

The impact of apartment vacancies on nearby housing rents over multiple time periods: application of smart meter data

Application of
smart meter
data

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Hiroki Baba

*Center for Southeast Asian Studies/Hakubi Center for Advanced Research,
Kyoto University, Kyoto, Japan, and*

Chihiro Shimizu

*Center for the Promotion of Social Data Science Education and Research,
Hitotsubashi University, Tokyo, Japan*

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Abstract

Purpose – This study aims to explore the spatial externalities of apartment vacancy rates on housing rent by considering multiple vacancy durations.

Design/methodology/approach – This research uses smart meter data to measure unobservable vacant houses. This study made a significant contribution by applying building-level smart meter data to housing market analysis. It examined whether vacancy duration significantly affected apartment rent and whether the relationship between apartment rent and vacancy rate differed depending on the level of housing rent.

Findings – The primary finding indicates that there is a significant negative correlation between apartment rent and vacancy duration. Considering the spatial externalities of apartment vacancy rates, the apartment vacancy rates of surrounding buildings did not show any statistical significance. Moreover, quantile regression results indicate that although the bottom 10% of apartment rent levels showed a negative correlation with all vacancy durations, the top 10% showed no statistical significance related to vacancies.

Practical implications – This study measures the extent of spatial externalities that can differentiate taxation based on housing vacancies.

Originality/value – The findings indicate that landlords have asymmetric information about their buildings compared with the surrounding buildings, and the extent to which price adjusts for long-term vacancies differs depending on the level of apartment rent.

Keywords Apartment, Long-term vacancy, Housing rent, Tokyo, Quantile regression, Electricity consumption

Paper type Research paper

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Introduction

Housing vacancies are emerging as a key issue in housing planning and policy formulation (Monkkonen, 2019; Nadalin and Iglori, 2017; Zhang *et al.*, 2016). The number of vacant properties has increased in developed countries, such as the UK (Couch and Cocks, 2013), Germany (Bernt, 2019) and the USA (Wiechmann and Pallagst, 2012). This is due to a number of factors, including population decline (Döringer *et al.*, 2020), strong land-use regulations (Cheshire *et al.*, 2018) and international real estate investments, resulting in a mismatch between demand and supply (Badarinza *et al.*, 2021). Although there is a reasonable vacancy rate for the real estate market, known as the natural vacancy rate (Rosen and Smith, 1983), an excessive increase in the vacancy rate may cause deterioration of the district (Baba and Asami, 2017; Morckel, 2014) and negatively influence neighboring properties (Han, 2014; Whitaker and Fitzpatrick, 2013). For example, inland cities in the USA have experienced a negative spatial effect from vacant detached houses (Mikelbank, 2008).

Owing to the increase in housing vacancies, countries worldwide have been striving to control the vacant housing rate. Spain's autonomous regions impose additional taxes on homeowners due to the lack of affordable rental housing (Dol *et al.*, 2017). Despite the increasing population of Vancouver, the city imposes an empty homes tax to increase the number of rental properties available. Here, residential property is considered vacant if it has been unoccupied for over six months, resulting in charge of 3% of the taxable assessed value of the property (City of Vancouver, 2020). Nevertheless, vacant housing policies have not yet been comprehensively discussed in terms of vacancy duration and the impact of vacant housing units on adjacent properties. In particular, apartment buildings lack sufficient empirical evidence to implement housing policies, as it is difficult to assess vacant housing units that have not appeared on the market.

It is difficult to identify vacant houses when trying to analyze the number of vacant houses and the length of time they have been vacant. Previous studies on real estate economics have attempted to gauge the number of properties on the market, whose duration is measured by their time on market (ToM) (Genesove and Han, 2012; Huang, 2017). The ToM indicates the length of time that a property has been on the market for sale or for rent. There is a trade-off between the ToM and housing prices (Anglin *et al.*, 2003). The ToM can only be observed when the owner intends to sell or rent the property. In Vancouver, however, if a foreign investor owns a property and does not intend to rent it out, it cannot be observed as vacant in the market. We must consider vacancies that are not listed on the market to avoid such undervaluation of vacancies. While the examination of the apartment vacancy rate involves several measurement methods, such as real estate transaction data (Ong and Koh, 2000), field observations (Silverman *et al.*, 2013) and public statistics data (Cheshire *et al.*, 2018), the use of infrastructure data such as electric consumption enables data collection to be accurate and timely. However, previous studies have not used such data sources due to privacy concerns.

This study aims to explore the spatial externalities of apartment vacancy rates on housing rent, considering multiple vacancy durations. It examined whether prolonged vacancy periods, such as those over six months, had a significant impact on apartment rent while controlling for both building and local environment attributes. The relationship between apartment rent and the vacancy rate was further estimated by dividing the level of housing rent into the top 10% and bottom 10%. This study used smart meter data to measure unobservable vacant houses and estimated the electricity consumption per housing unit as an indicator of vacancy. Smart meter data can be used to estimate the number of vacant housing units in a building continuously and in a timely manner, enabling the

analysis of the effects of long-term vacancies on a building by setting the duration of such vacancy.

