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Aging-Related Depreciation of Office Rents and Renovation Effects

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Aging-Related Depreciation of Office Rents and Renovation Effects[*]

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Abstract

The items of "Office space rental" in the Services Producer Price Index (SPPI), which is created and published by the Bank of Japan, considers the aging-related depreciation of office properties over time as a decline in service quality and reflects this in the index. However, the current method relies on empirical analysis derived from 2007 data, which does not adequately consider changes in external conditions since then. This study utilizes new lease contract rent and attribute data provided by the XYMAX Group, a leading office brokerage and management company, and applies the hedonic method to empirically analyze the impact of property depreciation on office rents. The primary findings of this study are as follows: (1) Office rents in Japan generally depreciate at a consistent rate of 1.4% annually for about 25 years after the building is newly constructed, after which the rate of depreciation gradually slows. This trend aligns with prior studies conducted on commercial property in the United States. (2) The pace of depreciation varies based on property size. Large-scale properties depreciate slightly faster than small-to-medium properties. However, while small-to-medium properties continue to depreciate even after the rate of depreciation has slowed, large properties tend to maintain a relatively stable state once their depreciation rate diminishes. (3) Renovations reverse depreciation by approximately 8.2 percentage points at most compared to rents at the time of new construction. This reversal effect lasts for about 16 years, during which an average mitigation effect of 5.4 percentage points in depreciation is observed.

Keywords: price index, quality adjustment, hedonic approach, office rent

JEL classification: C43, E31, R32, R33

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1. Introduction

Accurately measuring a rational value for rents, the source of real estate value in the form of cash flow, is crucial for enabling relevant authorities to implement appropriate economic and financial policies and for economic agents to make sound investment decisions and to take appropriate financing strategies (Yoshida and Kawai, 2020; Lopez and Yoshida, 2022). In this context, treating the depreciation of rents due to aging as a deterioration in the quality of real estate rental services and excluding the portion of rent changes attributable to quality deterioration from the overall rent changes is essential to ensuring the accuracy of macroeconomic statistics, such as price indices and real GDP calculated using those indices as deflators.

The *Services Producer Price Index* (SPPI), which the Bank of Japan has compiled and published monthly since January 1991, strives to create an accurate price index for real estate rental services by reflecting quality deterioration due to aging properly. Specifically, for each item included in the subcategory "Office space rental," which is part of the basic classification index, individual office rent data obtained through statistical surveys are indexed and aggregated. During this process, a decrease in the asset value of office properties due to aging is regarded as a decline in the quality of office rental services. Measures are taken to ensure that changes in rents caused by this quality deterioration are not reflected in the fluctuations of the price index. This approach aims to construct a price index that assumes constant quality. Conceptually, this is equivalent to continuously surveying rents for hypothetical properties whose asset values do not depreciate over time. Such measures are referred to as *quality adjustment* and are in line with standard methodologies in price statistics compilation (ILO *et al.*, 2004; OECD/Eurostat, 2014).

Pioneering empirical research on the rate of aging-related depreciation of office properties in Japan includes Saita and Higo (2010), which utilized data from REITs and other sources as of 2007. The current parameters of depreciation rate used in quality adjustments for the SPPI are based on estimates provided in that study. However, due to data constraints in their analysis, the study made the somewhat strong assumption that the rate of rent depreciation aligns with the rate of asset depreciation. Additionally, given that nearly 20 years have passed since that analysis was conducted, the study could not adequately reflect significant external changes over time, such as the recent upward trend in property prices, innovations in construction technologies, and the impact of the COVID-19 pandemic. As such, there is a risk of discrepancies arising when using this study as a basis for estimation compared with more recent estimates.

Under these circumstances, this study attempts to empirically measure aging-related depreciation of office rents in Japan using a highly accurate estimation method and up-to-date dataset. Specifically, we analyze the impact of property attributes, including building age, on rents by applying the hedonic method, a method used to quantify the influence of various property attributes on rents, using a comprehensive dataset on office rents and attributes owned by the XYMAX Group, a leading office brokerage and management company. By doing so, we aim to measure the aging-related depreciation rate of office rents in Japan and identify property attributes, apart from building age, that influence the pace of rent depreciation. Empirical analyses focusing on rental prices, as opposed to real estate prices, remain limited worldwide, whether in residential or commercial property. Our research contributes significantly not only to the creation of high-quality price statistics on this topic but also to a better understanding of the realities of the office rental market.

The structure of this paper is as follows: Section 2 reviews the existing literature and positions this study within this body of literature. Section 3 outlines the dataset and estimation models. Section 4 presents the estimation results and discusses their implications alongside robustness checks. Section 5 concludes the paper.

2. Literature Review

This section reviews previous studies conducted in the United States and Japan focusing on analyzing the impact of aging-related depreciation on property prices and rents. Building upon the findings of these studies, we clarify the position of this study within the context of academic literature.

2-1. Research Examples in the United States

Pioneering research in this field includes Hulton and Wykoff (1981). This study estimated the rates of aging-related depreciation for U.S. residential and commercial property prices (retail, office, warehouse, and industrial properties) based on survey data conducted by the U.S. Department of the Treasury. By applying a Box-Cox transformation to the age of properties and using the hedonic method to estimate depreciation rates, it was confirmed that the pace of building depreciation generally follows a geometric form. Moreover, the study estimated an annual depreciation rate for office properties among the analyzed samples was approximately 2.5%.

Bokhari and Geltner (2018) analyzed the rates and pace of aging-related depreciation for investment property prices in the United States. Compared to earlier studies, this research utilized a larger and more comprehensive dataset. It is particularly notable for employing actual transaction prices rather than appraised or asking prices, which may suffer from lag bias. The estimation results revealed that the average depreciation rate across all properties was 1.5% per year, with newly built properties showing a rate of 1.82% per year and 50-year-old properties a slower rate of 1.12% per year. The study also observed that residential properties depreciate slightly faster than commercial properties, and the level of depreciation rates varies significantly across metropolitan areas, with regions facing stricter supply constraints exhibiting relatively lower depreciation rates. Moreover, in a subsequent study, Bokhari and Geltner (2019), aiming to determine a more refined functional form of depreciation rates, conducted an estimation that incorporated land prices and continuous investments. Their findings indicated that depreciation rates decline rapidly up to around the 30th year of a building's age, then stabilize between 30 to 65 years, and further decline thereafter. The authors suggested that this phenomenon might occur because depreciation could be offset by ongoing investments in maintenance and renovations.

Other notable studies on residential rents include Lane, Randolph, and Berenson (1988), which estimated aging-related depreciation rates using the hedonic method based on CPI Housing Survey and Housing Census data. Randolph (1988) further developed this work, as did Campbell (2006). In terms of residential property prices, key studies include Goodman and Thibodeau (1995) and their subsequent work in Goodman and Thibodeau (1997), which incorporated new attribute variables. These studies highlighted the significant impact of the functional form of the age variable on estimation results. Moreover, Harding, Rosenthal, and Sirmans (2007) used data obtained from the American Housing Survey and applied the repeat-sales method to estimate aging-related depreciation rates for residential property prices.[1] They observed that factoring in the effects of property maintenance reduced the annual depreciation rate from approximately 2.5% to 2.0%. Finally, Lopez and Yoshida (2022) distinguished between physical deterioration, which refers to the physical wear and tear of buildings and equipment, and functional obsolescence, which occurs when advancements in technology or changes in societal needs render buildings and equipment outdated, in analyzing property aging-related depreciation. They pointed out that the higher depreciation rate of condominiums compared to that of detached houses is primarily influenced by functional obsolescence. The study also noted that depreciation rates may vary depending on factors such as the age and scale of the property.

2-2. Research Examples in Japan

Pioneering research on the empirical analysis of aging-related depreciation of office rents in Japan includes Saita and Higo (2010), as previously mentioned. Due to the difficulty of obtaining large-scale datasets that comprehensively cover office rents, in this study Saita and Higo employed an "asset value approach." This approach estimates the depreciation rate by utilizing a combination of REIT and other data sources, under the assumption that the decline in the asset value of office buildings corresponds to the quality deterioration of office rental services. The analysis in Saita and Higo (2010) and its subsequent paper development by Research and Statistics Department of Bank of Japan (2010) revealed several findings, including that the annual rate of quality deterioration of office leasing services due to aging is around 0.6% overall, the pace of quality deterioration decreases with the building's age, and the effects of aging-related depreciation are offset by renovation investments after 18 years, with the quality deterioration rate hovering near zero.

Diewert and Shimizu (2015, 2016) took a different approach by using the Builder’s Model, which enables a more refined estimation by decomposing the changes in real estate

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[1] The repeat-sales method is a technique that estimates changes in transaction prices over time by performing regression analysis using time dummy variables, based on data from the same property being transacted multiple times. Since this method only uses data from properties with multiple transaction records, it has the advantage of effectively controlling for differences in property attributes. However, particularly for office properties, there is a concern of data bias, such as a higher proportion of properties with high turnover rates. When the sample size and attribute data of each property are sufficiently collected, the hedonic method is generally considered more desirable.

asset values into contributions from land and building components. Using listing price data obtained from Recruit Group, they estimated a housing price index for Tokyo. Furthermore, Diewert and Shimizu (2017) applied the Builder's Model to J-REIT disclosure data to estimate a commercial property price index for Tokyo. According to their research, the pace of depreciation followed a geometric form, and its annual rate was estimated to be about 2.6%.

Lastly, Yoshida *et al.* (2024) estimated the depreciation rate of office rents in Tokyo's 23 wards using the same XYMAX Group dataset as this study. Similar to Lopez and Yoshida (2022), this research is characterized by its distinction between physical deterioration and functional obsolescence in analyzing aging-related depreciation and its integrated analysis of Capital Expenditures (CAPEX), which are capitalized and subject to depreciation, as well as the associated revenues. The study concludes that the depreciation rate of rents is less than half that of real estate prices, with new lease contract rents depreciating at an annual rate of 0.81% and continued lease rents depreciating at an annual rate of 0.58%.

