

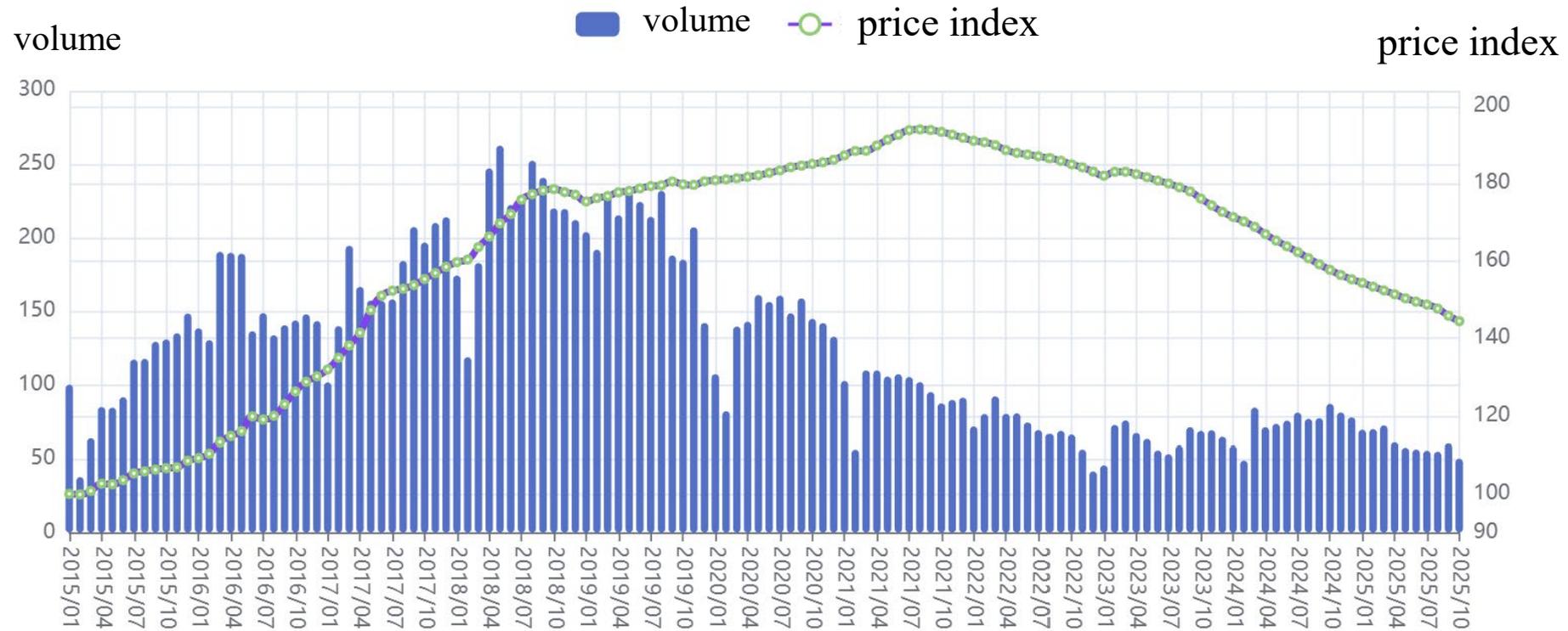
- Spatial Heterogeneity in Price-to-Rent Ratios in Tokyo, 1986–2025

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2026.2.20
ICRES, Tokyo

How to measure a housing bubble?

China's resale housing listing price index and volume



Source: ccindex

- ◆ **Definition:** If the reason that the price is high today is **only** because investors believe that the selling price will be high tomorrow – when “**fundamental**” factors do not seem to justify such a price – then a **bubble** exist.” (Stiglitz 1990)
- ◆ **Market Indicators:** House sale and rental price are central to examining these market disorders (McCarthy and Peach, 2004; Brunnermeier and Julliard, 2008; Campbell et al., 2009)

User Cost Model

- ◆ User cost model (Porterba 1984 and Himmelberg et al. 2005)

$$u_t = r_t^{rf} + \omega_t + \delta_t + \gamma_t - g_{t+1}$$

Rent yield (Rent/Price)	Risk-free Interest	Transaction and mortgage cost	Deprecia tion	Risk Premium	Expected Capital Gain
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- ◆ **Implication:** The **Price-to-Rent Ratio** serves as a proxy for this arbitrage condition. Deviations from the user cost suggest potential mispricing or bubbles (Campbell et al., 2009; Ambrose et al., 2013).

Challenge 1: The measurement gap in Price-to-Rent ratios

5

◆ **Macro Level:** Aggregate Indices

- ◆ City-level price/rent indices to compute PTR
- ◆ US(Gallin, 2008); Euro(Bourassa, Hoesli and Oikarinen; 2019); China(Wu, Gyourko and Deng, 2016)

◆ **Micro Level:** Quality-adjusted Price-to-rent Ratio

- ◆ Exact same unit (Bracke 2013, London)
- ◆ Characteristics Matching (Smith and Smith 2006, Hill and Syed 2012)
- ◆ Complex Matching (Baltagi and Li 2015)
- ◆ Hedonic Quality-adjusted(Hill and Syed 2016, Walzl 2018, Chen et al. 2022)

Challenge 2: Spatial Heterogeneities in Housing Data

🟡 The Spatial Challenge

- 🟣 Housing prices/rent exhibit strong spatial heterogeneity
- 🟣 Price appreciation is rarely uniform across a city (Liu et al., 2016).

🟡 From Global to Local Models

🟣 Spatial AR(Autoregression)

- 🟢 spatial interdependence

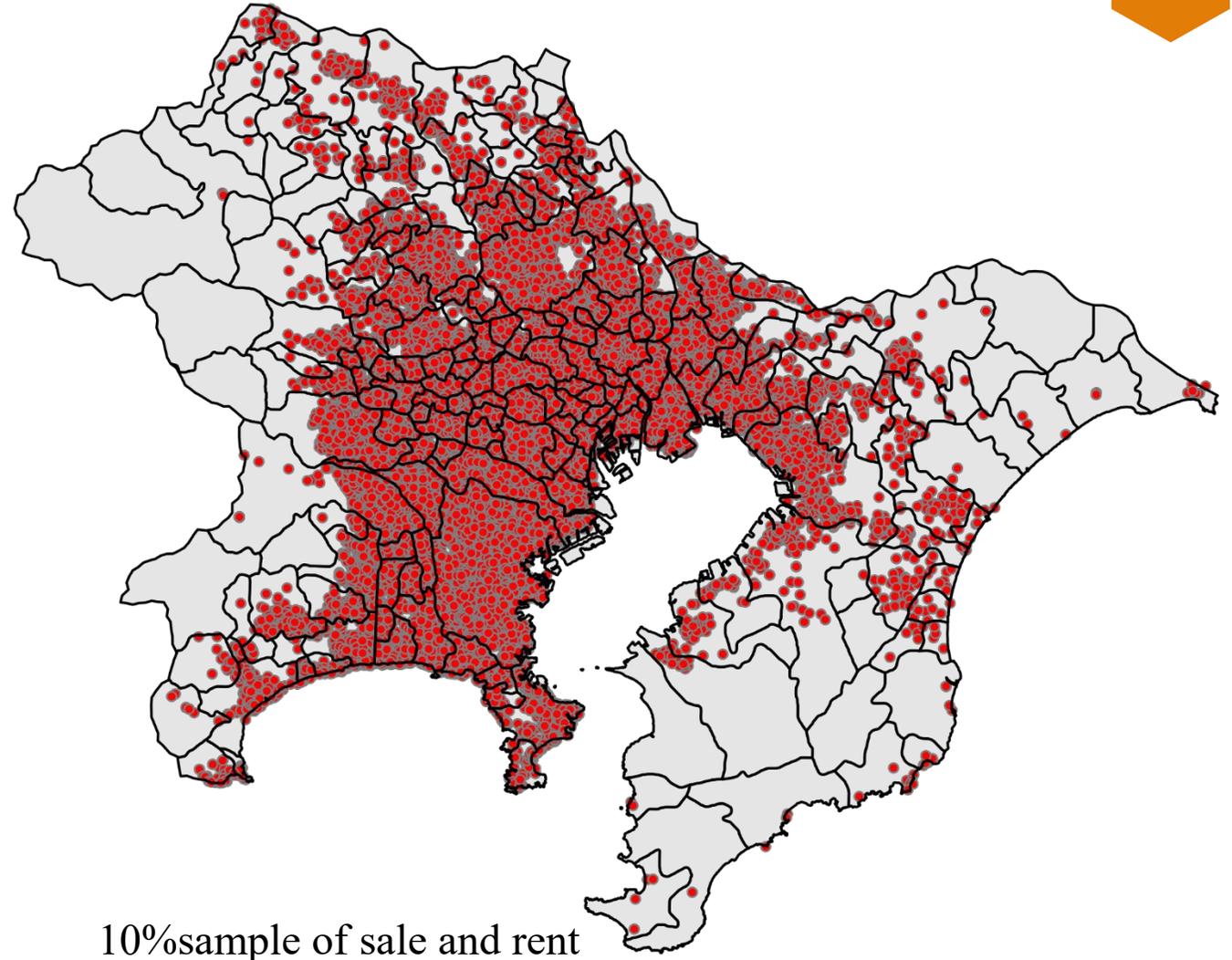
🟣 Locally (Geographically) Weighted Regression

- 🟢 LWR => GWR:
- 🟢 GTWR (time) using for Panel data
- 🟢 Multi-Scale GWR

1. Unprecedented Longitudinal Scope (1986–2025)
 - Integration of 40 years of micro-level transaction and listing data for Greater Tokyo, covering the full cycle from the 1990s bubble to the post-pandemic era.
2. Spatial Precision via GWR
 - We use GWR to capture the spatial heterogeneity, estimates the within-cities heterogeneity of Price-to-rent ratio over 40 years.
3. The "Standardized Unit" Solution
 - To solve the sample selection problem, we apply GWR Imputation at every location.

Data

- Micro-level Sale and Rental Data
 - Tokyo MSA(一都三県, *Itto Sanken*)
 - From 1985 to 2017
 - Provided by Recruit Co., Ltd.
 - Sale 1,233,203
 - Rental 7,860,990

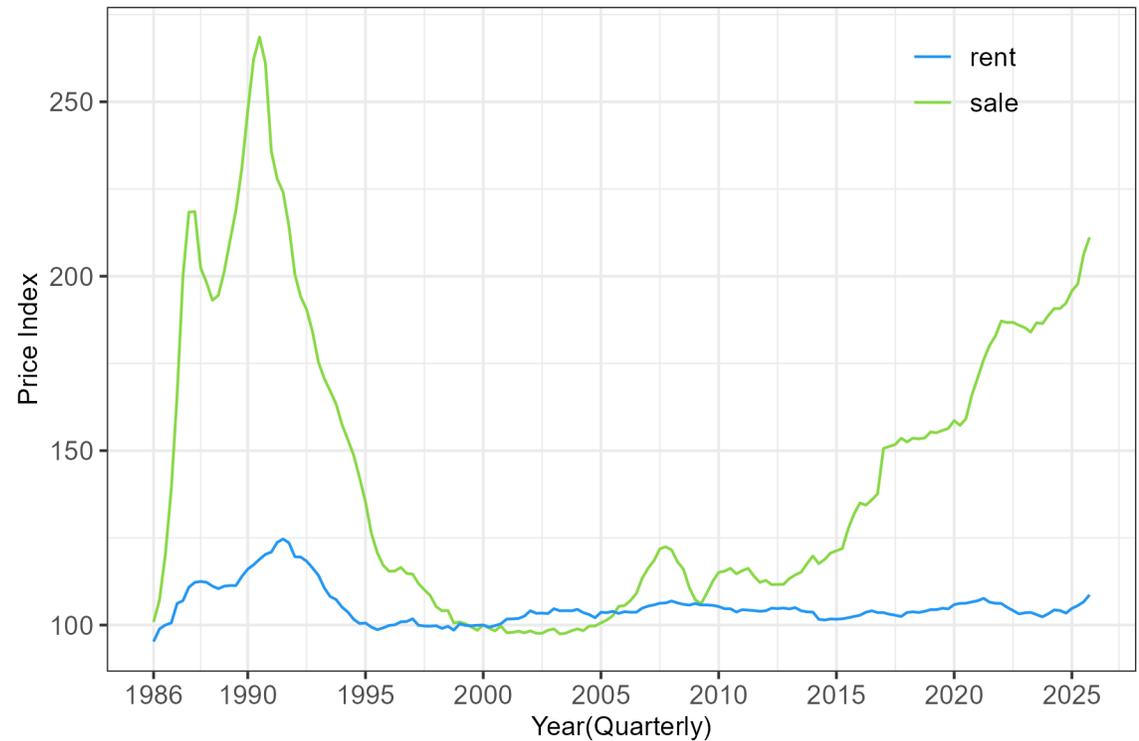


Japanese Housing Market

Japanese Housing Market

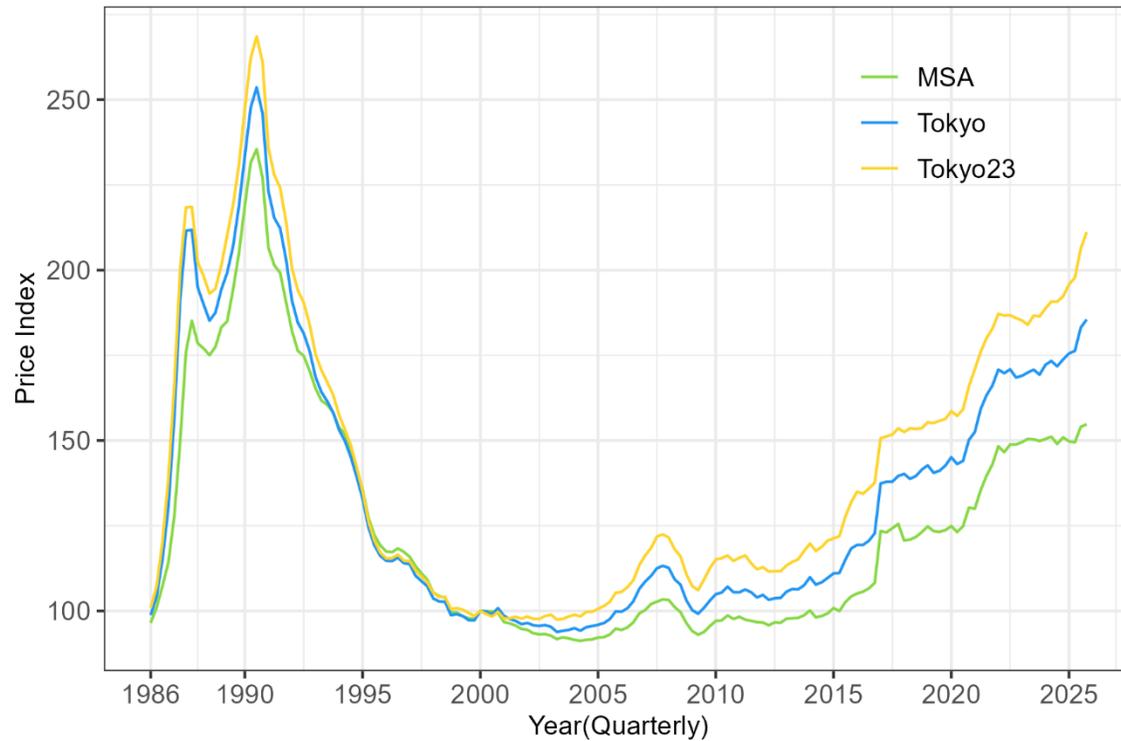
- Boom in late 1980s
- Recovery after 2000