This study contributes to the literature in several ways. This study makes significant contributions by applying the building-level smart meter data to urban and housing market analysis. Although a few studies have used smart meter data (Li *et al.*, 2019; Razavi *et al.*, 2019), building-level analysis has not been conducted owing to a privacy protection policy. Another contribution is that the findings obtained from this study provide us with insight into the extent of spatial externalities that can differentiate taxation regarding housing vacancies. As a result, policymakers can consider the extent to which the spatial externalities of housing vacancies are demonstrated.

Literature review and research hypotheses

We developed three hypotheses based on previous research. Vacant houses can have a significant impact on nearby properties values through two major mechanisms: first, abandoned buildings can affect the vitality and safety of neighborhoods due to the inadequate maintenance of vacant housing units (Cui and Walsh, 2015; Spelman, 1993), reducing the value of nearby properties (Frame, 2010; Han, 2014; Mikelbank, 2008). Second, landlords can adjust housing prices or rent by acknowledging the number of vacant properties nearby (Rosen and Smith, 1983). The price adjustment will depend on whether the owner perceives vacant housing units as a decline in demand (a negative sign) or as a constraint to supply (a positive sign). Moreover, these mechanisms may emerge differently depending on whether the market is segmented as rental or for-sale, or as luxury or austere (Hoekstra and Vakili-zad, 2011; Shimizu *et al.*, 2016). These viewpoints were further explored in relation to spatial externalities, vacancy durations and the relationship between the housing rent levels and vacant housing rates.

Although several studies have addressed the spatial externalities of vacant housing units, most have focused on the sale of detached houses (Mikelbank, 2008; Han, 2014). A negative correlation was observed between house prices and the number of vacant detached houses in the USA. For example, Mikelbank (2008) argued that house prices near vacant properties were \$4,000 less than those of other houses in Columbus, OH. However, given the difficulty in directly measuring the number of vacant housing units in multifamily houses, such as apartment buildings, several studies have used the number of vacant properties on the market as a proxy variable (Ong and Koh, 2000). Thus, the vacancy rate as measured by the number of vacant properties on the market may underestimate the number of vacant housing units. There is a difference in the geographical distribution of vacant properties when they do not appear on the market. Moreover, the degree of attachment to a place varies based on the type of housing and is negatively related to the building size (Lewicka, 2010), implying that detached houses have stronger spatial externalities than apartment buildings. In other words, we assume that although a price adjustment function that is based on the vacant housing units' works for a particular apartment building, it does not influence nearby buildings. Therefore, we propose the following hypothesis:

- H1.* Housing rent is negatively correlated with the apartment vacancy rate within a building. However, the housing rent does not correlate with the apartment vacancy rates of adjacent buildings.

Housing units which remain vacant for long durations are considered a waste of housing stock (Molloy, 2016). The reasons for this can range from properties not meeting tenants' expectations (Wheaton, 1990) to not being profitable enough to place on the market (Suzuki and Asami, 2020). Landlords adjust rent prices to approximate the rental price as closely as

possible to what the tenant will be willing to pay; the greater the discrepancy between the two, the longer the duration of vacancy (Jud *et al.*, 1996; Ong and Koh, 2000). Moreover, the number of vacant housing units is expected to increase in properties that cannot be rented because of the dilapidated state of their building. The worst-case may result in the abandonment of the entire building because of the inability to maintain it. Thus, an increase in the number of vacant housing units that are not marketable may result in a reduction in the rent level of buildings. Generally, a negative correlation with rent is expected to be more pronounced for properties that have been vacant for a longer duration than for those that have been vacant for a shorter duration. Thus, we propose the following hypothesis:

H2. The long-term apartment vacancy rates have a greater impact on apartment rents than short-term vacancy rates.

The reasons for vacancies differ in terms of house prices determined by market segmentation, causing an overall mixed effect of housing vacancies. An increase in the number of vacant housing units may have both positive and negative effects on house prices (Gentili and Hoekstra, 2019; Hoekstra and Vakili-zad, 2011). The quality of amenities in austere properties tends to be modest to minimize construction costs and several similar properties are newly constructed by developers. Consequently, the values of the existing similar properties will decline as they become obsolete, and the landlords will lower their prices to ensure occupancy. In contrast, luxury properties are distinguished by their amenities and locations, and landlords do not need to reduce their prices as they may still be able to find tenants who are willing to pay. As exemplified by Shimizu *et al.* (2016), the difference between the coefficients estimated by the hedonic approach and the actual values tends to be smaller for luxury properties than for austere properties. Moreover, luxury properties may be owned for speculative purposes because foreign investments are common in popular cities (Gyourko *et al.*, 2013). The increase in the number of vacant housing units caused by speculation has become a significant constraint on supply, leading to higher house prices (Glaeser *et al.*, 2006). Although such a phenomenon is primarily observed for sales properties, it is inevitable that such conditions will lead to long vacancy durations, thereby reducing the availability of rental properties. The following hypothesis was proposed in light of these divergent trends:

H3. The apartment vacancy rate is negatively correlated with the rent in properties with low rent levels, whereas such a relationship is not observed with high rent level properties.