2-3. Positioning of this Study

Building on the series of prior studies, this research seeks to perform a more comprehensive measurement and analysis of the aging-related depreciation rate of office rents in Japan, including the pace of its changes over time. In doing so, it also considers the potential application of the findings in the future development of price indices.

Specifically, instead of using the method employed by Yoshida *et al.* (2024), which categorizes building age into five-year intervals, this approach introduces individual age-specific dummy variables for each year of building age. This allows for a more detailed observation of changes in depreciation rates over time and an analysis of the shape of the cumulative depreciation rate function. Furthermore, this research expands its analysis beyond Tokyo's 23 wards to include data from Osaka City, and examines variations in the impact of property location differences on depreciation rates. In addition, considering the interest expressed by practitioners in the office rental market in Japan, it aims to clarify how differences in property size affect depreciation rates. It also endeavors to quantitatively capture the impact of renovations on mitigating aging-related depreciation by considering variables such as the presence of renovations and the number of elapsed years following renovations.

3. Overview of Dataset and Estimation Model

In this section, we provide an overview of the dataset provided by the XYMAX Group and formulate the estimation model utilizing the hedonic method. To appropriately capture the pace of aging-related depreciation, we adopt three different functional forms for the terms related to building age and provide a detailed explanation of each approach.

3-1. Dataset

In this study, we use rent data on transaction-based prices of newly signed tenant contracts and property attribute for properties located in Tokyo's 23 wards and Osaka City, focusing on transactions that took place between 2000 and 2024. The decision to use transaction prices, rather than appraisal or listing prices, aligns with the rationale presented by Bokhari and Geltner (2018). This approach ensures the estimations appropriately reflect the actual conditions of a market in supply-demand equilibrium while minimizing observational errors.

As noted by Shimizu, Nishimura, and Watanabe (2010) and Yoshida *et al.* (2024), in Japan, the stickiness of nominal prices poses a risk of renewed contract rents deviating from market equilibrium prices, even when transaction-based prices are used. Therefore, this study focuses exclusively on new lease contracts, which are considered less likely to exhibit price stickiness. To ensure the robustness of our estimation, we also conducted a supplementary analysis using a dataset that includes both new and renewed rents and confirmed that no significant differences were observed in the estimation results (see subsection 4-2).

The dataset comprises 80,057 observations. The variables used in the estimation model are selected with reference to how they were treated in the series of prior studies outlined in the previous section, as detailed in Chart 1. The dependent variable is the new lease contract rent per *tsubo* for tenants.[2] Independent variables include key property attributes such as building age, gross floor area, distance to the nearest station (in walking minutes), the number of above-ground floors, and a dummy variable indicating locations within the five central wards of Tokyo. Additional variables describe the presence of various property amenities, such as raised floors, individual air-conditioning system, and electronic security system, as well as

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[2] *Tsubo* is the traditional Japanese unit of measurement for the area of a property, with 1 *tsubo* corresponding to around 3.3 square meters.

factors like whether the property has undergone renovations and the time elapsed since renovations. Summary statistics for each variable are provided in Chart 2. Taking into account the data distribution and practical insights from office leasing operations, properties with a rent per *tsubo* of 6,000 yen or less, over 100,000 yen, a building age exceeding 60 years at the time of the contract, or a gross floor area of 300 *tsubo* or less were excluded from the estimation as outliers.

Since the distribution of building age, building age at the time of renovations, years elapsed since renovations, and the contract year of lease agreements within the dataset could potentially influence the estimation results, histograms are presented in Chart 3. When examining distribution by contract year, declines in the number of observations can be seen in 2008, 2012, and 2020. These decreases align with the timing of macroeconomic shocks such as the Global Financial Crisis, the Great East Japan Earthquake, and the COVID-19 pandemic. Accordingly, it was concluded that these trends do not reflect any dataset-specific bias.

3-2. Estimation Model

In this study, we adopt the hedonic method, as employed in many previous studies. By using this method, it becomes possible to control for variables other than building age that influence rents. Additionally, by estimating the coefficients for the terms related to building age, we can quantitatively evaluate the impact of aging-related depreciation. The precise estimation equation is given as follows in Equation (1).

$$\ln rent_t^{(i)} = f\left(age_t^{(i)}\right) + \alpha + \sum_{k=1}^{l} \gamma_k X_{k,t}^{(i)} + \sum_{k=1}^{m} \delta_k D_{k,t}^{(i)} + \theta^{(\gamma(i))} + \rho_t + u_t^{(i)}. \qquad (1)$$

$rent_t^{(i)}$ represents the rent for tenant i at the time of contract t, and $f\left(age_t^{(i)} \middle| age_t^{(i)} \in [0,\cdots,60]\right)$ denotes the term that captures the impact of the building's age, which tenant i occupies at the time of contract t. Among the property attributes, continuous variables are denoted as $X_{k,t}^{(i)}$, while those presented as dummy variables are denoted as $D_{k,t}^{(i)}$. Additionally, $\theta^{(\gamma(i))}$ denotes the group fixed effects that control for differences in Special Wards (e.g., Chiyoda Ward) and Administrative Wards (e.g., Kita Ward, Osaka City) $\gamma(i)$ where the building occupied by tenant i is located, ρ_t represents time fixed effects to control for macroeconomic conditions at the time of contract t. The residuals are represented as $u_t^{(i)}$.[3]

The sum of the six terms on the right-hand side of Equation (1) represents the reasonable rent for tenant i at building age of $age_t^{(i)}$ (hereinafter referred to as $\ln \widetilde{rent}\left(age_t^{(i)}\right)$.) Furthermore, when $age_t^{(i)}$ is set to zero, $\ln \widetilde{rent}\left(age_t^{(i)}\right)$ corresponds to the rent for tenant i that was newly constructed at time t (hereinafter referred to as $\ln \overline{rent_t}^{(i)}$). In other words, the difference between $f\left(age_t^{(i)}\right)$ and $f(0)$ represents the divergence between $\ln \widetilde{rent}\left(age_t^{(i)}\right)$ and $\ln \overline{rent_t}^{(i)}$. Since no depreciation occurs at the time of construction, $f(0) = 0$ holds true.

$$f\left(age_t^{(i)}\right) - f(0) = f\left(age_t^{(i)}\right) = \ln \widetilde{rent}\left(age_t^{(i)}\right) - \ln \overline{rent_t}^{(i)}.$$

In the following, $f\left(age_t^{(i)}\right)$ will be referred to as the *Cumulative depreciation rate*. In this context, it is evident that the annual depreciation occurring between building ages between $age_t^{(i)} - 1$ and $age_t^{(i)}$ years corresponds to the divergence between the rent for tenant i at building age of $age_t^{(i)} - 1$ years, represented as $\ln \widetilde{rent}\left(age_t^{(i)} - 1\right)$, and the rent at building age of $age_t^{(i)}$ years, represented as $\ln \widetilde{rent}\left(age_t^{(i)}\right)$. In this paper, we define the *Depreciation rate* $\Delta f\left(age_t^{(i)}\right)$ as follows:

$$\begin{aligned}
\Delta f\left(age_t^{(i)}\right) &\equiv f\left(age_t^{(i)}\right) - f\left(age_t^{(i)} - 1\right) \\
&= \left[\ln \widetilde{rent}\left(age_t^{(i)}\right) - \ln \overline{rent_t}^{(i)}\right] \\
&\qquad - \left[\ln \widetilde{rent}\left(age_t^{(i)} - 1\right) - \ln \overline{rent_t}^{(i)}\right] \\
&= \ln \widetilde{rent}\left(age_t^{(i)}\right) - \ln \widetilde{rent}\left(age_t^{(i)} - 1\right).
\end{aligned}$$

By defining the depreciation rate in this way, it becomes possible to quantify the extent of annual depreciation over time.

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[3] Instead of a model with two-way fixed effects, group fixed effects $\theta^{(\gamma(i))}$ and time fixed effects ρ_t, it is worth considering a model that generates a large number of dummy variables by constructing the direct product set of $\theta^{(\gamma(i))} \otimes \rho_t$. This approach accounts for the possibility that changes in macroeconomic conditions affecting rents could vary across administrative districts. Nevertheless, the difference in estimation results compared to the two-way fixed effects model is minimal and does not affect the discussion in this paper.

When conducting hedonic regressions, a critical consideration is how to formulate the functional form of $f\left(age_t^{(i)}\right)$, which represents the effects of building age. In this study, we aim to conduct a multifaceted analysis of aging-related depreciation of office properties in Japan by comparing and examining the following three functional forms: (1) Formulation with age dummy variables expresses changes in the depreciation rate with building age, allowing for a precise representation of the variations. (2) Formulation with Box-Cox transformation applies a non-linear transformation to the building age variable, enabling a more flexible functional form for the depreciation rate estimation. In addition, toward applications to statistical practices, (3) Formulation with kinked linear function approximates the estimates derived from age dummy variable model by using a combination of two linear functions.

(1) Formulation with Age Dummy Variables

To begin, following the approach of Bokhari and Geltner (2019), we consider formulating the cumulative depreciation function using age dummy variables set individually for each building age. Specifically, the function $f\left(age_t^{(i)}\right)$ is formulated as shown in Equation (2). $\mathbf{1}_{\{n\}}$ represents a binary function that takes the value of 1 when condition n is satisfied and 0 otherwise. In this case, the coefficient of age dummy variables, β_k, corresponds to the cumulative depreciation rate for building age k.

$$f\left(age_t^{(i)}\right) = \sum_{k=1}^{60} \beta_k \mathbf{1}_{\{age_t^{(i)}=k\}}. \tag{2}$$

(2) Formulation with Box-Cox Transformation

The formulation using age dummy variables has the advantage of finely expressing changes in the depreciation rates for each building age. However, as the functional form is not predetermined, the estimated depreciation rates, which should ideally exhibit continuous and smooth changes over time, are not always stable. For instance, a property might show a significant depreciation in one year and then unexpectedly appreciate the following year, displaying puzzling behavior. If such highly fluctuate ageing-related depreciation estimates were implemented as quality adjustment parameters in price indices, this could lead to indices reflecting unreasonable quality changes, which would be undesirable.