Sale and Rental Market

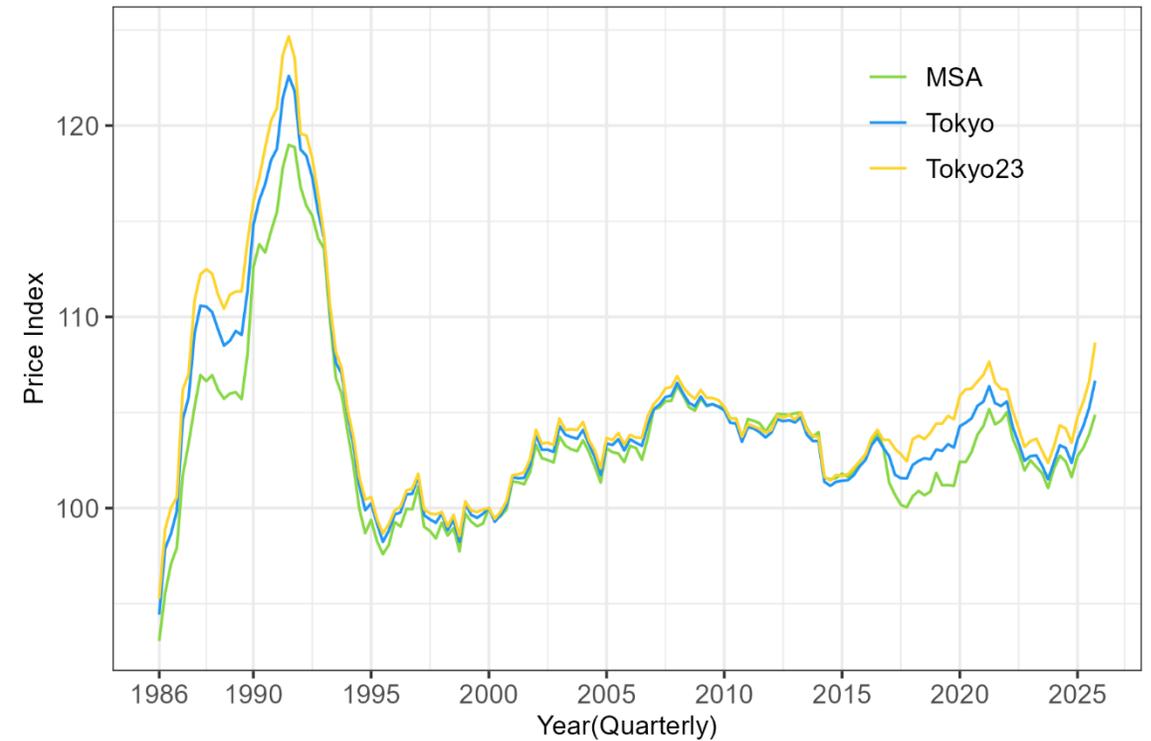


Real Price/Rent Index of Tokyo MSA

Japanese Housing Market



Price Index of Tokyo MSA, Tokyo-to, Tokyo 23Wards



Rent Index of Tokyo MSA, Tokyo-to, Tokyo 23Wards

Summary Statistics: by prefecture

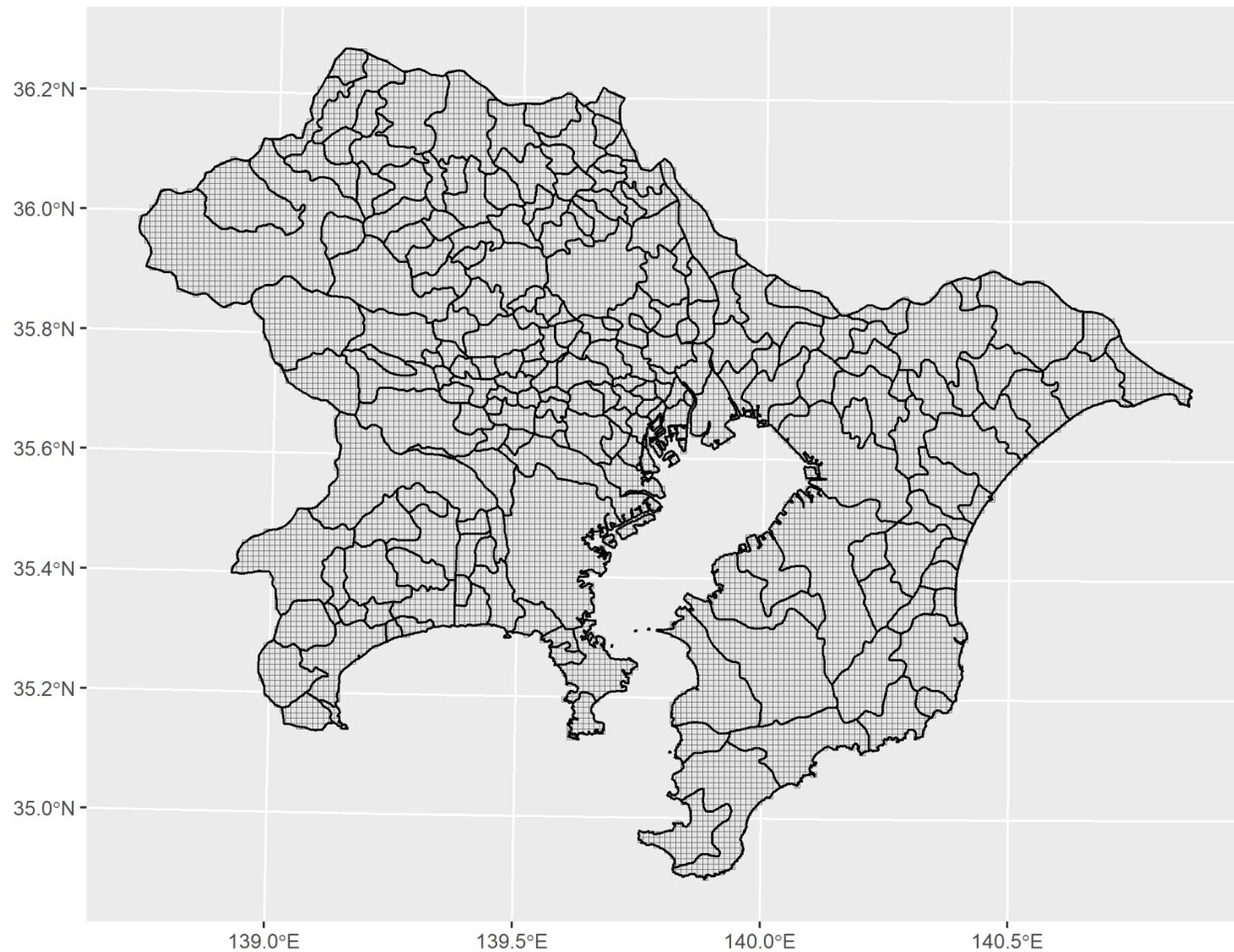
	(1) Saitama	(2) Chiba	(3) Tokyo	(4) Kanagawa	(5) Full
	Rental				
Annual Rent per m^2 (10000yen)	2.37	2.43	3.74	2.80	3.43
Floor Space (m^2)	40.86	41.35	36.55	40.05	37.65
Building Age	12.44	13.05	12.46	11.96	12.42
Walk Time to Nearest Station (min)	9.73	8.75	7.18	9.01	7.72
Distance to Tokyo Station (km)	24.36	22.26	10.57	28.62	14.83
Observations	717,021	561,735	6,918,526	1,340,197	9,537,479
	Sale				
Price per per m^2 (10000yen)	35.60	35.82	61.88	45.64	49.39
Floor Space (m^2)	82.10	84.21	71.30	79.06	77.01
Building Age	8.88	10.82	12.25	10.87	11.08
Walk Time to Nearest Station (min)	12.85	11.60	9.11	11.47	10.76
Distance to Tokyo Station(km)	28.17	26.10	15.15	32.92	23.96
Observations	228,381	150,108	528,282	375,564	1,282,335

Summary Statistics: by year

	(1) 1986	(2) 1991	(3) 2000	(4) 2015	(6) 2025	Full
	Rental					
Annual Rent per m^2 (10000yen)	3.06	3.94	3.40	3.42	3.49	3.47
Floor Space (m^2)	41.06	43.88	38.66	36.33	35.99	37.67
Building Age	2.63	4.19	10.11	14.40	23.88	12.43
Walk Time to Nearest Station (min)	7.38	8.41	8.39	7.50	7.12	7.72
Distance to Tokyo Station (km)	16.93	17.40	15.58	13.78	18.64	14.84
Observations	8,252	72,416	278,995	983,495	119,038	9,549,047
	Sale					
Price per per m^2 (10000yen)	42.90	80.74	40.39	42.51	64.85	49.46
Floor Space (m^2)	67.65	64.13	82.46	82.20	59.30	77.00
Building Age	7.96	10.17	11.36	11.20	33.68	11.09
Walk Time to Nearest Station (min)	10.29	10.03	11.21	11.22	8.12	10.75
Distance to Tokyo Station(km)	22.52	24.20	25.52	23.43	20.39	23.96
Observations	19,266	36,859	32,078	49,793	11,771	1,283,457

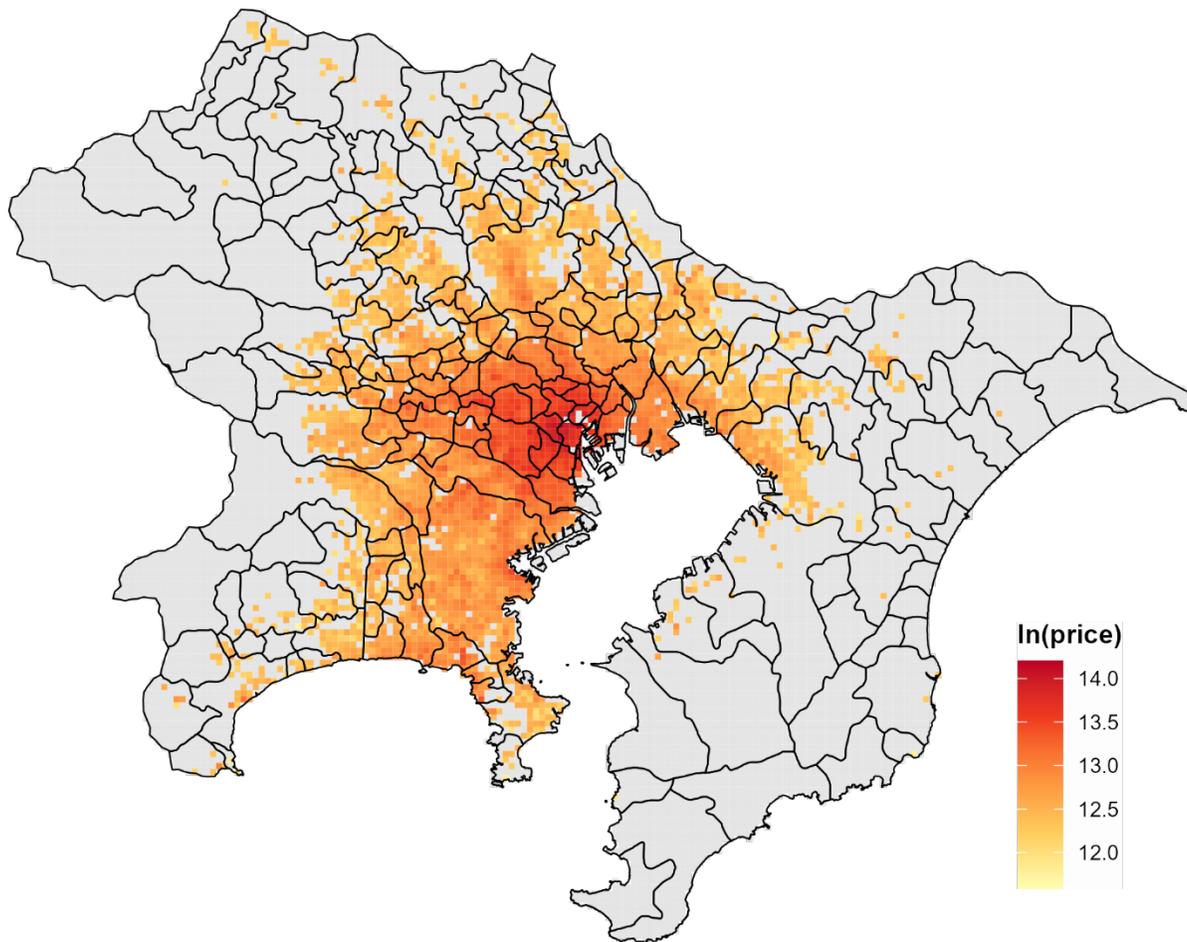
Fine Spatial Gradient (1km*1km)