Considering the aforementioned hypotheses, the use of smart meter data in this study enabled us to measure the vacancy rates and vacancy durations for each building, which has been difficult due to technical and privacy concerns. Researchers have applied smart meter data to urban studies (Li *et al.*, 2019) and attempted to determine household occupancy based on smart meter data (Razavi *et al.*, 2019). Similar to our study, Li *et al.* (2019) estimated the housing vacancy rate in China based on the electricity consumption data, emphasizing its accuracy, cost-effectiveness and scalability. However, since the data are not linked to real estate information, the authors were unable to observe housing attributes, such as the number of vacancies and the age of buildings. By combining smart meter data with property-level real estate information, this study determines how apartment vacancy rates are associated with apartment rents, taking into account both the housing and local environment attributes.

Methods

To test our hypotheses, three types of models were used. As a first step, a basic linear hedonic model was applied to determine whether apartment vacancy rates were associated with apartment rents and whether variations in apartment rent were controlled by housing and local environment attributes. The apartment vacancy rate was included as a significant variable in the model. The model for each apartment unit is described as follows:

$$\mathbf{p} = \mathbf{X}\boldsymbol{\beta} + \theta \mathbf{v} + \boldsymbol{\varepsilon} \quad (1)$$

where \mathbf{p} is a $(N \times 1)$ vector of the logarithmised housing rent per floor area, \mathbf{X} is a $(N \times K)$ matrix of the building and the local environment attributes, \mathbf{v} is a $(N \times 1)$ vector of the apartment vacancy rate, $\boldsymbol{\beta}$ is a $(K \times 1)$ vector of the parameters, θ is a scalar of the parameter and $\boldsymbol{\varepsilon}$ is a $(N \times 1)$ vector of the error term. If all the variables are exogenously determined, $\frac{\partial p_i}{\partial v_i} = \theta$ indicates the effect of the apartment vacancy rate on housing rent in the i th apartment unit:

As vacancy duration is an important factor influencing apartment rent, it was included in the model. The magnitude of the relationship between apartment rent and vacancy duration was observed by dividing the continuous apartment vacancy rate by month. The model can be expressed as follows:

$$\mathbf{p} = \mathbf{X}\boldsymbol{\beta} + \theta_m \mathbf{v}^{(m)} + \boldsymbol{\varepsilon} \quad (2)$$

where $\mathbf{v}^{(m)}$ is a $(N \times 1)$ vector of the apartment vacancy rate continuously for more than m months ($m = 1, 2, \dots, 11$), θ_m is the parameter scalar and $\boldsymbol{\varepsilon}$ is a $(N \times 1)$ vector of the error term.

The second model verifies whether spatial externalities exist by including a spatially weighted vacancy rate term that expresses the vacancy rates of the surrounding buildings decaying by distance. The model can be described as follows:

$$\mathbf{p} = \mathbf{X}\boldsymbol{\beta} + \theta_m \mathbf{v}^{(m)} + \lambda \mathbf{W} \mathbf{v}^{(m)} + \mathbf{u} \quad (3)$$

where ij th element is a $(N \times N)$ distance matrix and w_{ij} indicates:

$$w_{ij} = \begin{cases} d_{ij}^{-r} / \sum_l d_{il}^{-r}, & d_{ij}, d_{il} \leq L \\ 0, & d_{ij} > L \end{cases} \quad (4)$$

λ is the scalar parameter, and \mathbf{u} is a $(N \times 1)$ vector of the error term. w_{ij} is the distance-decay function. If the distance between i th and j th apartment units, d_{ij} , is below distance L , we assume that the apartment vacancy rate of nearby buildings affects the rent of the i th apartment unit. Function w_{ij} can obtain various forms by altering the distance resistance parameter r , and the radius of the coverage area L . $r = \{1, 2\}$ was calculated by assuming inverse proportional and gravitational decaying functions to verify spatial externalities, such as those common in the housing market analyses (Can, 1998). Based on the cut-off boundary of the coverage area L , the upper and lower limits were set according to the living area of the residents. Assuming that $L = \{100, 500\}$ for the analysis, in the case of $L = 100$, a resident could observe the view of the surrounding buildings, and in the case of $L = 500$, a resident could walk around the locality.

The third model used quantile regression because the levels of housing rent were considered in sections. Quantile regression provides researchers with the conditional distribution of responses with respect to a specific quantile (Koenker and Bassett, 1978; Koenker and Hallock, 2001); thus, facilitating the estimation of responses across different levels of rental prices. Assuming that the real estate market is segmented according to housing prices, as well as housing and local environment attributes (Nishi *et al.*, 2021), the demand curve for housing characteristics will differ depending on the income level of the tenants (Zietz *et al.*, 2008). The top 10% and bottom 10% quantile regression models were used to reflect the different characteristics of apartments based on rent.

Data for empirical analysis

For the empirical study, Setagaya, a suburban ward in Tokyo's central business district (CBD), has been selected because it has a wide range of housing types, ranging from detached houses to condominiums. As of July 2021, Setagaya's population was 945,647, and the public transportation system, such as trains, is well developed; it takes approximately 30 min by train to reach Tokyo's CBD. Although there are no large clusters of commercial or office buildings in the ward, the demand for housing and the average rent is relatively high because of the convenience and ease of living. In addition, there are both wealthy and relatively modest residential areas within the ward; thus, they were suitable for collecting samples of a variety of apartments.