As a second model, we consider a function that applies a Box-Cox transformation to the building age variable. This approach allows for the possibility of nonlinear changes in depreciation rates over time while aiming to stabilize the depreciation rate estimates for each building age. The use of the Box-Cox transformation for building age is a standard method that has been adopted in many studies on property depreciation rate estimation, originating with the pioneering work of Hulton and Wykoff (1981).

When applying the Box-Cox transformation, under the assumption of $f(0) = 0$ holds, the function $f\left(age_t^{(i)}\right)$ is formulated as shown in Equation (3). λ estimated by maximum likelihood is the Box-Cox parameter that adjusts the degree of nonlinearity in the function.

$$f\left(age_t^{(i)}\right) = \begin{cases} \dfrac{(age_t^{(i)} + 1)^{\lambda} - 1}{\lambda} & \text{if } \lambda \neq 0, \\ \ln\left(age_t^{(i)} + 1\right) & \text{if } \lambda = 0. \end{cases} \tag{3}$$

(3) Formulation with Kinked Linear Function

As will be detailed in the next section, when observing the cumulative depreciation rate function based on the age dummy variable formulation, the function demonstrates a pattern where depreciation occurs at a relatively consistent pace from the initial construction to around 25 years of age, after which the depreciation rate slows and remains nearly flat.

Therefore, this study attempts to describe such changes in the depreciation rate using a simplified function. Specifically, we assume that the cumulative depreciation rate function can be approximated by two linear functions, with the functions bending at a building age of T, i.e., the two linear functions are connected at $age_t^{(i)} = T$. Under the assumption that $f(0) = 0$, the function $f\left(age_t^{(i)}\right)$ and the associated constraint can be expressed as shown in Equation (4-1).

$$f\left(age_t^{(i)}\right) = \begin{cases} \beta_1 age_t^{(i)} & \text{if } 0 \leq age_t^{(i)} \leq T, \\ \beta_2 + \beta_3 age_t^{(i)} & \text{if } T < age_t^{(i)} \end{cases} \tag{4-1}$$

$$\text{s.t.} \;\; \beta_1 T = \beta_2 + \beta_3 T \;\leftrightarrow\; \beta_1 = \frac{(\beta_2 + \beta_3 T)}{T}.$$

At this point, the function $f\left(age_t^{(i)}\right)$ can be expressed as shown in Equation (4-2):

$$
\begin{aligned}
f\left(age_t^{(i)}\right) &= \mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}}\beta_1 age_t^{(i)} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\left(\beta_2+\beta_3 age_t^{(i)}\right)\\
&= \mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}}\frac{\beta_2+\beta_3 T}{T}age_t^{(i)} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\left(\beta_2+\beta_3 age_t^{(i)}\right)\\
&= \left(\mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}}\frac{1}{T}age_t^{(i)} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\right)\beta_2\\
&\qquad + \left(\mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\right)\beta_3 age_t^{(i)}\\
&= \left(\mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}}\frac{1}{T}age_t^{(i)} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\right)\beta_2 + \beta_3 age_t^{(i)}. \qquad (4\text{-}2)
\end{aligned}
$$

Hereafter, the term associated with the coefficient β_2, $\left(\mathbf{1}_{\left\{0\le age_t^{(i)}\le T\right\}}\frac{1}{T}age_t^{(i)} + \mathbf{1}_{\left\{T<age_t^{(i)}\right\}}\right)$, will be referred to as $kink_t^{(i)}$.

4. Estimation Results

In this section, we perform estimations using the models formulated in the previous section and evaluate the validity, respectively. Additionally, we provide a detailed discussion on how differences in property attributes and renovations influence the aging-related depreciation, and we derive the implications from these findings.

4-1. Baseline Estimations

A common feature observed in the estimation results of the three models formulated in this study is the non-linear change in the cumulative depreciation rate function for office rents, $f\left(age_t^{(i)}\right)$. Specifically, depreciation proceeds at a relatively steady pace from the time of construction to around 25 years of building age, after which the pace of depreciation significantly slows down and remains nearly flat. This pattern closely resembles the findings of Bokhari and Geltner (2019) in their analysis of commercial property depreciation in the United States. Previous studies have pointed out that such nonlinearity may be influenced by factors such as the presence of land that is not subject to depreciation or continuous investments made to maintain the value of properties. The estimation results of this study also suggest that these factors may have played a role.[4]

In this study, two types of variable configurations were incorporated into each of the three models for estimation: the *Basic model*, which includes only the key variables defining property attributes, and the *Full model*, which additionally includes dummy variables capturing amenity-related features such as raised floors, individual air-conditioning, and electronic security system dummies. However, as no significant differences were observed in the estimation results between the two configurations, this study proceeds with the basic model as the primary focus for clarifying the purpose of analysis. The key features of the estimation results for each model can be summarized as follows:

(1) Estimated Depreciation Rates from the Age Dummy Variable Model

The depreciation rates calculated based on the estimation results of the model using age dummy variables exhibit significant fluctuations, as previously mentioned. The average annual depreciation rate is 1.37% for the period up to 25 years of building age, when the pace of depreciation starts to slow, and the long-term average annual rate is 0.61% up to 60 years of building age (see Chart 4).[5,6] There is a tendency for greater fluctuations in estimated values for each building age as the building age increases. This is likely due to the decreasing number of properties included in the dataset for older buildings, as they are more likely to be demolished or removed, leading to reduced stability in estimation.

(2) Estimated Depreciation Rates from the Box-Cox Transformation Model

The depreciation rates calculated from the estimation results of the model using the Box-Cox transformation exhibit relatively smooth transitions, with an average annual rate of 1.03% up to 25 years of building age and a long-term average annual rate of 0.86% up to 60 years of

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[4] The impact of continuous investments will be separately examined in subsection 3 of this section by analyzing the presence of renovations.

[5] The cumulative depreciation rate $f(age_t^{(i)})$ and the depreciation rate $\Delta f(age_t^{(i)})$ are calculated as negative values in the estimation. However, for simplicity of explanation and to ensure consistency with prior research, these are referred to as cumulative depreciation rates and depreciation rates based on their absolute values throughout this paper.

[6] Saita and Higo (2010) pointed out that the annual rate of depreciation in office rent with building age averages between around 0.9% and 1.6% for buildings up to 20 years old, and between around 0.5% and 1.6% for those up to 30 years old. These findings are almost consistent with the results of our analysis.

building age (see Chart 5). Compared to the model using age dummy variables, the changes in the pace of depreciation with building age are more gradual.

(3) Estimated Depreciation Rates from the Kinked Linear Function Model

Finally, we examine the model formulated using a kinked function where two linear functions are connected at building age T. First, we sequentially tested the kinked function model for various values of T and identified 24 years as the point that minimizes the Akaike Information Criterion (AIC) and maximizes the adjusted R-squared. Subsequently, when estimating the kinked function model with this T value, the depreciation rates were calculated as follows: an average annual rate of 1.41% up to the connection point ($T = 24$ years), an average annual rate of 0.23% from the connection point to 60 years of building age, and a long-term average annual rate of 0.70% from the time of construction to 60 years of building age. These results are broadly comparable to the estimation outcomes of the age dummy variable model (see Charts 6 and 7).

(4) Comparison of the Shapes of Cumulative Depreciation Rate and Depreciation Rate Curves

When comparing the shape of the cumulative depreciation rate function $f\left(age_t^{(i)}\right)$ between the Box-Cox transformation model and the age dummy variable model, clear differences can be observed, as evidenced by the estimation results (see Chart 8). Specifically, the Box-Cox transformation, by its very nature, smooths the trajectory of the cumulative depreciation rate and struggles to accurately depict the distinct deceleration in the pace of depreciation around the 25-year mark. While the suppression of fluctuations in the depreciation rate $\Delta f\left(age_t^{(i)}\right)$ for individual building ages might seem desirable at first glance, it poses challenges in accurately capturing the shape of the cumulative depreciation rate curve for each building age. As previously mentioned, while the application of the Box-Cox transformation to the building age variable is a standard method widely applied in many prior studies, the smoothing effect could lead to an underestimation of the divergence in depreciation rates between newer and older properties. Therefore, caution is needed when interpreting the estimation results.

When comparing the shape of the cumulative depreciation rate function $f\left(age_t^{(i)}\right)$

between the kinked function model and the age dummy variable model, the kinked function model effectively suppresses the fluctuations in the depreciation rates $\Delta f\left(age_t^{(i)}\right)$ for individual building ages, while appropriately capturing the sharp deceleration in the pace of depreciation (see Chart 8). This indicates that the kinked function model appears to effectively address the challenges identified in both the age dummy variable model and the Box-Cox transformation model. It can thus be concluded that the estimates derived from the age dummy variable model can be satisfactorily approximated through the simpler formulation of a kinked function.[7]

(5) Estimation Results for Other Variables

Reviewing the estimation results for other explanatory variables, we find the following: The walking distance from the nearest station, $min_t^{(i)}$, the logarithm of gross floor area, $\ln GFA^{(i)}$, and the central five wards dummy, $D\_center^{(i)}$, are generally significant across all models.[8] However, the number of above-ground floors, $story^{(i)}$, shows limited significance. This suggests that the positive correlation between gross floor area and the number of floors, combined with the dominant explanatory power of the former in this estimation, may account for the lack of significance in the latter.

