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COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

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May 8, 2024

Abstract

This is the first comprehensive study on the age profile of new rents, average rents, operating expenses, net operating income, capital expenditure, and net cash flow for office properties in Tokyo. The Intrinsic Estimator method is employed to decompose the observed depreciation into two components: physical deterioration and functional obsolescence. There are four main findings. First, the rate of rental depreciation in Japan is low and explains less than half of the rate of depreciation of property prices, although it is higher in earlier years. Second, average rents exhibit nominal rigidity. Third, approximately half of the observed depreciation in new rents is due to physical deterioration as opposed to functional obsolescence, which is driven by changes in tenant preferences and advances in building technology. Last, operating expenses are independent of age, whereas capital expenditure increases in the first 20 years. Our study contributes to the literature by estimating depreciation rates for commercial real estate rents, costs, and cash flows, with new insights into the detailed age profile and sources of economic depreciation.

Keywords: commercial real estate, offices, Japan, depreciation, age-period-cohort decomposition, hedonic model.

JEL Codes: R33, L16, E31

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1 Introduction

Economic depreciation of real estate value is important, but existing studies find a wide range of estimated rates depending on the estimation method and data. These estimates are based on a relatively large literature on the depreciation of residential property value, but studies on the depreciation of rents and cash flows are scarce. There are only a small number of studies on residential rental depreciation rates (e.g., Lane et al., 1988a; Randolph, 1988a; Campbell, 2006; Lopez and Yoshida, 2022). Studies on commercial rents and cash flow depreciation are particularly scarce, with the exception of Taubman and Rasche (1969) who examine the age profile of operating expenses, Bokhari and Geltner (2019) who examine capital expenditures, and Bokhari and Geltner (2018) who estimate commercial rent depreciation. For Japanese office rents, the Bank of Japan (2010) introduced the Corporate Services Price Index, which takes into account the depreciation of office rents.

To the best of our knowledge, this is the first comprehensive study on the depreciation of commercial real estate rents, expenses, and cash flows. Using proprietary data from the property management of office properties in Tokyo between 2005 and 2016, we analyze not only rents but also operating expenses, net operating income (NOI), capital expenditures, and net cash flow (NCF). In addition, the marginal rent for newly signed leases is distinguished from the average rent paid by existing tenants to gain insights into the nominal rigidity of commercial real estate rents. Furthermore, we use a statistical technique called the Intrinsic Estimator (IE) method to decompose the effects of age, period, and cohort on rents and cash flows. The IE estimation allows us to decompose depreciation rates into physical deterioration and functional obsolescence.

There are four main findings. First, the rate of rental depreciation is low and can explain less than half of the depreciation in property values estimated in the existing studies. The average annual depreciation rate is 0.81% for new rents and 0.58% for average rents, both of which are significantly lower than the depreciation rate of the property value (1.1%) estimated by Yoshida (2020). Non-rent factors, such as the short economic life of the building, can be the other sources of depreciation in property value because early demolition of commercial buildings is common in Japan (Diewert and Shimizu, 2017; Yoshida, 2020). At the same time, the annual depreciation rate is higher in earlier years, consistent with the age profile of property value (e.g., Bokhari and Geltner, 2018; Yoshida, 2020): 1.47%/year for new rents and 0.92%/year for average rents up to age 20.

Second, the depreciation of average rents is 0.23% lower than that of new rents–there is nominal rigidity in office rental prices. This may be due to a lock-in effect because relocation is costly for existing tenants. Even if renewal rents do not depreciate as much as new rents, existing tenants may accept them.

Third, approximately half of the observed depreciation in new rents is due to functional obsolescence – physical deterioration accounts for only the remaining half. Specifically, for new rents between ages 1 and 50, the annual rate of functional obsolescence is 0.34%, whereas the annual rate of physical deterioration is 0.37%. Functional obsolescence for Tokyo office properties is found to be driven by changes in tenant preferences and advances in building technology, particularly changes in standard floor heights to accommodate high-speed network infrastructure.

Fourth, operating expenses do not vary with the age of the building, whereas capital expenditures increase significantly when a building is 16-20 years old and 46-50 years old. The average annual rate of increase in capital expenditures over 50 years is 2.4%. These findings are consistent with anecdotal evidence that a building typically requires major renovation after 15 years and significant modernization investment if it is not redeveloped. However, large capital expenditures appear to mitigate average rent depreciation by improving building quality.

The depreciation of rents and cash flows is a major source of the decline in asset prices due to aging, which is important for economic analysis (Hulten and Wykoff, 1981a). First, the depreciation rate of structures is a key parameter for macroeconomic models because it affects equilibrium consumption, saving, capital, and productivity (e.g., Greenwood and

Hercowitz, 1991; Davis and Heathcote, 2005; Davis and Van Nieuwerburgh, 2015). In particular, depreciation rates are central to understanding Japan's high saving rate (e.g., Hayashi, 1986, 1989, 1991; Hayashi et al., 1987; Dekle and Summers, 1991; Hayashi and Prescott, 2002; Imrohoroglu et al., 2006). Depreciation rates are also a key input into economic statistics such as gross domestic product and inflation rates, which influence monetary and other macroeconomic policies (Ambrose et al., 2015).

Rent depreciation itself also plays an important role in measuring inflation. Depreciation of office rents affects the producer price index, while depreciation of residential rents affects the consumer price index. This is because a repeatedly observed rental unit inevitably ages between observations when measuring rent changes. To estimate same-quality rent inflation, the observed rent changes must be adjusted upward for the age bias by adding the estimated depreciation rate to the observed rent changes. For example, in the US, the Bureau of Labor Statistics (2018) estimates depreciation rates using the models proposed by Lane et al. (1988b), Randolph (1988a), and Campbell (2006). Because facility costs, including office rents, are a large component of business expenditures and shelter is the largest component of consumption expenditures, these adjustments have a significant impact on the measurement of inflation. These measures of inflation, in turn, influence monetary and other macroeconomic policies (Ambrose et al., 2015).

Our study contributes to the literature on real estate depreciation by providing comprehensive age profiles of rents, expenses, and cash flows of office properties in a major global real estate market using proprietary data. These estimates serve as a basis for factor cost inflation, macroeconomic statistics such as gross domestic product, and business decisions for both office tenants and owners. Our study finds that physical deterioration accounts for only about half of rent depreciation, which in turn accounts for only a portion of property value depreciation, suggesting that it is important to understand how buildings become functionally obsolete and are demolished in each market.

The remainder of this paper is organized as follows. Section 2 reviews the literature on depreciation. Section 3 explains our empirical models and estimation methods, with a particular focus on the estimation of cohort effects by the IE method. Section 4 explains the data, Section 5 summarizes the results, and Section 6 concludes.

2 Literature Review

Existing studies estimate a wide range of depreciation rates depending on the scope, methodology, and data. The scope varies by city, property type, whether rents or prices are analyzed, and whether the land component is included. Methods are based on cross-sectional or panel hedonic regressions, accumulation of flow investments, and building lifespans. Data can be real estate transaction prices, national accounts, and building demolition data. Most studies estimate the depreciation of property values, in part because property value data are more readily available than rental rate data.

There are several different methods to estimate the rate of economic depreciation of property value. First, a hedonic regression for property value is most commonly used because transaction data for different properties of different ages are more readily available than panel data for the same properties (e.g., Hulten and Wykoff, 1981a,b; Goodman and Thibodeau, 1995, 1997, 1998; Clapp and Giaccotto, 1998; Coulson and McMillen, 2008; Bokhari and Geltner, 2019, 2018; Yoshida, 2020; Francke and van de Minne, 2017; Yoshida and Sugiura, 2015). Second, several studies estimate the implicit depreciation rate in a stock accumulation equation directly from the national accounts by combining the aggregate flow investment data and the real estate stock data (e.g., Hulten and Wykoff, 1981a,b; Hayashi, 1991; Yoshida and Chun, 2001; Davis and Heathcote, 2005; Economic and Social Research Institute, 2011). The third method uses the age of the building at the time of demolition (Diewert and Shimizu, 2017; Yoshida, 2020).

The estimated depreciation rate for U.S. commercial structures based on asset prices is 2.0% for retail, 2.5% for office, 2.7% for warehouse, and 3.6% for factory (Hulten and Wykoff, 1981a). In more recent studies based on asset prices, the depreciation rate is approximately 3% for all commercial structures and 3.3%-4.0%for residential structures (e.g., Fisher et al., 2005; Bokhari and Geltner, 2019). However, based on the implicit rate in the national accounts published by the Bureau of Economic Analysis, the depreciation rate for nonresidential structures is approximately 6% (e.g., Hulten and Wykoff, 1981b; Hayashi, 1991). Estimates of the depreciation of Japanese commercial structures are relatively scarce and vary widely. A panel regression for appraisal values yields 2.0% for office structures (Diewert and Shimizu, 2017), studies using national accounts report 5.7%-7.2% (e.g., Hayashi, 1991; Economic and Social Research Institute, 2011), hedonic regressions give 9.8%-10.8% (Yoshida, 2020), and demolition data suggest 11.7% (Yoshida, 2020). In contrast, depreciation rates for residential structures in the U.S. fall within a relatively narrow range: 1.36% (Leigh, 1980), 1.89% (Knight and Sirmans, 1996), and 1.94% (Harding et al., 2007). Based on national accounts, the rate is 1.57% between 1948 and 2001 (Davis and Heathcote, 2005).

There are two major sources of bias in estimating depreciation rates for property values. First, there is a survivorship bias, in the sense that older buildings in the market tend to be of high quality because lower-quality buildings have been demolished earlier. This bias can reduce the estimated depreciation rate for older properties (Hulten and Wykoff, 1981b; Yoshida, 2020). Although there are methods to correct for this bias (e.g., Hulten and Wykoff, 1981b; Bokhari and Geltner, 2018; Yoshida, 2020), we do not use them in the current study because these methods are designed for the property value depreciation rather than rent depreciation. Developing a bias correction method for rents is a future task.

Second, economic depreciation for older properties is also affected by redevelopment options (e.g., Clapp and Salavei, 2010; Clapp et al., 2012; Munneke and Womack, 2020). In the hedonic model, the value of the property consists of both the present value of the rental stream from the current structure and the option to redevelop the property. Omitting the option component, which tends to increase in value with age, biases the estimated depreciation rate downward. However, this issue does not significantly impact the present study because real options primarily affect property values instead of periodic rents and expenditures.

The property value depreciates due to both rent depreciation and a shorter structure life (Lopez and Yoshida, 2022). In general, the property value depreciation rate is higher than the rent depreciation rate in the U.S., where slowly depreciating structures account for a significant portion of the property value, but the opposite is true in China where land value is significant (e.g., Xu et al., 2018). Overall, for a relatively new building, the effect of a shorter remaining life is negligible, so we expect similar depreciation rates for both rents and property values. However, for older buildings, property value depreciation rates may be higher or lower than rent depreciation rates due to several competing factors: shorter economic life, redevelopment options, and a survivorship bias.

When estimating depreciation rates, most hedonic regression studies omit cohort effects, which could lead to a biased estimate of the rate of physical deterioration (Browning et al., 2012). A small number of studies control for cohort effects (Coulson and McMillen, 2008; Francke and van de Minne, 2017; Lopez and Yoshida, 2022). In particular, Lopez and Yoshida (2022) show that the depreciation rate is significantly lower after controlling for cohort effects. This lower depreciation rate after controlling for cohort effects can be interpreted as physical deterioration–wear and tear of the structure, whereas negative effects of older cohorts can be interpreted as functional obsolescence due to technological progress and changes in consumer tastes (Francke and van de Minne, 2017; Lopez and Yoshida, 2022). Functional obsolescence can also be caused by a change in neighborhood characteristics (Wilhelmsson, 2008). For the purpose of inflation measurement and national accounts, the relevant concept of depreciation is the total economic depreciation due to both deterioration and obsolescence.

Dixon et al. (1999) call for more elaborate studies on rental depreciation as a basis for price depreciation. There is a small literature on rental depreciation for residential property. For example, Randolph (1988b) estimates the average rent depreciation rate for the nation (0.36%) and major metropolitan statistical areas (MSAs), ranging from 0.76% for Anchorage to −0.40% (appreciation) for Washington D.C. Similar rates are estimated by Lane et al.

(1988a); Campbell (1997) and used to adjust rent inflation statistics. Malpezzi et al. (1987) use the American Housing Survey and estimate average rent depreciation for a large number of MSAs. Lopez and Yoshida (2022) estimate that the annual rent depreciation rate in the Las Vegas MSA is 0.9% for new single-family homes and 1.5% for new condominiums.

3 Empirical strategy

3.1 The Baseline Model

We estimate the age profile of rents, expenses, and cash flows. Our first model is the following hedonic model:

$$\ln Y_{it} = f\left(A_{it}\right) + \boldsymbol{X}_{it}\beta + \gamma_j + \tau_t + \epsilon_{it}, \tag{1}$$

where the dependent variable $\ln Y_{it}$ for building i observed at year t includes the natural logarithm of new rents, average rents, operating expenses, NOI, capital expenditure, and NCF. $f\left(A_{it}\right)$ denotes a function of building age A_{it}, τ_t denotes year fixed effects, and γ_j denotes area (ward) fixed effects. The vector $\boldsymbol{X}_{it}$ is a set of building characteristics, including the logarithm of the gross floor area, the walking minutes to the nearest train station, and an indicator of whether the building was renovated before time t. As a robustness check, we also estimate the model with non-linear controls by controlling for quartile groups for gross floor area and the walking minutes (Appendix E).

For the age function f, we follow the literature (e.g., Bokhari and Geltner, 2018) and specify a log-linear function and a non-linear step function based on age groups:

$$f\left(A_{it}\right) = \alpha_1 A_{it}, \tag{2}$$

and

$$f\left(A_{it}\right) = \sum_{n=2}^{10} \alpha_{2,n} I_n\left(A_{it}\right), \tag{3}$$

where a five-year age group indicator $I_n(A_{it}) = 1$ if $A_{it} \in [5n-4, 5n]$ for $n = \{1, ..., 10\}$. We omit I_1 as the reference group in equation (3). These five-year age groups are also used in the IE estimation to compare the results with and without cohort controls. The estimated coefficient α_1 represents the average annual rate of change in Y for all building ages, whereas coefficient $\alpha_{2,n}$ represents the log difference in Y between age group $[5n-4, 5n]$ and the reference age group $[1, 5]$.