To conduct an empirical analysis, two independent datasets were integrated. A data set of vacant apartments measured by electricity consumption was obtained by the Grid Data Bank Lab. limited liability partnership [Grid Data Bank Lab (GDBL)], whose data were originally provided by TEPCO Power Grid. This was incorporated for demonstration purposes. The second source was a rental housing data set from LIFULL Co., Ltd.

Smart meter data

The apartment vacancy rates were calculated using the smart electricity data provided by GDBL. The GDBL collects and aggregates data related to household electricity consumption as well as building-level vacancy rates. The vacancy is determined by the amount of electricity consumption, and in the case where continuous consumption exceeds the standby consumption, the vacancy occurs. The data were extracted from April 2018 to March 2019. The number of vacant apartment units and the duration of vacancies for each building were identified. These data were aggregated as the number of vacant properties per month, and the duration of each vacancy was subsequently calculated based on the smart meter data ranging from one to 12 months.

Smart electricity meters enable measurements of building-level vacancy rates, which are difficult to obtain through field observations. As opposed to ToM, the data used in this study showed vacant housing units that were not listed on the market. Smart electricity meters do not provide any data unless a household meter is replaced with a new one. As of March 2021, smart meters under the control of the Tokyo Electric Power Company have been installed for almost all households and offices, except for some locations where it is difficult to replace them (TEPCO Power Grid, Incorporated [TEPCO], 2021).

Rental housing data

Data on housing rents were provided by LIFULL Co., Ltd. Apartments for rent advertised on the LIFULL HOME website (<https://www.homes.co.jp/>) in FY2018 were used. These data were based on listings of properties requested by real estate brokers and posted on the website. Among the attributes considered for the analysis were the address, monthly rent,

floor area, building age, number of stories, number of apartment units and category of the floor plan. Geocoding addresses and converting them to coordinates enables the calculation of distances to the nearest station and to Tokyo's CBD, which affects the rent in the Tokyo Metropolitan Area (Shimizu *et al.*, 2016).

Data integration

Since data from smart meters and rental housing were obtained independently, they were combined with the building footprint, for which we used a housing map (Zmap TOWN II) provided by ZENRIN CO., LTD. Initially, a total of 39,828 smart-meter samples were geocoded, and 39,400 unique buildings were identified. The footprints of the buildings and smart meter samples were then intersected in geographic information system, matching 34,285 buildings. In addition, two-meter building buffers were created, and the smart meter samples that failed to match were combined under the condition that if the data of more than one smart meter corresponded to the same building, the one with the closest distance between the building centroid and the smart meter point was matched. Consequently, 39,020 smart meter samples were matched with the building footprints. In the same manner, rental apartment data with 27,800 building units were geocoded and 26,985 buildings were matched. However, since the smart meter data capture both rental apartments and occupied apartments, several samples were omitted; samples that contained both smart meter data and rental apartment data were captured, including 9,251 building units, which corresponds to 37,209 apartment units. As of March 2019, this study used cross-sectional data to measure long-term vacant housing units; consequently, the total number of apartment units analyzed was 3,627.

Figure 1 illustrates the geographical distribution of the average apartment vacancy rate and the rent per floor area. The analysis of both the data suggests that apartment vacancy rates are distributed randomly regardless of the distance to the nearest station and to Tokyo's CBD. However, the average rent per floor area appears to be affected by the distance to Tokyo's CBD and is likely to be higher near the stations.

Table 1 presents the descriptive statistics. Apartments have an average floor area of 30.97 square meters, indicating that the majority of apartments are rented to individuals. The floor plan category uses Japanese symbols, with numbers indicating the number of rooms: "R" for room, "K" for kitchen, "D" for dining and "L" for living. For example, 1R implies one room with a simple kitchen, 2K implies two rooms with a small kitchen and 3LDK implies three rooms with living, dining and kitchen areas. The average distance to the nearest train station and to Tokyo's CBD is 465 m and 6,171 m, respectively, which indicates that most of the rental apartments are located in convenient areas.

Figure 2 illustrates the relationship between the vacancy rate per building and the duration of the vacancy. The highest value of the total vacancy rate was 5.4%, regardless of the duration of the vacancy. Accordingly, the longer the duration of the vacancy, the greater the exponential decline in the vacancy rate. As exemplified by the vacancy rates of 1, 6 and 11 months, which are 3.6%, 0.8% and 0.1%, respectively.

Results

The first step involved conducting three types of estimations by extracting the total vacancy rate as well as vacancy rates of more than 6 and 11 months. Then, standard errors were clustered by building units using ordinary least squares regression. Table 2 shows the results of the parameter estimation. In Setagaya, the age of the buildings and various floor plans showed negative signs, indicating that old apartments with spacious floor plans did not satisfy the demand. Similarly, distances to both the nearest station and Tokyo's CBD