Regarding the amenity-related variables included in the full model estimation, the raised floors dummy, $D\_RF_t^{(i)}$, is significant. On the other hand, the individual air-conditioning system dummy, $D\_AC_t^{(i)}$, and the electronic security system dummy, $D\_machine_t^{(i)}$, are not particularly significant. This indicates that the explanatory power of these variables varies, with some being more influential than others.

4-2. Robustness Check

In this subsection, we examine the potential effects on the estimation results when

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[7] In this paper, we will proceed with additional analyses primarily focusing on the standard age dummy variable model and the Box-Cox transformation model, as established in prior research. However, the finding that the age dummy variable model can be approximated by the more practical and user-friendly kinked function model is valuable for price statisticians, which may face the necessity of implementing estimation results in real-world statistical practice.

[8] These central five wards refer to *Chiyoda-ku*, *Chuo-ku*, *Minato-ku*, *Shibuya-ku*, and *Shinjuku-ku*, which are located in the center of Tokyo's 23 wards. The dummy is set with properties located in *Chuo-ku* serving as the benchmark.

modifications such as redefining variables or adding new ones are applied to the basic model used in the baseline estimation conducted in the previous subsection. This analysis aims to evaluate the robustness of the estimation results.

(1) Differences between New and Renewed Rents

In this study, we have adopted the approach of focusing exclusively on new lease contracts, taking into account the adverse effects that nominal price stickiness may have on the estimation results. However, as previously mentioned, the dataset covering properties managed by the XYMAX Group contains information on both new and renewed lease contract rents. To examine the impact of these different contract types on the estimated rates of aging-related depreciation, we conducted a subsample analysis by incorporating an interaction term between the renewed lease contract dummy $D\_renew_t^{(i)}$ and building age into the estimation for the XYMAX Group-managed properties.[9]

The estimation results revealed that, except for minor fluctuations observed in a few specific building ages, it is generally clear that the difference between new and renewed rents has a limited impact on age-related depreciation (see Chart 9). Based on these findings, and considering the need to ensure estimation accuracy, this study determines it appropriate to focus on new rents as the analysis subject, not only for XYMAX Group-managed properties but also for properties managed by other companies.

(2) Property Location

This study focuses on properties located in Tokyo's 23 wards and Osaka City. If significant differences in the aging-related depreciation rates between these two regions are observed, it would be necessary to appropriately control for location differences in the estimation. Therefore, we conducted an estimation by adding an interaction term between the Osaka City dummy $D\_Osaka^{(i)}$ and building age. The results show that, apart from certain periods

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[9] It is important to note that the data for properties managed by the XYMAX Group, which includes both new and renewed rent data, has limited coverage compared to the new rent data that encompasses properties managed by other companies. While the former comprises 80,057 observations, the latter is limited to 14,531 observations. Since the renewed lease contract dummy is meaningful only for properties managed by the XYMAX Group, it is omitted from the list of variables in Chart 1 to avoid confusion.

around 9 to 13 years and 28 to 36 years of building age, there is no significant difference in the shapes of the cumulative depreciation rate functions between the two regions (see Chart 10). In other words, the impact of regional differences on age-related depreciation appears to be minimal.

(3) Property Scale

By estimating an interaction term between the large property dummy variable $D\_large^{(i)}$ defined as properties with a gross floor area exceeding 5,000 *tsubo*, primarily to identify flagship properties in central urban redevelopment areas, and building age, it was found that there are differences in the pace of depreciation between large-scale properties and other mid- to small-scale properties. Upon closer examination, large-scale properties experience a faster pace of depreciation compared to mid- to small-scale properties for a certain period following their construction. However, around 38 years after construction, while mid- to small-scale properties continue to exhibit a gradual decline in rents, large-scale properties shift from their previously rapid depreciation pace to a nearly stagnant level, remaining relatively stable thereafter (see Chart 11).

A new property premium can be positioned as one hypothesis to explain the observed differences. Rents for flagship properties developed through urban redevelopment tend to include a premium at the time of construction due to the symbolic significance of such properties. However, this premium diminishes rapidly during the early years of the property's lifecycle, suggesting that at this stage, larger properties may depreciate at a faster rate compared to smaller properties. In contrast, as the building ages, differences in the financial capacity of property-owning entities become evident. Larger properties are more likely to undergo timely and appropriate maintenance and repairs, supported by the resources of their owners. The presence of such ongoing investments in maintenance may act as a mitigating factor against further depreciation. Moreover, when analyzing the ratio of land to building value in a property, it is generally observed that larger-scale developments, which fully utilize the maximum floor-area ratio, tend to have a higher proportion of building value relative to the overall property value (Saita and Higo, 2010). This characteristic may also contribute to a steeper curvature in the cumulative depreciation rate function for large-scale properties, suggesting a possible influence on differences in their depreciation curves.

4-3. Renovation Effects

Buildings that have depreciated over time are not necessarily demolished and rebuilt as-is. Instead, there are many cases where their asset value is restored through renovation, taking into account factors such as equipment lifespan, costs, and profitability. When analyzing the aging-related depreciation of properties, it is crucial to accurately measure the effects of renovation, the extent to which accumulated depreciation is reversed when a property undergoes renovations. Generally, renovations contribute to increasing property value and enhancing the office environment, thereby helping to raise office rents. For this reason, incorporating variables that capture the presence or absence of renovations—as well as the time elapsed since renovations—into the estimation model is highly useful for analyzing the relationship between aging-related depreciation and rents.[10]

(1) Presence of Renovation

First, we aim to verify the impact of renovations by estimating the cumulative depreciation rate of office rents. To achieve this, we include an interaction term that combines the renovation dummy variable $D\_renov_t^{(i)}$, which takes a value of 1 if the building tenant i occupies has undergone renovations, with the building age.

As a result of the estimation, it was found that the cumulative depreciation rate function shifted significantly upward due to renovations for buildings. The average magnitude of this upward shift was 5.74 percentage points for the 17-to-38-year age range and 3.47 percentage points as a long-term average up to 60 years (see Chart 12). It is natural for depreciation to be pushed back following renovations, and this result aligns with expectations. Furthermore, considering that renovations are typically carried out on properties that have reached a certain degree of aging, it is reasonable to conclude that the starting age of 17 years for the significant effects of renovations also makes sense.

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[10] Even though renovations can vary significantly, from minor interior refurbishments to full-scale renovations that utilize existing structures, this study distinguishes them using a single dummy variable regardless of these differences due to data limitations.

(2) Time Elapsed Since Renovations

Next, we examine how the effect of reversing depreciation, achieved through a renovation, erodes over time as the building continues to age. In this analysis, instead of using the renovation dummy variable, we incorporate dummies of post-renovation elapsed time into the estimation, as formulated in Equation (5). These dummies take a value of 1 based on the years elapsed since renovations was carried out for each property. Here, the coefficient φ_k of the dummy variables corresponds to the renovation effect as a function of the number of years elapsed since renovations, denoted by $recency_t^{(i)}$.

$$g\left(recency_t^{(i)}\right) = \sum_{k=1}^{60} \varphi_k \mathbf{1}_{\{recency_t^{(i)}=k\}}. \tag{5}$$

The estimation results reveal that the implementation of renovations can reverse the cumulative depreciation rate of the property by 8.23 percentage points at most immediately after renovations (see Chart 13). In other words, by controlling for the time elapsed since renovations, we can demonstrate a significant relationship whereby office rents increase following a renovation. While the renovation effect gradually diminishes over time, a significant effect in mitigating depreciation persists for up to roughly 16 years post-renovation, albeit to varying extents. On average, this reduces depreciation by 5.43 percentage points during this period.

Furthermore, when observing the rent increase effect of renovations categorized by building age at the time of renovations and the years elapsed since renovations, it is evident that older buildings and properties with shorter periods since renovations generally experience a larger rent increase effect (see Chart 14).

In this way, the reversal effect on depreciation associated with renovations, when observed on an individual property basis, is substantial and to persist over the long term. This suggests the necessity of considering the impact of renovations when analyzing the depreciation of office rent over time. However, in the dataset used for this study, only about one-fifth of the properties underwent renovations. Additionally, even among the renovated properties in the dataset, there were many cases where the elapsed years since renovations were substantial, and the reversal effect of renovations had already diminished. The impact of renovations on ageing-related depreciation is significant and cannot be overlooked when examining individual properties. However, from the perspective of the overall rental market, it can be concluded that this does not contradict the findings presented thus far.

5. Concluding Remarks

The empirical findings on ageing-related depreciation of office rents offer valuable insights that can contribute to improving the accuracy of economic statistics, such as price indices and the System of National Accounts. These findings are also promising when viewed as information that can help operate real estate business in a more strategic and effective manner. In this study, we quantitatively evaluated the impact of ageing-related depreciation on office rents in Japan by applying the hedonic method, which has been extensively used in prior research, on a large dataset of new lease contract rents and property attributes for office buildings provided by the XYMAX Group. During the analysis, we examined multiple formulations of the key parameter related to building age, while also performing robustness checks by utilizing variables in the dataset to enhance the reliability of the estimation results.

The estimation results revealed several key findings about office rents in Japan: (1) rents depreciate at an annual rate of 1.37% on average from the time a building is newly constructed until it is approximately 25 years old, after which the rate of depreciation slows; (2) the pace of depreciation varies by property scale, with larger properties depreciating faster initially but eventually stabilizing, unlike smaller properties that continue to depreciate over time; and (3) renovations reverse depreciation by approximately 8.23 percentage points at most after being carried out, with the effect lasting for about 16 years. In contrast, differences between new and renewed contract rents, as well as differences between properties located in Tokyo and Osaka, were found to have no significant impact on the pace of ageing-related depreciation.