3.2 Cohort Effects

In equation (1), we assume the absence of cohort effects. It is a standard assumption for many hedonic studies (e.g., Randolph, 1988b; Lane et al., 1988a). However, building cohorts may have a significant effect on office rents because of large changes in building and business technologies after WWII. In this case, the omission of cohort effects will result in a biased estimate of the age effect (Browning et al., 2012). Moreover, the estimated cohort effect will provide valuable information about functional obsolescence–a major component of economic depreciation. Francke and van de Minne (2017) argue that functional obsolescence is associated with the time of construction (i.e., cohort effects) because the functional characteristics of a building are determined largely by the taste and technology prevalent at the time of construction. Cohort effects also include additional vintage premium or discounts associated with construction qualities (Coulson and McMillen, 2008). Thus, by controlling for cohort effects, Francke and van de Minne (2017) interpret age coefficients as representing physical deterioration. Furthermore, Lopez and Yoshida (2022) decompose cohort effects into functional obsolescence and vintage effects by recognizing that cohort effects tend to exhibit an upward trend; rents for an earlier cohort tend to be lower than those for a recent cohort. This upward trend is arguably caused by cumulative functional obsolescence.

However, it is an empirical challenge to estimate cohort effects with period and age effects because age is a linear combination of the year built and the observation year. Thus, simply including age, period, and cohort dummy variables will create a collinearity problem. There are several methods to address collinearity and include cohorts in addition to age and period variables. A simple solution is to assume that log rents are a quadratic function of age while keeping the other two effects flexible. However, there is evidence that a quadratic function cannot represent the age function (Coulson and McMillen, 2008; Francke and van de Minne, 2017). Coulson and McMillen (2008) address this empirical challenge by using a variant of constrained generalized linear models proposed by McKenzie (2006). Specifically, they estimate the second differences of age, period, and cohort effects with no normalization restrictions. Then, they recover the function for each effect by "integrating" the second differences by setting an arbitrary slope for a base segment of each function. However, this method is sensitive to the arbitrary choice of the identifying constraint, which is a common issue for any constrained linear models (Browning et al., 2012). Alternatively, Francke and van de Minne (2017) address the multi-collinearity problem by imposing a constraint based on the economic decomposition of property value into structure and land. Their constraint is that the age coefficient represents the physical deterioration of structures, the cohort coefficient represents the sum of functional obsolescence and vintage effects, and the time coefficient represents the effect of land price and current construction costs. A key identifying assumption is that functional obsolescence depends only on the time of construction.

3.3 The Intrinsic Estimator Method

In our study, we follow Lopez and Yoshida (2022) and use the intrinsic estimator method, which is widely used in demography and epidemiological research to address collinearity among age, period, and cohort (Yang et al., 2004, 2008). This method has also been used in economics (Diamond et al., 2020) and finance (Fagereng et al., 2017).

Consider the model that includes cohort effects in addition to age and period effects:

$$Y_{it} = X_i\beta + \gamma_j + \alpha_a + \pi_p + \kappa_c + \epsilon_{it}, \tag{4}$$

where X denotes the same set of controls as in equation (1), α_a denotes an age effect for the 5-year age group between $a-4$ and a years old for $a = \{5, 10, ..., 50\}$, π_p denotes period effects for the 5-year period group between p and $p+4$ for $p = \{2005, 2010, 2015\}$, and κ_c denotes a cohort effect for the 5-year cohort group between c and $c+4$ for $c = \{1955, 1960, ..., 2010\}$ based on the year built. Specifically, we first specify five-year groups for age (e.g., 1–5, 6–10, and 11-15) and cohort (e.g., 1955–1959 and 1960–1964) and define the period as the sum of these two group values ($p = c + a$). This five-year grouping scheme is standard practice and allows us to avoid an under-identification problem arising from too few observations in any age-period-cohort intersection (see Yang et al., 2008).

This model cannot be estimated by ordinary least squares because of collinearity. The IE method addresses this age-period-cohort multicollinearity problem using a principal components regression method. The method essentially decomposes parameters and removes the component that causes the singularity of regressors (i.e., the component corresponding to the eigenvalue zero). The IE is consistent and unbiased and is more efficient than constrained linear estimators (Yang et al., 2004, 2008). Browning et al. (2012) show that the IE and their maximum entropy estimator provide more reasonable estimates than linear estimators with arbitrary constraints. The IE method is further explained in Appendix A.

4 Data

The data are provided by Xymax Corporation, one of the largest property management companies in Japan. The data set includes information on newly signed leases between 2005 and 2016 for properties in the central 23 wards of Tokyo managed by both Xymax and other property managers. This data set is a representative sample of office properties in Tokyo with a gross floor area (GFA) greater than $1,000\,m^2$.

The data set also includes a smaller sample of properties with additional cash flow information for the properties managed by Xymax. It includes monthly rents for each rental unit in a property, property-level operating expenses between 2007 and 2016, and property-level capital expenditure between 2005 and 2015. Annual operating expense data include maintenance, management fees, utilities, insurance, and other expenses related to the operation of the property, whereas capital expenditure data include total annual payments for various repairs and renovations to maintain and improve building functionality. We excluded trust-related costs and other unconventional expenses that occur under special circumstances. We further calculated NOI and NCF for the properties for which both rental revenue and expenses are available.

These new rents and other cash flow records are matched with building characteristic data. Gross floor area is the total floor area of a building, including both leased and common areas. Building age is the difference between the completion year and the observation year. Walking minutes to the nearest train or subway station is calculated by dividing the route distance by a walking speed of 80 meters/minute. Using the postal address, we constructed location ward dummy variables. We also constructed a renewal dummy to indicate whether a building had undergone a major renovation by the time of observation.

The Xymax data set excludes observations with low and high rents to keep the observations with monthly rents ranging from $6,000$ to $100,000$ JPY/tsubo, where tsubo is a unit of building area equal to 35.54 square feet (sqft). With an exchange rate of 150 JPY/USD, this range corresponds to 14 and 225 USD/sqft/year. We further cleaned the data by restricting our attention to buildings up to 50 years old to estimate the age group coefficients reliably.

To consistently analyze unit-level rents and building-level cash flows, we aggregate unit-specific rents at the building level. The building-level new rents are calculated as the simple average of the newly contracted rents for a building in each year. The average rent is the annual weighted average of monthly rents for all existing tenants, weighted by the rental space share of each unit.

Table 1 shows the descriptive statistics of the cleaned data set. The definitions of the variables are summarized in Table A1. Note that a smaller sample is used for each regression analysis depending on whether the dependent variable is available. The descriptive statistics of regression subsamples are shown in Appendix C. For the variables of interest, the number of observations is 19,600 for new rents, 1,902 for average rents, 875 for operating expenses, 1,965 for capital expenditure, 796 for NOI, and 680 for NCF. We further excluded a small number of building-year observations with negative values of NOI and NCF and took the natural logarithm of these cash flows. After the removal, the number of observations slightly decreased from 796 to 783 for NOI (Table A10) and from 680 to 666 (Table A12). Because each building has multiple years of observations, the number of buildings is 6,041 for new rents, 292 for average rents, 229 for operating expenses, 328 for capital expenditure, 212 for NOI, and 148 for NCF.

For characteristic variables such as YEAR, the number of observations is larger (21,007) because these characteristic variables are associated with all of the non-overlapping cash flow observations. In a regression analysis, we use the largest sample available for each dependent variable (see Appendix C) but also conduct robustness checks by using the subsample that consistently includes all of the dependent variables (Appendix D).

[Table 1 about here.]

The mean new rent is 64,219 JPY/m^2/year, and the mean average rent is 63,369 JPY/m^2/year (approximately 40 USD/sqft/year at a currency exchange rate of 150 JPY/USD). These rents include a flat monthly property management fee (Kyou-eki-hi), which covers common area maintenance. The mean operating expense is 18,265 JPY/m^2/year. If both average rents and operating expenses are available for a property, NOI can be calculated. The mean NOI at the property level is 46,883 JPY/m^2/year, which is approximately 74.0% of the mean average rent. This high proportion of NOI reflects the fact that the standard office lease type in Japan is the modified gross lease, in which tenants reimburse the metered electricity cost for their leased space while the landlord pays the other operating expenses. The mean capital expenditure is 4,152 JPY/m^2/year, or approximately 8.9% of NOI. The mean NCF after capital expenditure is 42,760 JPY/m^2/year.

In the entire sample, observation years range between 2005 and 2016. Building ages range from 1 to 50 years, with an average age of 22.7 years, but approximately 16% of the buildings had major renovations. The average gross floor area is $12,387\,m^2$, located approximately 5 minutes from the nearest train station.[1] Figure 1 shows the map of central Tokyo with building locations in the sample. Buildings are distributed across all 23 wards, including major office districts such as Marunouchi and Shinjuku. The void at the center is the Imperial Palace.

[Figure 1 about here.]

The sample of $6,102$ buildings shown in Table 1 is reasonably representative of the population of Tokyo rental office properties in Tokyo's 23 wards. One of the comprehensive surveys on rental office properties is the National Office Property Survey by Japan Real Estate Institute.[2] In this survey, the average GFA per property in Tokyo's 23 wards is $14,836\,m^2$, and the average building age is approximately 25 years. These figures are comparable to the average GFA and age in our sample. This sample roughly corresponds to the new rent sample (Table A2).

The samples for average rents, expenditures, and cash flows (Tables A4–A12) also exhibit similar characteristics, with the exception of GFA. For instance, the mean GFA in the average rent sample is smaller at $7,217\,m^2$. However, this discrepancy in GFA corresponds to only a relatively minor difference in percentiles. Specifically, $7,217\,m^2$ corresponds to the 79th percentile, while $12,387\,m^2$ corresponds to the 88th percentile of the entire distribution. This is due to the highly skewed distribution of GFA. Consequently, we take a natural logarithm of GFA in regression analysis.

Tokyo is one of the largest office markets comparable to New York and London markets, and its office properties are traded as core assets by global real estate investors. The operation

[1]There are 18 properties that have GFA smaller than $1,000\,m^2$, but they account for only 1% of the sample.

[2]For the 2023 survey, see `https://www.reinet.or.jp/wp-content/uploads/2023/10/a44c25fe4221c029c67cc54cf64c2518.pdf`.

of leasing and asset markets is largely similar to the other major markets despite some differences in business practice. However, Tokyo's office building stock is relatively new compared to that of the New York and London markets because of the rapid development that occurred in Tokyo after WWII. Thus, we limit our sample to 50 years old or newer.

5 Results

5.1 Aging Effects on Rents, Expenses, and Cash Flows

We estimate the depreciation rate of new rents, average rents, operating expenses, NOI, capital expenditure, and NCF as the coefficient for the linear age function (equation (2)) in the hedonic regression of a log dependent variable (equation (1)). Thus, the age coefficient can be interpreted as the average annual depreciation rate for all building ages. In addition to the main regression analysis, we also report the results of robustness checks using the subsample that includes all of the dependent variables (Appendix D) and using non-linear control of building size and walking minutes (Appendix E). These robustness-check results are consistent with the main results.

Table 2 summarizes the results. Column (1) shows the estimation results for log new rents, which can be interpreted as the marginal rent determined in the current rental market. The average annual depreciation rate for new rents is 0.81%. This depreciation rate, which is precisely estimated with a standard error of 0.02%, is significantly lower than the property value depreciation rate estimated in existing studies. For example, Yoshida (2020) estimates an average depreciation rate of 1.1% at the property level, including land. As Yoshida (2020) demonstrates, the difference between value and rent depreciation rates should be largely attributed to the shortened economic life of a building, which is sometimes described as the cap rate creep (Bokhari and Geltner, 2019). The estimated coefficients on other variables are consistent with the conventional view. For example, rents are 0.15% higher for a 1% larger building, 2.3% lower for a one-minute longer walk to the nearest train station, and

5.2% higher for a renovated building.

[Table 2 about here.]

Column (2) shows the results for log average rents, which determines the potential gross revenue and serves as the basis for the property value. The average annual depreciation rate is 0.58% with a standard error of 0.12%. Although this rate is lower than the rate for new rents, it is consistent with the rate used by Bank of Japan (2010) in constructing the Corporate Services Price Index. The Bank of Japan estimates the depreciation rate for average office rents in Tokyo as 0.55% by adjusting for quality in a similar manner using the average rents of office buildings in Tokyo.

These estimated annual depreciation rates suggest that the age discount for a lease renewal is 0.23 percentage points smaller than for a new lease. A possible reason is that gross floor area is significantly smaller in the average rent sample ($7,217\,m^2$) than in the new rent sample ($12,842\,m^2$) (Tables A2 and A4). A smaller building size corresponds to a lower floor-to-area ratio, although the value share of land may not be higher because the land price per m^2 tends to be lower for smaller buildings due to locational differences. Other characteristics are comparable between these samples. To check the robustness of the results to sample differences, we estimate the same model using a subsample that consistently includes all of the rent, expense, and cash flow information (Appendix D). Table A15 shows the results that are qualitatively consistent with the main results. The average annual rate of depreciation is larger for new rents (0.69%) than for average rents (0.52%).

This lower depreciation rate for average rents suggests a significant rigidity of rents for renewed leases (cf. Shimizu et al., 2010). This rigidity may be explained by office relocation costs for the current tenant. Alternatively, market inflation adjustments may be small for existing tenants. Then, after a period of high rent inflation, existing tenants may still pay a renewal rent that is lower than the marginal rent for a new lease, even after a smaller depreciation adjustment.

Column (3) shows the results for log operating expenses. As indicated by a low adjusted R-squared (0.11), our hedonic model explains only a small fraction of the variation in operating expenses. None of the estimated coefficients are statistically significant. Although the point estimate for age is negative, the estimated age coefficient is not statistically significant.

Column (4) shows the results for log NOI, which is equivalent to vacancy-adjusted income from net leases and is the basis for property valuation. However, the estimated age coefficient (−0.23%) is not statistically significant. This rate is significantly lower than the rate for property value in the literature. Thus, this result rules out the possibility that NOI depreciation is the main source of the property depreciation rate. Rather, the shortened remaining life of the building can be a major source of depreciation, especially when a building's lifespan is short because the annual change in the remaining life of the building is significant. Thus, our result suggests that the main cause of the high depreciation rate for Japanese office property value is the short economic life of buildings.