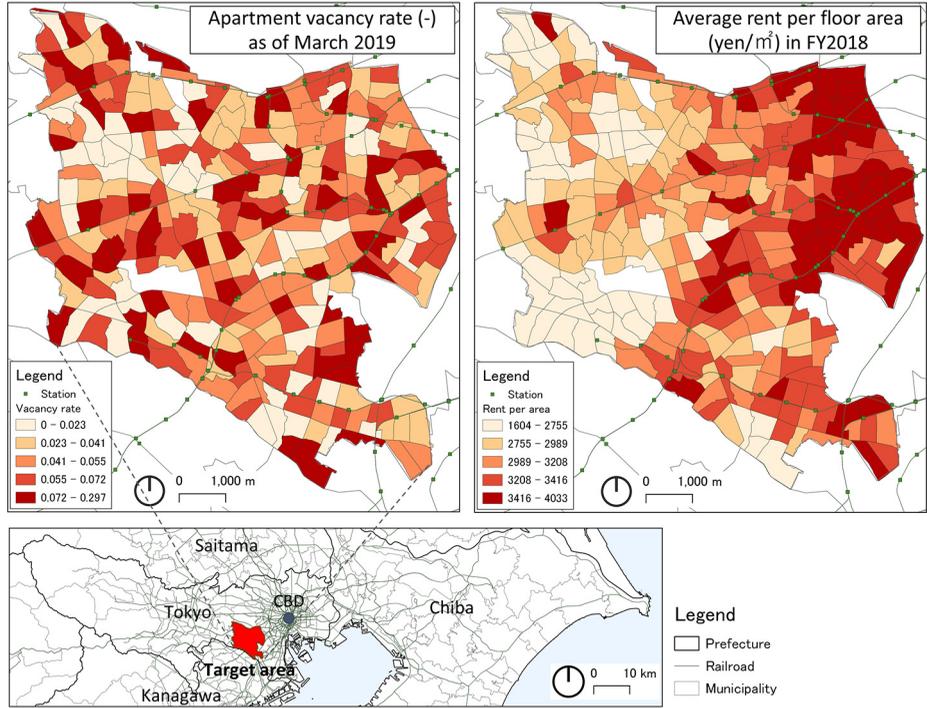


Figure 1.
Geographical location
of average apartment
vacancy rate and rent
per floor area

Notes: This map was created using municipal boundaries provided by ESRI Japan Corp. (<https://www.esri.com/products/japan-shp>) and railroad and stations provided by National land numerical information, Ministry of Land, Infrastructure (<https://nlftp.mlit.go.jp/ksj/index.html>)

Table 1.
Descriptive statistics

Variable	Unit	Mean	SD	Min	Max
Monthly rent per floor area	10 ³ yen	95.99	53.36	20.2	1,250
Floor area	m ²	30.97	17.71	10	309.68
Building age	year	26.52	11.45	1	68
Number of stories	Story	2.45	1.78	1	25
Total number of apartment units	Housing unit	19.59	24.86	3	277
Floor plan_1R	(Binary)	0.21	0.41	0	1
Floor plan_1K	(Binary)	0.41	0.49	0	1
Floor plan_1DK, 1LDK	(Binary)	0.15	0.36	0	1
Floor plan_2K	(Binary)	0.02	0.15	0	1
Floor plan_2DK, 2LDK, 3K	(Binary)	0.15	0.36	0	1
Floor plan_3DK, 3LDK	(Binary)	0.05	0.22	0	1
Floor plan_4DK and more	(Binary)	0.01	0.08	0	1
Distance to the nearest station	m	465.47	300.95	15.168	1,517.63
Distance to the Tokyo CBD	m	6,171.08	2,199.62	1,896.24	1,0855.5
Obs.	3,627				