● Create Raster of 1km*1km

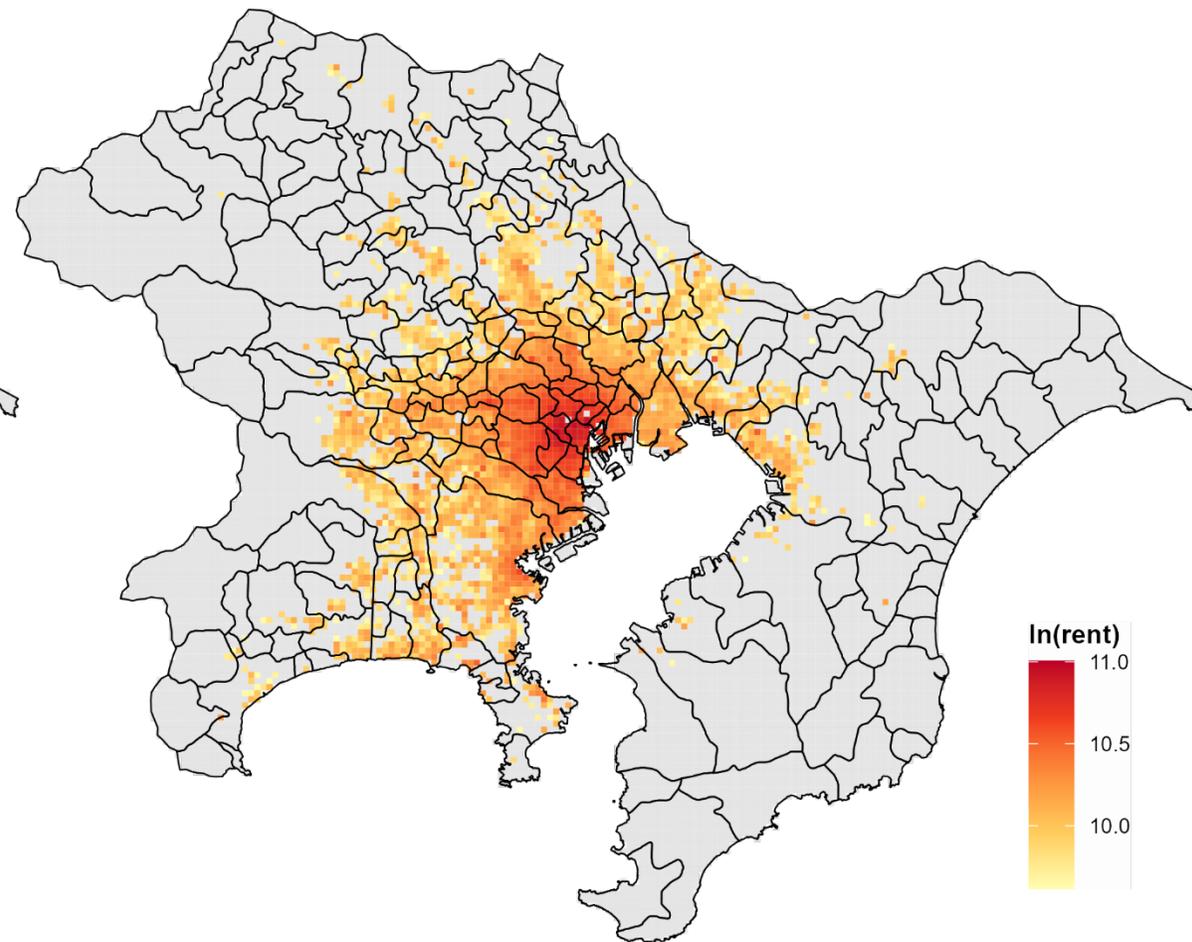


Summary: Price and Rent

◆ Sale: 2015

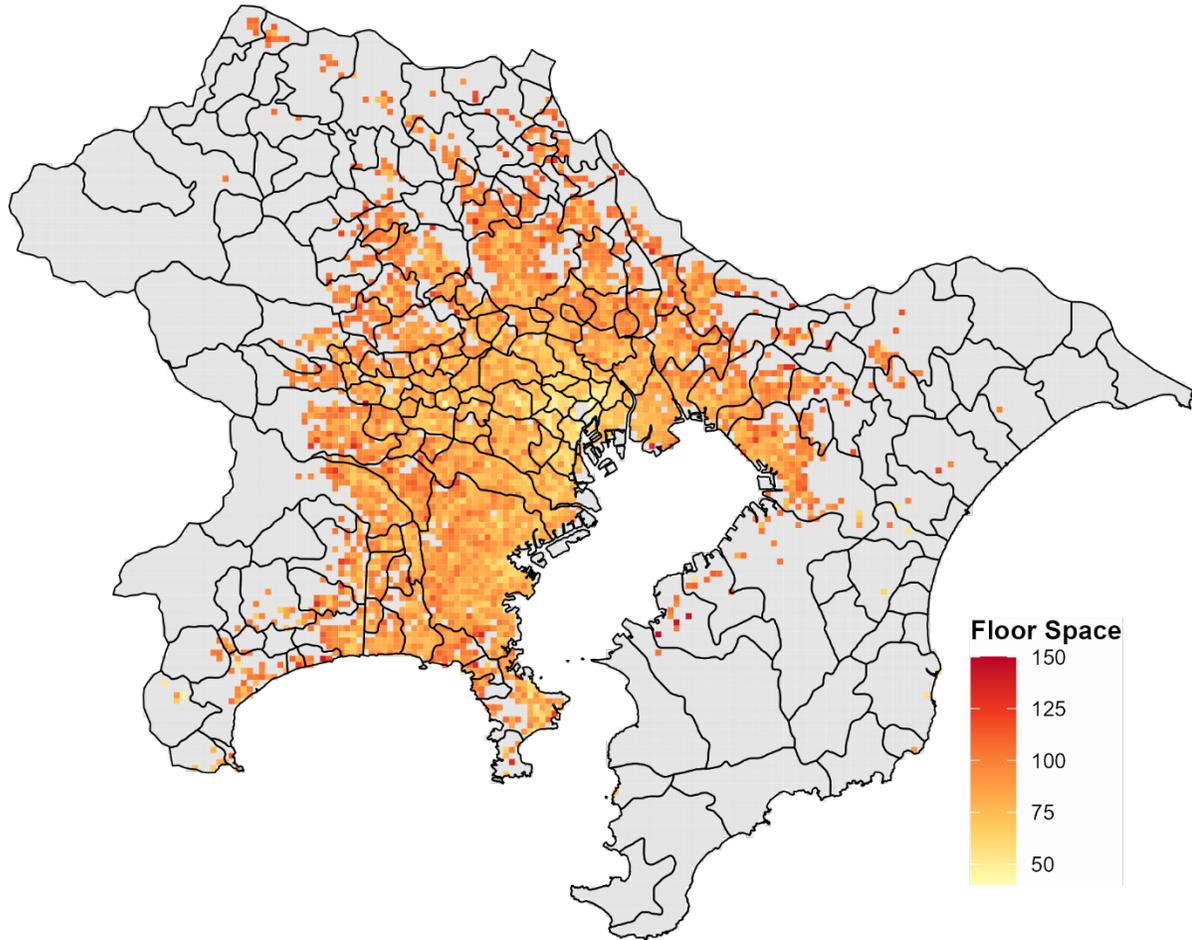


◆ Rent: 2015

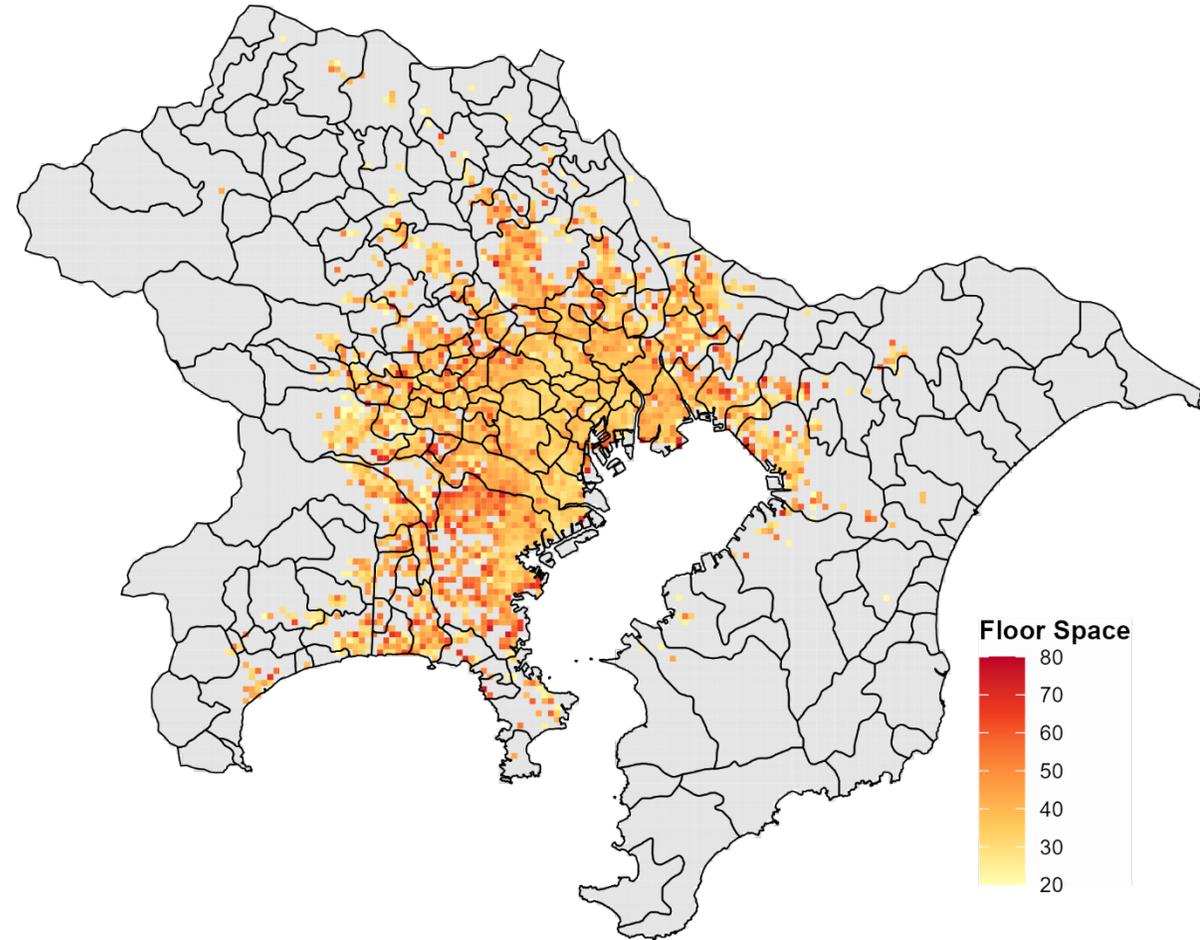


Summary: Floor Space (sqm)