Column (5) shows the results for log capital expenditure. The model cannot explain the majority of variations in capital expenditure with an adjusted R-squared of only 0.06. However, among many idiosyncratic determinants of capital expenditure, age has a small positive effect that is statistically significant at the 1% level. The average annual increase is 2.4% in the baseline model, suggesting that capital expenditure tends to increase with building age.

Column (6) shows the results for log NCF. The estimated annual depreciation rate is 0.50%, which is statistically significant at the 10% level. It is larger than the NOI depreciation rate because of the increasing capital expenditure with age.

In addition, we conduct a robustness check by controlling for quartile dummy variables for GFA and MINUTES to address a concern that the potentially non-monotonic and nonlinear effect of these variables may affect the estimated depreciation rate. Table A16 in Appendix E shows that the estimated depreciation rates are consistent with the main results for all variables. The largest difference in the age coefficient is only −0.0011 for NCF.

5.2 Depreciation by Age Group

To allow the annual depreciation rate to vary by building age, we estimate the hedonic model using the age group step function as specified in equation (3). Tables 3, 5, and 6 show the results of the OLS estimation for rents, expenses, and cash flows, respectively. The estimated coefficient for each age group indicates the log difference from the reference group of ages 1-5. Additionally, for rents, columns (1) and (4) of Table 4 present the implied average annual total depreciation rate for different age groups.

Column (1) of Table 3 shows that discounts in log new rents become monotonically larger with building age. The dotted line in Figure 2a visualizes the estimated coefficients with a 95% confidence interval. The slope of the log rent function is steepest between the 6-10 and 11-15 age groups, and new rents for the 11-15 age group are 15.9% lower than those for newer buildings after controlling for rent inflation over time. The rent discount reaches a maximum of 34.5% when the building is between 41 and 45 years old.

[Table 3 about here.]

[Figure 2 about here.]

Overall, the depreciation rate is higher in the early years and lower in the later years. Table 4 shows the implied average annual total depreciation rate for each age group. The results suggest that the depreciation rate for new rents (column (1)) is highest between ages 1 and 15 with an annual rate of 1.59%. As the building ages, the depreciation rate steadily decreases. For longer ranges 1-45 and 1-50, the average depreciation rate is 0.86% and 0.71%, respectively, comparable to the result from the linear model (0.81%). This age profile is qualitatively similar to that for property values and prices (e.g., Bokhari and Geltner, 2019; Yoshida, 2020).

Column (3) of Table 3 and Figure 2b show that average rents also exhibit a general age discount. Although age discounts are negligible up to age 15, they increase significantly between ages 11-15 and 16-20. As a result, average rents for ages 21-25 and 26-30 are approximately 17% lower than that for newer buildings. After 30 years, the age profile shows an interesting bump between 31 and 45 years. This bump could be caused by several factors. First, observed average rents could be improved by capital expenditure. As we discuss in the subsequent section, there is a negative correlation between the age profile of average rents and that of capital expenditure. Annual capital expenditure gradually increases until 30 years old. Thus, it is possible that significant capital expenditure for these age groups prevents the average rents from declining further by improving the physical condition of the building. Second, particular cohorts correlated with ages 36-40 may be affecting the aging effect. As is discussed in the next section, once cohort effects are controlled for, the bump becomes negligible (Figure 2b). Third, the rent bump may be due to unique sample characteristics. When the same model is estimated using the consistent subsample, the bump becomes negligible. Thus, it is unclear whether this bump is economically meaningful age characteristics. Overall, column (4) of Table 4 shows that the largest implied depreciation rate is 0.92% between ages 1 and 20. For the entire age range, the average depreciation rate is 0.55%, which is consistent with the depreciation rate based on the linear model as well as the rate used by Bank of Japan (2010).

[Table 4 about here.]

Column (1) of Table 5 and Figure 3a show the results for operating expenses. Although there is a decreasing trend up to ages 31-35, the estimated coefficients are not distinguished from zero because of large standard errors. Thus, we do not find a meaningful age profile for operating expenses.

[Table 5 about here.]

[Figure 3 about here.]

In contrast, capital expenditure exhibits a clear age pattern. Column (3) of Table 5 and Figure 3b show that capital expenditure tends to increase until age 16-20 and level off until age 26-30. The capital expenditure in ages 16-20 is 187% greater than the amount spent between ages 1-5. This finding is consistent with anecdotal evidence. The need for capital expenditure is minimal while the building is relatively new. However, when the building reaches about 15 years of age, major renovations are undertaken, such as exterior wall tiling and rooftop waterproofing, to maintain the physical condition of the building. In addition, major equipment, such as the ventilation and air conditioning system, reaches the end of its useful life. However, after 30 years, capital expenditure decreases until age 45. Once the building is past the age for major renovations, significant capital expenditures are deferred in anticipation of redevelopment (e.g., Clapp and Salavei, 2010; Clapp et al., 2012; Munneke and Womack, 2020). The buildings that survived without rehabilitation would require additional major capital expenditures to replace elevators and modernize the building after 46 years.

Table 6 and Figure 4 show the results for NOI and NCF. For NOI (column 1), the estimated coefficients hover around zero and do not clearly exhibit depreciation. Because of large standard errors, none of these coefficients are statistically different from zero. For NCF (column 3), the estimated coefficients are consistently negative for ages 11-15 or older. Although standard errors are also large, the coefficient is statistically different from zero at the 5% level for ages 16-20, 21-25, and 46-50. This result is consistent with a marginally significant average depreciation rate based on the log-linear model.

[Table 6 about here.]

[Figure 4 about here.]

5.3 Physical Deterioration and Functional Obsolescence

The OLS age coefficients are estimated in the previous section under the assumption of no cohort effects. When there are non-zero cohort effects, as we discussed in Section 3, the cohort-controlled effect of age is interpreted as physical deterioration, whereas the difference between the age coefficients with and without cohort control is interpreted as functional obsolescence. The IE estimation results for rents are shown in columns (2) and (4) of Table

3. Also, the bold solid lines in Figure 2 visualize the IE age profile for rents after controlling for cohort effects. The full estimation results are presented in Table A17 in Appendix F.

Age discounts in rents are significantly smaller after controlling for cohort effects. In other words, physical deterioration accounts for only a fraction of total rent depreciation. Specifically, the effect of physical deterioration for ages 46-50 is only 16.5% on new rents and 13.8% on average rents. Similar to the age profile without cohort control, the slope is steepest until 25 or 30 years old. Comparing rents for the 21-25 age group with those for the 1-5 age group, the rent discounts are 12.3% for new rents and 4.0% for average rents.

Table 4 shows the decomposition of total depreciation into physical deterioration (Column (2)) and functional obsolescence (Column (3)). For most age ranges, the majority of depreciation is caused by functional obsolescence rather than physical deterioration. In particular, for the first 20 years, functional obsolescence (0.89%/year) accounts for 61% of the total depreciation. For the entire range between 1 and 50 years, the annual average rate of functional obsolescence is 0.34%, accounting for 48% of the total depreciation rate. Similarly, column (6) shows that the contribution of functional obsolescence to depreciation is large; for the first 20 years, the rate of functional obsolescence (0.8%/year) accounts for 87% of the total depreciation. For the entire 50 years, the annual average rate of functional obsolescence is 0.24%, accounting for 44% of the total depreciation rate.

The large functional obsolescence for newer buildings can be better understood by looking at the estimated cohort effect. Figure 5a shows the cohort effect on new rents (the bold solid line) and average rents (the dotted line) after removing age and time effects using the IE method. Starting with the latest cohort 2010-2014 as the reference, the slope is steep since the 1999s, whereas the line is almost flat until the 1980s. In other words, there are large rent discounts for the 1990s and earlier cohorts, resulting in a larger annual rate of functional obsolescence for newer buildings shown in Table 4.

[Figure 5 about here.]

What causes the steep slope between the 1995-1999 and 2005-2009 cohorts? This large shift in the rent level is consistent with a significant change in the standard configuration of office buildings; the intensive use of information technology in offices since the 1990s has required greater floor heights to enclose high-speed networks above the ceiling or under the floor. Because the floor height is determined at the time of construction and cannot be changed later, it creates a cohort effect that is closely tied to the functionality of the building. Hara (2016) shows that the average height of office buildings in Tokyo was approximately 350 cm between 1930 and 1990, except for a dip in the 1960s, but increased rapidly to 400 cm by 2000. This cohort profile of average floor height almost perfectly matches the cohort profile of rents. Thus, the effect of functional obsolescence on rents is driven by changes in tenant preferences and advances in building technology.

Columns (2) and (4) of Table 5 show the IE estimation results for operating expenses and capital expenditure, respectively. In addition, the bold solid lines in Figure 3 show the age coefficients after controlling for cohort effects. Unlike the results for rents, the age profile of operating expenses does not show a clear difference with or without cohort controls. Thus, operating expenses do not depend on the physical age of the building or specific cohorts; that is, past building characteristics are not associated with particularly high or low costs of operation. Consistently, the cohort effect shown in Figure 5b exhibits no consistent pattern for operating expenses.

However, an increase in capital expenditure due to age becomes smaller after controlling for cohort effects, although the difference is not statistically significant due to large standard errors. This smaller increase in capital expenditure may be caused by specific cohorts that are correlated with ages 21-35. Figure 5b shows that capital expenditure tends to be large for cohorts 1975-1989, which approximately corresponds to these ages. After removing these cohort effects, the age-dependent capital expenditure exhibits clearer peaks for ages 16-20 and 46-50, consistent with conventional wisdom.

Columns (2) and (4) of Table 6 show the IE estimation results for NOI and NCF, respectively. In addition, the bold solid lines in Figure 4 show the age coefficients after controlling for cohort effects. The age profile of NOI does not change significantly by controlling for cohort effects. NOI does not seem to depreciate significantly with building age. Similarly, the overall age profile of capital expenditure does not change significantly.

Overall, functional obsolescence associated with particular cohorts has significant impacts on new rents, average rents, and capital expenditure. In particular, rent depreciation rates change significantly by controlling for cohort effects. Functional obsolescence accounts for the majority of the annual rate of depreciation for most age ranges.

6 Conclusion

This study empirically analyzes the depreciation of rents and other cash flow components of office properties in Tokyo. We construct an annual building panel data set for new rents, average rents, operating expenses, capital expenditure, NOI, and NCF. The estimated average rent depreciation rate is significantly lower than the price depreciation rate, although the rates in the early years are significantly higher than the overall average rate. Average rents exhibit nominal rigidity relative to new rents, possibly due to sticky renewal rents for long-term tenants. Operating expenses do not change with building age, whereas capital expenditure increases with age until leveling off around age 20. The Intrinsic Estimator (IE) method is employed to decompose the observed depreciation into two components: physical deterioration and functional obsolescence. Our IE estimate shows that approximately half of the rental depreciation is due to physical deterioration and the remaining half to functional obsolescence, which is critically affected by standard building specifications and tenant preferences. However, a limitation of the present study is that it does not correct for survivorship bias because demolition data are unavailable. This bias may be significant for office properties in Tokyo, where the average economic life of a building is short.

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Tables

Table 1: Descriptive Statistics

VARIABLES	(1) Observations	(2) Buildings	(3) mean	(4) sd	(5) min	(6) max
NEW_RENT	19,600	6,041	64,218.87	22,697.70	22,143.00	254,100.01
AVG_RENT	1,902	292	63,368.99	17,232.51	32,514.43	165,010.29
OPEX	875	229	18,265.10	12,097.49	295.43	164,039.65
NOI	796	212	46,883.15	20,277.88	-118,565.43	141,168.31
CAPEX	1,965	328	4,151.94	9,280.73	2.26	222,806.52
NCF	680	148	42,760.88	21,948.16	-127,933.14	141,015.08
YEAR	21,007	6,102	2,011.18	3.29	2,005.00	2,016.00
AGE	21,007	6,102	22.67	10.68	1.00	50.00
COMPL_YEAR	21,007	6,102	1,988.50	10.42	1,956.00	2,014.00
GFA	21,007	6,102	12,386.88	28,017.84	379.64	379,447.92
MINUTES	21,007	6,102	4.96	2.45	0.00	23.68
RENEW	21,007	6,102	0.16	0.37	0.00	1.00

Table 2: Average Annual Depreciation for Rents, Expenditures, and Cash Flows

Dependent Variable:	New Rents (log) (1)	Average Rents (log) (2)	Operating Expenses (log) (3)	NOI (log) (4)	Capial Expenditure (log) (5)	NCF (log) (6)
AGE	-0.0081***	-0.0058***	-0.0059	-0.0023	0.0239***	-0.0050*
	(0.0002)	(0.0012)	(0.0041)	(0.0023)	(0.0065)	(0.0026)
GFA (log)	0.1528***	0.1139***	0.0525	0.1318***	-0.0066	0.1496***
	(0.0024)	(0.0140)	(0.0496)	(0.0336)	(0.0608)	(0.0437)
MINUTES	-0.0233***	-0.0206***	-0.0136	-0.0129*	-0.0003	-0.0155
	(0.0011)	(0.0043)	(0.0172)	(0.0077)	(0.0260)	(0.0099)
RENEW	0.0516***	-0.0247	0.0173	-0.0379	0.1268	-0.0526
	(0.0067)	(0.0299)	(0.1210)	(0.0610)	(0.1657)	(0.0777)
Constant	10.3346***	10.3634***	10.0860***	9.9760***	7.4418***	9.9764***
	(0.1483)	(0.1761)	(0.8365)	(0.2913)	(0.9451)	(0.3955)
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,600	1,902	875	783	1,965	666
Buildings	6,041	292	229	328	212	148
adj. R2	0.6456	0.4983	0.1121	0.4179	0.0559	0.3255

This table shows the OLS estimation result of the hedonic model specified by equation (1) for the natural logarithm of new rents (column 1), average rents (column 2), operating expenses (column 3), NOI (column 4), capital expenditure (column 5), and NCF (column 6) for office properties in Tokyo. The age function takes a log-linear form as specified by equation (1). Property characteristics include log gross floor area (GFA_LOG), walking minutes to the nearest subway or train station (MINUTES), a dummy for past renovation (RENEW), year and ward fixed effects, and a constant. Table A1 provides the definitions of the variables. The sample period is between 2008 and 2016. Robust standard errors clustered at the property level are shown in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 3: Rent Depreciation by Age Group