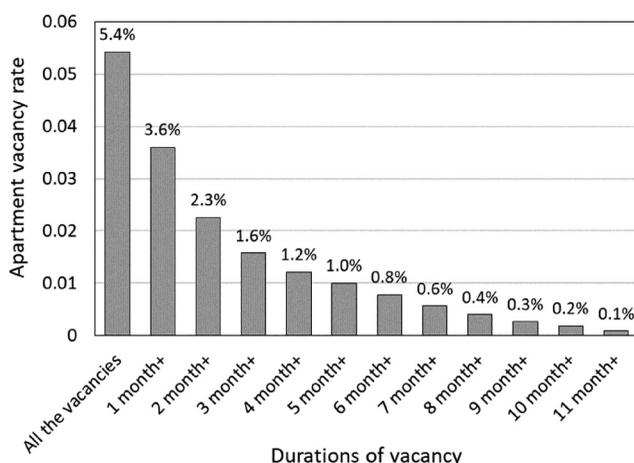


Figure 2. Apartment vacancy rate by duration of vacancies

	(I) Total vacancy rate		(II) Vacancy rate of 6 months+		(II) Vacancy rate of 11 months+	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Ln(floor area)	0.761	0.020***	0.765	0.020***	0.764	0.020***
Ln(building age)	-0.097	0.008***	-0.094	0.008***	-0.093	0.008***
Ln(number of stories)	0.040	0.006***	0.040	0.006***	0.040	0.006***
Ln(total number of apartment units)	0.053	0.006***	0.049	0.005***	0.049	0.005***
Floor plan_1R	(reference term)		(reference term)		(reference term)	
Floor plan_1K	-0.006	0.007	-0.005	0.007	-0.006	0.007
Floor plan_1DK, 1LDK	-0.031	0.014*	-0.032	0.014*	-0.032	0.014*
Floor plan_2K	-0.106	0.020***	-0.107	0.020***	-0.107	0.020***
Floor plan_2DK, 2LDK, 3K	-0.034	0.020†	-0.036	0.020†	-0.036	0.020†
Floor plan_3DK, 3LDK	0.012	0.025	0.011	0.025	0.011	0.025
Floor plan_4DK and more	0.051	0.043	0.047	0.043	0.047	0.043
Ln(distance to the nearest station)	-0.041	0.005***	-0.041	0.005***	-0.041	0.005***
Ln(distance to the Tokyo CBD)	-0.146	0.009***	-0.147	0.009***	-0.147	0.009***
Total vacancy rate	-0.067	0.033*	-	-	-	-
Vacancy rate of 6 months+	-	-	-0.110	0.056*	-	-
Vacancy rate of 11 months+	-	-	-	-	-0.214	0.074**
Intercept	10.518	0.106***	10.508	0.104***	10.510	0.104***
Obs.	3,627		3,627		3,627	
F(12, 2438)	907.92***		878.59***		880.58***	
R-squared	0.875		0.875		0.875	
Root MSE	0.141		0.141		0.141	

Table 2. Estimation results by three types of vacancy rates

Notes: Statistical significance levels: ***0.1%; **1%; *5%; †10%. The response variable is ln(monthly rent). Standard errors are clustered by building unit

were negatively correlated with apartment rentals, which corresponds to a previous finding (Shimizu *et al.*, 2016). In contrast, the number of floors and the total number of apartment units showed positive coefficients, indicating that the larger the building volume, the higher the apartment rent. The vacancy rates were all negatively correlated and statistically

significant. Furthermore, the coefficients were larger for longer vacancy durations, which were further addressed in the subsequent analysis by integrating them with the external diseconomies of apartment vacancies.

The existence of spatial externalities was tested by analyzing the relationship between the apartment rent and vacancy duration, including the vacancy rate of nearby buildings. Table 3 shows a series of coefficients that reflect the summed vacancy rates for buildings in L 's vicinity of the i th building based on equation (3).

In the case of $L = 0$, the statistical significance of the vacancy rate varies depending on the duration of the vacancy and the coefficients are negatively statistically significant, except for the vacancy rate of more than one month. The magnitude of the coefficients increases negatively with vacancy duration, supporting Han's (2014) findings on detached housing. Moreover, when the vacancy duration exceeds eight months, the coefficients reach 1% with statistical significance, indicating that the confidence interval becomes smaller as the vacancy duration increases. For $L = \{100, 500\}$ —considering the vacancy rate of nearby buildings, no statistical significance has been observed for any vacancy duration, which contradicts the findings for detached houses (Mikelbank, 2008). Alternatively, the effective range of spatial externalities of vacant housing units differs depending on the type of

Model number	Periods of vacancy	Distance-decay function	(I) $L = 0$		(II) $L \leq 100$		(III) $L \leq 500$	
			Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
1–5	All the vacancies	Inverse	−0.067	0.033*	0.069	0.069	0.043	0.296
		Inverse squared			0.044	0.059	0.012	0.101
6–10	1 month+	Inverse	−0.057	0.035	0.114	0.082	0.218	0.389
		Inverse squared			0.095	0.073	0.069	0.136
11–15	2 months+	Inverse	−0.078	0.037*	0.126	0.110	0.151	0.481
		Inverse squared			0.114	0.092	0.118	0.162
16–20	3 months+	Inverse	−0.093	0.042*	0.160	0.133	0.285	0.567
		Inverse squared			0.149	0.116	0.188	0.214
21–25	4 months+	Inverse	−0.111	0.047*	0.185	0.155	0.305	0.616
		Inverse squared			0.150	0.131	0.173	0.231
26–30	5 months+	Inverse	−0.102	0.053†	0.177	0.161	0.567	0.675
		Inverse squared			0.140	0.139	0.172	0.248
31–35	6 months+	Inverse	−0.110	0.056*	0.097	0.188	0.374	0.778
		Inverse squared			0.114	0.162	0.174	0.281
36–40	7 months+	Inverse	−0.148	0.060*	0.165	0.213	1.036	0.874
		Inverse squared			0.212	0.184	0.405	0.312
41–45	8 months+	Inverse	−0.164	0.063**	0.048	0.233	−0.656	1.006
		Inverse squared			0.133	0.200	0.110	0.369
46–50	9 months+	Inverse	−0.179	0.066**	0.120	0.288	0.311	1.106
		Inverse squared			0.288	0.212	0.413	0.367
51–55	10 months+	Inverse	−0.193	0.068**	0.223	0.317	1.117	1.171
		Inverse squared			0.357	0.229	0.559	0.393
56–60	11 months+	Inverse	−0.214	0.074**	2.342	1.572	7.125	5.811
		Inverse squared			2.888	1.729	4.390	3.446
Obs.			3,627					

Table 3. Estimated spatial externalities by duration of vacancies and coverage area

Notes: Statistical significance levels: ***0.1%; **1%; *5%; †10%. The response variable is $\ln(\text{monthly rent})$. The independent variables are $\ln(\text{floor area})$, $\ln(\text{building age})$, $\ln(\text{number of stories})$, $\ln(\text{total number of apartment units})$, floor plans, $\ln(\text{distance to the nearest station})$, and $\ln(\text{distance to the Tokyo CBD})$. Standard errors are clustered by building unit

housing. In apartment buildings, the impact of housing vacancies is shared within the building, but does not spill over to neighboring buildings.