Sale:2015

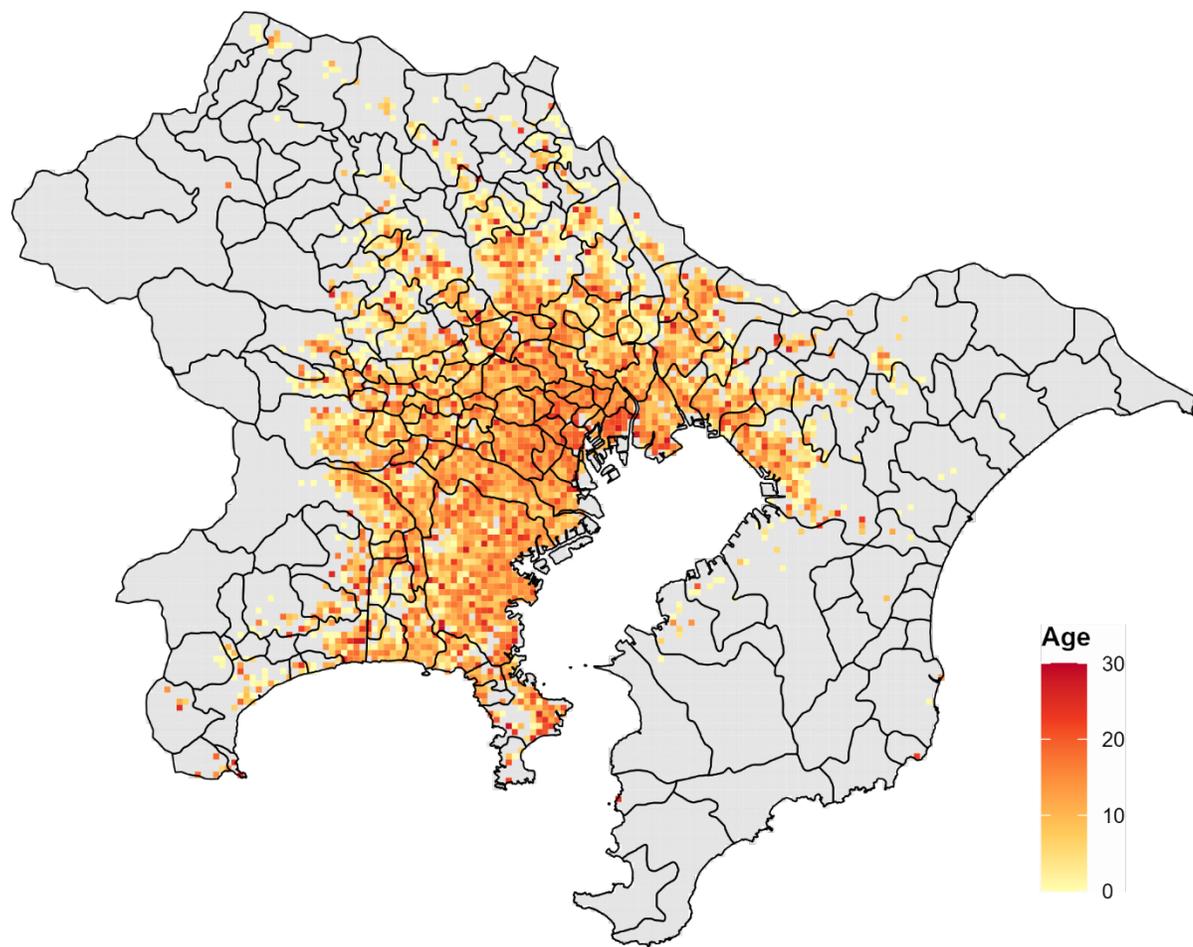


Rent:2015

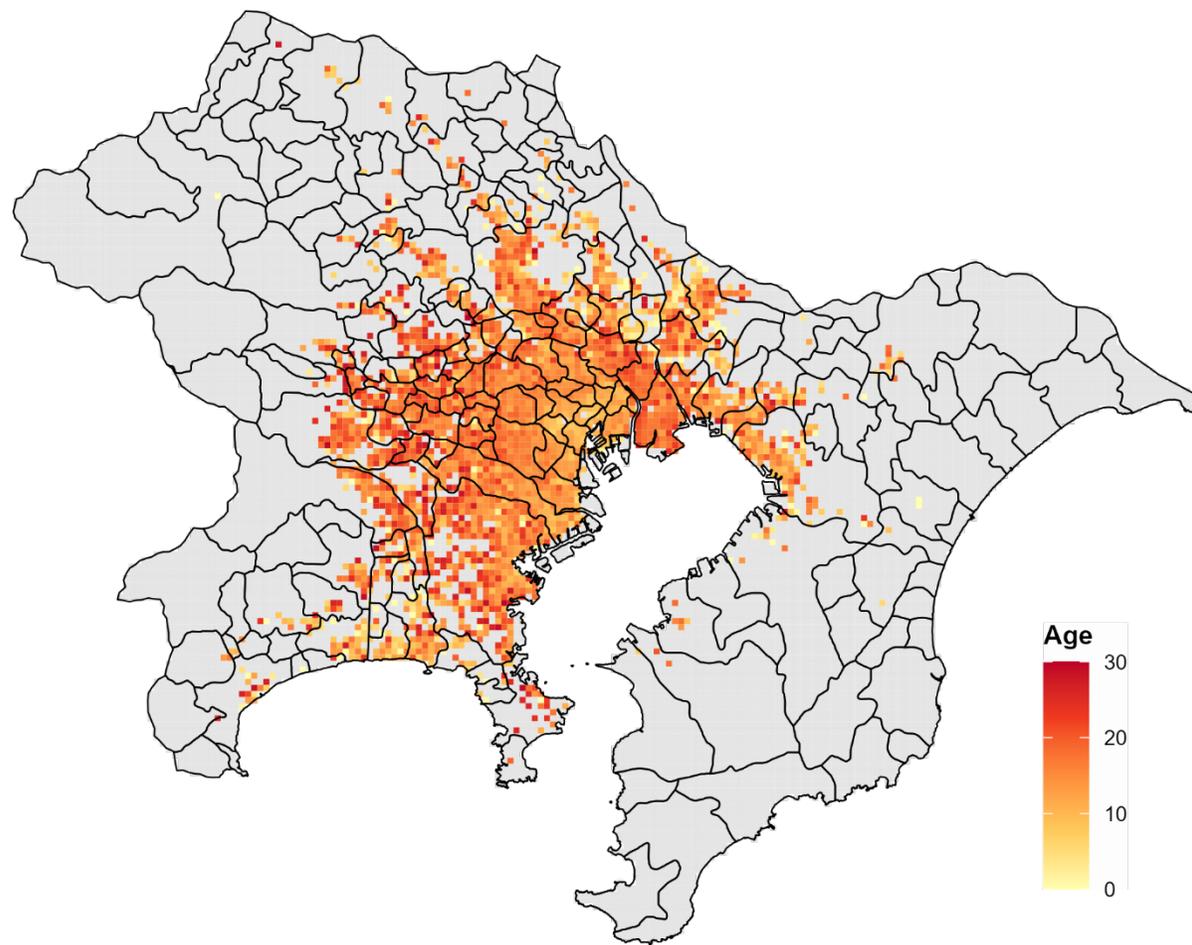


Summary: Building Age (Year)

◆ Sale:2015



◆ Rent:2015



◆ Hedonic OLS model:

$$\blacklozenge \ln P = \alpha + \underbrace{\beta_1 \ln(\text{Size}) + \beta_2 \text{Age}}_{\text{Structural}} + \underbrace{\beta_3 t_{\text{station}} + \beta_4 d_{\text{center}} + D_{\text{citycode}} \delta}_{\text{Locational}} + \underbrace{D_{\text{qtr}} \gamma}_{\text{Time}} + \varepsilon$$

#Note: not use of any longitude and latitude information.

$\beta_1 \sim \beta_5$ may vary over space is suitable for GWR.

Time Dummies are not used in hedonic Imputation

- Before GWR, we run a simple OLS for data of one year(e.g. 2015)

- $$\ln P = \alpha + \beta_1 \ln S + \beta_2 \text{Age} + \beta_3 t_{\text{station}} + \beta_4 d_{\text{tokyo}} + \varepsilon$$

- Omitted variables for locational

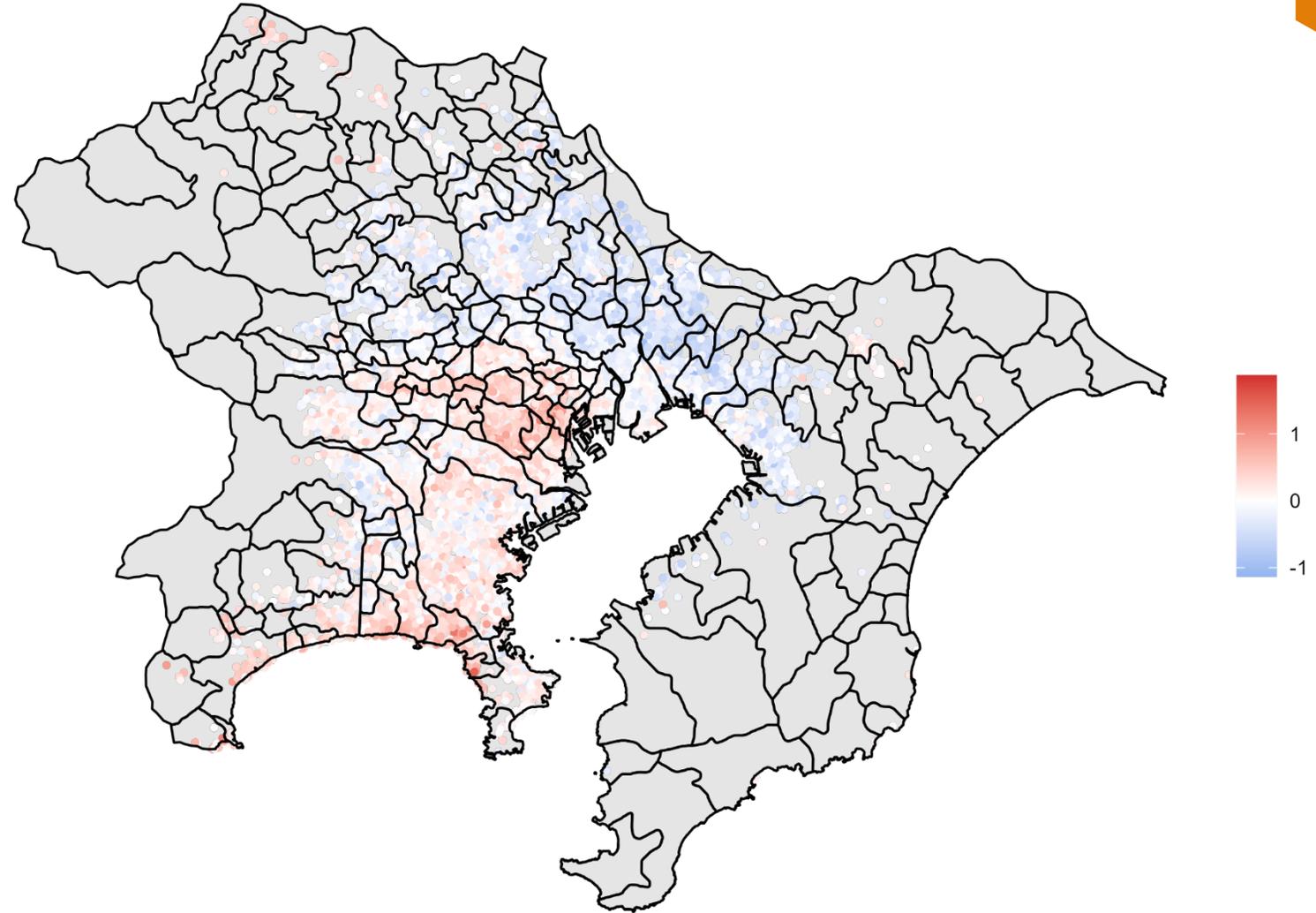
- $$\ln P = 14.947 - 0.309 \ln S - 0.011 \text{Age} - 0.019 \text{TS} - 0.016 \text{DT} + \varepsilon$$

(0.023) (0.005) (0.0001) (0.0002) (0.0001)

- $R^2 = 0.488$

OLS Results

- OLS Residuals
 - Highly spatial correlated



Computational Performance

- Complexity: $O(N^2)$ for GWR and $O(N^2 \log N)$ for bandwidth selection.
 - Processing Time Scaling for Single Processing
60k obs $\approx 0.5h$, 100k obs $\approx 1.5h$, 200k obs $\approx 1.7days$, 1000k obs $\approx 7.2days$
 - CUDA, Multi-Processing to improve efficiency
- Annual resale observations peak at 56k. For years where rent data exceeds 60k, we utilize random sampling to maintain a consistent sample size of 60,000.
- We use adaptive bandwidth (N-th nearest observations), Gaussian kernel for GWR

Estimation Steps: GWR

Step 1: GWR Estimation

- Bandwidth optimization via Golden Section Search
- Running GWR for price and rent observations

Step 2: Quality-Adjusted Imputation

- Estimate \hat{l}_p and \hat{l}_r using standardized attributes ($S=60$, $=10$)

Step 3: 1km*1km Spatial Aggregation

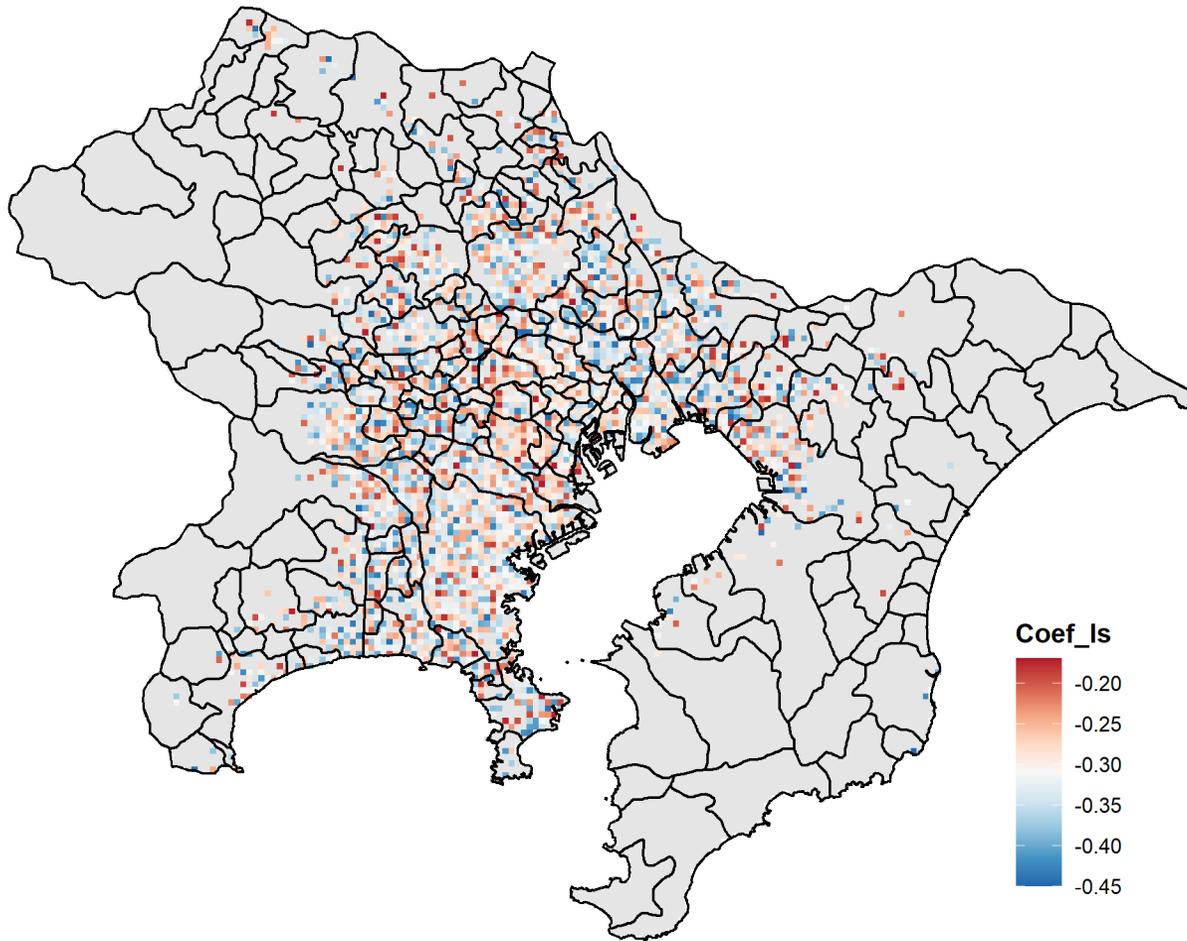
- Compute grid-level averages for \hat{l}_p and \hat{l}_r
- Derive the Price-to-Rent Ratio for each grid

GWR model

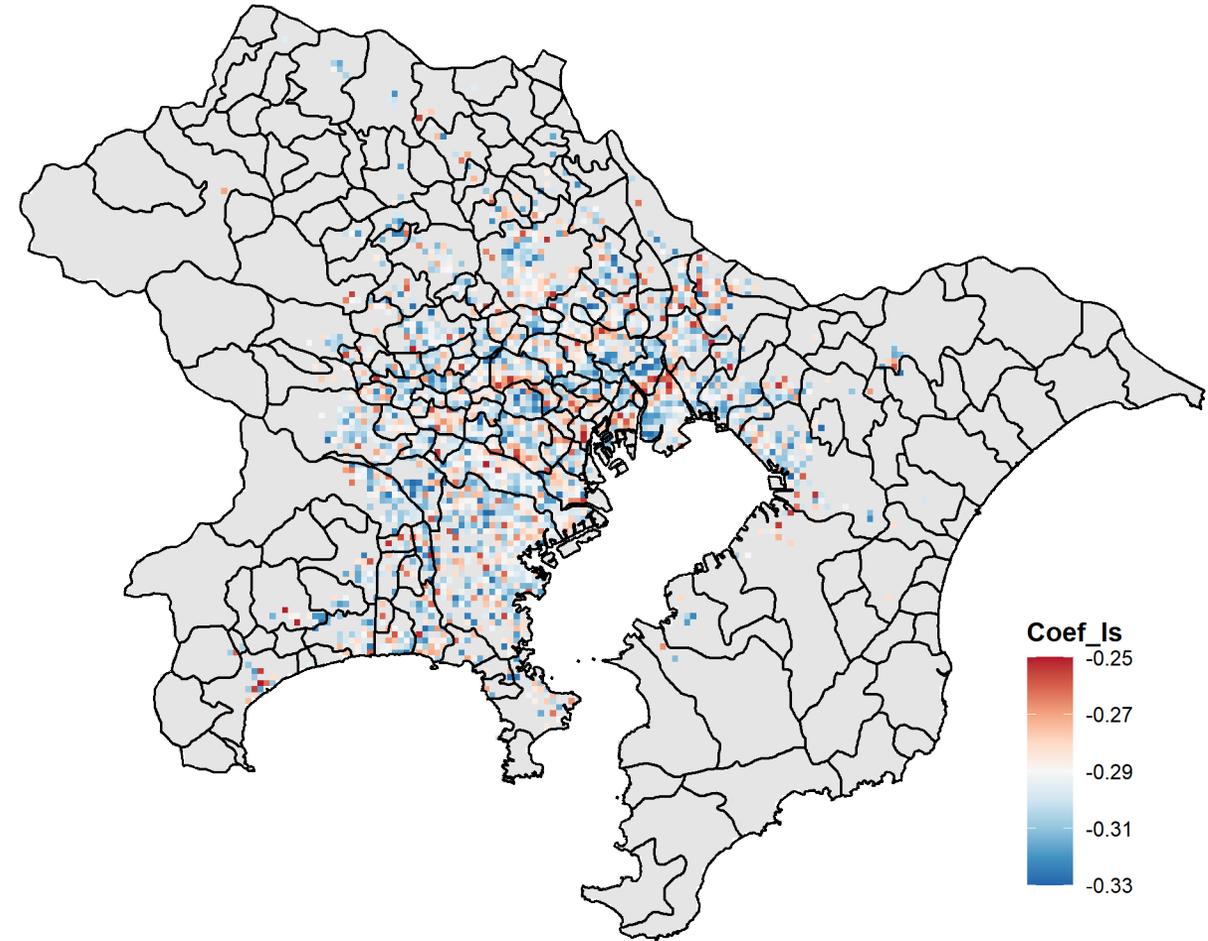
year	type	obs_full	obs_reg	bw	time_gwr	time_bw	gwr_AICc	gwr_adjR2	ols_AICc	ols_adjR2
1986	sale	19266	19266	305	72	68	15611.51	0.30	15955.67	0.28
1986	rent	8252	8252	90	13	13	-1090.95	0.62	810.85	0.52
1991	sale	36859	36859	131	269	509	9936.92	0.51	12625.14	0.47
1991	rent	72416	60000	310	679	951	-2742.28	0.62	10037.25	0.53
2000	sale	32078	32078	44	394	435	8509.05	0.46	11863.75	0.38
2000	rent	278995	60000	121	1074	955	-33051.11	0.65	-27327.74	0.61
2015	sale	49793	49793	66	487	979	16696.1	0.55	22087.46	0.49
2015	rent	983495	60000	276	681	949	-41195.05	0.69	-33571.97	0.65
2025	sale	11771	11771	16	28	29	11065.1	0.64	11356.15	0.58
2025	rent	119038	60000	17	734	1792	-40599.19	0.81	-27639.26	0.74