Dependent Variable:	Log New Rents		Log Average Rents	
	OLS	IE	OLS	IE
	(1)	(2)	(3)	(4)
Age Group 1-5	(Reference)	(Reference)	(Reference)	(Reference)
Age Group 6-10	-0.0638	-0.0243	0.0377	0.0336
	(0.0094)	(0.0088)	(0.0358)	(0.0233)
Age Group 11-15	-0.1593	-0.0563	-0.0252	0.0198
	(0.0092)	(0.0066)	(0.0418)	(0.0201)
Age Group 16-20	-0.2199	-0.0868	-0.1373	-0.0176
	(0.0089)	(0.0061)	(0.0354)	(0.0212)
Age Group 21-25	-0.2737	-0.1232	-0.1698	-0.0401
	(0.0088)	(0.0057)	(0.0374)	(0.027)
Age Group 26-30	-0.2964	-0.1316	-0.1690	-0.0562
	(0.0096)	(0.0067)	(0.0455)	(0.0344)
Age Group 31-35	-0.2977	-0.1327	-0.1368	-0.0627
	(0.0103)	(0.0078)	(0.047)	(0.0414)
Age Group 36-40	-0.3409	-0.1647	-0.1041	-0.0376
	(0.0108)	(0.0083)	(0.0522)	(0.0388)
Age Group 41-45	-0.3448	-0.1648	-0.1495	-0.0907
	(0.0114)	(0.0084)	(0.056)	(0.0381)
Age Group 46-50	-0.3191	-0.1646	-0.2469	-0.1376
	(0.0144)	(0.0124)	(0.0645)	(0.0527)
Cohort Effects	No	Yes	No	Yes
Period Effects	Yes	Yes	Yes	Yes
Property Characteristics	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes
Observations	19,600	19,600	1,902	1,795
Buildings	6,041	6,041	292	290
R-squared	0.6539	-	0.5282	-
Log pseudo-likelihood	-	4736.5	-	594.57

This table shows the estimation result of aging effects on log new rents (columns 1 and 2) and log average rents (columns 3 and 4), based on the OLS (equations (1) and (3)) and the IE model. Property characteristics include log gross floor area, distance to the nearest subway/train station measured in walking minutes, a dummy for recent renovation, ward fixed effects, and a constant. Period effects are based on dummies for 2001-2005, 2006-2010, and 2011-2015. Table A1 shows the definitions of the variables, Tables A2-A5 show the descriptive statistics of the sample used for each estimation, and TableA17 reports the coefficients for suppressed variables. Robust standard errors are in parentheses and clustered by building.

Table 4: The Implied Annual Rent Depreciation Rate

	New Rents			Average Rents		
	Total Depreciation (%/year)	Physical Deterioration (%/year)	Functional Obsolescence (%/year) (1) − (2)	Total Depreciation (%/year)	Physical Deterioration (%/year)	Functional Obsolescence (%/year) (4) − (5)
Age range	(1)	(2)	(3)	(4)	(5)	(6)
From 1 to 10	1.28	0.49	0.79	-0.75	-0.67	-0.08
From 1 to 15	1.59	0.56	1.03	0.25	-0.2	0.45
From 1 to 20	1.47	0.58	0.89	0.92	0.12	0.80
From 1 to 25	1.37	0.62	0.75	0.85	0.2	0.65
From 1 to 30	1.19	0.53	0.66	0.68	0.22	0.46
From 1 to 35	0.99	0.44	0.55	0.46	0.21	0.25
From 1 to 40	0.97	0.47	0.50	0.3	0.11	0.19
From 1 to 45	0.86	0.41	0.45	0.37	0.23	0.14
From 1 to 50	0.71	0.37	0.34	0.55	0.31	0.24

This table shows the implied average annual depreciation rate for new rents (columns 1-3) and average rents (columns 4-6) based on the IE model. Average annual depreciation rates are calculated by dividing the estimated age coefficient in Table 3 by the mean year difference between the subject group and the reference group. Total depreciation rate (columns 1 and 4) are decomposed into physical deterioration (columns 2 and 5) and functional obsolescence (columns 3 and 6).

Table 5: The Age Profile of Expenditures

Dependent Variable:	Log Operating Expenses		Log Capital Expenditure	
	OLS	IE	OLS	IE
	(1)	(2)	(3)	(4)
Age Group 1-5	(Reference)	(Reference)	(Reference)	(Reference)
Age Group 6-10	-0.0534	-0.2195	0.8621	0.8877
	(0.1503)	(0.1193)	(0.2092)	(0.1927)
Age Group 11-15	-0.0543	-0.3498	1.6576	1.4912
	(0.1854)	(0.1207)	(0.2117)	(0.1966)
Age Group 16-20	-0.1034	-0.2382	1.8738	1.6493
	(0.1593)	(0.1392)	(0.2086)	(0.2459)
Age Group 21-25	-0.2516	-0.3231	1.7423	1.2943
	(0.1805)	(0.1664)	(0.2234)	(0.2492)
Age Group 26-30	-0.3243	-0.1621	1.7710	1.1072
	(0.2119)	(0.2006)	(0.237)	(0.274)
Age Group 31-35	-0.4135	-0.2408	1.2797	0.5299
	(0.207)	(0.1807)	(0.303)	(0.3012)
Age Group 36-40	0.0061	-0.0599	1.1349	0.8501
	(0.1792)	(0.1603)	(0.3187)	(0.2945)
Age Group 41-45	-0.3376	-0.4738	1.2276	0.9687
	(0.2563)	(0.1661)	(0.2914)	(0.2926)
Age Group 46-50	0.0005	0.0085	2.0414	1.7530
	(0.1834)	(0.1796)	(0.3986)	(0.4957)
Cohort Effects	No	Yes	No	Yes
Period Effects	Yes	Yes	Yes	Yes
Property Characteristics	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes
Observations	875	816	1,965	1,511
Buildings	229	223	328	294
R-squared	0.1331	-	0.1335	-
Log pseudo-likelihood	-	-802.52	-	-2679.48

This table shows the estimation result of age effects on log operating expenses (columns 1 and 2) and log capital expenditure (columns 3 and 4), based on OLS (equations (1) and (3)) and the IE model. Property characteristics include log gross floor area, distance to the nearest subway/train station measured in walking minutes, a dummy for recent renovation, ward fixed effects, and a constant. Period effects are based on dummies for 2001-2005, 2006-2010, and 2011-2015. Table A1 shows the definitions of the variables, Tables A6-A9 show the descriptive statistics of the sample used for each estimation, and TableA17 reports the coefficients for suppressed variables. Robust standard errors are in parentheses and clustered by building.

Table 6: The Age Profile of Cash Flows

Dependent Variable:	Log NOI		Log NCF	
	OLS	IE	OLS	IE
	(1)	(2)	(3)	(4)
Age Group 1-5	(Reference)	(Reference)	(Reference)	(Reference)
Age Group 6-10	0.0990	0.1045	0.0820	0.0831
	(0.0939)	(0.0539)	(0.0952)	(0.08)
Age Group 11-15	0.0577	0.1279	-0.0306	0.1096
	(0.0946)	(0.0599)	(0.1028)	(0.1068)
Age Group 16-20	-0.1076	-0.0519	-0.2049	-0.3318
	(0.0882)	(0.0781)	(0.0967)	(0.1465)
Age Group 21-25	-0.0944	-0.0830	-0.2037	-0.3975
	(0.0973)	(0.0768)	(0.1028)	(0.1325)
Age Group 26-30	-0.0235	-0.1037	-0.2230	-0.3927
	(0.1039)	(0.0801)	(0.1404)	(0.1289)
Age Group 31-35	0.0609	-0.0189	-0.0140	0.0004
	(0.0993)	(0.0822)	(0.1014)	(0.117)
Age Group 36-40	-0.0614	-0.0469	-0.1043	-0.0602
	(0.1181)	(0.0706)	(0.1298)	(0.0929)
Age Group 41-45	0.0264	0.0289	-0.0732	-0.0881
	(0.1267)	(0.0659)	(0.1294)	(0.0896)
Age Group 46-50	-0.1262	0.0359	-0.2501	-0.0216
	(0.1217)	(0.081)	(0.118)	(0.1282)
Cohort Effects	No	Yes	No	Yes
Period Effects	Yes	Yes	Yes	Yes
Property Characteristics	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes
Observations	783	747	666	631
Buildings	206	202	146	143
R-squared	0.4499	-	0.3561	-
Log pseudo-likelihood	-	-802.52	-	-2679.48

This table shows the estimation result of age effects on log NOI (columns 1 and 2) and log NCF (columns 3 and 4), based on OLS (equations (1) and (3)) and the IE model. Property characteristics include log gross floor area, distance to the nearest subway/train station measured in walking minutes, a dummy for recent renovation, ward fixed effects, and a constant. Period effects are based on dummies for 2001-2005, 2006-2010, and 2011-2015. Table A1 shows the definitions of the variables, Tables A10-A13 show the descriptive statistics of the sample used for each estimation, and TableA17 reports the coefficients for suppressed variables. Robust standard errors are in parentheses and clustered by building.

Figures

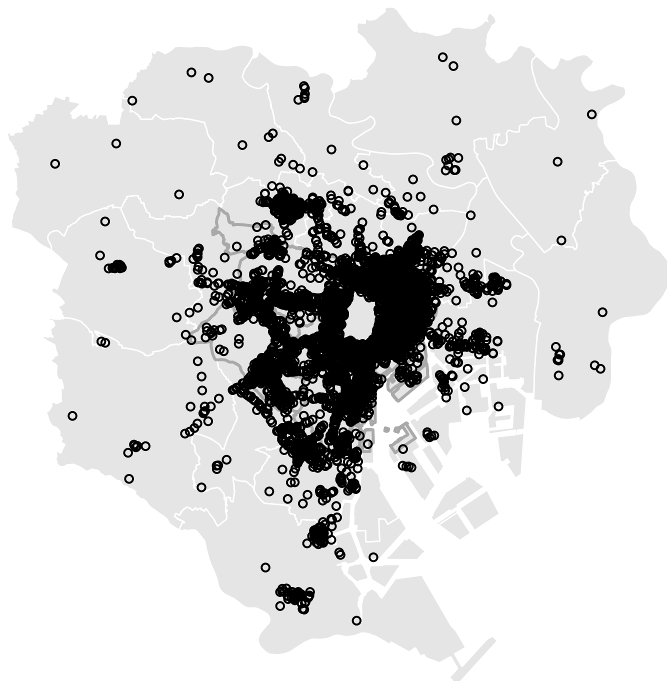
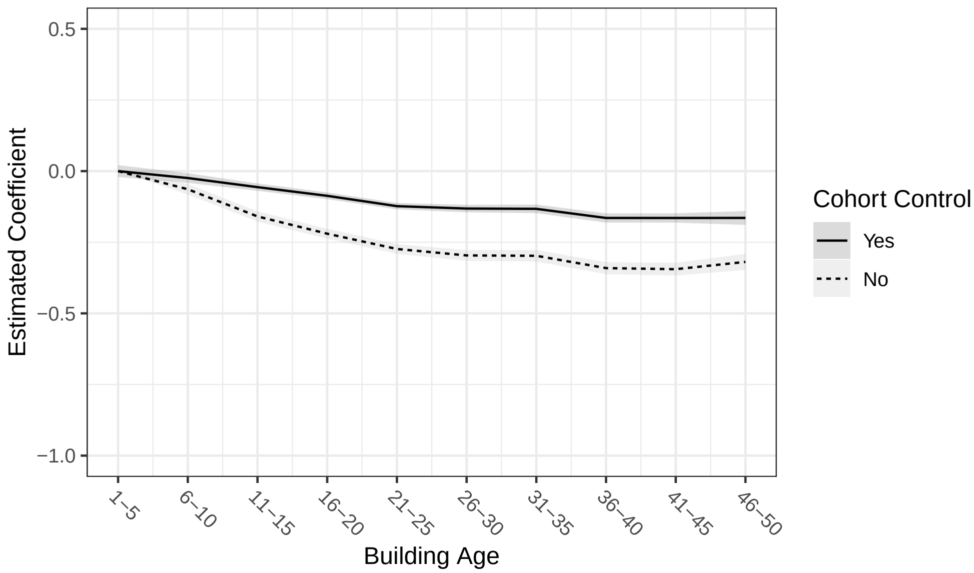
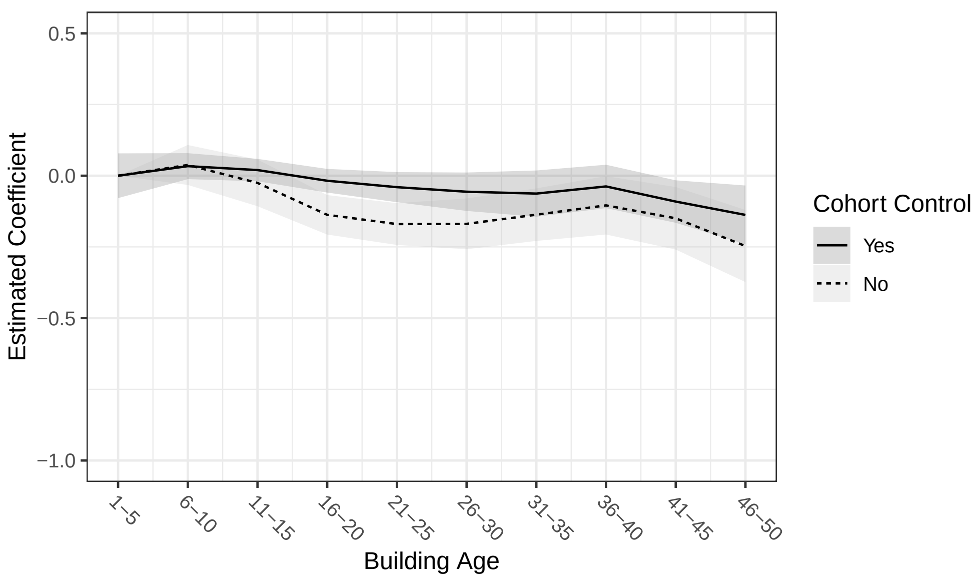