Unlike empirical analyses of real estate prices, studies focusing on rental prices are limited worldwide. Our analysis provides valuable insights into the ageing-related depreciation of office properties. Moving forward, we intend to explore specific methods to implement the ageing-related depreciation rates estimated in this study into the items of the

SPPI for "office space rental." Additionally, to address limitations in data and other challenges not explicitly covered in this study, we plan to tackle more advanced issues. These include distinguishing between physical deterioration and functional obsolescence in ageing-related depreciation, accounting for survival bias in older properties, implementing more rigorous controls for property locations by linking them with geographic information, and addressing endogeneity regarding the aging of buildings and the implementation of renovation. Through these efforts, we aim to further deepen our analysis of office rents in Japan.

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(Chart 1) List of Variables

Variable name	Definition of the variable
Continuous variables	
$rent_t^{(i)}$	Rent of tenant i at the time of contract t. (JPY per *tsubo*)
$age_t^{(i)}$	Age of the building which tenant i occupies at the time of contract t. (in years)
$min_t^{(i)}$	Walking distance from the nearest station to the building which tenant i occupies at the time of contract t. (in minutes)
$GFA^{(i)}$	Gross floor area of the building which tenant i occupies. (in *tsubo*)
$story^{(i)}$	Number of above-ground floors in the building which tenant i occupies.
$recency_t^{(i)}$	Years elapsed since renovations to the building which tenant i occupies at the time of contract t.
Dummy variables	
$D\_center^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is in one of the five central wards of Tokyo. (*Chiyoda-ku*, *Chuo-ku*, *Minato-ku*, *Shibuya-ku*, and *Shinjuku-ku*)
$D\_Osaka^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is in Osaka City.
$D\_large^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is a large-scale property (with a gross floor area of 5,000 *tsubo* or more).
$D\_RF_t^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is equipped with raised floors (OA floors) at the time of contract t.
$D\_AC_t^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is equipped with an individual air-conditioning system at the time of contract t.
$D\_machine_t^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies is equipped with an electronic security system at the time of contract t.
$D\_renov_t^{(i)}$	A dummy variable that takes the value of 1 if the building which tenant i occupies has undergone renovations or other upgrades at the time of contract t.

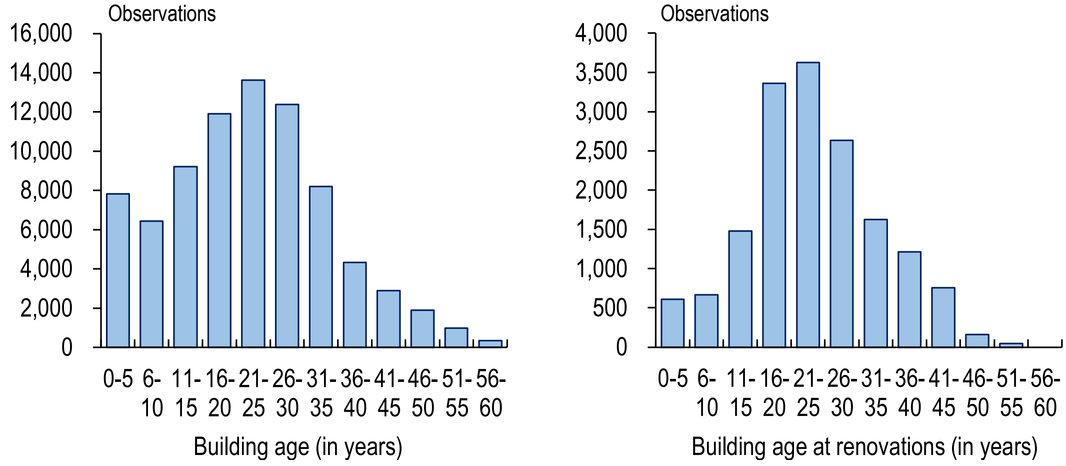
(Chart 2) Summary Statistics

Variable name	Minimum	Mean	Median	Maximum	S.D.	Exclusion criteria
Continuous variables						
$rent_t^{(i)}$	6,003	18,474	17,000	94,025	7,523	6,000 JPY or less/ over 100,000 JPY
$age_t^{(i)}$	0.0	22.3	22.0	60.0	12.2	Over 60 years
$min_t^{(i)}$	0.0	3.1	3.0	19.0	2.1	—
$GFA^{(i)}$	300	7,243	2,200	139,685	12,895	300 *tsubo* or less
$story^{(i)}$	2.0	13.3	10.0	64.0	8.8	—
$recency_t^{(i)}$	0.0	8.6	7.0	57.0	7.1	—
Dummy variables						
$D\_center^{(i)}$	0.00	0.41	0.00	1.00	—	—
$D\_Osaka^{(i)}$	0.00	0.25	0.00	1.00	—	—
$D\_large^{(i)}$	0.00	0.31	0.00	1.00	—	—
$D\_RF_t^{(i)}$	0.00	0.83	1.00	1.00	—	—
$D\_AC_t^{(i)}$	0.00	0.82	1.00	1.00	—	—
$D\_machine_t^{(i)}$	0.00	0.96	1.00	1.00	—	—
$D\_renov_t^{(i)}$	0.00	0.20	0.00	1.00	—	—

(Chart 3) Histograms

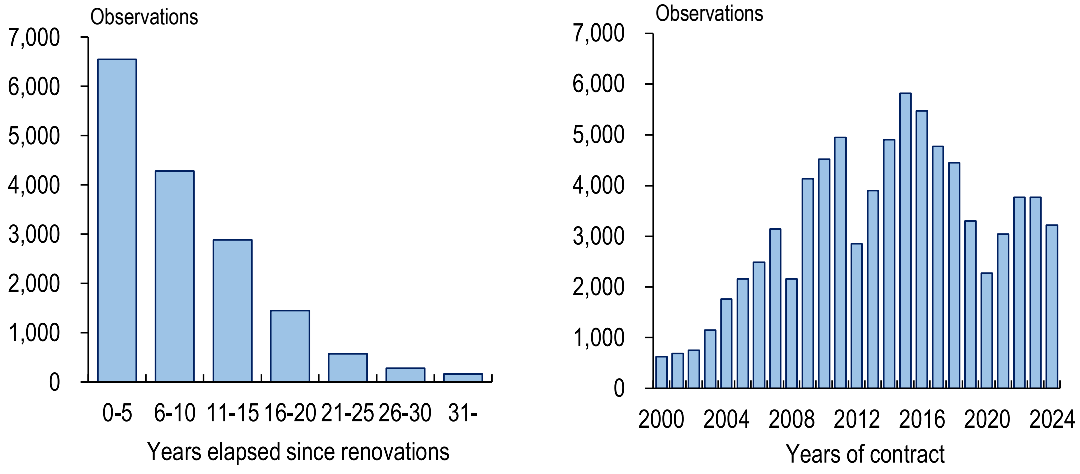
Distribution of building age $age_t^{(i)}$

Distribution of building age at the time of renovations



Distribution of years elapsed since renovations $recency_t^{(i)}$

Distribution of contract years of lease agreements



Note: Under the data specifications, only the most recent renovation year for the property is recorded. Therefore, it is important to note that renovations may have been carried out prior to that date as well.

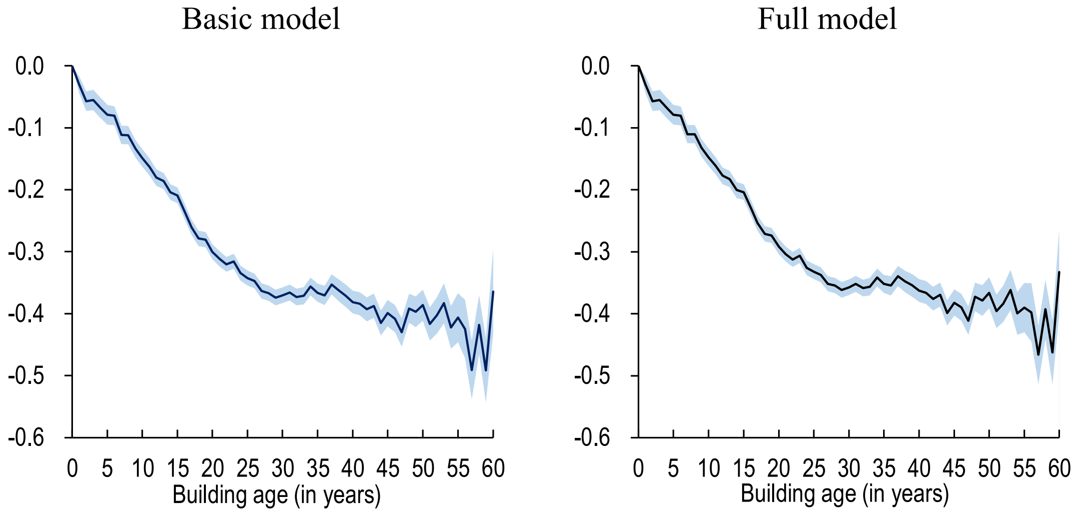
(Chart 4) Estimation Results of the Age Dummy Variable Model

(1) Estimated coefficient

Explanatory variables	Basic model		Full model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		See below	
$min_t^{(i)}$	-0.028 ***	0.000	-0.028 ***	0.000
$\ln GFA^{(i)}$	0.123 ***	0.001	0.118 ***	0.001
$story^{(i)}$	-4.896×10^{-5}	0.000	2.587×10^{-4} *	0.000
$D\_center^{(i)}$	0.561 ***	0.031	0.543 ***	0.031
$D\_RF_t^{(i)}$	—		0.054 ***	0.002
$D\_AC_t^{(i)}$	—		-0.002	0.002
$D\_machine_t^{(i)}$	—		0.007 *	0.004
$const.$	8.641 ***	0.037	8.641 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.697		0.699	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Shape of the cumulative depreciation rate curves $f\left(age_t^{(i)}\right)$



Note: The shading in graphs represents a band of ±2 standard deviations.

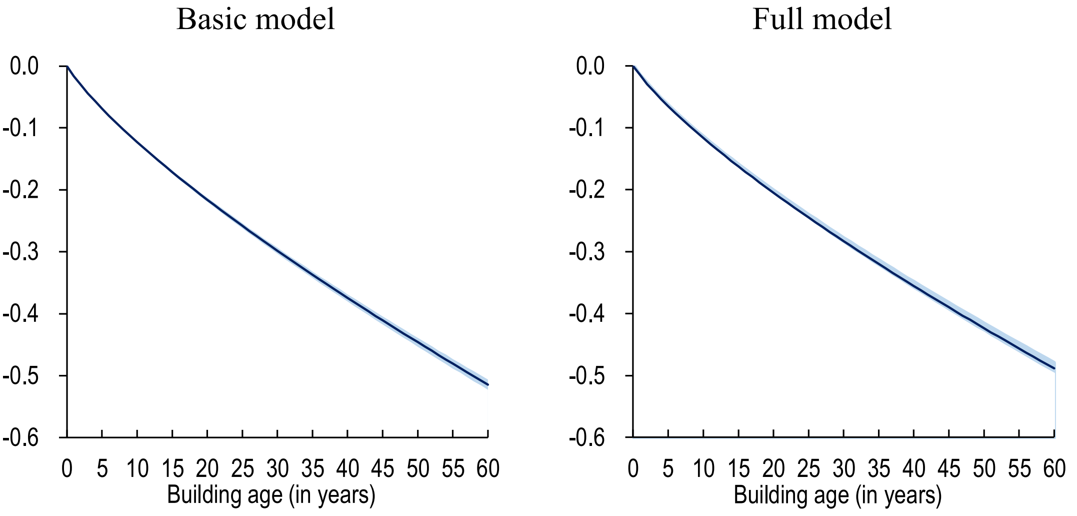
(Chart 5) Estimation Results of the Box-Cox Transformation Model

(1) Estimated coefficient

Explanatory variables	Basic model		Full model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	-0.018 ***	0.000	-0.017 ***	0.000
$min_t^{(i)}$	-0.029 ***	0.000	-0.029 ***	0.000
$\ln GFA^{(i)}$	0.127 ***	0.001	0.123 ***	0.001
$story^{(i)}$	-2.969×10^{-4} *	0.000	6.647×10^{-5}	0.000
$D\_center^{(i)}$	0.588 ***	0.031	0.570 ***	0.031
$D\_RF_t^{(i)}$	—		0.054 ***	0.002
$D\_AC_t^{(i)}$	—		0.005 *	0.002
$D\_machine_t^{(i)}$	—		-0.003	0.004
$const.$	8.569 ***	0.037	8.564 ***	0.037
λ	0.759		0.759	
Observations	80,057		80,057	
Adj. R^2	0.689		0.691	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Shape of the cumulative depreciation rate curves $f\left(age_t^{(i)}\right)$



Note: The shading in graphs represents a band of ±2 standard deviations.

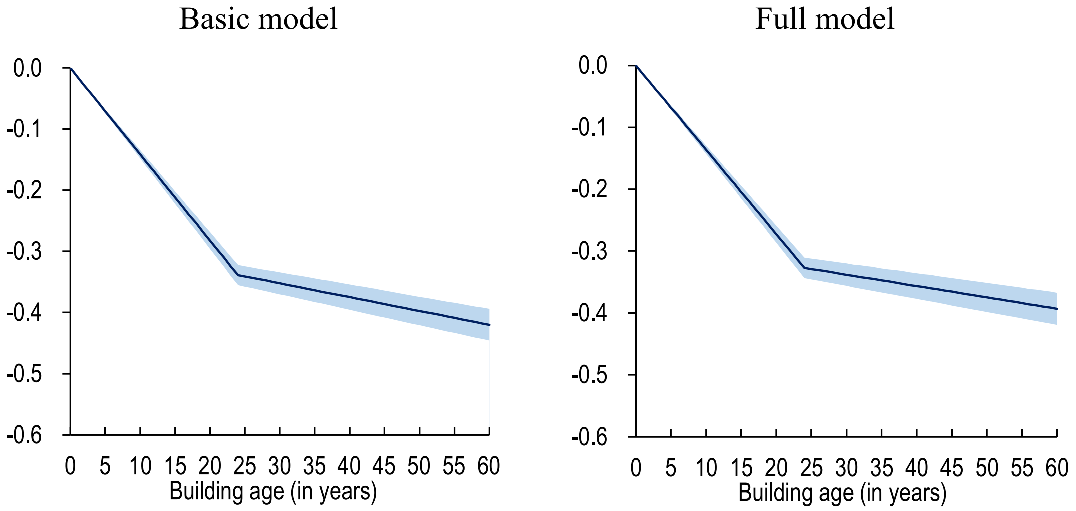
(Chart 6) Estimation Results of the Kinked Linear Function Model

(1) Estimated coefficient

Explanatory variables	Basic model		Full model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$age_t^{(i)}$	-0.002 ***	0.000	-0.002 ***	0.000
$kink_t^{(i)}$	-0.284 ***	0.005	-0.283 ***	0.005
$min_t^{(i)}$	-0.028 ***	0.000	-0.028 ***	0.000
$\ln GFA^{(i)}$	0.124 ***	0.001	0.119 ***	0.001
$story^{(i)}$	-6.400×10^{-5}	0.000	2.430×10^{-4}	0.000
$D\_center^{(i)}$	0.564 ***	0.031	0.546 ***	0.031
$D\_RF_t^{(i)}$	—		0.054 ***	0.002
$D\_AC_t^{(i)}$	—		-0.002	0.002
$D\_machine_t^{(i)}$	—		0.007 *	0.004
$const.$	8.630 ***	0.037	8.628 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.696		0.699	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Shape of the cumulative depreciation rate curves $f\left(age_t^{(i)}\right)$



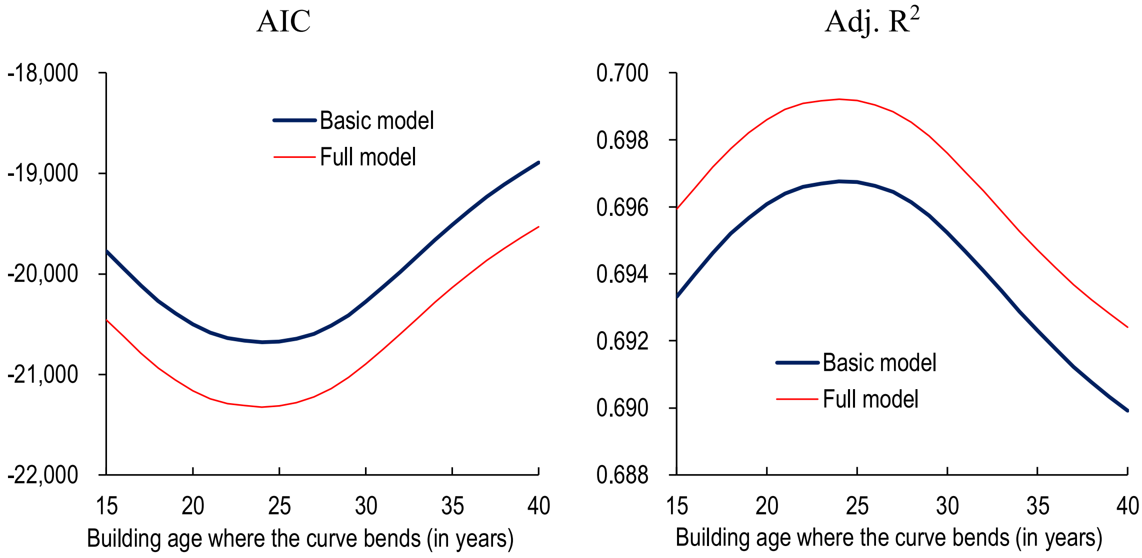
Note: The shading in graphs represents a band of ±2 standard deviations.

(Chart 7) Identifying the Connection Point of the Kinked Linear Function Model

(1) Changes in AIC and adjusted R-squared associated with the connection point of the Kinked Linear Function