GWR Coefficient: ln(Floor Space) 2015

◆ Sale:2015

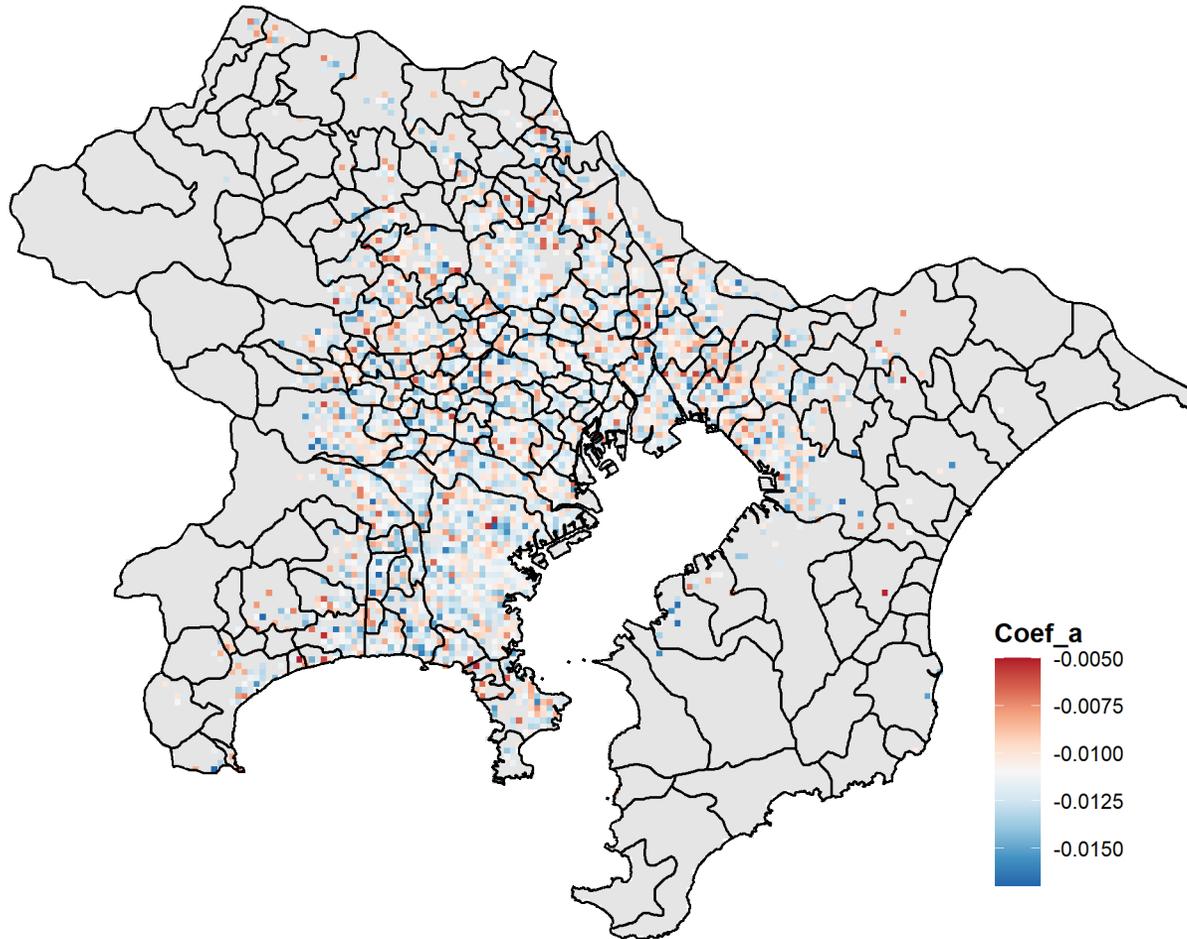


◆ Rent:2015

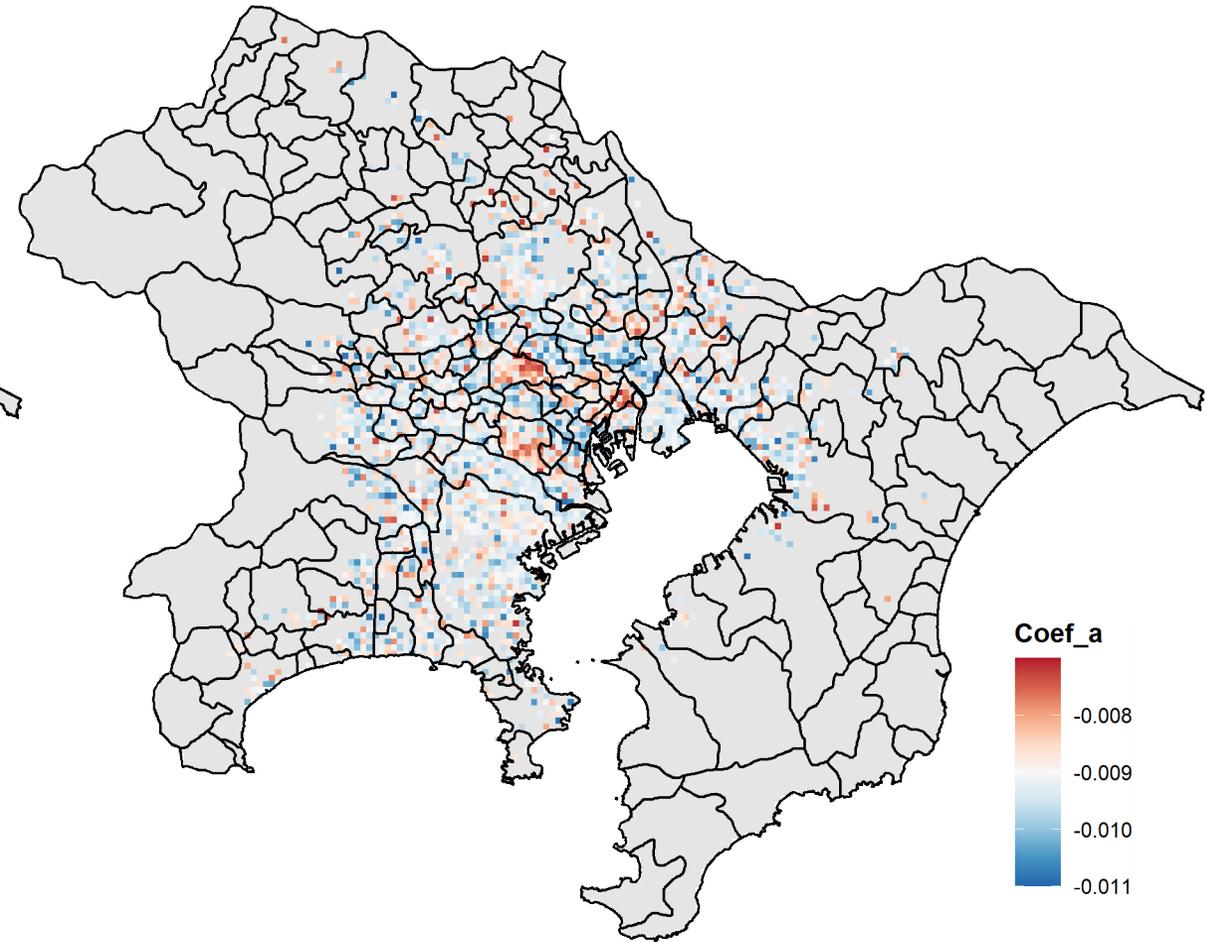


GWR Coefficient: Age 2015

◆ Sale:2015

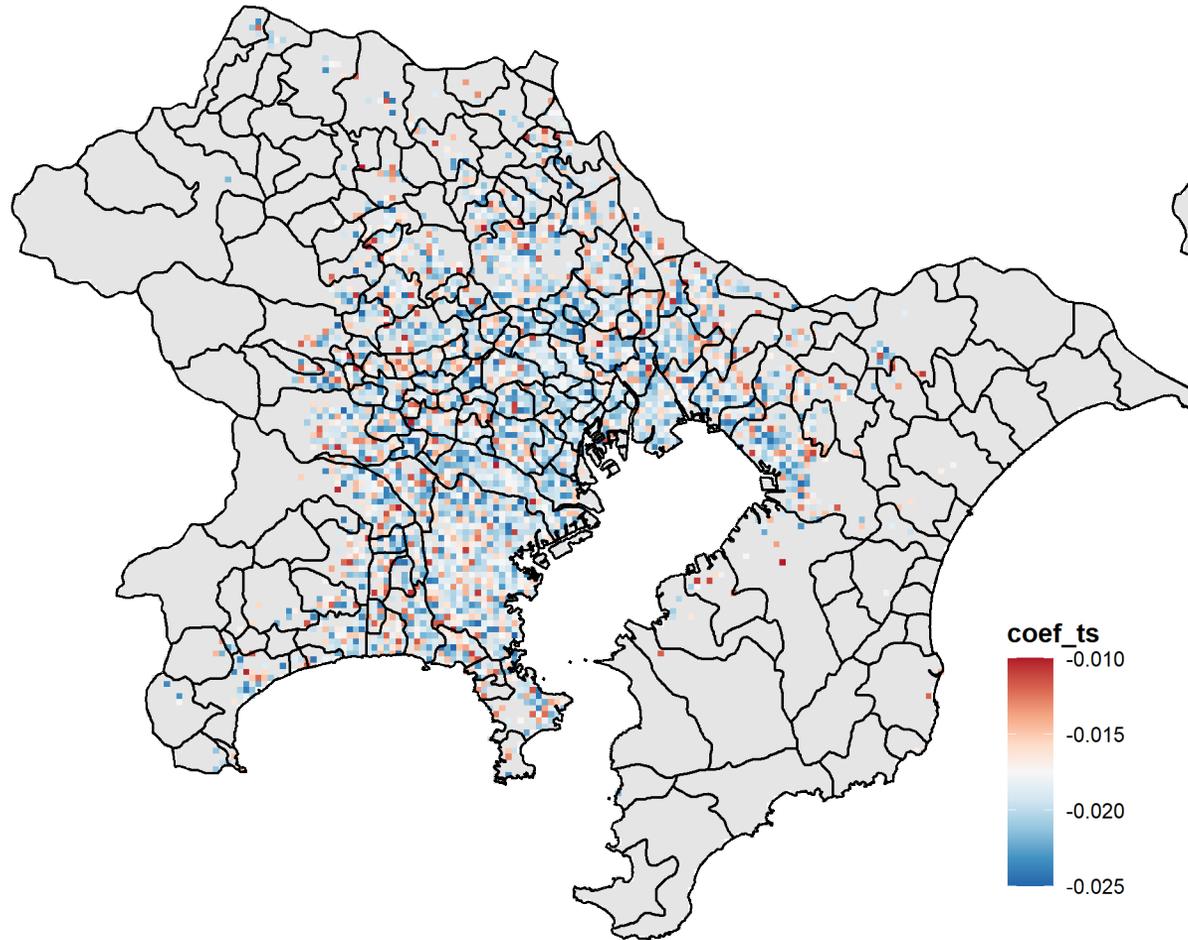


◆ Rent:2015

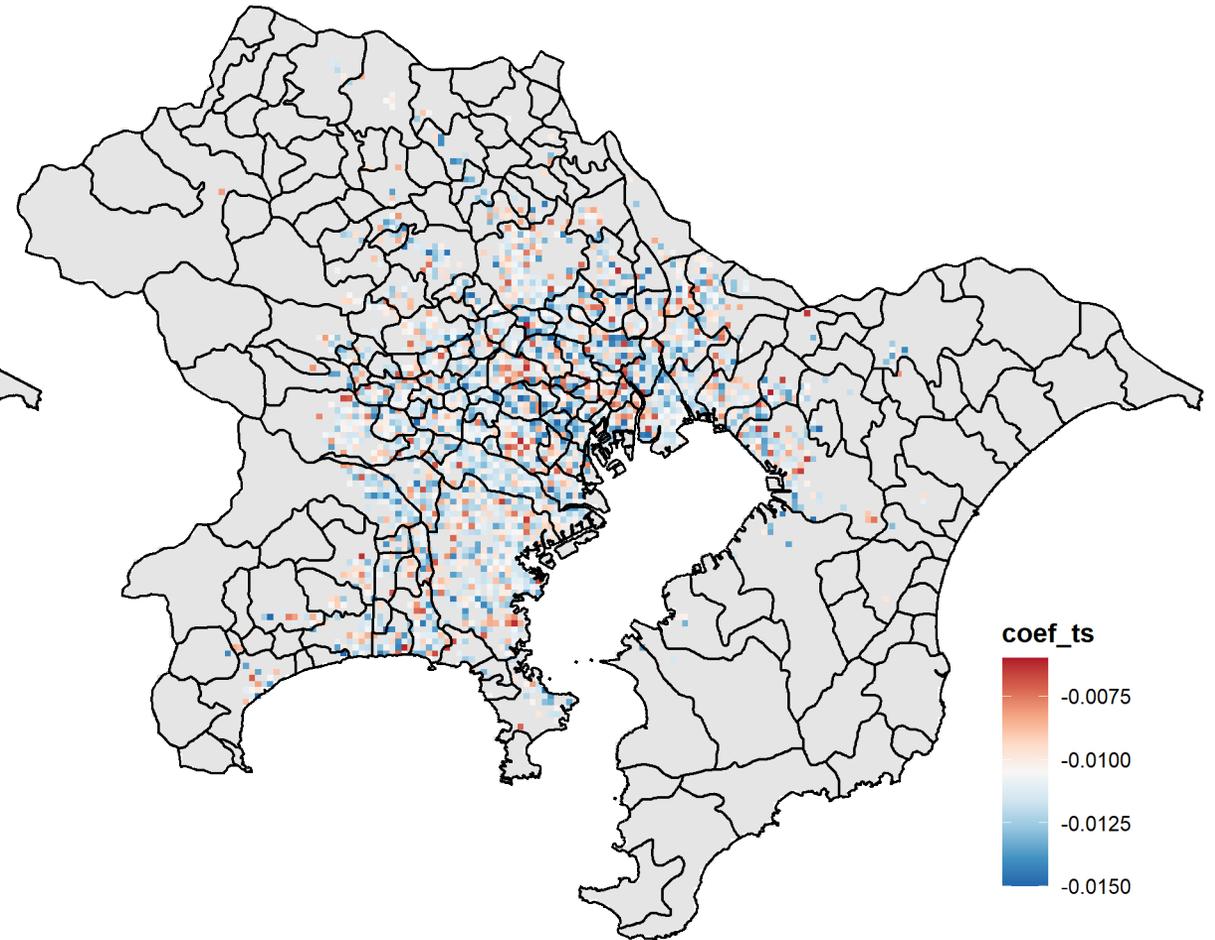


GWR Coefficient: Time to Station 2015

◆ Sale:2015

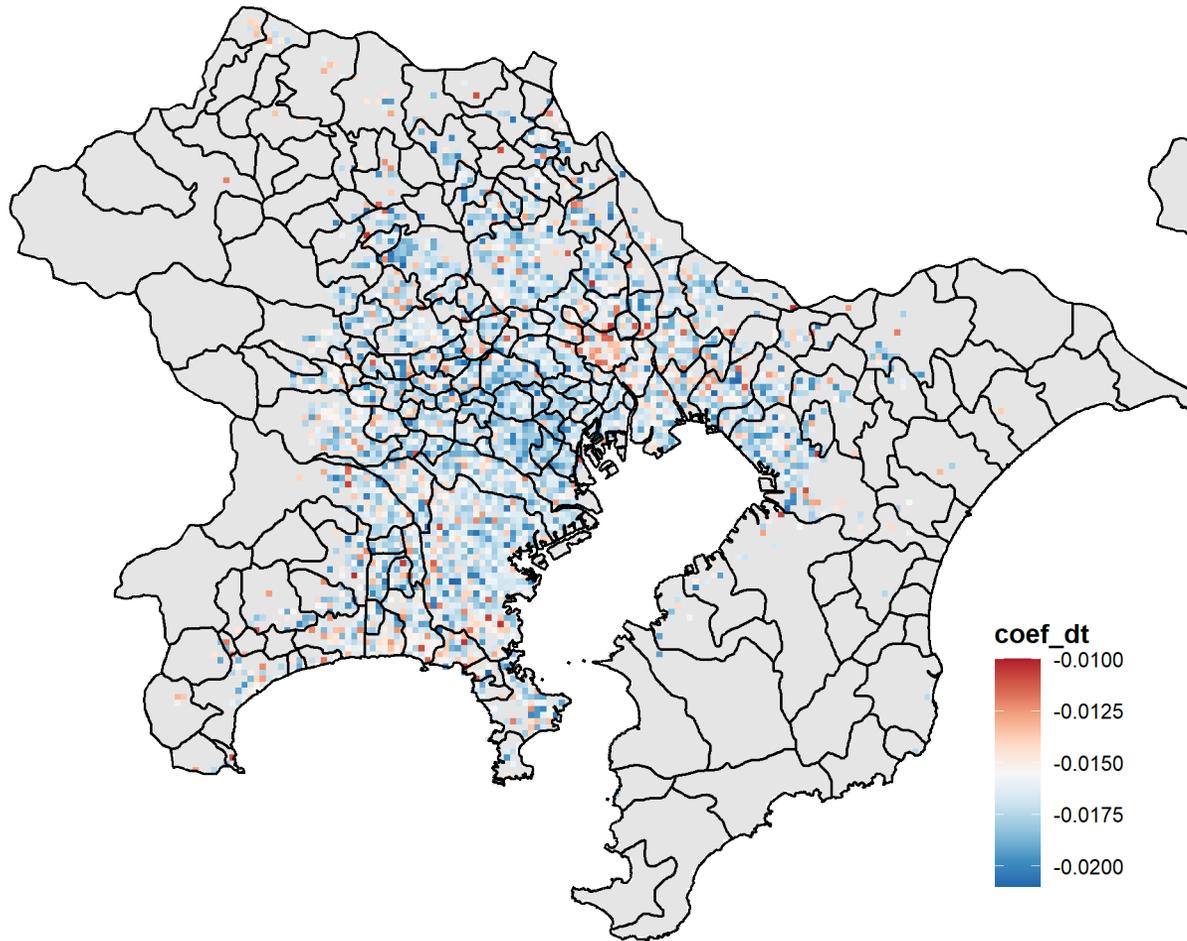


◆ Rent:2015