Figure 1: Geographical Distribution of Buildings



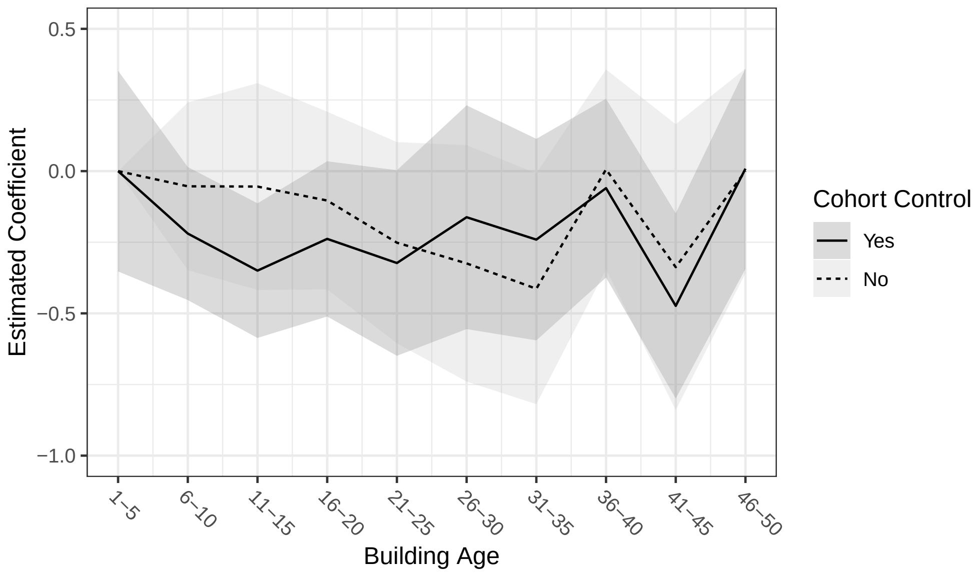
(a) New Rents



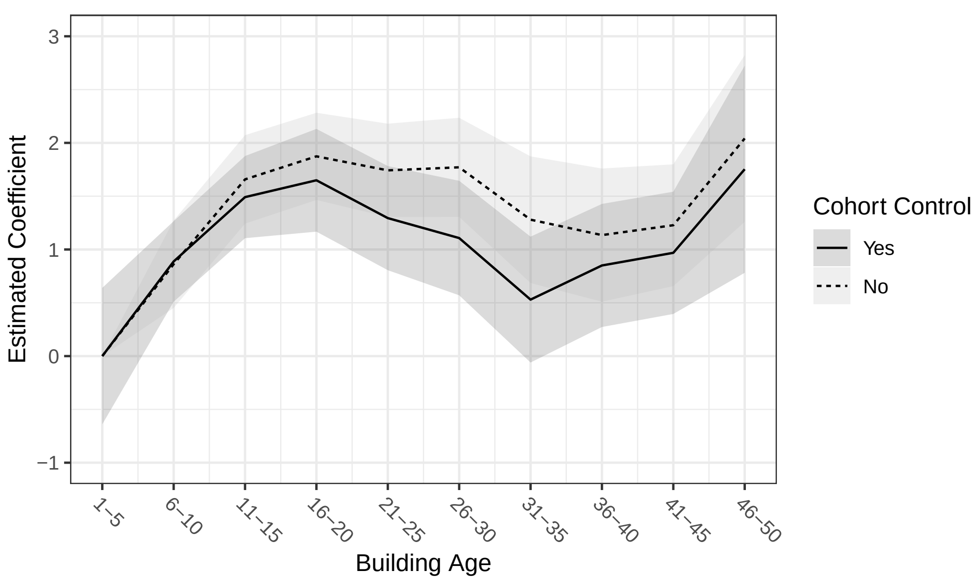
(b) Average Rents

Figure 2: Age Profile of Rents With and Without Cohort Controls

This figure depicts the age profile of log new rents (panel a) and log average rents (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line). The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.



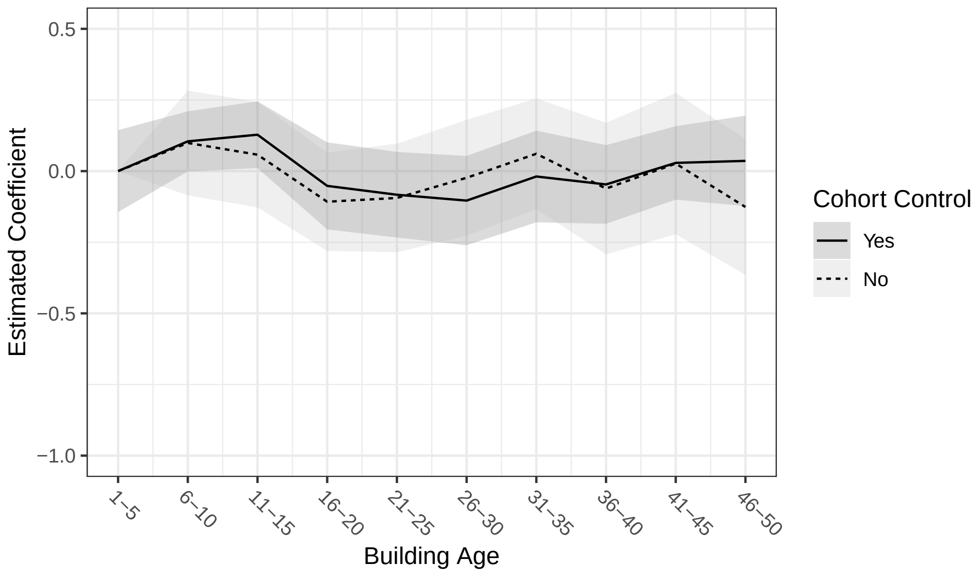
(a) Operating Expense



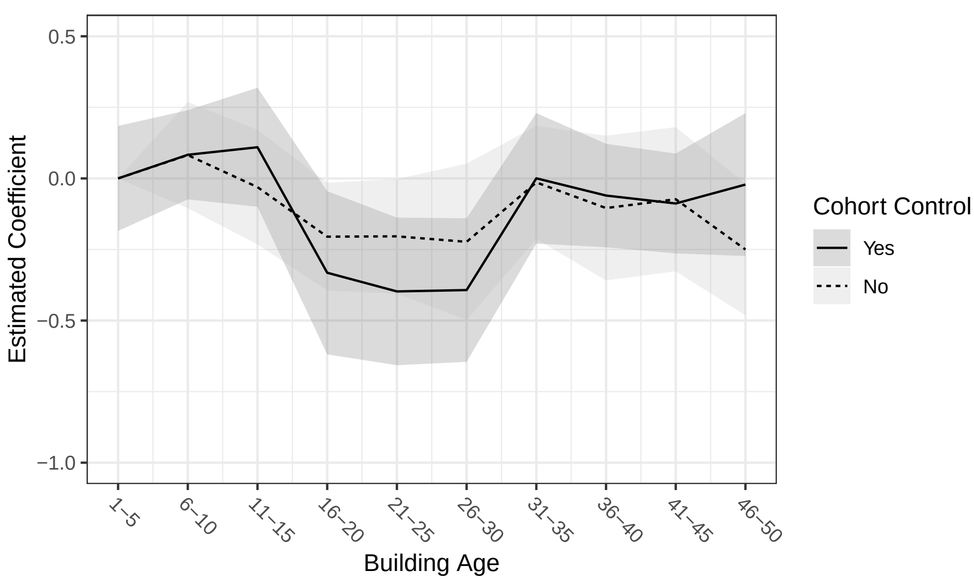
(b) Capital Expenditures

Figure 3: Age Profile of Expenditures With and Without Cohort Controls

This figure depicts the age profile of log operating expenses (panel a) and log capital expenditure (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line). The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.



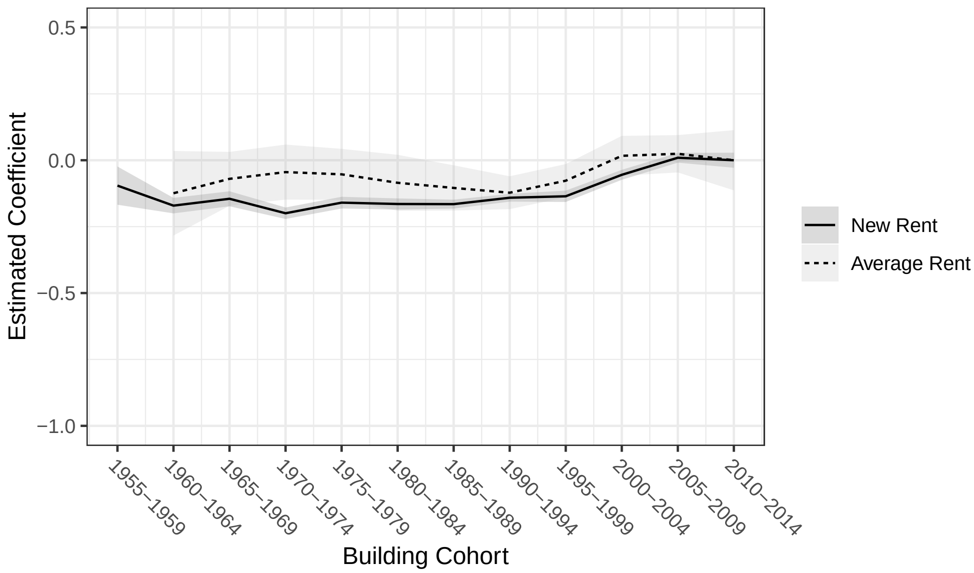
(a) Net Operating Income (NOI)



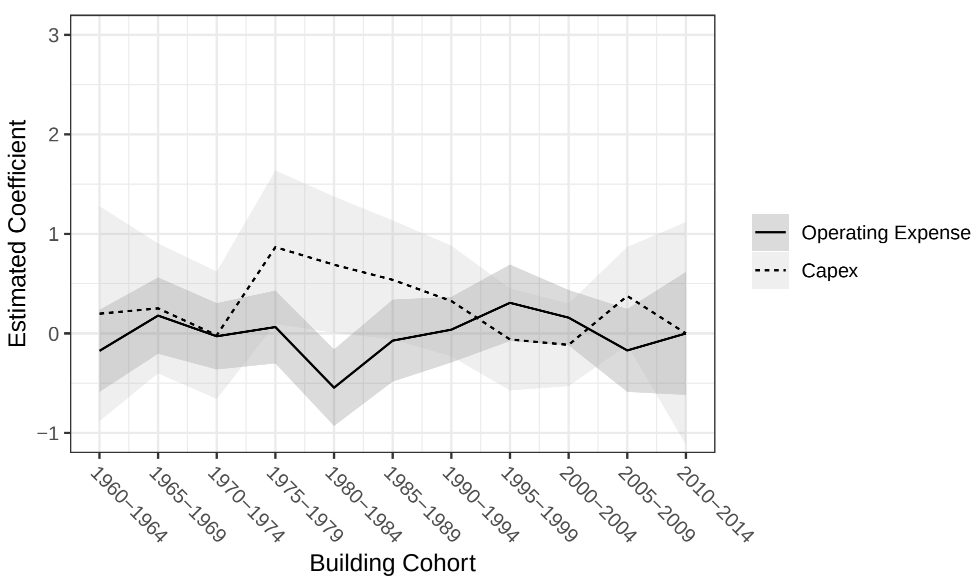
(b) Net Cash Flow (NCF)

Figure 4: Age Profile of Cash Flows With and Without Cohort Controls

This figure depicts the age profile of log NOI (panel a) and log NCF (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line). The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.



(a) Rents



(b) Operating Expenses and Capital Expenditure

Figure 5: Cohort Effects

This figure depicts the estimated cohort effects on log rents (panel a) and log expenses (panel b) based on the IE method. The estimated coefficient for the reference cohort of 2010–2014 is normalized to zero. The shaded areas represent 95% confidence intervals.

Appendix A The Intrinsic Estimator Model

To illustrate the IE method, let us define $\mathcal{Y} \equiv Y - X_i\beta - \gamma_j$ and rewrite equation (4) as:

$$\mathcal{Y} = Z\theta + \epsilon, \tag{A.1}$$

where $\theta = (\alpha_5, \alpha_{10}, ..., \alpha_{45}, \pi_{2005}, \pi_{2010}, \kappa_{1955}, \kappa_{1960}, ..., \kappa_{2005})'$ by omitting α_{50}, π_{2015}, and κ_{2010}. Matrix Z consists of a set of dummy variables for age, period, and cohort groups. The ordinary least squares estimator $\hat{\theta} = (Z'Z)^{-1}Z'\mathcal{Y}$ is not defined well because of singularity of Z. However, because Z is one less than full column rank, the parameter space of the regression model (A.1) can be decomposed into the direct sum of two linear subspaces that are parpendicular to each other. One subspace corresponds to the unique zero eigenvalue of $Z'Z$, which is termed the null subspace of Z. Because of orthogonality, non-unique parameter vector θ can be written as:

$$\theta = T + sT_0, \tag{A.2}$$

where T_0 is a unique eigenvector of unit length in the null subspace of Z, and s is a scalar corresponding to a specific set of parameter values. Vector T_0 is independent of $\mathcal{Y}$ and satisfies $ZT_0 = 0$ because of the singularity of Z. Parameter vector T is the intrinsic estimator (IE) corresponding to the projection of the parameter vector θ onto the non-null space of Z: $T = (I - T_0T_0')\theta$.

We estimate IE parameters by applying a principal components regression. We first apply an orthonormal matrix transformation to $Z'Z$ to produces the nonzero eigenvalues and corresponding eigenvectors of the matrix. We use these eigenvectors are used to estimate the principal components regression model. Then, we transform the estimated coefficients and the variance-covariance matrix of the principal components regression model back to the space of age, period, and cohort coodinates to make the coefficients interpretable. In the last step, we impose the constraint that the sum of coefficients in each set is zero ($\Sigma_a \gamma_a = \Sigma_p \tau_p = \Sigma_c \kappa_c = 0$) instead of omitting one reference category from each set of indicator variables.[3]

In the actual application, the actual contract year may differ from the five-year period group. For example, if a building built in 1988 is observed in 2014 at age 26, then the age group would be 30, the cohort group would be 1985, and the calculated period group would be 2015-2019, even though the actual observation year is 2014. Although this discrepancy creates a measurement error in the period group dummy, the error will not cause a serious empirical problem because our main focus is on the effect of age and cohort.

[3]We use the statistical software package for Stata by Schulhofer-Wohl and Yang (2006). See Rutherford et al. (2010) for details on the procedure.