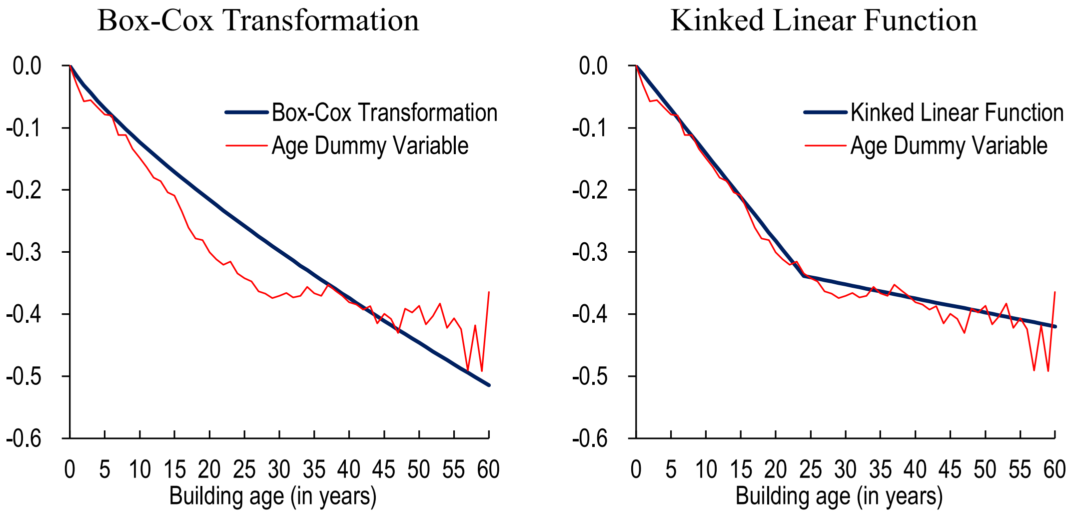
Age (T)	Basic model		Full model	
	AIC	Adj. R^2	AIC	Adj. R^2
15	-19,776	0.6933	-20,455	0.6959
16	-19,947	0.6940	-20,622	0.6966
17	-20,117	0.6946	-20,787	0.6972
18	-20,269	0.6952	-20,935	0.6977
19	-20,394	0.6957	-21,057	0.6982
20	-20,503	0.6961	-21,162	0.6986
21	-20,585	0.6964	-21,241	0.6989
22	-20,637	0.6966	-21,290	0.6991
23	-20,662	0.6967	-21,311	0.6992
24	-20,680	0.6968	-21,325	0.6992
25	-20,674	0.6967	-21,314	0.6992
26	-20,645	0.6966	-21,279	0.6990
27	-20,596	0.6964	-21,225	0.6988
28	-20,516	0.6961	-21,141	0.6985
29	-20,410	0.6957	-21,032	0.6981
30	-20,277	0.6952	-20,896	0.6976
31	-20,130	0.6947	-20,748	0.6970
32	-19,979	0.6941	-20,597	0.6965
33	-19,822	0.6935	-20,441	0.6959
34	-19,661	0.6929	-20,283	0.6953
35	-19,511	0.6923	-20,137	0.6947
36	-19,370	0.6918	-19,999	0.6942
37	-19,233	0.6912	-19,865	0.6937
38	-19,112	0.6908	-19,747	0.6932
39	-19,000	0.6903	-19,637	0.6928
40	-18,893	0.6899	-19,533	0.6924

(2) Shape of the changes in AIC and adjusted R-squared



(Chart 8) Comparison of the Cumulative Depreciation Rate and Depreciation Rate Curves

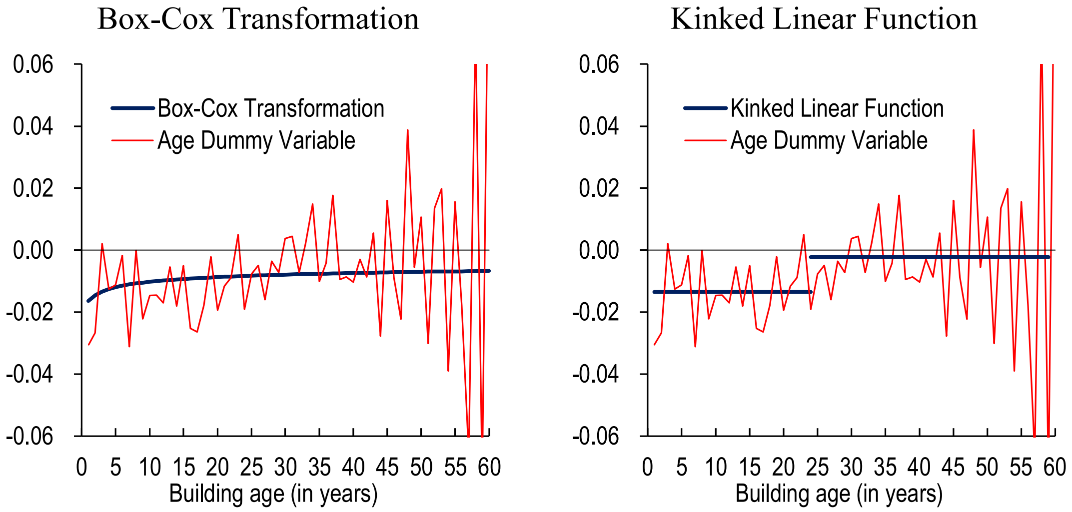
(1) Comparison of the cumulative depreciation rate curves $f\left(age_t^{(i)}\right)$



Box-Cox Transformation

Kinked Linear Function

(2) Comparison of the depreciation rate curves $\Delta f\left(age_t^{(i)}\right)$



Box-Cox Transformation

Kinked Linear Function

(Chart 9) Differences between New and Renewed Lease Contract Rents

(1) Estimated coefficient – Basic model

Explanatory variables	Age Dummy Variable model		Box-Cox Transformation model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		-0.017 ***	0.000
$f(age_t^{(i)}) \times D\_renew_t^{(i)}$	See below		-0.001 **	0.000
$D\_renew_t^{(i)}$	0.087 **	0.037	0.021 ***	0.004
$min_t^{(i)}$	-0.024 ***	0.000	-0.027 ***	0.000
$\ln GFA^{(i)}$	0.109 ***	0.001	0.110 ***	0.001
$story^{(i)}$	0.002 ***	0.000	0.001 ***	0.000
$D\_center^{(i)}$	0.372 ***	0.005	0.393 ***	0.005
$const.$	8.949 ***	0.031	8.949 ***	0.009
Observations	14,531		14,531	
Adj. R^2	0.616		0.604	

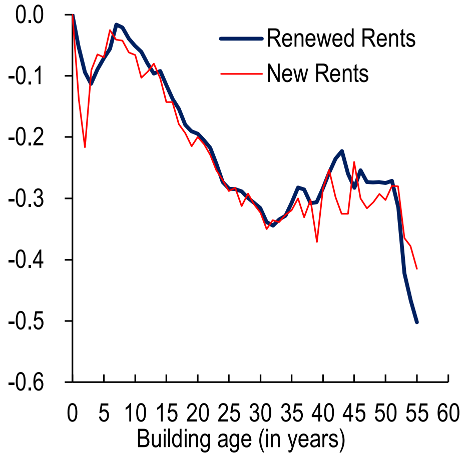
Notes 1: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

Notes 2: Since renewed rent data is available only for properties managed by the XYMAX Group, the sample size is significantly smaller compared to new rent data that includes properties managed by other companies. These estimates should therefore be viewed with caution.

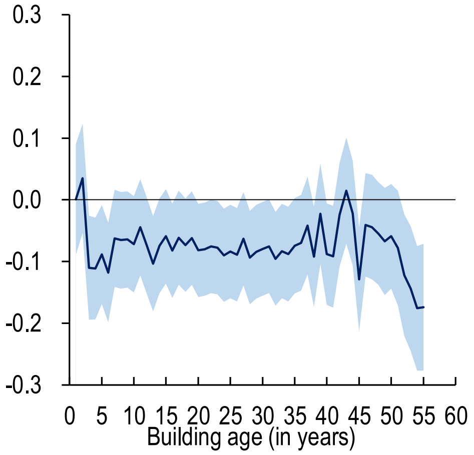
Notes 3: $D\_renew_t^{(i)}$ is a dummy variable that takes the value of 1 if tenant i renews contract at the time of contract t. Since this dummy variable is locally defined and that is meaningful only for properties managed by the XYMAX Group, it has been omitted from the list of variables in Chart 1 to avoid confusion.

(2) Comparison of the cumulative depreciation rate curves and the estimated coefficients of the interaction terms with $D\_renew_t^{(i)}$

Cumulative depreciation rate curves



Estimated coefficients
of the interaction terms



Note: The shading in graph represents a band of ±2 standard deviations.

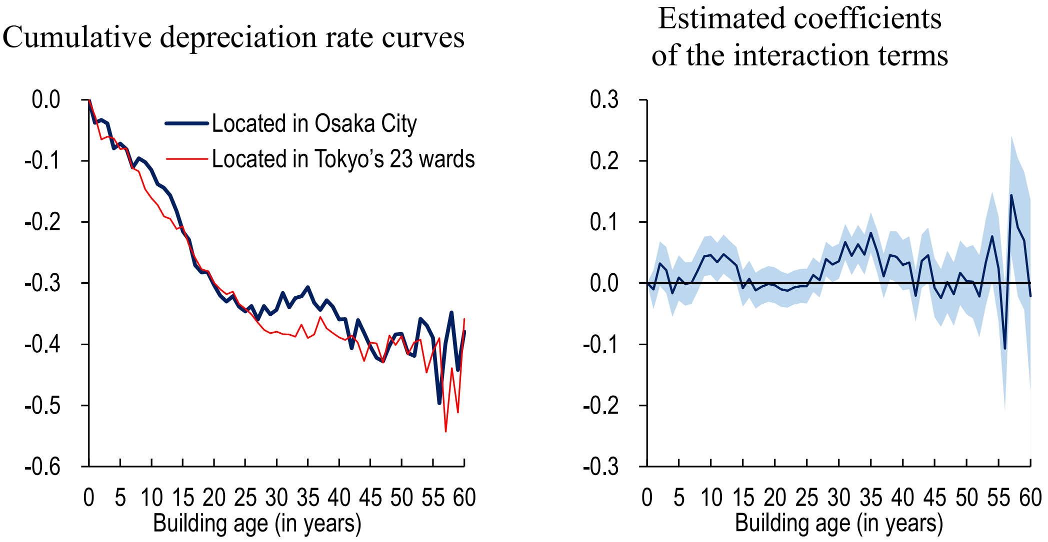
(Chart 10) Differences in Property Locations

(1) Estimated coefficient – Basic model

Explanatory variables	Age Dummy Variable model		Box-Cox Transformation model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		-0.018 ***	0.000
$f(age_t^{(i)}) \times D\_Osaka^{(i)}$	See below		0.001 ***	0.000
$D\_Osaka^{(i)}$	Estimated as the group fixed effects		Estimated as the group fixed effects	
$min_t^{(i)}$	-0.028 ***	0.000	-0.029 ***	0.000
$\ln GFA^{(i)}$	0.123 ***	0.001	0.127 ***	0.001
$story^{(i)}$	4.208×10^{-5}	0.000	-2.484×10^{-4}	0.000
$D\_center^{(i)}$	0.561 ***	0.031	0.587 ***	0.031
$const.$	8.650 ***	0.037	8.574 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.697		0.689	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Comparison of the cumulative depreciation rate curves and the estimated coefficients of the interaction terms with $D\_Osaka^{(i)}$



Cumulative depreciation rate curves

Estimated coefficients of the interaction terms

Note: The shading in graph represents a band of ±2 standard deviations.

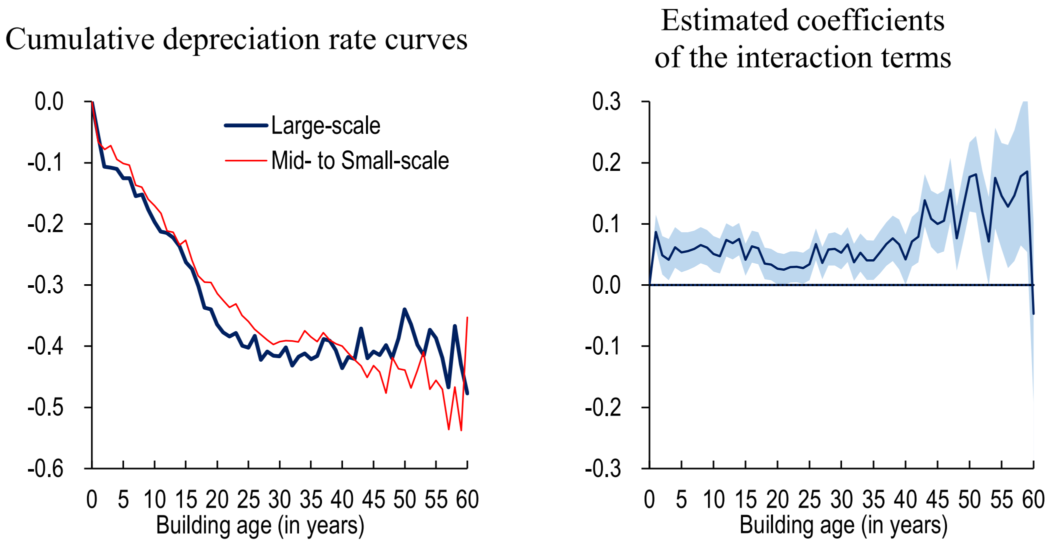
(Chart 11) Differences in Property Scales

(1) Estimated coefficient – Basic model

Explanatory variables	Age Dummy Variable model		Box-Cox Transformation model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		-0.018 ***	0.000
$f(age_t^{(i)}) \times D\_large^{(i)}$	See below		2.523×10^{-4}	0.000
$D\_large^{(i)}$	-0.077 ***	0.009	-0.030 ***	0.005
$min_t^{(i)}$	-0.028 ***	0.000	-0.029 ***	0.000
$\ln GFA^{(i)}$	0.129 ***	0.001	0.134 ***	0.001
$story^{(i)}$	2.451×10^{-4}	0.000	-6.658×10^{-5}	0.000
$D\_center^{(i)}$	0.561 ***	0.031	0.586 ***	0.031
$const.$	8.624 ***	0.037	8.524 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.698		0.689	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Comparison of the cumulative depreciation rate curves and the estimated coefficients of the interaction terms with $D\_large^{(i)}$


Cumulative depreciation rate curves

Estimated coefficients of the interaction terms

Note: The shading in graph represents a band of ±2 standard deviations.

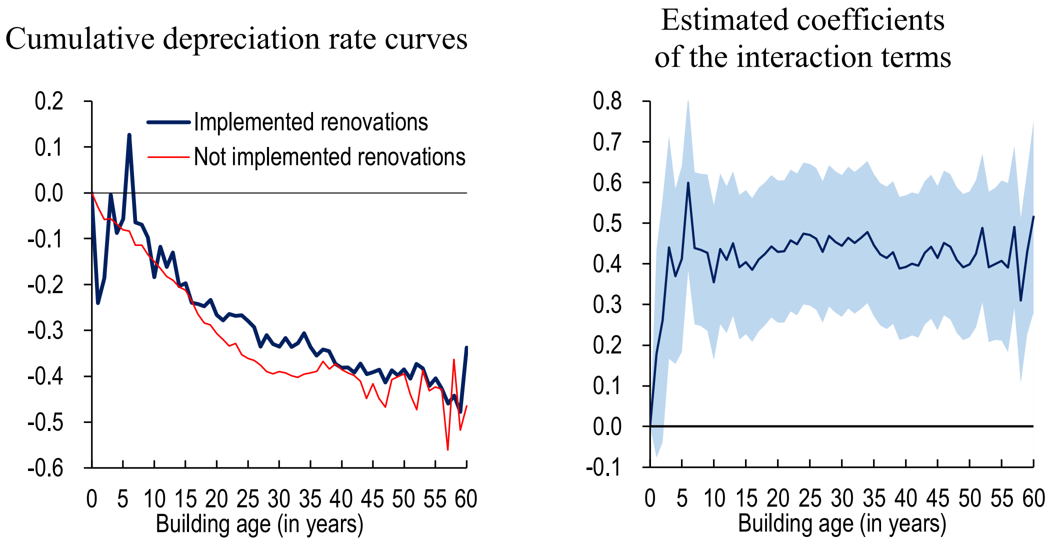
(Chart 12) Renovation Effects

(1) Estimated coefficient – Basic model

Explanatory variables	Age Dummy Variable model		Box-Cox Transformation model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		-0.021 ***	0.000
$f(age_t^{(i)}) \times D\_renov_t^{(i)}$	See below		0.008 ***	0.000
$D\_renov_t^{(i)}$	-0.389 ***	0.087	-0.077 ***	0.007
$min_t^{(i)}$	-0.028 ***	0.000	-0.029 ***	0.000
$\ln GFA^{(i)}$	0.120 ***	0.001	0.123 ***	0.001
$story^{(i)}$	2.660×10^{-4} *	0.000	1.824×10^{-4}	0.000
$D\_center^{(i)}$	0.570 ***	0.031	0.588 ***	0.031
$const.$	8.653 ***	0.037	8.615 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.700		0.694	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Comparison of the cumulative depreciation rate curves and the estimated coefficients of the interaction terms with $D\_renov_t^{(i)}$



Cumulative depreciation rate curves

Estimated coefficients of the interaction terms

Note: The shading in graph represents a band of ±2 standard deviations.

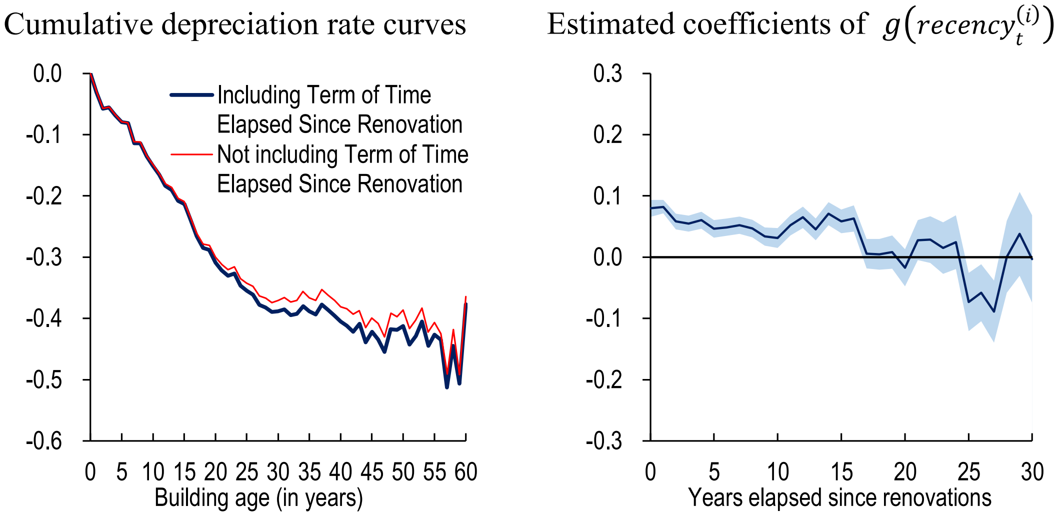
(Chart 13) Time Elapsed Since Renovations

(1) Estimated coefficient – Basic model

Explanatory variables	Age Dummy Variable model		Box-Cox Transformation model	
	Estimated coefficients	S.E.	Estimated coefficients	S.E.
$f(age_t^{(i)})$	See below		-0.020 ***	0.000
$g(recency_t^{(i)})$	See below		Omitted	
$min_t^{(i)}$	-0.028 ***	0.000	-0.029 ***	0.000
$\ln GFA^{(i)}$	0.120 ***	0.001	0.124 ***	0.001
$story^{(i)}$	2.190×10^{-4}	0.000	8.430×10^{-5}	0.000
$D\_center^{(i)}$	0.570 ***	0.031	0.593 ***	0.031
$const.$	8.652 ***	0.037	8.597 ***	0.037
Observations	80,057		80,057	
Adj. R^2	0.700		0.693	

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.

(2) Comparison of the cumulative depreciation rate curves and the estimated coefficients of $g\left(recency_t^{(i)}\right)$



Note: The shading in graph represents a band of ±2 standard deviations.

(Chart 14) Effect of Renovation on Rent Increases

Building age at the time of renovations	Years elapsed since renovations	Effect of renovation on rent increases		Observations
Ages 11 to 30	0-5 years	5.9%	***	1,716
	6-10 years	4.6%	***	1,458
	11-15 years	4.3%	***	1,021
	16 years or more	-1.5%	**	734
Ages 31 and older	0-5 years	13.5%	***	1,328
	6-10 years	7.4%	***	459
	11-15 years	11.6%	***	301
	16 years or more	4.7%	***	189

Note: *** indicates significance at the 1% level, ** at the 5% level, and * at the 10% level.