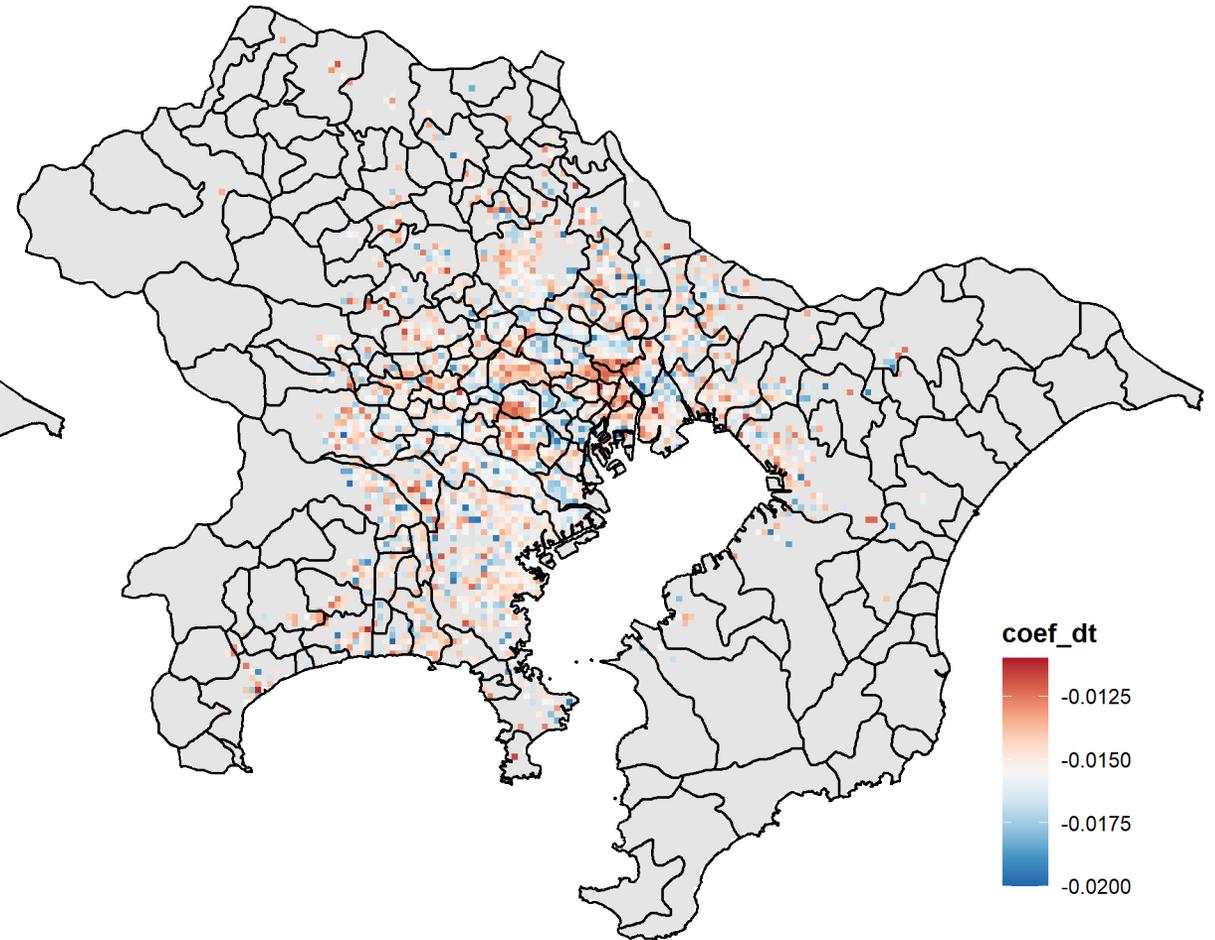


GWR Coefficient: Time to Station PTR 2015

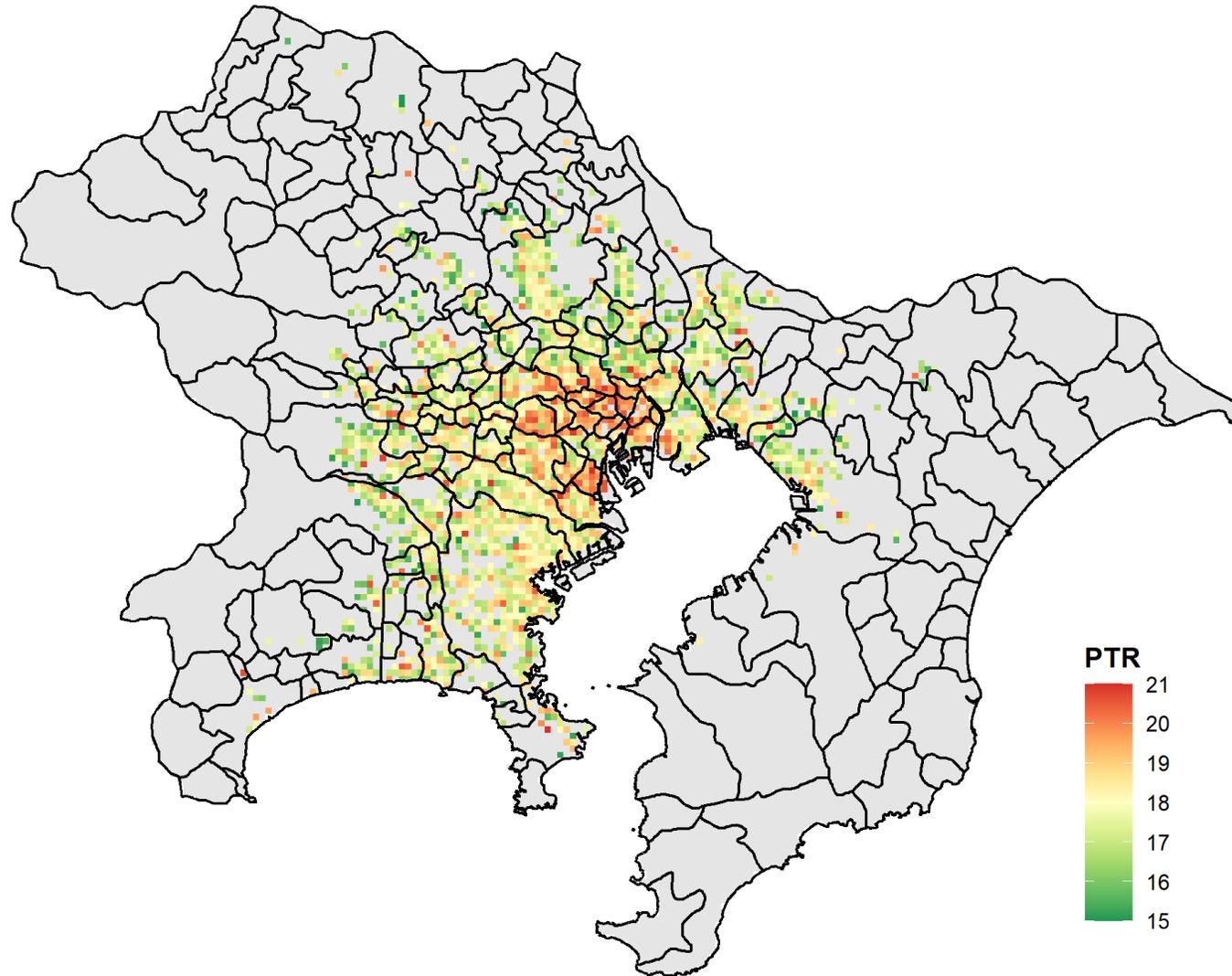
◆ Sale:2015



◆ Rent:2015

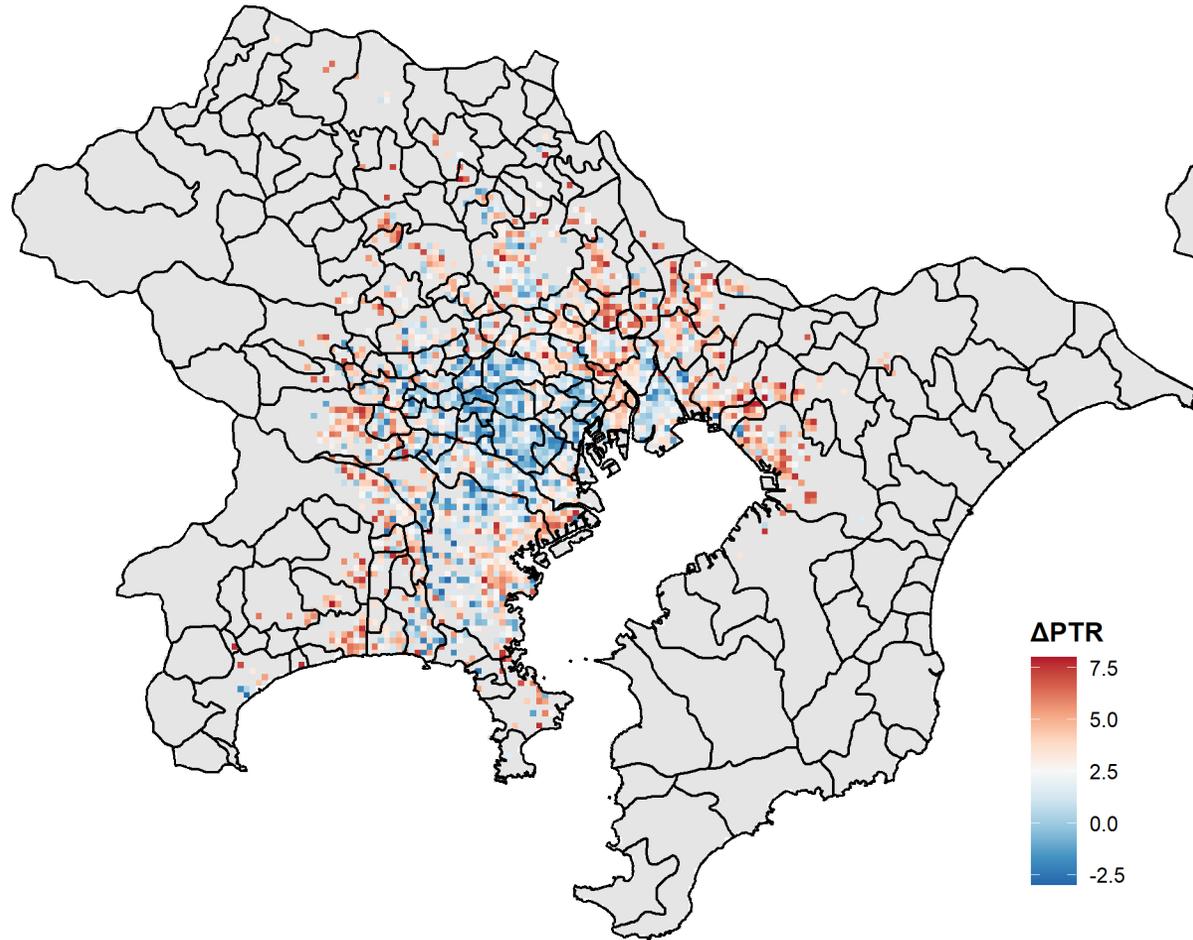


Price-to-Rent Ratio 2015

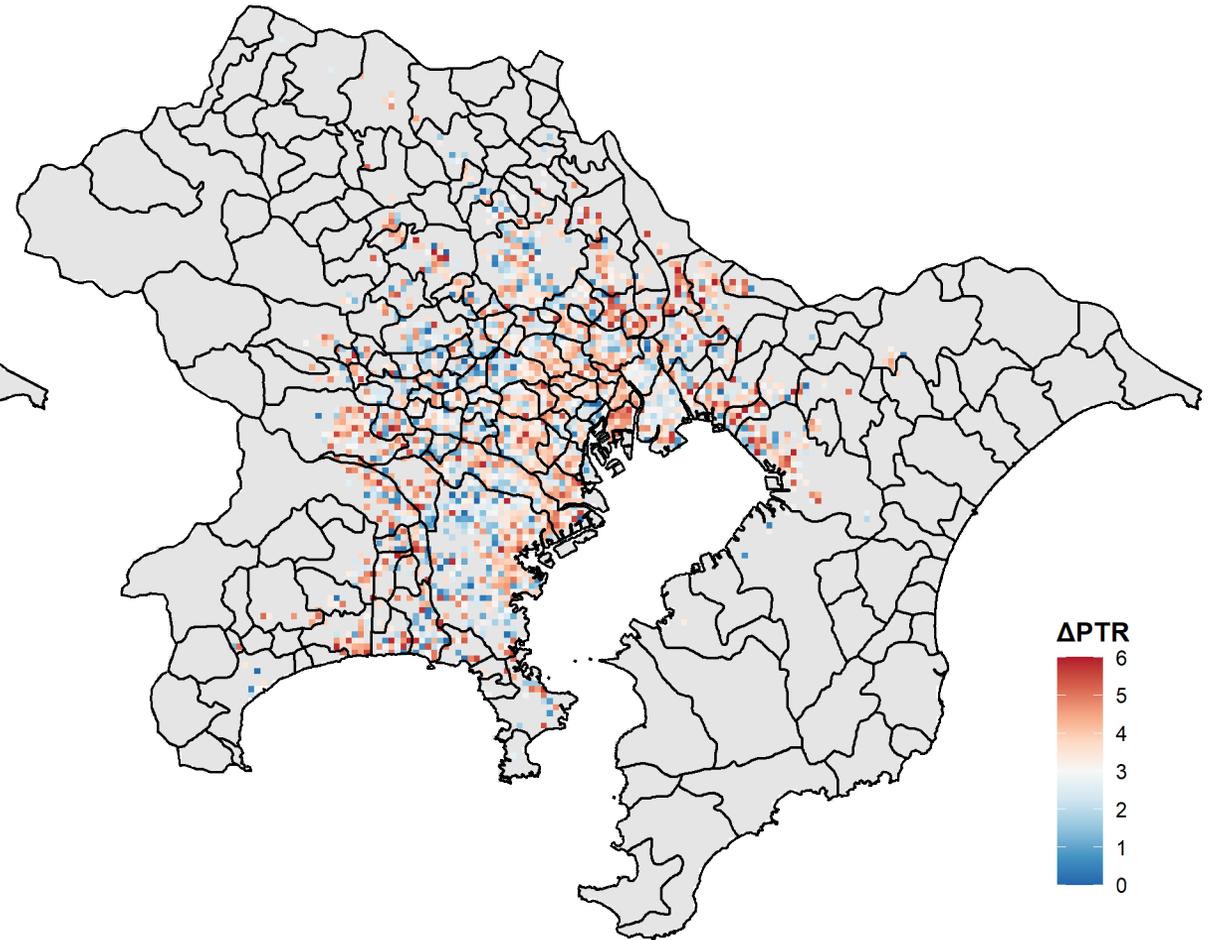


Price-to-Rent Ratio 2015

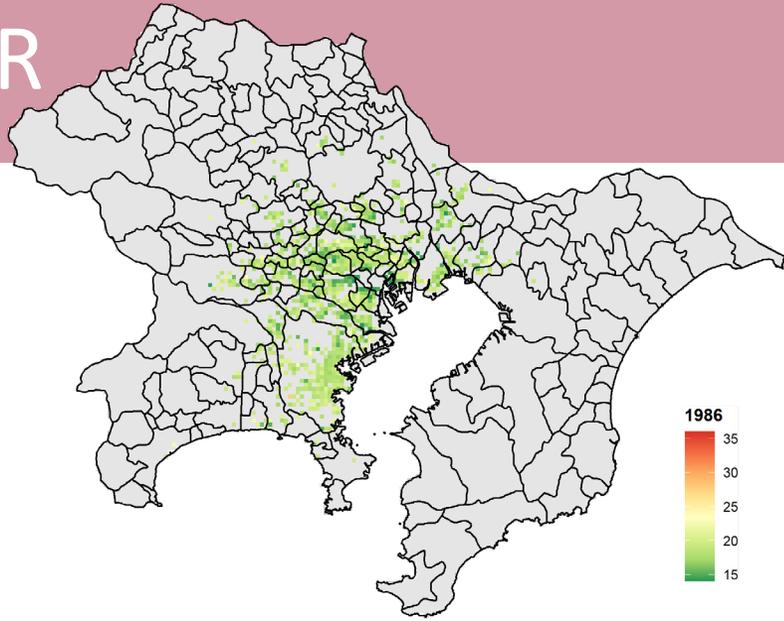
● $\hat{y}_{\text{quality-adjust}} - y$



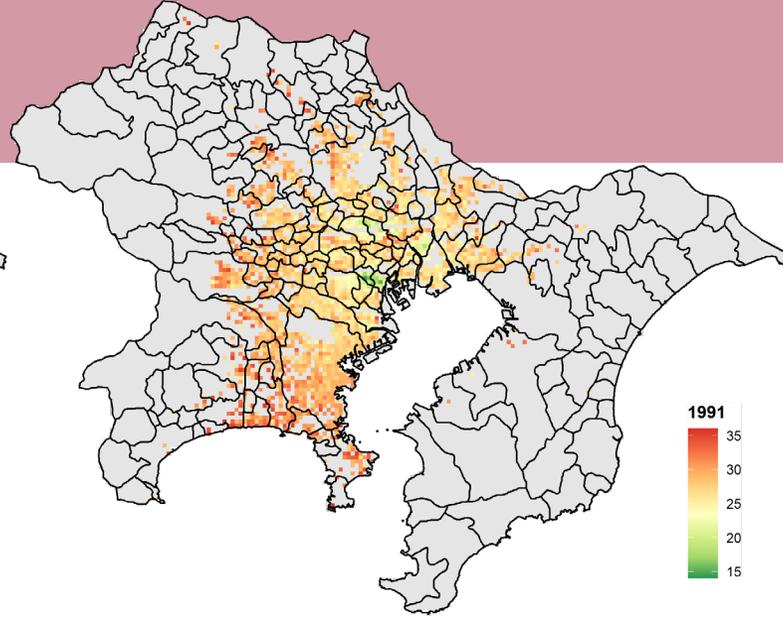