Despite the correlation between apartment rent and vacancy duration in the overall housing market, as shown in Tables 2 and 3, the market may be segmented based on rent levels (Nishi *et al.*, 2021). Table 4 presents the results of using a series of quantile regressions. Figure 3 illustrates the coefficients and 95% CIs associated with each duration of vacancy.

For Model (II), which focuses on the bottom 10% of the sample, the coefficients are negatively significant for all vacancy durations, except for those exceeding seven months, whose magnitude is greater than that of Model (I). This indicates that the vacancy rate and vacancy duration are strongly correlated with the rent for properties with modest rents. Model (III) also shows significant negative correlations for virtually all vacancy durations, although the magnitude of the coefficients is not as small as that of Model (II). Even though the coefficients are comparable to those of Model (I), the latter has smaller standard errors, which indicates that apartment rent and vacancy duration are significantly negatively correlated, even for the median properties.

The top 10% of the samples, however, do not show a significant negative correlation regardless of the vacancy duration; rather, at the 10% significance level, there is a positive but weak correlation for a vacancy rate of longer than two months. This indicates that the rent of luxury properties is not affected by vacancy rates in apartment buildings. Considering that the study area is within one of Tokyo’s special districts, an increase in vacant luxury properties would act as a supply constraint, indicating that landlords might be vacating the properties for speculative purposes. Anyhow, it is clear that the relationship between rent and vacancy duration differs from that of the segmented sub-markets.

Discussion and conclusion

This study used smart meter data to examine the relationship between apartment rent and the duration of apartment vacancies in Setagaya, Tokyo. A theoretical explanation was proposed for the following findings:

Model number	Periods of vacancy	(I) Mean		(II) Bottom 10%		(III) Median		(IV) Top 10%	
		Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
1–4	All the vacancies	-0.067	0.033*	-0.107	0.028***	-0.056	0.018**	-0.013	0.033
5–8	1 month+	-0.057	0.035	-0.131	0.030***	-0.043	0.031	0.019	0.028
9–12	2 month+	-0.078	0.037*	-0.150	0.034***	-0.085	0.030**	0.054	0.028†
13–16	3 month+	-0.093	0.042*	-0.161	0.027***	-0.100	0.038**	0.051	0.039
17–20	4 month+	-0.111	0.047*	-0.173	0.039***	-0.137	0.037***	0.049	0.038
21–24	5 month+	-0.102	0.053+	-0.222	0.039***	-0.123	0.043**	0.062	0.069
25–28	6 month+	-0.110	0.056*	-0.232	0.082**	-0.123	0.050*	0.058	0.070
29–32	7 month+	-0.148	0.060*	-0.236	0.926	-0.151	0.034***	-0.042	0.045
33–36	8 month+	-0.164	0.063**	-0.277	0.096**	-0.161	0.053**	-0.049	0.072
37–40	9 month+	-0.179	0.066**	-0.279	0.087**	-0.195	0.039***	-0.049	0.046
41–44	10 month+	-0.193	0.068**	-0.321	0.102**	-0.190	0.047***	-0.050	0.047
45–48	11 month+	-0.214	0.074**	-0.355	0.129**	-0.212	0.051***	-0.053	0.058
Obs.					3,627				

Notes: Statistical significance levels: *** 0.1%; ** 1%; * 5%; † 10%. The response variable is ln(monthly rent). The independent variables are ln(floor area), ln(building age), ln(number of stories), ln(total number of apartment units), floor plans, ln(distance to the nearest station), and ln(distance to the Tokyo CBD). Standard errors are calculated by bootstrap sampling with 20 repetitions

