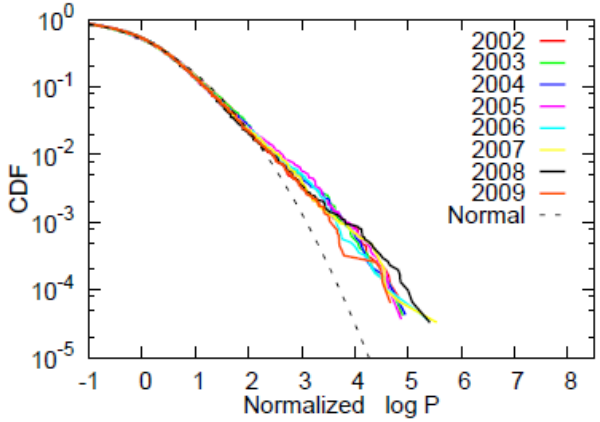
# CDF of size-adjusted prices in 2008



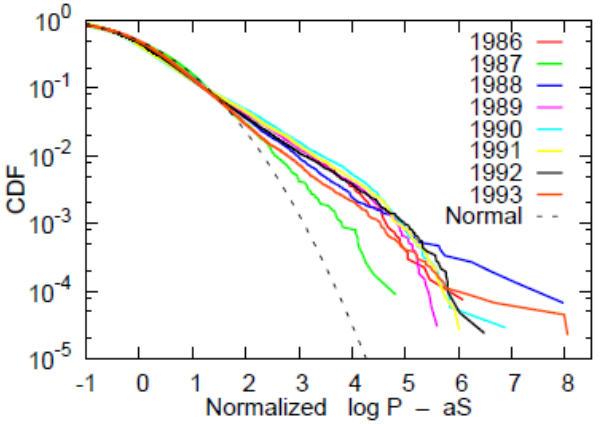
Original prices

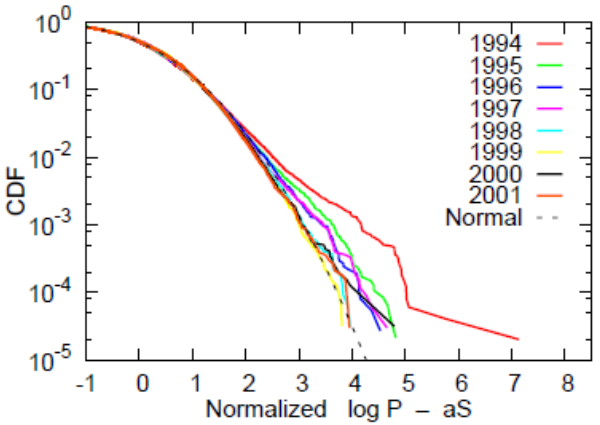


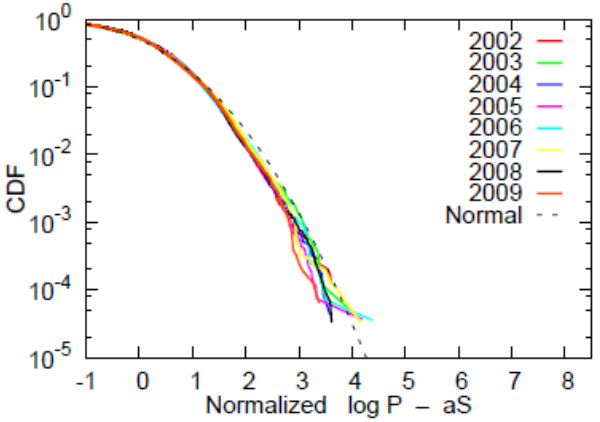




Size-adjusted prices



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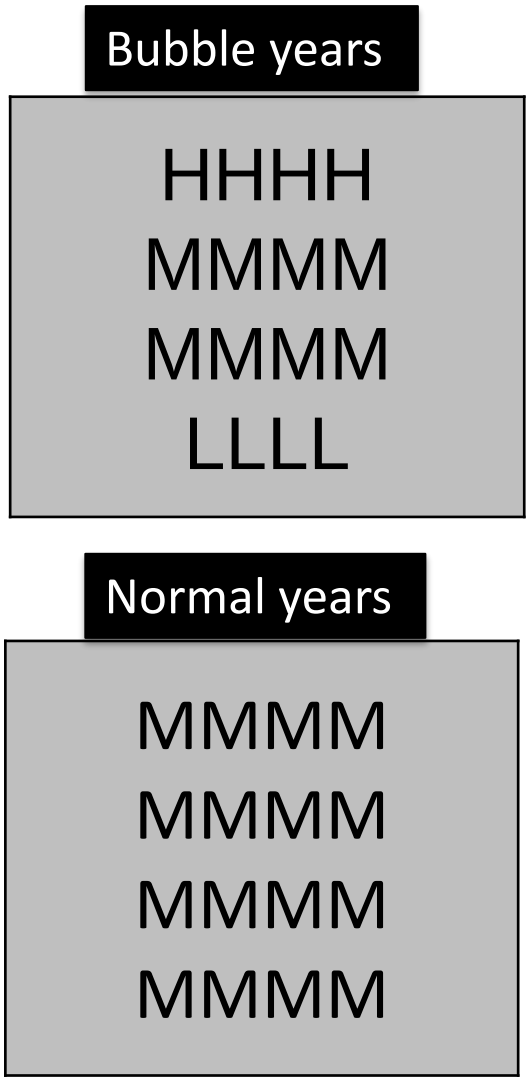
# Submarket hypothesis