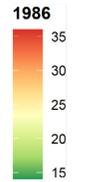
● $\hat{y}_{\text{quality-adjust}} - \hat{y}_{\text{raw}}$



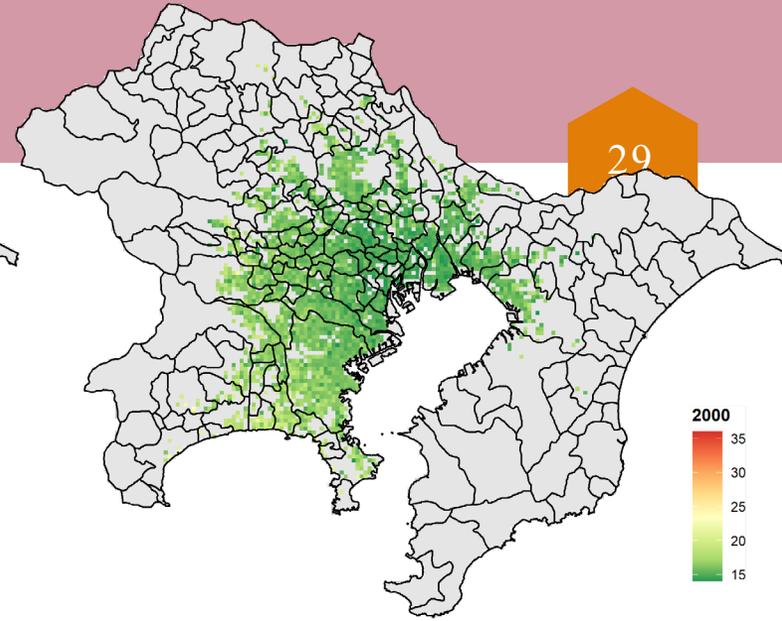
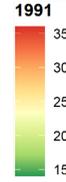
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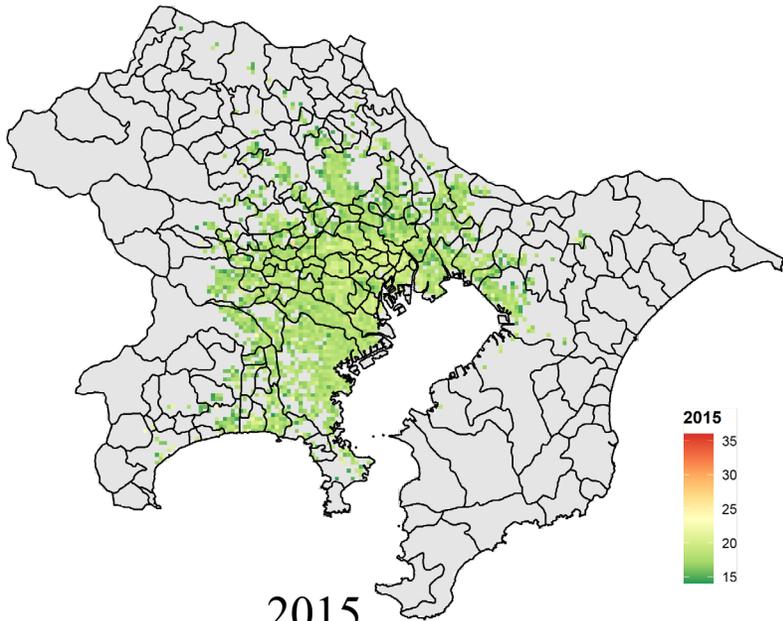
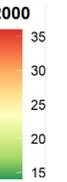
1986



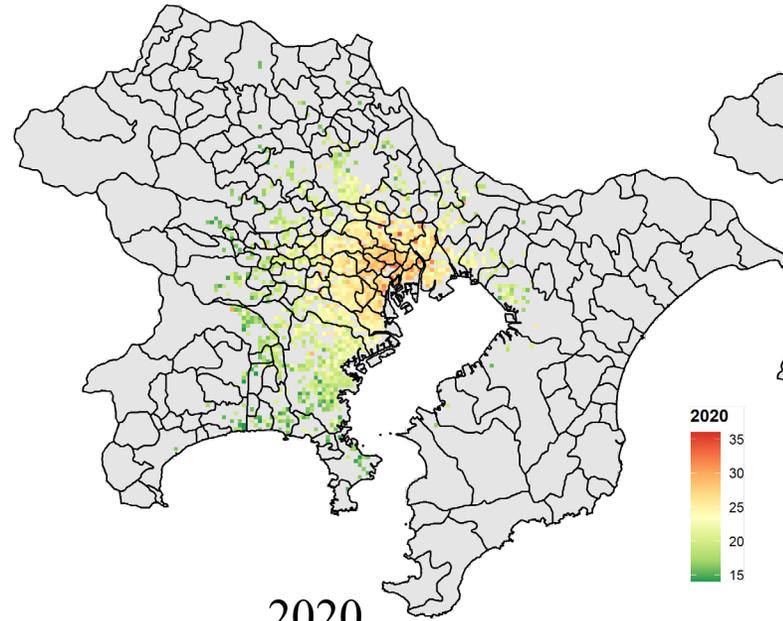
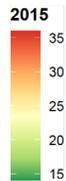
1991



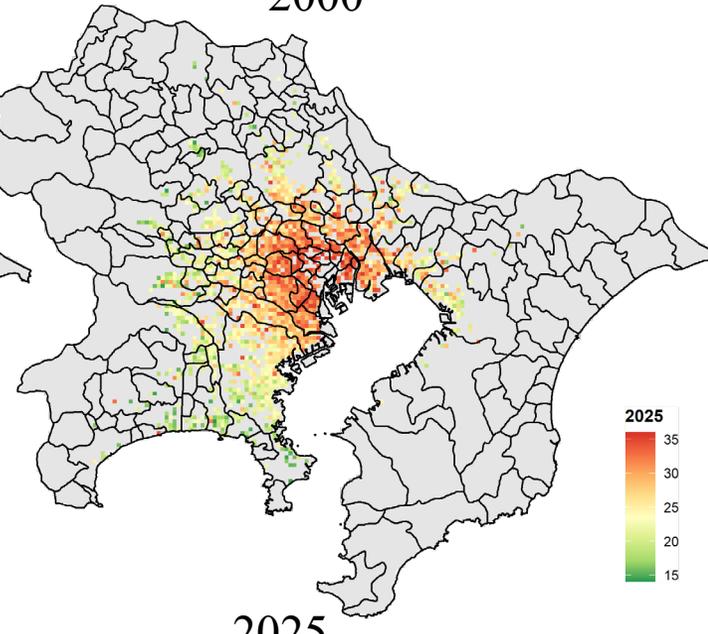
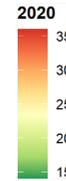
2000



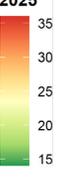
2015



2020

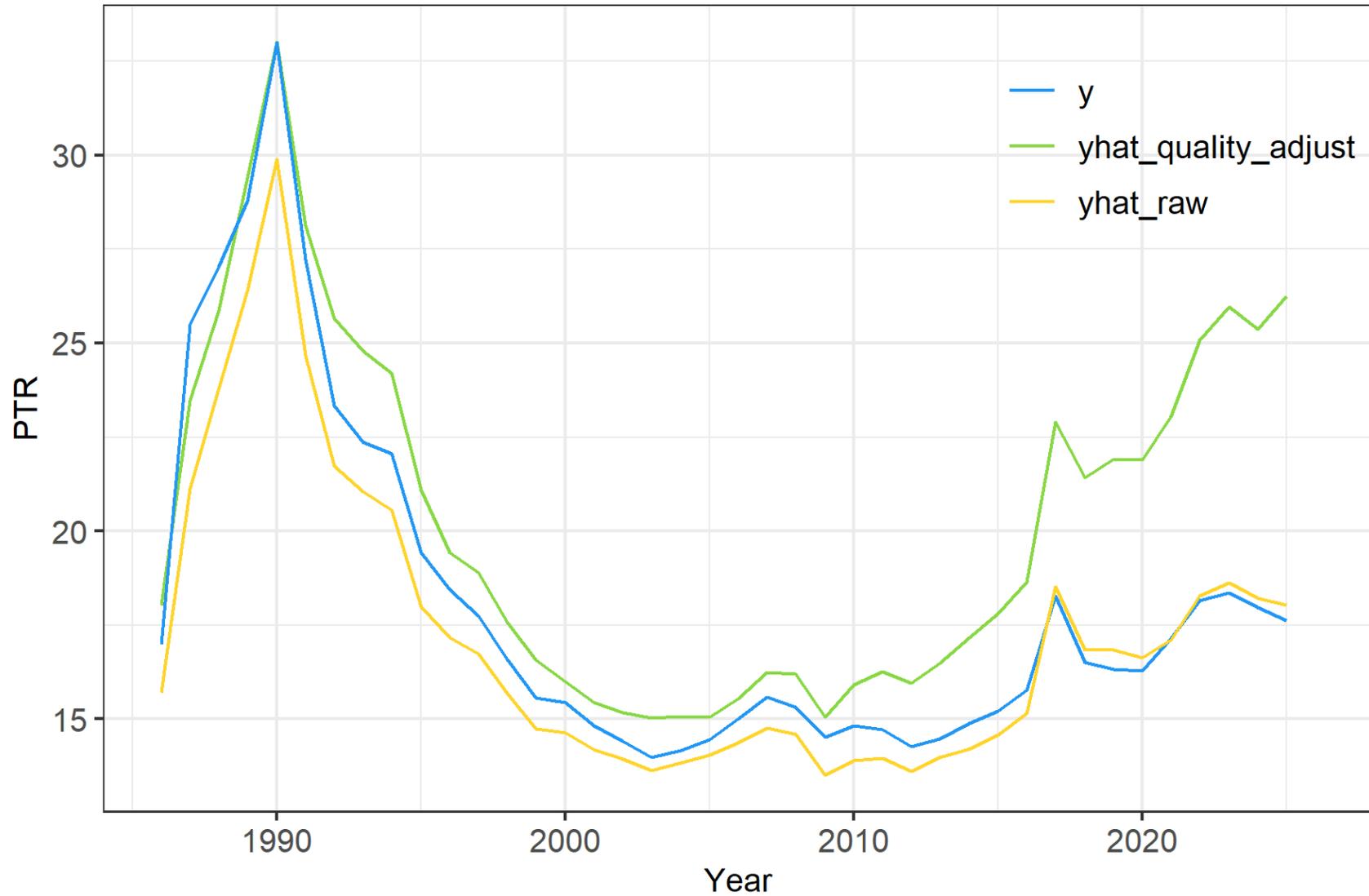


2025

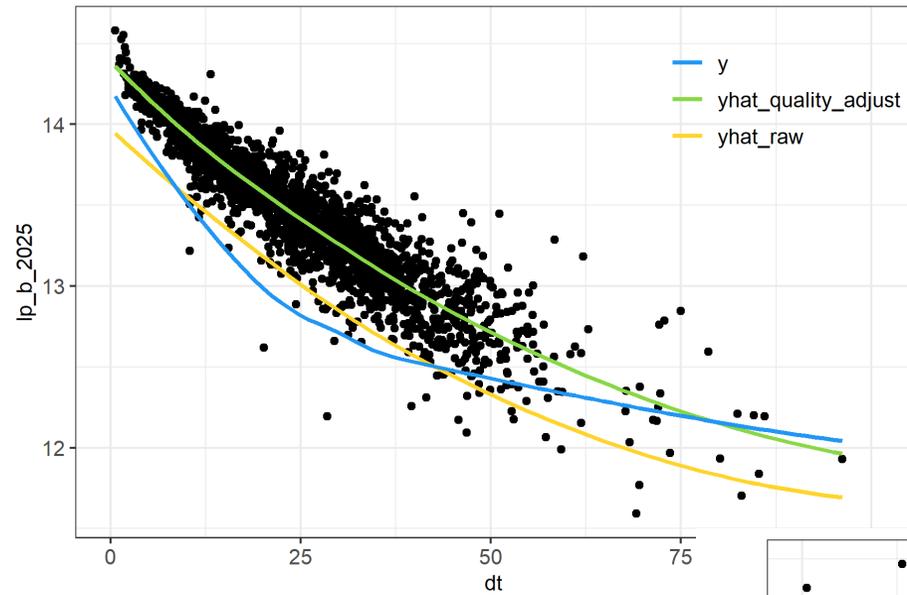


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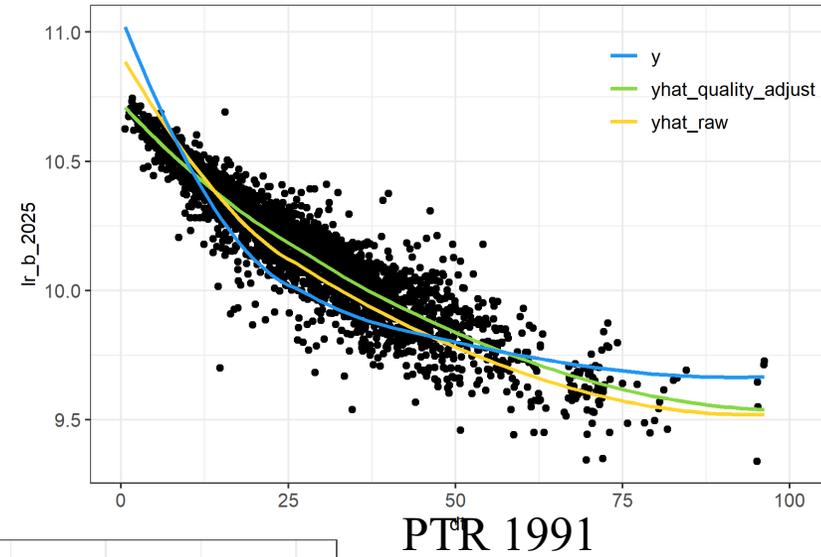
Price-to-Rent Ratio: Quality Adjusted



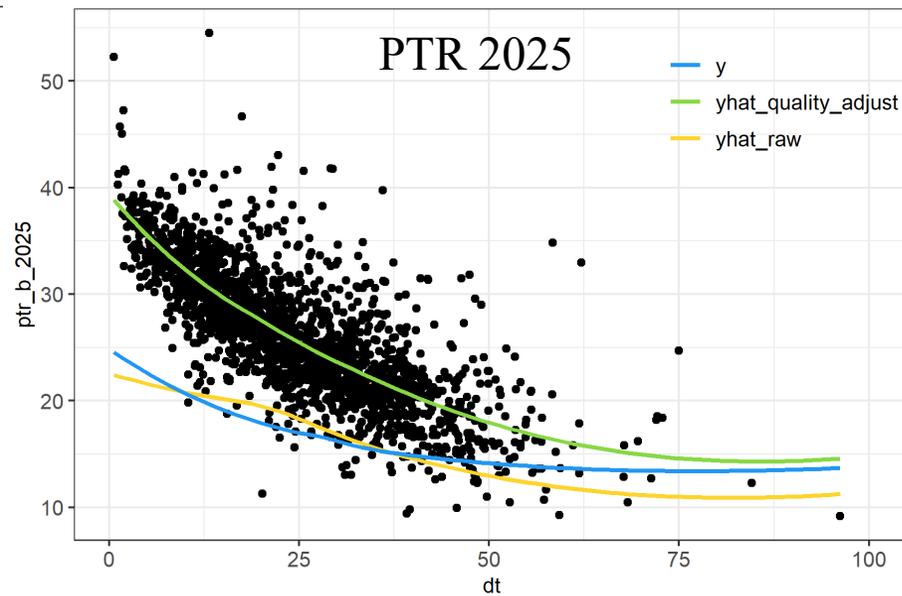
Two-way Analysis (with distance to CBD)



lnP 2025

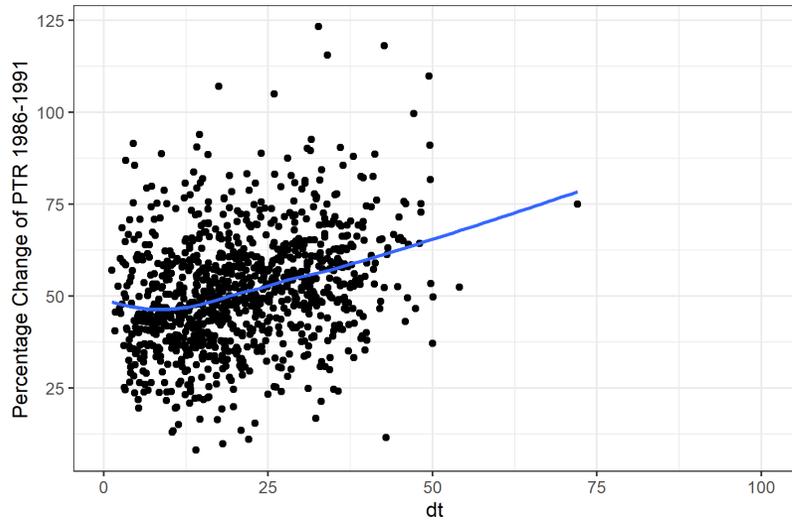


lnR 2025

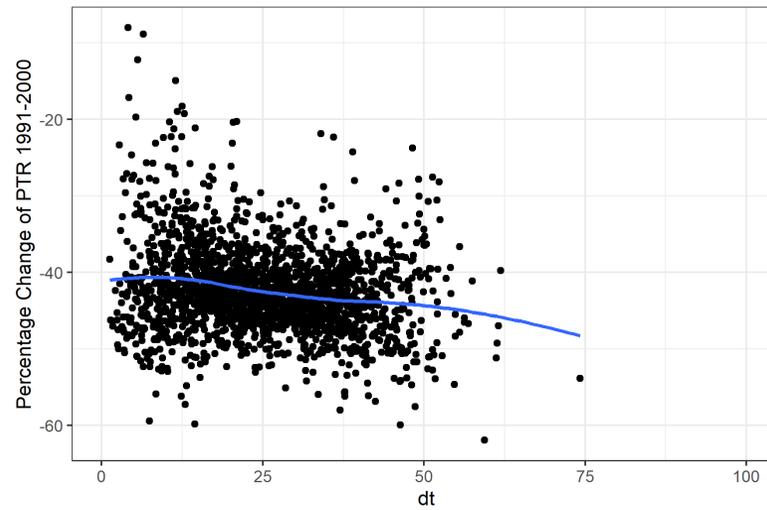


PTR 1991

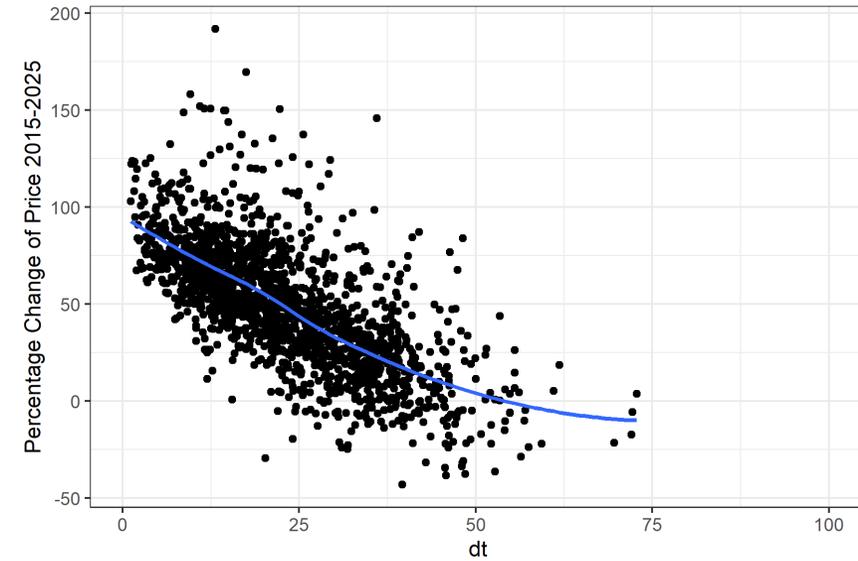
Two-Way Analysis (with distance to CBD)



Δ PTR 1986 - 1991



Δ PTR 1991 - 2000



Δ PTR 2015-2025



Thanks!