Appendix B Variable List

Table A1: Variable List

Variable	Short name	Unit	Description
Building ID	BLDG_ID	-	Unique ID for the building
Year	YEAR	-	Year of observation
New rent	NR	JPY/m^2/year	New contract rent per net rentable area per annum
Average rent	AR	JPY/m^2/year	Average rent per net rentable area per annum
Capital expenditures	CAPEX	JPY/m^2/year	Annual total of capital expenditure per net rentable area per annum
Operating expenses	OPEX	JPY/m^2/year	Annual total of operating expenses per net rentable area per annum (excl. land lease, deposit and trust cost)
Net operating income	NOI	JPY/m^2/year	Calculated from AVG_RENT and OPEX
Net cash flows	NCF	JPY/m^2/year	Calculated from NOI and CAPEX
Gross floor area	GFA	m^2	Gross floor area
Net rentable area	NRA	m^2	Net rentable area
Minutes	MINUTES	minutes	Walking minutes to the nearest station
Age	AGE	years	Age of the building
Completion year	CPL_YEAR	-	Year the building built
Renewal	RENEW	-	Dummy variable to indicate renovation
Renewal year	RENEW_YEAR	-	Year renovated

Appendix C Descriptive Statistics of Regression Subsamples

Table A2: New Rent Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	19,600	2,011	3.290	2,005	2,016
NEW_RENT	19,600	64,219	22,698	22,143	254,100
GFA	19,600	12,842	28,832	1,000	379,448
MINUTES	19,600	4.963	2.442	0	23.68
AGE	19,600	22.80	10.74	1	50
CPL_YEAR	19,600	1,988	10.48	1,956	2,014
RENEW	19,600	0.165	0.371	0	1

Table A3: New Rent IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	19,600	2,011	3.290	2,005	2,016
NEW_RENT	19,600	64,219	22,698	22,143	254,100
GFA	19,600	12,842	28,832	1,000	379,448
MINUTES	19,600	4.963	2.442	0	23.68
AGE	19,600	22.80	10.74	1	50
CPL_YEAR	19,600	1,988	10.48	1,956	2,014
RENEW	19,600	0.165	0.371	0	1

Table A4: Average Rent Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	1,902	2,012	2.478	2,008	2,016
AVG_RENT	1,902	63,369	17,233	32,514	165,010
GFA	1,902	7,217	12,265	379.6	102,605
MINUTES	1,902	5.040	2.416	0	13.55
AGE	1,902	21.18	9.742	1	50
CPL_YEAR	1,902	1,991	9.643	1,959	2,014
RENEW	1,902	0.181	0.385	0	1

Table A5: Average Rent IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	1,795	2,012	2.376	2,008	2,016
AVG_RENT	1,795	63,093	17,294	32,514	165,010
GFA	1,795	7,258	12,497	379.6	102,605
MINUTES	1,795	5.043	2.417	0	13.55
AGE	1,795	21.26	9.656	1	50
CPL_YEAR	1,795	1,991	9.545	1,962	2,014
RENEW	1,795	0.177	0.381	0	1

Table A6: Operating Expenses Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	875	2,012	2.739	2,007	2,016
OPEX	875	18,265	12,097	295.4	164,040
GFA	875	8,801	14,933	447.4	102,605
MINUTES	875	4.949	2.634	0	13.55
AGE	875	21.43	9.976	1	50
CPL_YEAR	875	1,990	10.00	1,962	2,014
RENEW	875	0.192	0.394	0	1

Table A7: Operating Expenses IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	816	2,012	2.592	2,007	2,016
OPEX	816	18,342	12,304	340.7	164,040
GFA	816	9,035	15,389	447.4	102,605
MINUTES	816	5.008	2.647	0	13.55
AGE	816	21.50	9.963	1	50
CPL_YEAR	816	1,991	9.965	1,962	2,014
RENEW	816	0.191	0.393	0	1

Table A8: Capital Expenditure Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	1,965	2,010	3.079	2,005	2,015
CAPEX	1,965	4,152	9,281	2.264	222,807
GFA	1,965	6,950	11,645	379.6	102,605
MINUTES	1,965	5.012	2.486	0	13.55
AGE	1,965	19.98	9.712	1	50
CPL_YEAR	1,965	1,990	9.518	1,962	2,014
RENEW	1,965	0.169	0.375	0	1

Table A9: Capital Expenditure IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	1,511	2,011	2.438	2,006	2,015
CAPEX	1,511	4,117	7,637	2.264	98,847
GFA	1,511	7,301	12,818	379.6	102,605
MINUTES	1,511	5.048	2.483	0	13.55
AGE	1,511	20.77	9.671	1	50
CPL_YEAR	1,511	1,991	9.553	1,962	2,014
RENEW	1,511	0.172	0.378	0	1

Table A10: NOI Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	783	2,012	2.567	2,008	2,016
NOI	783	48,096	17,672	7,532	141,168
GFA	783	9,034	15,604	447.4	102,605
MINUTES	783	4.902	2.584	0	13.55
AGE	783	21.54	10.14	1	50
CPL_YEAR	783	1,991	10.22	1,962	2,014
RENEW	783	0.190	0.393	0	1

Table A11: NOI IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	747	2,012	2.488	2,008	2,016
NOI	747	48,231	17,662	7,532	141,168
GFA	747	9,211	15,925	447.4	102,605
MINUTES	747	4.932	2.581	0	13.55
AGE	747	21.51	10.11	1	50
CPL_YEAR	747	1,991	10.14	1,962	2,014
RENEW	747	0.187	0.391	0	1

Table A12: NCF Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	666	2,011	2.200	2,008	2,015
NCF	666	44,305	18,795	1,699	141,015
GFA	666	9,097	15,930	447.4	102,605
MINUTES	666	4.850	2.609	0	13.55
AGE	666	21.25	10.31	1	50
CPL_YEAR	666	1,990	10.36	1,962	2,014
RENEW	666	0.189	0.392	0	1

Table A13: NCF IE Estimation

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
YEAR	631	2,012	2.129	2,008	2,015
NCF	631	44,512	18,866	1,851	141,015
GFA	631	9,304	16,308	447.4	102,605
MINUTES	631	4.879	2.607	0	13.55
AGE	631	21.23	10.28	1	50
CPL_YEAR	631	1,990	10.30	1,962	2,014
RENEW	631	0.187	0.390	0	1

Appendix D Consistent Subsample Analysis

This appendix shows the results of a robustness check based on a consistent subsample, which consistently includes information about rents, expenses, and cash flows.

Table A14: Descriptive Statistics of Consistent Subsample

VARIABLES	(1) Observations	(2) Buildings	(3) mean	(4) sd	(5) min	(6) max
Year	286	107	2,011.49	2.12	2,008.00	2,015.00
AGE	286	107	20.30	10.36	1.00	50.00
COMPL_YEAR	286	107	1,991.20	10.39	1,962.00	2,013.00
GFA	286	107	10,324.88	17,849.25	1,000.53	102,604.95
MINUTES	286	107	4.96	2.51	0.00	13.55
RENEW	286	107	0.24	0.43	0.00	1.00
NEW_RENT	286	107	61,752.27	19,312.51	32,670.00	161,055.85
AVG_RENT	286	107	67,980.78	17,832.02	38,720.00	154,911.97
OPEX	286	107	18,293.75	8,581.02	340.68	59,154.02
CAPEX	286	107	4,809.24	6,273.39	64.50	38,487.67
NOI	286	107	49,687.03	16,958.43	12,691.12	131,871.35
NCF	286	107	44,877.79	18,376.17	1,939.27	131,493.56

This subsample includes information for all rents, expenses, and cash flows.

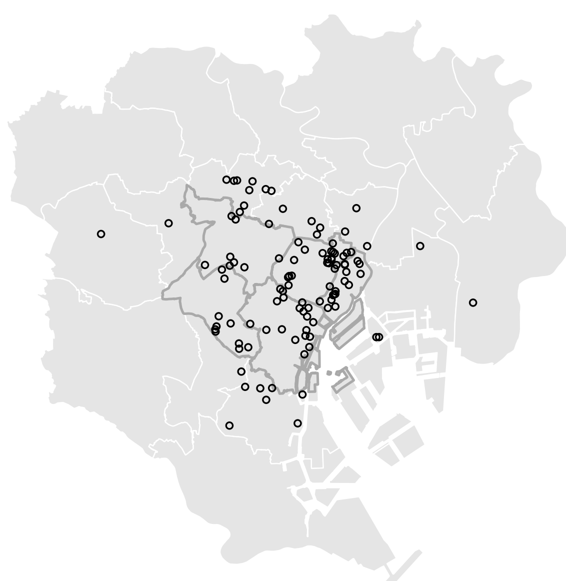
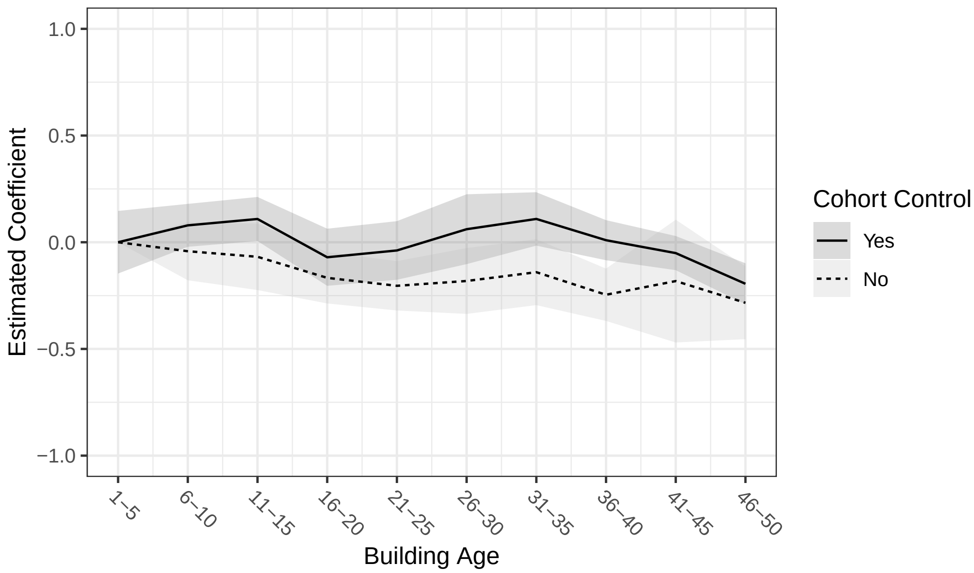


Figure A1: Geographical Distribution of Buildings in the Consistent Subsample

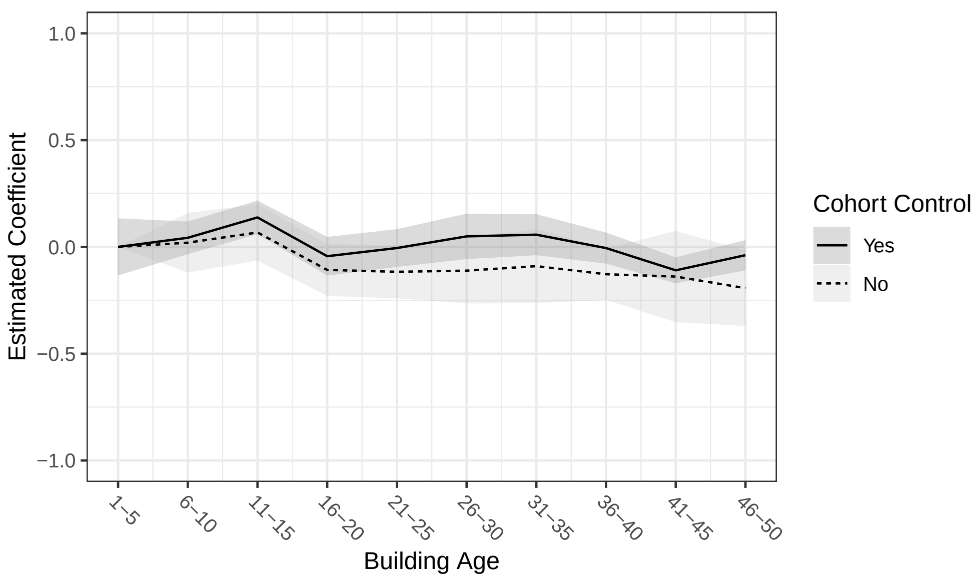
Table A15: Average Annual Depreciation for Rents, Expenditures, and Cash Flows (Consistent Subsample)

Dependent Variable:	(1) New Rents (log)	(2) Average Rents (log)	(3) Operating Expenses (log)	(4) NOI (log)	(5) Capial Expenditure (log)	(6) NCF (log)
AGE	-0.0069***	-0.0052***	-0.0015	-0.0063**	0.0216*	-0.0093***
	(0.0016)	(0.0016)	(0.0041)	(0.0026)	(0.0120)	(0.0029)
GFA_LOG	0.1462***	0.1252***	-0.0331	0.1406***	-0.0390	0.1423***
	(0.0172)	(0.0208)	(0.1082)	(0.0365)	(0.1171)	(0.0504)
MINUTES	-0.0249***	-0.0168***	-0.0052	-0.0172**	-0.0062	-0.0237**
	(0.0066)	(0.0063)	(0.0173)	(0.0080)	(0.0518)	(0.0109)
RENEW	-0.0822*	-0.0918*	-0.1890	-0.0371	0.2245	-0.0258
	(0.0488)	(0.0465)	(0.1426)	(0.0663)	(0.2756)	(0.0863)
Constant	10.0562***	10.2975***	9.9123***	9.9449***	7.5402***	9.9305***
	(0.1475)	(0.1744)	(0.8476)	(0.3075)	(1.0435)	(0.4215)
Cohort f.e.	No	No	No	No	No	No
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	286	286	286	286	286	286
Buildings	107	107	107	107	107	107
adj. R2	0.6511	0.6579	0.1295	0.5525	0.1362	0.4404

This table shows the OLS estimation result of the hedonic model specified by equation (1) for the natural logarithm of new rents (column 1), average rents (column 2), operating expenses (column 3), NOI (column 4), capital expenditure (column 5), and NCF (column 6) for office properties in Tokyo. The age function takes a log-linear form as specified by equation (1). Property characteristics include log gross floor area (GFA_LOG), walking minutes to the nearest subway or train station (MINUTES), a dummy for past renovation (RENEW), year and ward fixed effects, and a constant. Table A1 provides the definitions of the variables. The sample period is between 2008 and 2016. Robust standard errors clustered at the property level are shown in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.