**The size-adjusted prices follow a distribution with a heavier tail than a log-normal distribution**

**The size-adjusted prices follow a log-normal distribution**

# Submarket hypothesis

**Bubble years**

| |
|---|
| HHHH |
| MMMM |
| MMMM |
| LLLL |

**Randomly distributed**

| | |
|---|---|
| HM<br>ML | HM<br>ML |
| HM<br>ML | HM<br>ML |

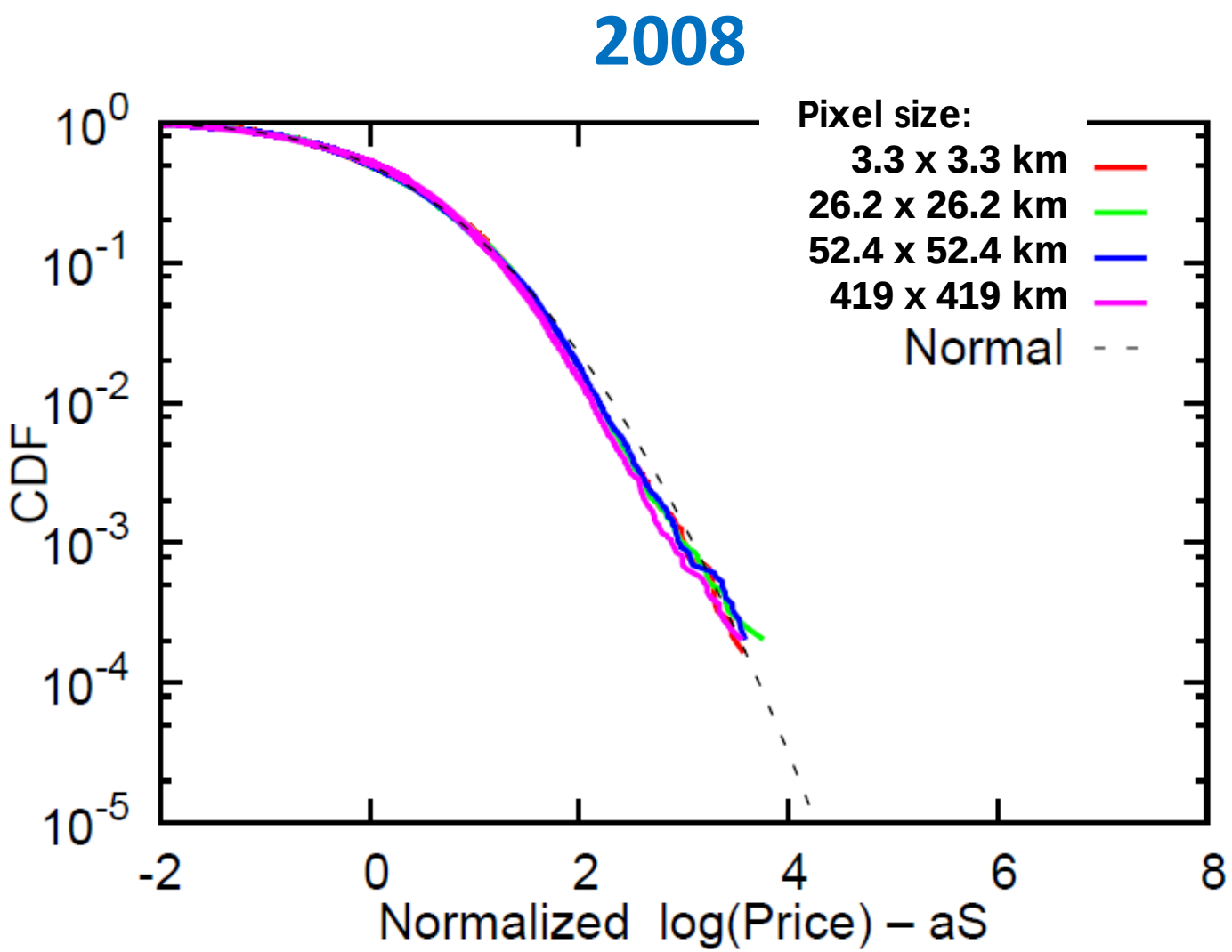
**Heterogeneous within each submarket but homogeneous across different submarkets**

**Clustered**

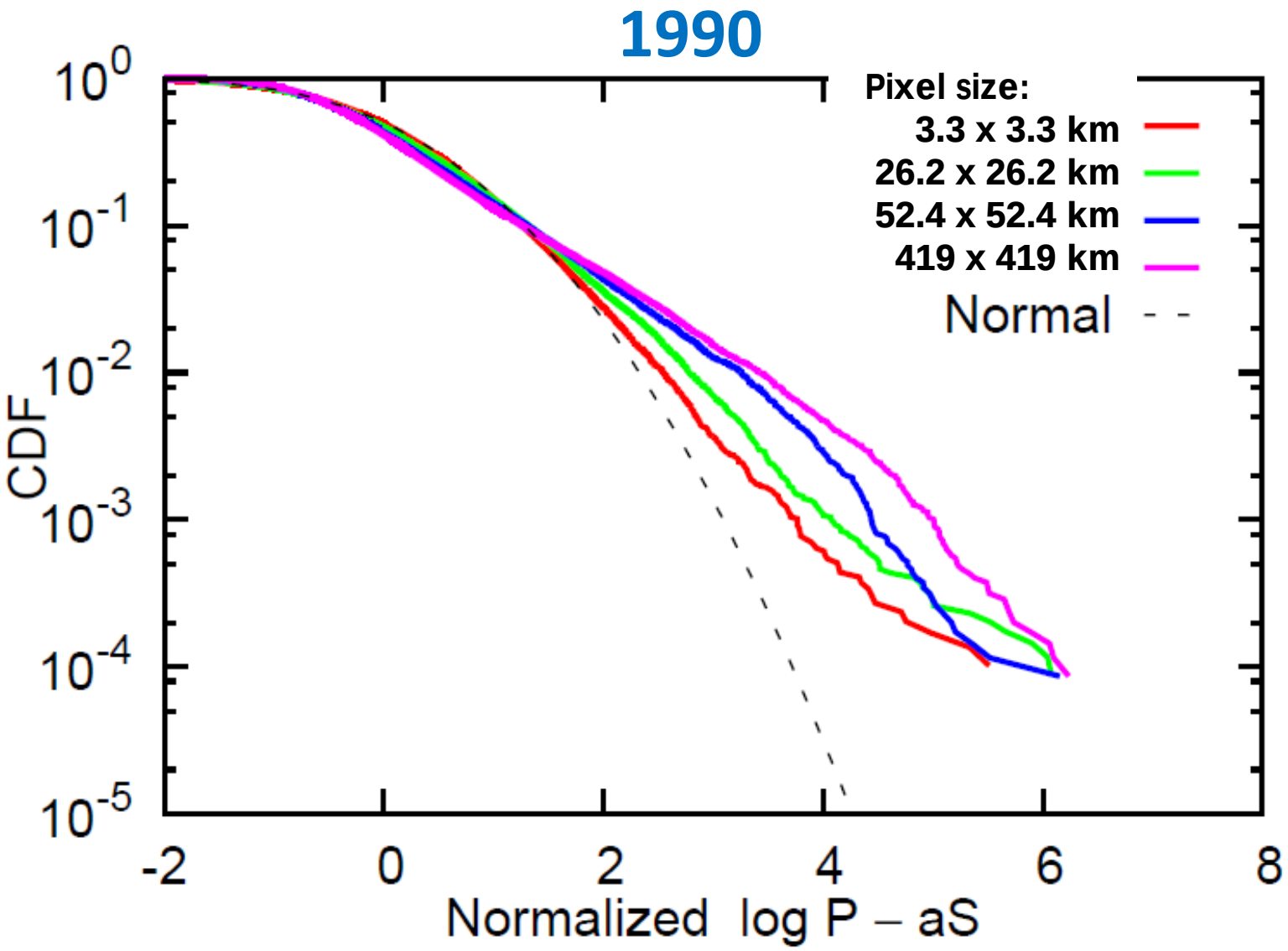
| | |
|---|---|
| HH<br>HH | MM<br>MM |
| MM<br>MM | LL<br>LL |

**Homogeneous within each submarket but heterogeneous across different submarkets**

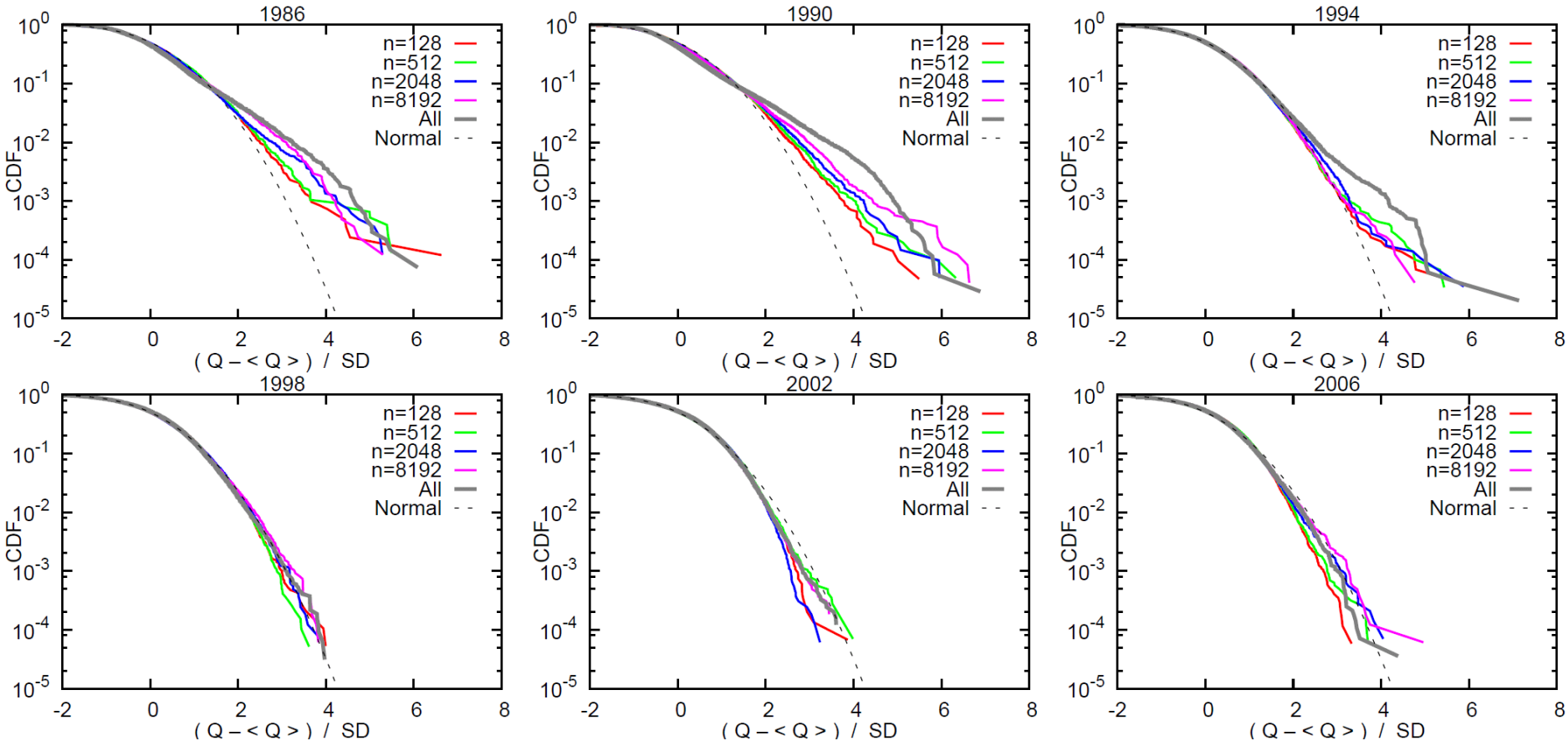
Size-adjusted prices that are normalized at the pixel level



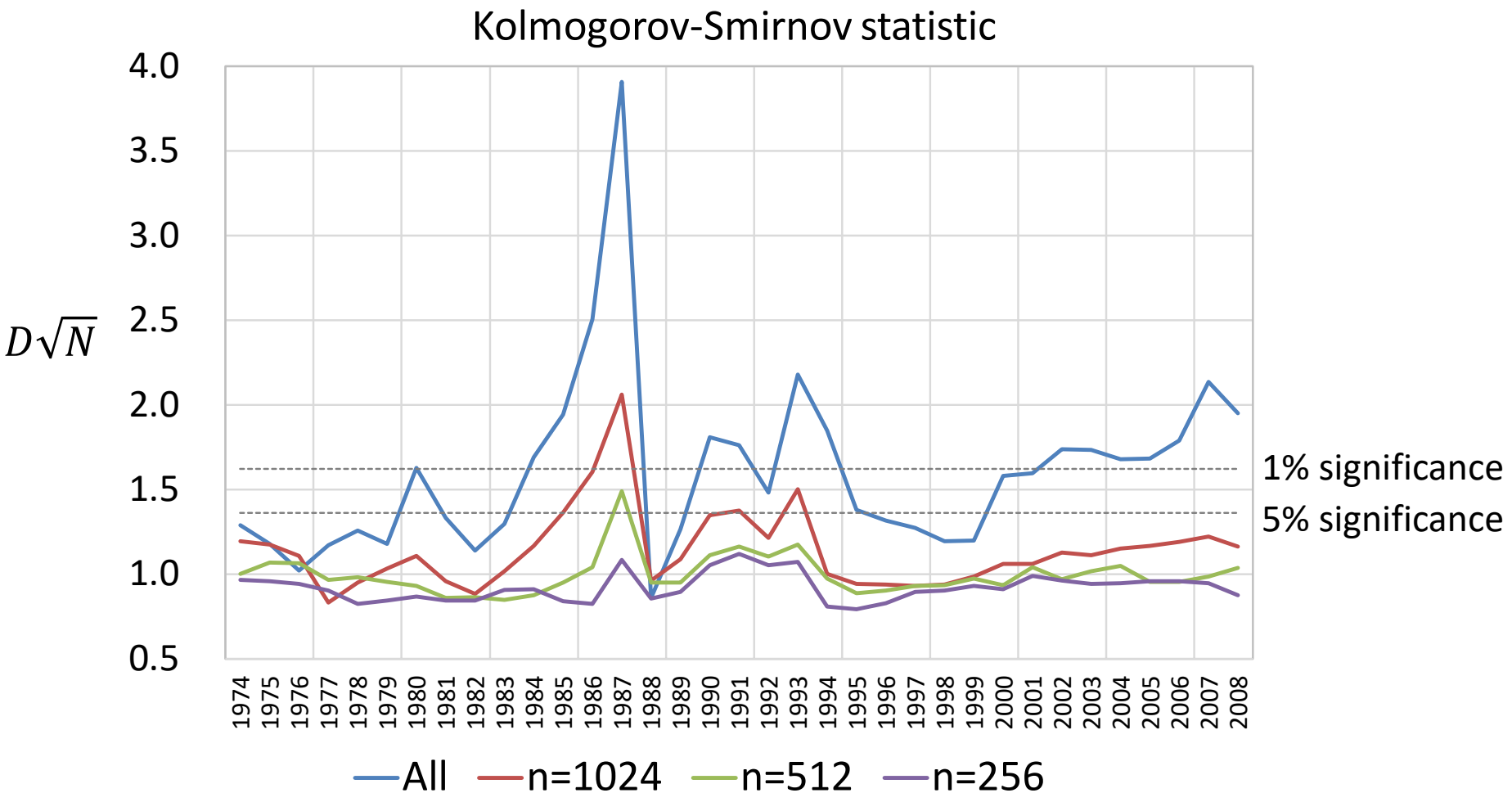
Size adjusted prices that are normalized at the pixel level



# Distributions of size-adjusted prices for different pixel sizes

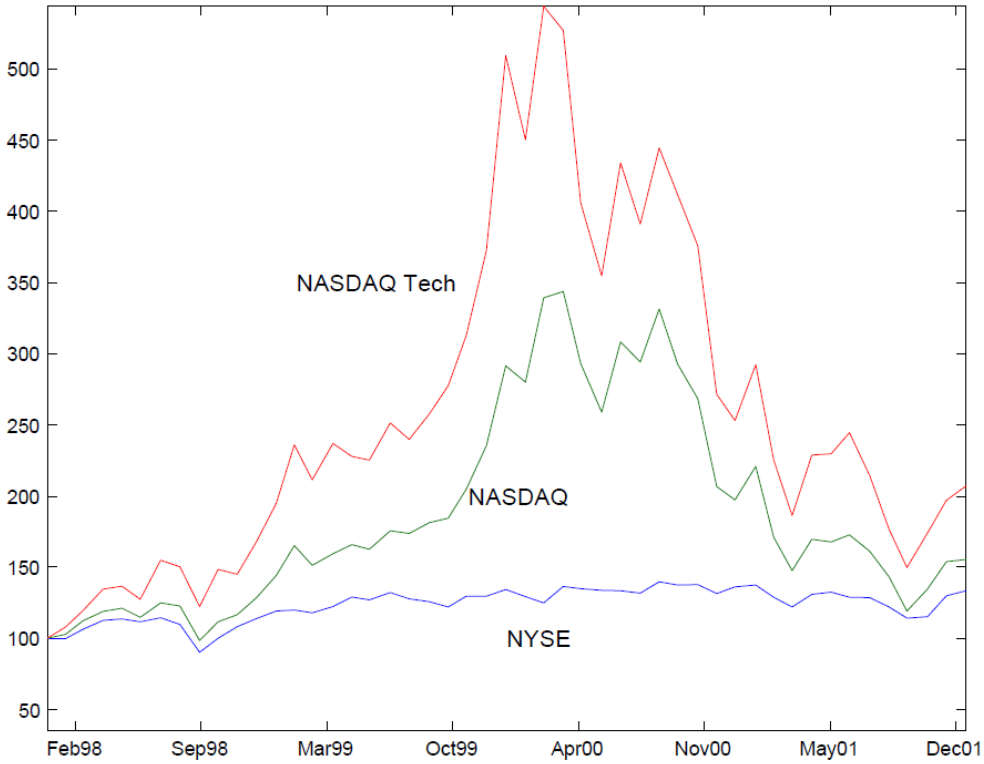


# Deviation from the standard normal distribution: Official Land Price data



# Law of One Price during the tech bubble

- Lamont and Thaler (2001); Ofek and Ricardson (2001, 2002)
- Cochrane (2002): **The "bubble" was concentrated**. … [I]f there was a "bubble," or some behavioral overenthusiasm for stocks, it was concentrated on Nasdaq stocks, and Nasdaq tech and internet stocks in particular.



# Procedure to estimate the size of a submarket within which house prices follow a log-normal distribution

❶ For a house $i$, we collect $n$-1 nearest houses.

❷ We calculate a size-adjusted price $Q$ for each of the $n$ houses (i.e. house $i$ and the $n-1$ nearest houses) and conduct Geary's test to see whether the log of $Q$ follows a normal distribution.

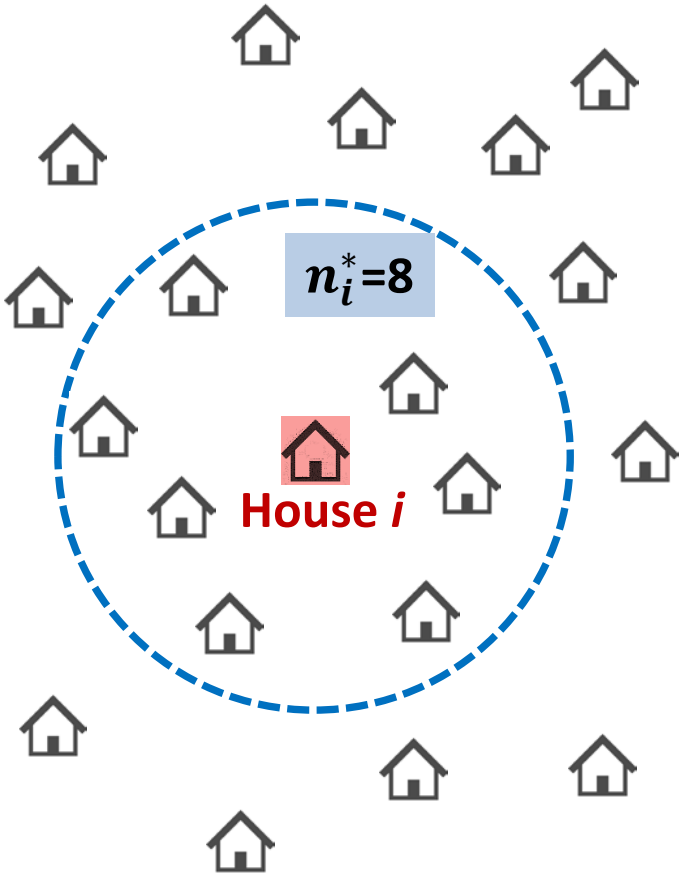
❸ We start this from a small value for $n$ and repeat this exercise until we find $n_i^*$ such that the null is rejected for values greater than $n_i^*$.

❹ We define $\Theta_{it}$ for house $i$ transacted in month $t$ as:

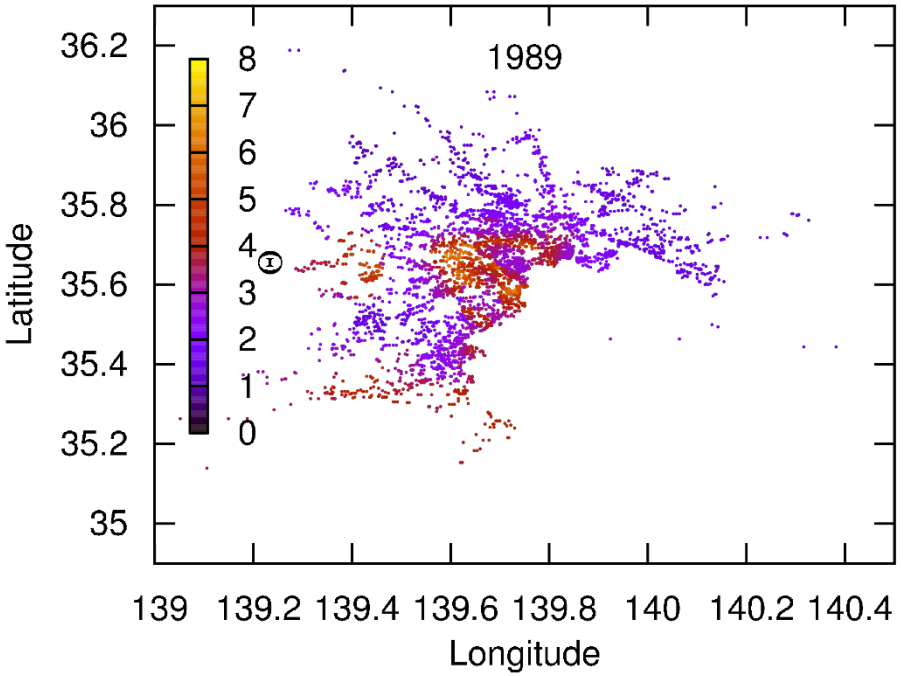
$$\Theta_{it} \equiv -\log \frac{n_i^*}{N_t}$$

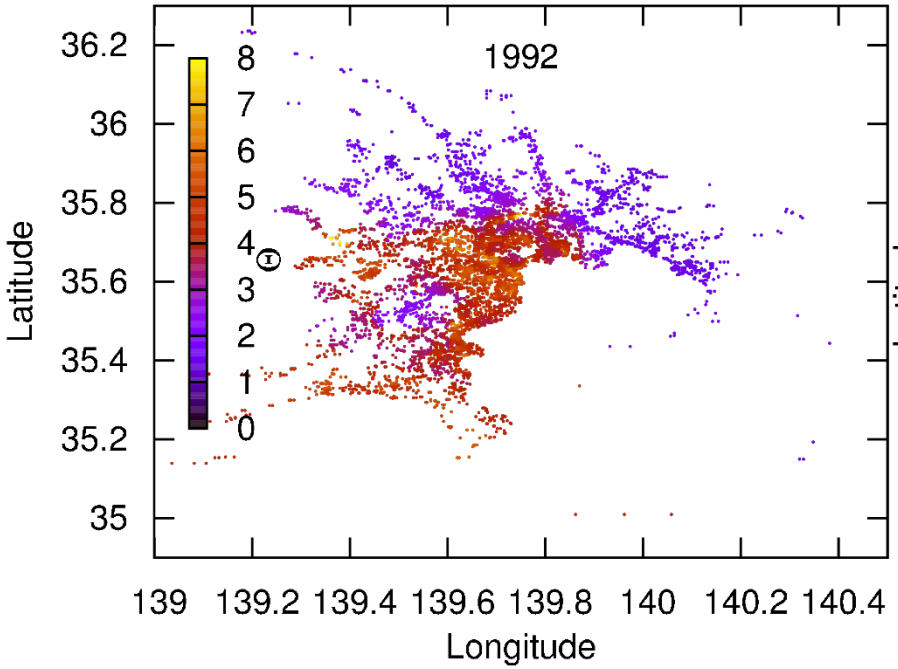
where $N_t$ is the number of houses transacted in month $t$.

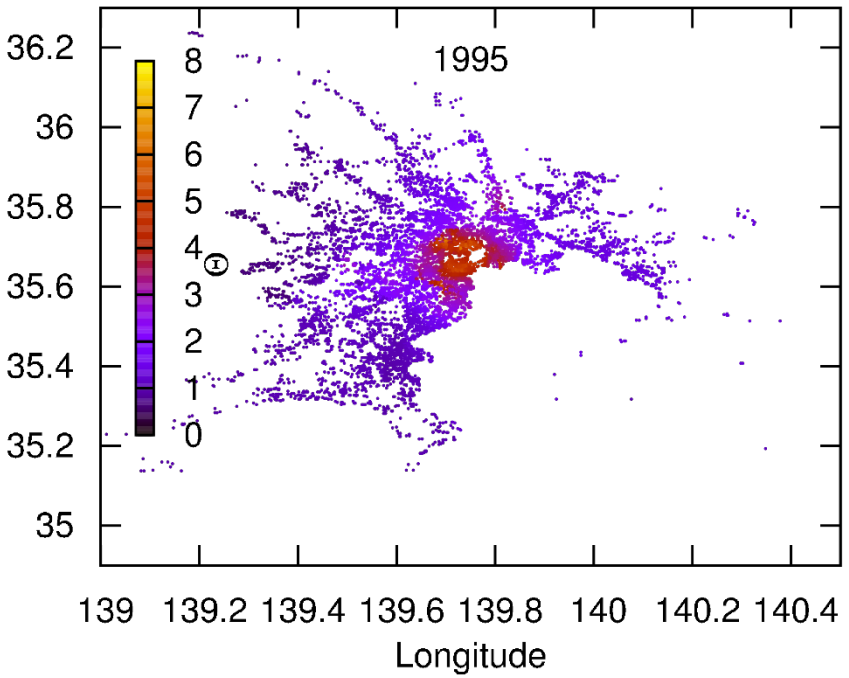
❺ We calculate $\Theta_{it}$ for each house transacted in each month of the sample period.



Estimates of Θ for individual property listings in 1989, 1992, and 1995

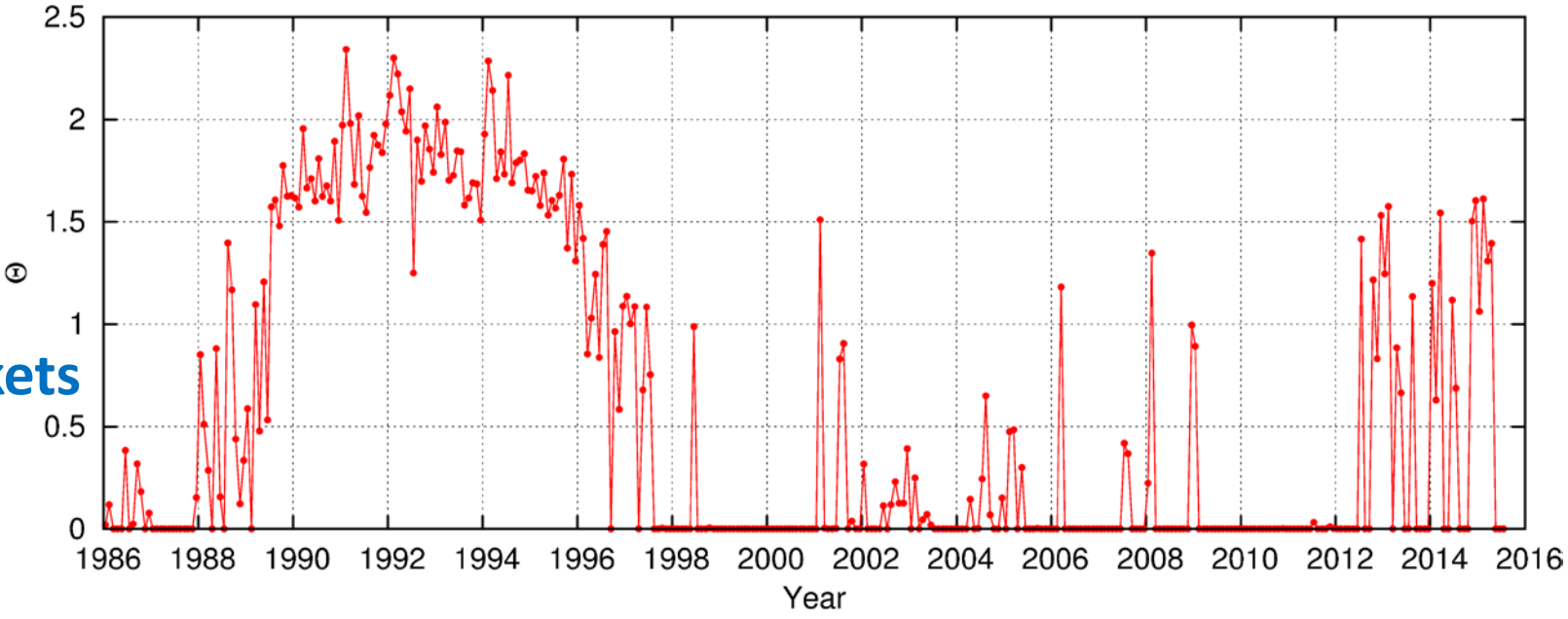


Mean of $\Theta_i$ over individual houses at the monthly frequency

**Smaller submarkets**



# Conclusion

- We show that
  - House price distribution in Tokyo had a power law tail during the bubble period in the late 1980s, while it was very close to a lognormal after the bubble period.
  - House price distribution within a submarket was close to a lognormal even during the bubble period, but the mean and variance of the lognormal distribution differed substantially across submarkets.
- This spatial heterogeneity is the source of the power law tail observed during the bubble period, and can be regarded as evidence for the lack of price arbitrage across submarkets.
- We argue that the shape of the cross-sectional distribution of prices, especially the tail part of the distribution, may contain information useful for the detection of housing bubbles.

# References on heterogeneity in house prices


1. Andersson, C., Hellervik, A., Lindgren, K., Hagson, A., & Tornberg, J. (2003). Urban economy as a scale-free network. Physical Review E, 68(3), 036124.
2. Blackwell, Calvin. "Power Laws in Real Estate Prices? Some Evidence." The Quarterly Review of Economics and Finance 69 (2018): 90-98.
3. Bogin, Alexander, William Doerner, and William Larson. "Local house price dynamics: New indices and stylized facts." Real Estate Economics (2018).
4. Case, Karl E., and Christopher J. Mayer. "Housing price dynamics within a metropolitan area." Regional Science and Urban Economics 26.3-4 (1996): 387-407.
5. Deng, Yongheng, Daniel P. McMillen, and Tien Foo Sing. "Private residential price indices in Singapore: a matching approach." Regional Science and Urban Economics 42.3 (2012): 485-494.
6. Ferreira, Fernando, and Joseph Gyourko. "Heterogeneity in neighborhood-level price growth in the united states, 1993-2009." American Economic Review 102.3 (2012): 134-40.
7. Ferreira, Fernando, and Joseph Gyourko. Anatomy of the beginning of the housing boom: US neighborhoods and metropolitan areas, 1993-2009. November 2017.
8. Glaeser, Edward L., Joshua D. Gottlieb, and Kristina Tobio. "Housing booms and city centers." American Economic Review 102.3 (2012): 127-33.
9. Guerrieri, Veronica, Daniel Hartley, and Erik Hurst. "Endogenous gentrification and housing price dynamics." Journal of Public Economics 100 (2013): 45-60.

# References on heterogeneity in house prices


10. Guerrieri, Veronica, Daniel Hartley, and Erik Hurst. "Endogenous gentrification and housing price dynamics." Journal of Public Economics 100 (2013): 45-60.
11. Gyourko, Joseph, Christopher Mayer, and Todd Sinai. "Superstar cities." American Economic Journal: Economic Policy 5.4 (2013): 167-99.
12. Lyons, Ronan C. "East, west, boom and bust: the spread of house prices and rents in Ireland, 2007–2012." Journal of Property Research 32.1 (2015): 77-101.
13. McMillen, Daniel P. "Changes in the distribution of house prices over time: Structural characteristics, neighborhood, or coefficients?." Journal of Urban Economics 64.3 (2008): 573-589.
14. Sinai, Todd. "House Price Moments in Boom-Bust Cycles." Housing and the Financial Crisis. University of Chicago Press, 2012. 19-68.
15. Van Nieuwerburgh, Stijn, and Pierre-Olivier Weill. "Why has house price dispersion gone up?." The Review of Economic Studies 77.4 (2010): 1567-1606.
16. Villar, Jaume García, and Josep Maria Raya. "Use of a Gini index to examine housing price heterogeneity: A quantile approach." Journal of Housing Economics 29 (2015): 59-71.
17. Waltl, Sofie R. "Variation across price segments and locations: A comprehensive quantile regression analysis of the Sydney housing market." Real Estate Economics (2016).
18. Zhang, Lei, and Yimin Yi. "What contributes to the rising house prices in Beijing? A decomposition approach." Journal of Housing Economics 41 (2018): 72-84.
19. Zhu, E., Wu, J., Liu, H., & Li, X. (2018). Within-City House Price Distribution, Heterogeneity and Diffusion: Evidence from a Spatiotemporal Index for Beijing.

# References on assignment models of housing markets


1. Landvoigt, Tim, Monika Piazzesi, and Martin Schneider. "The housing market (s) of San Diego." American Economic Review 105.4 (2015): 1371-1407.
2. Määttänen, Niku, and Marko Terviö. "Income distribution and housing prices: An assignment model approach." Journal of Economic Theory 151 (2014): 381-410.
3. Piazzesi, Monika, and Martin Schneider. "Housing and macroeconomics." Handbook of macroeconomics. Vol. 2. Elsevier, 2016. 1547-1640.
4. Rosen, Sherwin. "Hedonic prices and implicit markets: product differentiation in pure competition." Journal of Political Economy 82.1 (1974): 34-55.
5. Rios-Rull, Jose-Victor, and Virginia Sanchez-Marcos. "An aggregate economy with different size houses." Journal of the European Economic Association 6.2-3 (2008): 705-714.