Table 4. Results of quantile regression by duration of vacancies

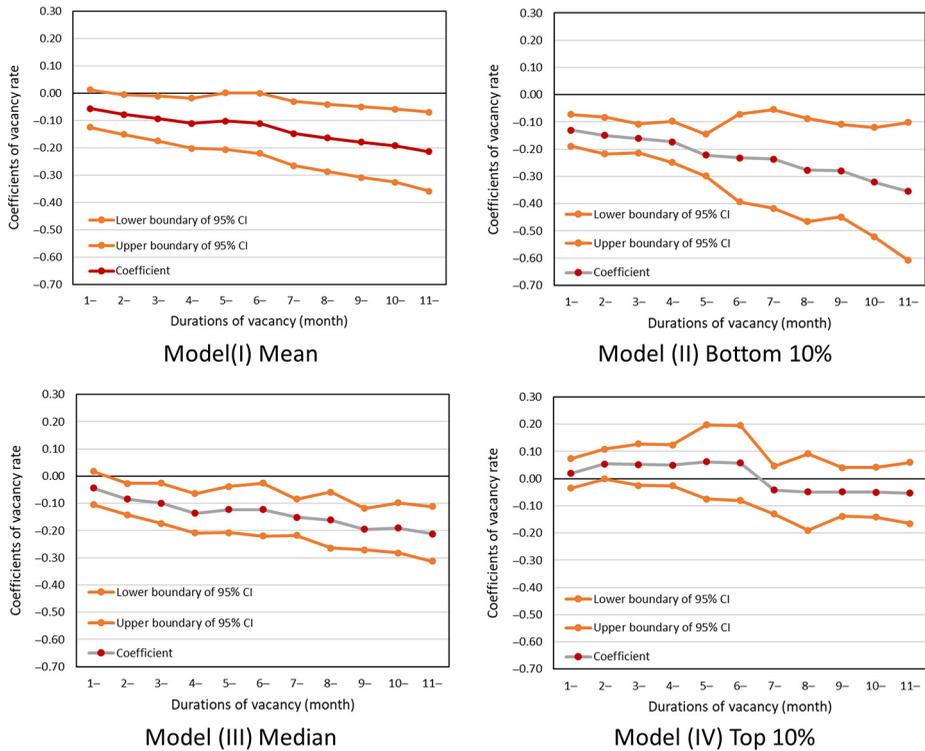


Figure 3.
Coefficients of
vacancy rate by
duration of vacancies
and quantile
regression models

There are significant negative correlations between apartment rent and vacancy duration, which is in line with previous studies (Gabriel and Nothhaft, 2001; Wheaton, 1990). In particular, the magnitude of the relationship was found to be negatively stronger for longer vacancy durations, confirming *H2*. This suggests that several long-term vacancies in an apartment building, including those that have not yet appeared on the market, signify a lack of demand, which could contribute to a decline in apartment rent (Molloy, 2016). There is a possibility that if there are insufficient residents living in an apartment building, the management association may not function properly or, in the worst case, may be unable to collect maintenance fees, thereby reducing the value of the building.

When evaluating the apartment vacancy rate of other nearby buildings in light of the spatial externalities of apartment vacancy rates, no statistical significance was found. Although this proves *H1*, the opposite holds true for detached houses, where adjacent vacant or abandoned houses result in declining house prices (Frame, 2010; Han, 2014; Mikelbank, 2008). Conceivably, when a detached house becomes vacant and deteriorates, the neighborhood may also suffer from a decline in quality. In an apartment building, however, a vacant apartment unit does not affect the quality of the building unless the entire building is maintained by the maintenance association. Furthermore, this result implies that landlords have asymmetric information about their buildings compared with the surrounding buildings. Unlike detached houses, even when there are vacancies in the surrounding buildings, price adjustment does not function in a neighborhood; therefore, there are no negative spatial externalities.

After dividing the levels of apartment rent, it was found that there was a variation in the magnitude of the relationship between apartment vacancies and rent, which partially supports *H3*. Although the bottom 10% of the apartment rent level was negatively related to all vacancy durations, the top 10% showed no statistical significance. As [Hoekstra and Vakili-zad \(2011\)](#) argue, an increase in housing vacancies does not always result in a decrease in apartment rent but rather an increase, particularly in popular cities. Considering that the selected site for this study is in a special district of Tokyo, one of the most popular cities in the world, it is plausible that luxury rental housing would not reduce their rent even if the vacancy rate increased overtime in anticipation of a certain level of demand. Furthermore, luxury properties are often owned for speculative purposes or for secondary use, and in such cases, rent increases in proportion to the number of vacancies that exist due to supply constraints ([Glaeser et al., 2006](#)). However, the results of this study did not demonstrate an increase in luxury housing rent due to supply constraints. In contrast, since apartment buildings with high vacancy rates are associated with decreasing rent, landlords of the bottom 10% rent level suffer from a downward spiral of increasing vacancy rates and decreasing rent. Therefore, early detection and intervention of such buildings are necessary for neighborhood stability.

Although this study empirically confirms that long-term vacancies are negatively associated with apartment rent, the target area of this study retains a strong demand for apartments. The results varied between suburban areas and the surrounding cities. Moreover, there may be reverse causality between apartment rents and vacancy rates. Future studies should examine how to omit the statistical bias from the data and draw a more accurate inference. The results obtained from the quantile regressions reveal the extent of reverse causality, but further controls using instrumental variables, as used by [Huang \(2017\)](#), are necessary. Nevertheless, this is the first study to use smart meter data to observe apartment vacancies; it not only confirms the association between vacancies and rent in apartment buildings but also highlights the importance of vacancy duration and the scope of spatial externalities.

The results can be applied to urban and housing policies. It was found that the longer the vacancy duration, the stronger the negative correlation with rent, particularly for austere apartments. As argued by [Immergluck \(2016\)](#), there are socially marginalized areas with high long-term vacancy rates. Thus, it is necessary to regularly monitor areas that are known to have high long-term vacancy rates. This study used smart meters to identify the geographical distribution of long-term vacancies in buildings to identify potential hotspots at an early stage. The visualization of the apartment vacancy rate and the price index across neighborhoods can reduce information asymmetry and allow for price adjustments according to surrounding apartments. Moreover, active policies are required to encourage vacant properties to enter the market in areas where there are a variety of income levels. A plausible way to achieve this goal is by introducing a progressive vacant house tax based on vacancy durations as measured by smart meter data. Overall, this study enables users of housing policies to consider not only the number of vacant houses but also the duration of vacancy and rent levels, which could help in addressing apartment vacancy problems in popular cities such as Tokyo.

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Corresponding author

Hiroki Baba can be contacted at: hbaba@cseas.kyoto-u.ac.jp

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