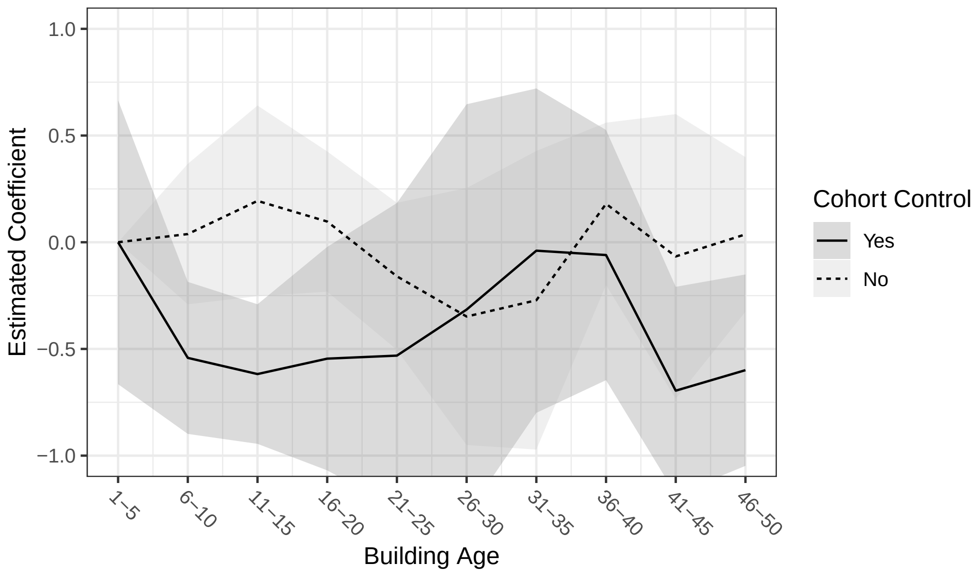
(a) New Rents



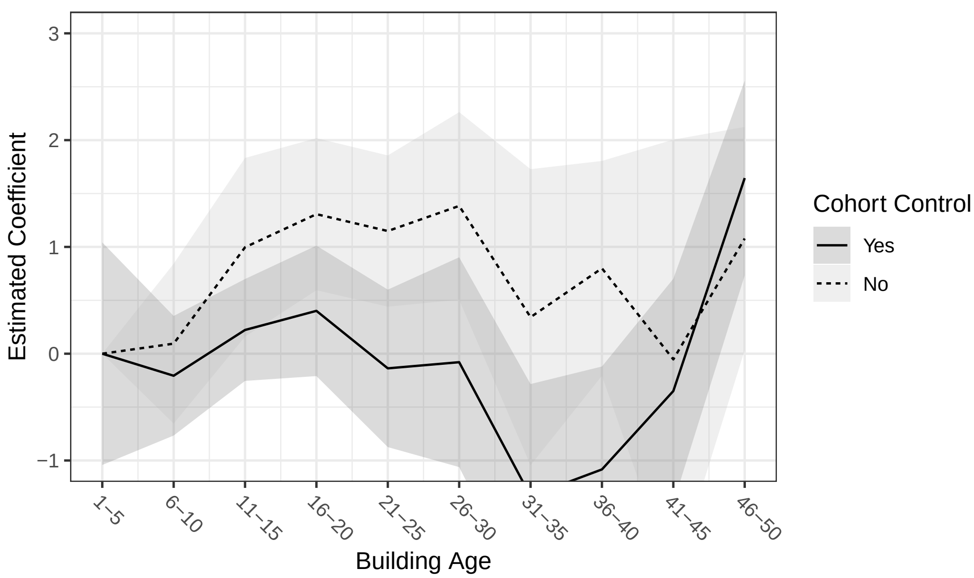
(b) Average Rents

Figure A2: Age profile of rents with and without cohort controls (Consistent Subsample)

This figure depicts the age profile of log new rents (panel a) and log average rents (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line) using the consistent subsample for all estimations. The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.



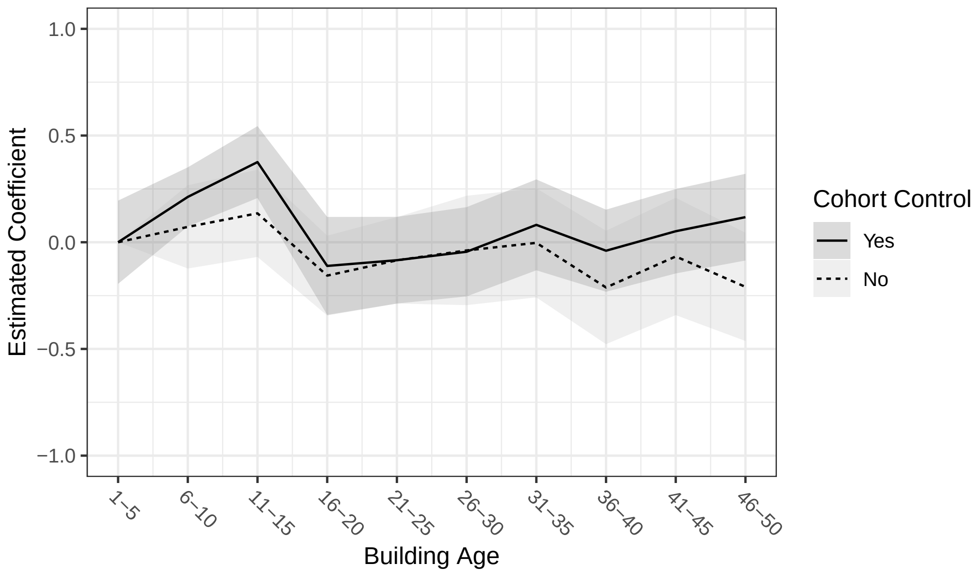
(a) Operating Expenses



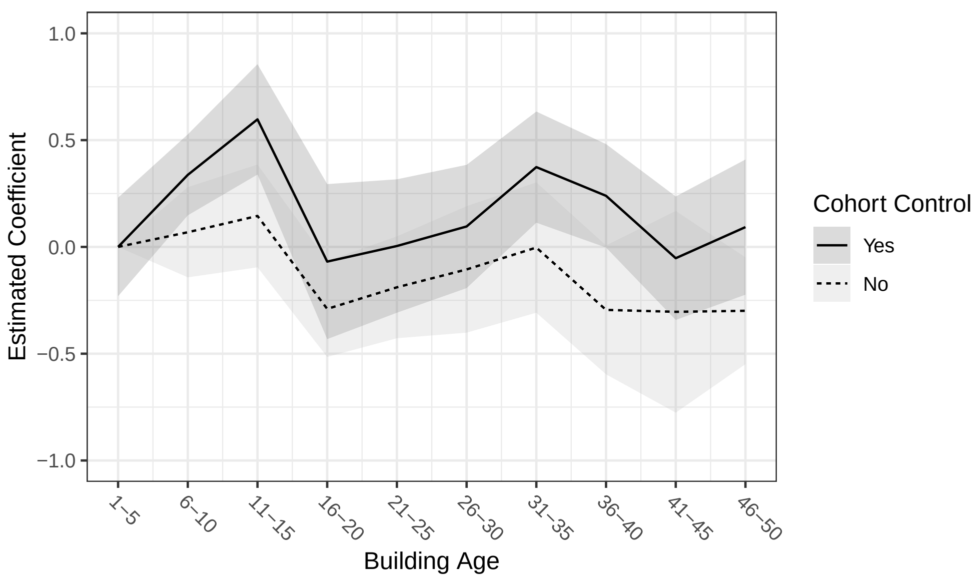
(b) Capital Expenditure

Figure A3: Age profile of expenditures with and without cohort controls (Consistent Subsample)

This figure depicts the age profile of operating expenses (panel a) and capital expenditure (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line) using the consistent subsample for all estimations. The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.



(a) Net Operating Income (NOI)



(b) Net Cash Flow (NCF)

Figure A4: Age profile of cash flows with and without cohort controls (Consistent Subsample)

This figure depicts the age profile of log operating expenses (panel a) and log capital expenditure (panel b), based on the hedonic regression without cohort control (the dotted line) and the IE method with cohort control (the solid line) using the consistent subsample for all estimations. The estimated age coefficients for the 1-5 year old reference group are normalized to zero. The shaded areas represent 95% confidence intervals.

Appendix E Non-Linear Control for GFA and MINUTES

Table A16: Average Annual Depreciation for Rents, Expenditures, and Cash Flows (Non-Linear Control)

Dependent Variable:	(1) New Rents (log)	(2) Average Rents (log)	(3) Operating Expenses (log)	(4) NOI (log)	(5) Capial Expenditure (log)	(6) NCF (log)
AGE	-0.0089***	-0.0061***	-0.0073*	-0.0033	0.0236***	-0.0061**
	(0.0003)	(0.0013)	(0.0042)	(0.0024)	(0.0066)	(0.0028)
4 quantiles of GFA = 2	0.0945***	0.0904***	0.1032	0.0961*	0.1142	-0.0032
	(0.0062)	(0.0290)	(0.0874)	(0.0495)	(0.1482)	(0.0651)
4 quantiles of GFA = 3	0.2197***	0.1815***	0.0432	0.2808***	-0.3185*	0.2966***
	(0.0067)	(0.0313)	(0.1139)	(0.0411)	(0.1669)	(0.0531)
4 quantiles of GFA = 4	0.4234***	0.2700***	0.1951	0.2990***	-0.0196	0.3254***
	(0.0090)	(0.0339)	(0.1362)	(0.0728)	(0.1712)	(0.0855)
4 quantiles of MINUTES = 2	-0.0333***	-0.0564*	-0.2353*	-0.0601	-0.0252	-0.0421
	(0.0076)	(0.0305)	(0.1230)	(0.0507)	(0.1639)	(0.0645)
4 quantiles of MINUTES = 3	-0.0711***	-0.0915***	-0.1866*	-0.0058	-0.0060	-0.0023
	(0.0079)	(0.0339)	(0.1113)	(0.0582)	(0.1537)	(0.0741)
4 quantiles of MINUTES = 4	-0.1389***	-0.1423***	-0.1184	-0.1220**	-0.0016	-0.1409**
	(0.0081)	(0.0278)	(0.1127)	(0.0513)	(0.1725)	(0.0709)
RENEW	0.0536***	-0.0255	0.0129	-0.0193	0.1745	-0.0391
	(0.0078)	(0.0302)	(0.1246)	(0.0559)	(0.1690)	(0.0722)
Constant	10.0562***	10.2975***	9.9123***	9.9449***	7.5402***	9.9305***
	(0.1475)	(0.1744)	(0.8476)	(0.3075)	(1.0435)	(0.4215)
Cohort f.e.	No	No	No	No	No	No
Year f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Ward f.e.	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,600	1,902	875	783	1,965	666
Buildings	6,041	292	229	328	212	148
R-squared	0.5925	0.4757	0.1269	0.4210	0.0656	0.3375

This table shows the OLS estimation result of the hedonic model specified by equation (1) for log new rents (column 1), log average rents (column 2), log operating expenses (column 3), NOI (column 4), capital expenditure (column 5), and NCF (column 6) for office properties in Tokyo. The age function takes a linear form as specified by equation (1). Property characteristics include log gross floor area (GFA (log)), walking minutes to the nearest subway or train station (MINUTES), a dummy for past renovation (RENEW), year and ward fixed effects, and a constant. Table A1 shows the definitions of the variables. The sample period is between 2008 and 2016. In parentheses are t-statistics based on robust standard errors clustered by building. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Appendix F IE Estimation Results

Table A17: IE Estimation Results

		Log New Rents		Log Average Rents		Log Operating Expenses		Log NOI		Log Capital Expenditure		Log NCF	
		OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
GFA_LOG		0.1465***	0.1458***	0.1112***	0.1091***	0.0459	0.0489	0.1264***	0.1232***	0.0153	0.0505	0.1446***	0.1332***
		(0.0023)	(0.0023)	(0.0127)	(0.0124)	(0.0491)	(0.0452)	(0.0303)	(0.0281)	(0.0517)	(0.0597)	(0.0400)	(0.0339)
MINUTES		-0.0218***	-0.0218***	-0.0160***	-0.0162***	-0.0088	-0.0061	-0.0093	-0.0091	-0.0305	-0.0268	-0.0090	-0.0060
		(0.0010)	(0.0010)	(0.0041)	(0.0043)	(0.0177)	(0.0190)	(0.0081)	(0.0090)	(0.0236)	(0.0261)	(0.0104)	(0.0114)
RNW		0.0387***	0.0357***	-0.0280	-0.0351	0.0266	0.0144	-0.0365	-0.0392	0.2364	0.1667	-0.0704	-0.1189
		(0.0065)	(0.0064)	(0.0283)	(0.0291)	(0.1203)	(0.1165)	(0.0611)	(0.0611)	(0.1563)	(0.1629)	(0.0760)	(0.0791)
Age	1 - 5		0.1049***		0.0389		0.2059		0.0007		-1.0531***		0.1099
			(0.0106)		(0.0401)		(0.1800)		(0.0734)		(0.3265)		(0.0943)
Age	6 - 10	-0.0638***	0.0806***	0.0377	0.0725***	-0.0534	-0.0136	0.0990	0.1053*	0.8621***	-0.1654	0.0820	0.1930**
		(0.0094)	(0.0088)	(0.0356)	(0.0233)	(0.1495)	(0.1193)	(0.0934)	(0.0539)	(0.2085)	(0.1927)	(0.0945)	(0.0800)
Age	11 - 15	-0.1593***	0.0486***	-0.0252	0.0588***	-0.0543	-0.1439	0.0577	0.1287**	1.6576***	0.4381**	-0.0306	0.2195**
		(0.0092)	(0.0066)	(0.0416)	(0.0201)	(0.1844)	(0.1207)	(0.0941)	(0.0599)	(0.2109)	(0.1966)	(0.1020)	(0.1068)
Age	16 - 20	-0.2199***	0.0181***	-0.1373***	0.0213	-0.1034	-0.0323	-0.1076	-0.0512	1.8738***	0.5961**	-0.2049**	-0.2219
		(0.0089)	(0.0061)	(0.0352)	(0.0212)	(0.1585)	(0.1392)	(0.0877)	(0.0781)	(0.2078)	(0.2459)	(0.0959)	(0.1465)
Age	21 - 25	-0.2737***	-0.0183***	-0.1698***	-0.0012	-0.2516	-0.1172	-0.0944	-0.0823	1.7423***	0.2411	-0.2037**	-0.2876**
		(0.0088)	(0.0057)	(0.0373)	(0.0270)	(0.1795)	(0.1664)	(0.0967)	(0.0768)	(0.2225)	(0.2492)	(0.1019)	(0.1325)
Age	26 - 30	-0.2964***	-0.0267***	-0.1690***	-0.0173	-0.3243	0.0438	-0.0235	-0.1030	1.7710***	0.0541	-0.2230	-0.2828**
		(0.0096)	(0.0067)	(0.0453)	(0.0344)	(0.2108)	(0.2006)	(0.1033)	(0.0801)	(0.2361)	(0.2740)	(0.1392)	(0.1289)
Age	31 - 35	-0.2977***	-0.0278***	-0.1368***	-0.0238	-0.4135**	-0.0349	0.0609	-0.0182	1.2797***	-0.5232*	-0.0140	0.1103
		(0.0103)	(0.0078)	(0.0468)	(0.0414)	(0.2059)	(0.1807)	(0.0987)	(0.0822)	(0.3019)	(0.3012)	(0.1006)	(0.1170)
Age	36 - 40	-0.3409***	-0.0598***	-0.1041**	0.0013	0.0061	0.1460	-0.0614	-0.0462	1.1349***	-0.2030	-0.1043	0.0497
		(0.0108)	(0.0083)	(0.0520)	(0.0388)	(0.1783)	(0.1603)	(0.1174)	(0.0706)	(0.3175)	(0.2945)	(0.1288)	(0.0929)
Age	41 - 45	-0.3448***	-0.0599***	-0.1495***	-0.0518	-0.3376	-0.2679	0.0264	0.0296	1.2276***	-0.0844	-0.0732	0.0218
		(0.0114)	(0.0084)	(0.0558)	(0.0381)	(0.2549)	(0.1661)	(0.1260)	(0.0659)	(0.2904)	(0.2926)	(0.1283)	(0.0896)
Age	46 - 50	-0.3191***	-0.0597***	-0.2469***	-0.0987*	0.0005	0.2143	-0.1262	0.0366	2.0414***	0.6999	-0.2501**	0.0883
		(0.0144)	(0.0124)	(0.0643)	(0.0527)	(0.1825)	(0.1796)	(0.1210)	(0.0810)	(0.3972)	(0.4957)	(0.1171)	(0.1282)
Cohort	1955		0.0230										
			(0.0367)										
Cohort	1960		-0.0523***		-0.0662		-0.1532		-0.1879		-0.0792		-0.2787**
			(0.0149)		(0.0812)		(0.2110)		(0.1159)		(0.5519)		(0.1416)
Cohort	1965		-0.0265*		-0.0119		0.2015		-0.0078		-0.0258		0.0134
			(0.0144)		(0.0518)		(0.1958)		(0.0868)		(0.3332)		(0.1261)
Cohort	1970		-0.0810***		0.0135		-0.0064		0.0196		-0.2963		0.0343
			(0.0110)		(0.0529)		(0.1704)		(0.0980)		(0.3267)		(0.1117)

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Table A17 – continued from previous page

		Log New Rents		Log Average Rents		Log Operating Expenses		Log NOI		Log Capital Expenditure		Log NCF	
		OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Cohort	1975		-0.0411***		0.0051		0.0865		-0.0018		0.5892		-0.1032
			(0.0113)		(0.0490)		(0.1870)		(0.0995)		(0.3932)		(0.1307)
Cohort	1980		-0.0461***		-0.0268		-0.5227***		0.1538		0.4127		0.1041
			(0.0107)		(0.0538)		(0.1968)		(0.0943)		(0.3499)		(0.1358)
Cohort	1985		-0.0467***		-0.0461		-0.0500		0.0782		0.2609		0.2752*
			(0.0086)		(0.0434)		(0.2106)		(0.0959)		(0.3050)		(0.1583)
Cohort	1990		-0.0226***		-0.0641**		0.0601		-0.0240		0.0478		0.1437
			(0.0075)		(0.0315)		(0.1683)		(0.0849)		(0.2841)		(0.1551)
Cohort	1995		-0.0171		-0.0189		0.3298*		-0.0992		-0.3380		-0.1758
			(0.0109)		(0.0320)		(0.1963)		(0.0769)		(0.2614)		(0.1326)
Cohort	2000		0.0637***		0.0748*		0.1806		0.0160		-0.3924*		-0.0071
			(0.0096)		(0.0382)		(0.1421)		(0.0700)		(0.2118)		(0.0962)
Cohort	2005		0.1280***		0.0825**		-0.1486		0.0119		0.0987		-0.0312
			(0.0094)		(0.0359)		(0.2130)		(0.0774)		(0.2515)		(0.0902)
Cohort	2010		0.1186***		0.0581		0.0224		0.0412		-0.2776		0.0253
			(0.0145)		(0.0578)		(0.3154)		(0.1637)		(0.5711)		(0.1841)
Period	2005		0.1197***										
			(0.0031)										
Period	2010	-0.1174***	-0.0206***	-0.0287	0.0446***	0.0934	0.0378	0.0649	0.0616***	0.1851*	-0.0675	0.1094	0.0647**
		(0.0048)	(0.0024)	(0.0200)	(0.0066)	(0.1069)	(0.0366)	(0.0529)	(0.0147)	(0.1016)	(0.0543)	(0.0845)	(0.0254)
Period	2015	-0.1790***	-0.0991***	-0.1104***	-0.0446***	0.0576	-0.0378	-0.0784	-0.0616***	0.2013*	0.0675	-0.0299	-0.0647**
		(0.0050)	(0.0027)	(0.0255)	(0.0066)	(0.1410)	(0.0366)	(0.0607)	(0.0147)	(0.1194)	(0.0543)	(0.0920)	(0.0254)
Constant		10.2613***	9.9560***	10.4252***	10.2673***	9.3770***	9.2486***	9.8376***	9.8372***	5.7409***	6.9241***	9.6256***	9.6331***
		(0.0226)	(0.0208)	(0.1091)	(0.0997)	(0.4123)	(0.3866)	(0.2649)	(0.2355)	(0.4679)	(0.5041)	(0.3434)	(0.2914)
City	13102	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)
City	13102	-0.0247***	-0.0253***	-0.0276	-0.0356	-0.1575	-0.1562	0.0078	0.0080	-0.1537	0.0286	0.0363	0.0578
		(0.0080)	(0.0080)	(0.0400)	(0.0416)	(0.1477)	(0.1524)	(0.0639)	(0.0710)	(0.1799)	(0.1956)	(0.0752)	(0.0844)
City	13103	0.0374***	0.0370***	-0.0103	-0.0110	-0.0043	0.0411	-0.0463	-0.0656	-0.1549	-0.0505	-0.0404	-0.0401
		(0.0065)	(0.0065)	(0.0340)	(0.0340)	(0.1138)	(0.0998)	(0.0709)	(0.0716)	(0.1641)	(0.1673)	(0.0843)	(0.0821)
City	13104	-0.0872***	-0.0848***	-0.0748*	-0.0862**	-0.0303	0.0103	-0.1301	-0.1575*	-0.3125*	-0.2075	-0.1280	-0.1415
		(0.0099)	(0.0098)	(0.0423)	(0.0421)	(0.1780)	(0.1756)	(0.0908)	(0.0859)	(0.1890)	(0.2102)	(0.1106)	(0.1072)
City	13105	-0.2032***	-0.2012***	-0.1497**	-0.1445**	-0.2859*	-0.2555	-0.1984*	-0.2139*	-0.1614	-0.0667	-0.2402	-0.2646
		(0.0127)	(0.0127)	(0.0585)	(0.0632)	(0.1615)	(0.1593)	(0.1193)	(0.1252)	(0.3524)	(0.3550)	(0.2085)	(0.2153)
City	13106	-0.2578***	-0.2558***	-0.2884***	-0.2721***	-0.0804	-0.2016	-0.3354***	-0.3082**	0.0331	-0.4568	-0.2970***	-0.2921***

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Table A17 – continued from previous page

		Log New Rents		Log Average Rents		Log Operating Expenses		Log NOI		Log Capital Expenditure		Log NCF	
		OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		(0.0119)	(0.0119)	(0.0673)	(0.0716)	(0.2486)	(0.3311)	(0.1216)	(0.1391)	(0.3431)	(0.3236)	(0.1079)	(0.1000)
City	13107	-0.3394***	-0.3338***	-0.5324***	-0.4954***	-0.1529	-0.3588	-0.4958***	-0.4470***	-0.8182***	-0.4757*		
		(0.0253)	(0.0248)	(0.0313)	(0.0366)	(0.1170)	(0.2200)	(0.0585)	(0.1380)	(0.1376)	(0.2715)		
City	13108	-0.4229***	-0.4186***	-0.3268***	-0.3420***	0.3292	0.3865	-0.4610**	-0.5171***	0.0757	0.4006	-0.6135**	-0.6825***
		(0.0153)	(0.0149)	(0.0512)	(0.0490)	(0.3766)	(0.3705)	(0.1894)	(0.1658)	(0.3216)	(0.3318)	(0.2750)	(0.2376)
City	13109	-0.2495***	-0.2472***	-0.2004***	-0.1972***	0.1954	0.2101	-0.2547***	-0.2455***	-0.0699	-0.0668	-0.2590***	-0.2609***
		(0.0122)	(0.0121)	(0.0508)	(0.0489)	(0.1430)	(0.1283)	(0.0804)	(0.0719)	(0.1966)	(0.2133)	(0.0980)	(0.0831)
City	13110	-0.1131***	-0.1112***	-0.1903***	-0.2015***	0.0423	0.1664	-0.2740***	-0.2686***	0.0183	0.1079	-0.3280***	-0.2930***
		(0.0222)	(0.0225)	(0.0302)	(0.0324)	(0.3571)	(0.4448)	(0.0898)	(0.0939)	(0.2936)	(0.3970)	(0.0842)	(0.0845)
City	13111	-0.3793***	-0.3766***							-2.3916***	-1.5933***		
		(0.0231)	(0.0219)							(0.8126)	(0.2448)		
City	13112	-0.2526***	-0.2469***	-0.1666***	-0.1428***	-0.1197	-0.1294	-0.2152***	-0.2119***	0.1200	0.0024	-0.3159**	-0.3405**
		(0.0445)	(0.0430)	(0.0365)	(0.0330)	(0.1025)	(0.1005)	(0.0516)	(0.0549)	(0.2934)	(0.3029)	(0.1292)	(0.1489)
City	13113	0.1887***	0.1886***	0.1537***	0.1488***	0.2682**	0.3097**	0.1250	0.1171	0.2965	0.3110	0.0638	0.0876
		(0.0093)	(0.0093)	(0.0439)	(0.0450)	(0.1337)	(0.1305)	(0.0821)	(0.0771)	(0.1907)	(0.1946)	(0.1049)	(0.0850)
City	13114	-0.2574***	-0.2541***	-0.2119***	-0.2090***	-0.3569	-0.4651**	-0.3303***	-0.2923***	0.1538	0.0817	-0.5095***	-0.4687***
		(0.0287)	(0.0285)	(0.0772)	(0.0800)	(0.2374)	(0.2038)	(0.1019)	(0.1011)	(0.4019)	(0.4639)	(0.0621)	(0.0542)
City	13115	-0.2732***	-0.2700***	-0.3408***	-0.3338***	-0.4097	-0.4171	-0.7421***	-0.7570***	0.4395*	0.4972**	-1.1573***	-0.7302***
		(0.0446)	(0.0442)	(0.0376)	(0.0408)	(0.5940)	(0.6446)	(0.0915)	(0.1031)	(0.2452)	(0.2028)	(0.3107)	(0.0925)
City	13116	-0.1387***	-0.1372***	-0.1682***	-0.1571***	-0.0814	-0.0460	-0.1698*	-0.1574	-0.1888	-0.1576	-0.1842*	-0.1949*
		(0.0129)	(0.0128)	(0.0523)	(0.0505)	(0.1387)	(0.1543)	(0.1009)	(0.1006)	(0.1905)	(0.2418)	(0.1020)	(0.1006)
City	13117	-0.2791***	-0.2742***										
		(0.0547)	(0.0544)										
City	13118	-0.3914***	-0.3884***	-0.3423***	-0.3624***					0.1795	0.5308**		
		(0.0311)	(0.0310)	(0.0390)	(0.0497)					(0.1591)	(0.2064)		
City	13119	-0.5565***	-0.5555***	-0.6955***	-0.6864***	-0.8074***	-0.5553***	-0.8488***	-0.8447***	-0.3293**	-0.5494***	-0.8231***	-0.8118***
		(0.0494)	(0.0499)	(0.0328)	(0.0333)	(0.0986)	(0.0894)	(0.0679)	(0.0635)	(0.1294)	(0.1577)	(0.0868)	(0.0709)
City	13120	-0.3764***	-0.3740***	-0.4609***	-0.4429***	-0.8757***	-0.8862***	-0.3469***	-0.3205***	-0.9524***	-0.9049***		
		(0.1143)	(0.1139)	(0.0397)	(0.0422)	(0.1495)	(0.1535)	(0.0787)	(0.0844)	(0.2290)	(0.2375)		
City	13121	-0.3724***	-0.3714***	-0.5067***	-0.5093***	-3.0951***	-3.1722***	-0.2201**	-0.2069*	-2.6096**	-3.6868***	-0.2223*	-0.1851
		(0.0486)	(0.0483)	(0.0538)	(0.0602)	(0.1311)	(0.1102)	(0.1089)	(0.1136)	(1.1496)	(0.2040)	(0.1155)	(0.1173)
City	13122	-0.5146***	-0.5137***										
		(0.1002)	(0.1049)										
City	13123	-0.4730***	-0.4726***	-0.3446***	-0.3292***	0.5551***	0.5009***	-0.9999***	-0.9452***	0.0493	0.3359	-1.0497***	-0.9656***
		(0.0359)	(0.0359)	(0.0415)	(0.0426)	(0.1370)	(0.1308)	(0.0871)	(0.0899)	(0.3874)	(0.2397)	(0.0966)	(0.0983)

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Table A17 – continued from previous page

	Log New Rents		Log Average Rents		Log Operating Expenses		Log NOI		Log Capital Expenditure		Log NCF	
	OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE	OLS	IE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Observations	19,600	19,600	1,902	1,795	875	816	783	747	1,965	1,511	666	631
Buildings	6,041	6,041	292	290	229	223	206	202	328	294	146	143
R-squared	0.6539		0.5282		0.1331		0.4499		0.1335		0.3561	
Ward FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes