How Rents and Expenditures Depreciate: A Case of Tokyo Office Properties

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Abstract

This is the first comprehensive study on the age profile of newly contracted rents, rents for sitting tenants, the average rents, operating expenses, net operating income, capital expenditures, and net cash flows for office properties. We use the proprietary data of a major property management firm about Tokyo office market and find: (1) The average annual rent depreciation rate (i.e., the aging effect) is 0.8% for new leases, 0.4% for leases by sitting tenants, and 0.5% on average; (2) the rent function is more convex in age than the logarithmic function; (3) Smaller buildings tend to experience larger rent depreciation; (4) A tenant that occupies a larger proportion of building experiences larger rent depreciation; (5) Operating expenses depreciate annually at 0.6%; (6) Net operating income (NOI) depreciates annually at 0.4%; (7) Capital expenditures generally increase over time; and (8) Net cash flows (NCF) depreciates at 0.6% per year. The level of the depreciation rate is much smaller for rents and cash flows than for property values. This study is the first step toward understanding the link among the rent depreciation, the economic life of buildings, and the property depreciation.

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Introduction

The economic depreciation in property value is caused by two factors: cash flow depreciation and a shorter remaining life of a building. There is a large literature on the depreciation in property value. There are also many engineering studies on physical lifespan of buildings and the appraisal guideline about the economic life of buildings. However, studies are much scarcer on the cash flow depreciation. We are aware of only one study on residential rent depreciation (Lane, Randolph, and Berenson, 1988), which is currently used to construct the US Consumer Price Index. In their study, the estimated effect of aging on residential rents ranges from 0.11% to 0.36% per year in the United States. We are not aware of any study on the commercial property rent depreciation. There are only a few studies on the age profile of operating expenses (Taubman and Rasche, 1969), capital expenditures (Geltner and Bokhari, 2015), and net cash flows.

This is the first comprehensive study on the age profile of newly contracted rents, rents for sitting tenants, the average rents, operating expenses, net operating income, capital expenditures, and net cash flows for office properties. We first explain the conceptual framework of this study based on the value of the existing building and a redevelopment option. In our empirical analysis, we use the proprietary data of a major property management firm about Tokyo office market and construct the leasing unit panel and the building panel between 2008 and 2017.[1] The lease term is typically two years, but the median duration of tenancy is ten years based on the Kaplan-Meier method (Xymax Real Estate Institute, 2014).

[1] The standard office lease contract is the partial gross lease in Japan. The landlord primarily pays operating expenses, but tenants reimburse the metered electricity cost for their leased space. Tenants do not reimburse other expenses for the common area such as water and maintenance.

Our findings are summarized as follows.

1. The average annual rent depreciation rate (i.e., the aging effect) is 0.8% for new leases, 0.4% for leases by sitting tenants, and 0.5% on average. These rates are significantly smaller than the property value depreciation rate in the extant studies.

2. The spline rent function is more convex in age than the logarithmic function; i.e., the depreciation rate is larger for new buildings than for old buildings.

3. Smaller buildings tend to experience larger rent depreciation than larger buildings.

4. A tenant that occupies a larger proportion of building experiences larger rent depreciation.

5. Operating expenses depreciate at 0.6% per year although the cross-sectional variation is large.

6. Net operating income (NOI) depreciates at approximately 0.4% per year.

7. Capital expenditures generally increase over time but exhibit a peak between 15 and 30 years old.

8. Net cash flows (NCF) depreciates at 0.6% per year. This rate is significantly smaller than the property value depreciation rate in the extant studies.

The findings of the present study exhibit some similarities to and differences from the age profile of property value found in the existing studies. For example, Geltner and Bokhari (2015) and Yoshida (2017) also find that the property value depreciation rate is larger for early years whereas it is smaller for later years. However, the level of the depreciation rate is much smaller for rents and cash flows than for property values. The discrepancy may be explained by the early redevelopment of office properties because early demolition is common in Japan (Diewert and Shimizu, 2015). This study is the first step toward understanding the link among the rent depreciation, the economic life of buildings, and the property depreciation.

The economic depreciation in real estate value is important for various economic analyses. For example, in macroeconomics, the depreciation rate for structure is a key parameter for the models of economic growth and business cycles (e.g., Greenwood and Hercowitz 1991, Davis and Heathcote 2005, and Davis and Van Nieuwerburgh 2015). It is because depreciation rates affect the equilibrium level capital, consumption, saving, and productivity. In particular, the measurement of depreciation rates is central to understanding Japan's high saving rate (e.g., Hayashi 1986, Hayashi 1989, Hayashi 1991, Hayashi etal 1987, Dekle and Summers 1991, Hayashi and Prescott 2002, and Chenetal 2006). Depreciation rates are also a key input to economic statistics such as gross domestic product and inflation rates, which influence monetary and other macroeconomic policies (Ambrose, Coulson and Yoshida 2015). Depreciation rates also affect housing choice and consumer welfare because a large depreciation rate increases the user cost and rental cost of housing. A larger rental cost of housing makes households to spend a larger share of income on housing because housing services are complementary to other goods (Davidoff and Yoshida, 2013).

However, the estimated rate of property depreciation varies by estimation method and data. The estimated depreciation rates for the U.S. commercial structures are large and exhibit variations; they are 2.0% for retail, 2.5% for office, 2.7% for warehouse, and 3.6% for factory based on asset prices (Hulten and Wikoff, 1981) but 5.2%-7.2% based on the implicit rate in the National Accounts published by the Buerau of Economic Analysis (Hulten and Wykoff, 1981b, Hayashi, 1991). In a recent study that uses asset prices, the rate is approximately 3% for all commercial real estate and 3.3%-4.0% for apartments (Fisher et al., 2005, Geltner and Bokhari, 2015). The structure depreciation estimate for Japanese commercial properties is relatively scarce; a few studies that use the National Accounts report 5.7%-7.2% (Hayashi, 1991 and ESRI, 2011); a study by hedonic regression reports 9.8-10.8% (Yoshida, 2017); a study by demolition data reports 11.7% (Yoshida, 2017).[2]

The rate of economic depreciation in property value is estimated by several different methods. For example, Hulten and Wykoff (1981b), Coulson and McMillen (2008), Yoshida and Sugiura (2015), Geltner and Bokhari (2015), and Yoshida (2017), and Diewert and Shimizu (2017) use time-series or cross-sectional variations in asset prices.[3] Alternatively, Hulten and Wykoff (1981b), Hayashi (1991), Yoshida and Ha (2001), and ESRI (2011) use the flow investment data and the real estate stock data, typically in the National Accounts. The third method utilizes the data on demolished buildings (Yoshida, 2017). Structure depreciation rates are estimated by the building age at the time of demolition. This is more common in engineering studies.

Conceptual framework

A property of age a generates a net cash flow $N_{a,t}$ at time t. To simplify the model, assume that we can completely control for the property heterogeneity and the time-dependent market conditions. After removing the time-dependent component, the net cash flow is a function of only age: N_a. Assume that the age profile of the net cash flows is deterministic.[4]

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[2] There is larger literature on residential depreciation; e.g., Leigh (1980), Knight and Sirmans (1996), Harding et al. (2007) based on the US asset prices; Davis and Heathcote (2005) based on the US National Accounts; Seko (1998), Yoshida and Ha (2001), Hayashi (1991), and ESRI (2011).

[3] Diewert, Fox, and Shimizu (2016) use the time-series variation to estimate a property price index.

[4] We can analyze stochastic cash flows in the same framework by replacing the deterministic future cash flow with the certainty equivalence under the equivalent martingale measure (EMM).

In this study, we will analyze the age profile of net cash flows and its implication on the property value depreciation rate.

Let S_a denote the present discounted value of the net cash flows for the physical life span T of the existing building:

(1) $S_a = \int_a^T e^{-r(u-a)} N_u du,$

where r denotes the discount rate. The property value V_a consists of the value deriving from the existing building and the redevelopment option premium O_a.

(2) $V_a = S_a + O_a,$

The redevelopment option is an American call option. By exercising the option, the property owner obtains the value of newly developed property V_0 (the underlying asset) but loses the sum of the construction cost I and the present value of the remaining cash flows from the existing structure (the exercise price). At the same time, the owner loses the option to redevelop later. The economic life of the existing building $D \in (0, T)$ is endogenously determined by the optimal exercise of the redevelopment option. The owner exercises the option when the payoff from the immediate exercise first becomes greater than the option premium:

(3) $D = \min\{a | V_0 - I - S_a \geq O_a\}.$

Although there is no analytical solution to this American option value, the option is characterized by the usual value-matching condition, $O_D = V_0 - I - S_D$, and the smooth-pasting condition, $O'_D = -S'_D$ (the prime denotes derivatives). For this option, the value of the underlying asset V_0 is constant, but the exercise price $(I + S_a)$ continusouly decreases because the value of the existing building decrease over time $(S'_a < 0)$. At the same time, the option premium continuously increases $(O'_a > 0)$ as the option becomes less out of the money.

The marginal decrease in the value of existing building is greater than or equal to the marginal increase in the option premium:

(4) $S'_a + O'_a \leq 0$.

As a result, the property value V_a depreciates over time ($V'_a \leq 0$). However, the increase in the option premium accelerates as the building age approaches the optimal exercise time: $O''_a \geq 0$. At the time of the optimal exercise, the equation (4) holds with equality, which is the smooth-pasting condition. We obtain the first characterization of the property value depreciation rate.

Characterization 1: *The property depreciation rate is decreasing in age and becomes zero when the property is redeveloped;* i.e., $V'_a \leq 0, V''_a \geq 0$ *for any* $a \in (0, D)$, *and* $V'_D = 0$.

It is common that the estimated hedonic price function for property values is convex in age (e.g., Geltner and Bokhari, 2015, and Yoshida, 2017). Geltner and Bokhari (2015) attributes the flat age profile of old buildings to the complete depreciation of structure and unobserved capital expenditures whereas Yoshida (2017) analyzes a survivorship bias. However, in this study, we demonstrate that the age profile is always convex because of the increasing value of a redevelopment option even without unobserved capital expenditures or a survivorship bias. Furthermore, the completely flat age profile does not indicate the full depreciation of structure because value-matching and smooth-pasting conditions can hold when $S_a > 0$.[9]

Characterization 2: *A property may be redeveloped before the physical life of the existing building; i.e.,* $\exists D\ s.t.\ D < T$.

The depreciation in the value of existing building depends on the age profile of the net cash flow N_a. In this study, we analyze the age profile of the gross rental income, operating expenses, net operating income, capital expenditures, and net cash flows.

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[9] The loss of structure value due to the early demolition is studied by Diewert and Shimizu (2016).

[TO BE ADDED: the relation between the cash flow depreciation and the property value depreciation]

Empirical strategy

We estimate the age profile of rents, operating expenses, capital expenditures, net operating income and net cash flows by hedonic models. We use the following semi-log model for rents:

(5) $\ln R_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + \epsilon_{it}$,

where R_{it} denotes the rent of building i in time t, A_{it} denotes the age of building i at time t, and Y_t denotes year fixed effects. $\boldsymbol{X_{it}}$ is a vector of building characteristics of building i including the natural logarithmic of gross floor area, walk minutes from the nearest train station, city code of location and a dummy variable to indicate whether the building has been renovated as of time t. We estimate several variations of the age function f: (1) the linear model, $f(A_{it}) = a_1 A_{it}$; and (2) the spline function, $f(A_{it}) = \sum_{n=0}^{T} a_{1,n} I_n$, where I_n is the indicator function for $A_{it} = n \in [0, T]$. We analyze several alternative rental rates: newly contracted rents, rents for siting tenants, and the average rents. We also estimate the same equation by using the leasing unit-specific rent.[10]

A challenge to estimating the age profile from a cross-sectional hedonic model is the collinearity between the building age, the year built, and the year of observation (i.e., the year of rent payment). In the baseline model, we only control for the year of observation (year fixed effects) by assuming the absence of cohort effects. In addition to the basic model (5), we also estimate the model that includes cohort fixed effects:

[10] A leasing unit generally corresponds to a tenant, but a tenant can lease multiple leasing unit in the same building at different leasing rates.

(6) $\ln R_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + C_d + \epsilon_{it}$,

where C_d denotes decennial cohort effects. The decennial cohort is defined by the indicator variables for the built year between 1960-1969, 1970-1979, etc.

For operating expenses and capital expenditures, we estimate the same model as equation (5):

(7) $\ln OE_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + \epsilon_{it}$

(8) $\ln CP_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + \epsilon_{it}$

For net operating income and net cash flows, we cannot use the logarithmic value because they sometimes take negative values. Thus, we estimate the following linear models using the same explanatory variables.

(9) $NOI_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + \epsilon_{it}$

(10) $NCF_{it} = a_0 + f(A_{it}) + \boldsymbol{X_{it}b} + Y_t + \epsilon_{it}$

Data

Data source

This study uses three different data sets provided by Xymax Corporation, a real estate management company in Japan. The first dataset includes the information on location and property characteristics for over 10,000 office buildings in Tokyo 23 wards. The data is organized as a part of Xymax's management and brokerage services. Thus, the data set does not include the buildings that do not appear in the market such as owner-occupied buildings and rental building with a small number of long-term sitting tenants. The second data set contains the information about newly contracted rents since 2005 to 2016 through Xymax's brokerage service and other market sources. Each lease entry is matched with the building data set mentioned above. The third data set is obtained from Xymax's accounting operations in its property management service. The data set contains every money transfer including both income and expense for over 200 Xymax-managed buildings in Tokyo 23 wards. The dataset contains income records of monthly individual lease rates from every lease unit in the buildings since 2008 to 2016 and expense records of operating expenses since 2008 to 2016 and capital expenditures for repair works since 2005 to 2015.

Building characteristics data

Gross floor area, walking minutes from the nearest station, renewal date, completion date and location are used in this research among various features. Gross floor area is total floor area of the building including both leased area and common area. Walking minutes from the nearest station is calculated from route distance to the nearest train/subway station which is analyzed on GIS where assuming walking speed is 80m/minute. Building age is calculated from completion date as a difference between subject date/year and completion date/year. We generate location dummy variable which indicates which of Tokyo 23 special wards the building is located using the postal address. Another variable we generate to use in estimation models is "renewal dummy" to indicate whether the building has been renovated at the subject time. Renewal dummy indicates a building is renovated when the subject date is after the renewal date recorded in the dataset.

Unit-level rent data

The original rent datasets are two "unit-level" datasets ("unit panel") including newly contracted rent and individual lease rates. In contrast with newly contracted rent that is observed once a tenant concluded lease agreement with a landlord, the individual lease rates are observed sequentially every month while a tenant occupies a space. The unit-level new rent data is drawn from 6,069 buildings. The average characteristics of the buildings are 18,135 sqm of gross floor area, 22.51 years old and walking minutes from the nearest station is 5 minutes. The average new rent is 66,822 yen/sqm/year. Individual lease rates are drawn from 295 buildings. The average characteristics of buildings that individual lease rates are available are 14,192 sqm of gross floor area, 21.68 years old and walking minutes from the nearest station is approximately 5 minutes. The average lease rates are 66,748 yen/sqm/year. New rent data is obtained from broader sources than individual lease rates, however, the average characteristics of buildings are similar except the point that gross floor area of the buildings individual lease rates are available is smaller.

Building-level panel data: New rent, average rent and sitting tenant's rent

To illustrate changes with advancing building age, we calculated annually summarized "building-level" panel data ("building panel"). Within the building panel, new rent is calculated from unit panel as annual average of newly contract rent. Average rent is calculated alike as annual average of unit-level individual lease rates. The building panel also includes sitting tenant's rent which represents rent level of tenants continuously occupying space in the building. This illustrates the effect of building age on rent from which the influence of newly contract rent which fluctuates being affected by market rent level is excluded. Sitting tenant's rent is cumulatively calculated by annual rate of change in unit-level individual lease rates (fraction of the subject year's average rent and the previous year's average rent) drawn only from the tenants occupying the identical space consecutively from the previous year or before. Definition of variables included in the building panel is shown in Tables 1 and 2 show the descriptive statistics for the building panel data. The average of new rent is 64,178 yen/sqm/year, average rent is 63,351 yen/sqm/year and sitting tenant's rent is 67,934 yen/sqm/year.

Subsample datasets

Large buildings / small buildings

We organize large buildings subset and small buildings subset to analyze the difference of age profile by gross floor area of buildings. Large building and small building subsets are created for new rent, average rent and sitting tenant's rent on building panel. The large building subset is the rent data from the buildings with top 25% gross floor area, whereas the small building subset is the rent data of the buildings with bottom 25% gross floor area within each dataset where new rent, average rent or sitting tenant's rent is available.

Descriptive statistics for each subset data are shown in Table A.10 and A.11 in appendix. Large buildings subset includes 7,486 new rent observations and 620 average rent observations. Small buildings subset includes 2,762 new rent observations and 230 average rent observations. Although we picked up an equal number of buildings for each subset, number of observations is not equal because larger buildings have more units and tenants move in and out more frequently than smaller buildings. Thus, the larger buildings appears more in the panel data.

Large tenants / small tenants

We also organize large tenants subset and small tenants subset from unit-level rent data to analyze the difference of age profile by relative size of tenants that is calculated as a fraction of leased unit size and total leasable area within a building. Descriptive statistics for each subset data are shown in Tables A.12. and A.13 in appendix.

Operating expenses and net operating income

We also add annual total operating expenses in the building panel. Operating expenses are drawn from 239 buildings where average gross floor area is 8,846 sqm, 21.38 years old and approximately 5 minutes from the nearest stations. The average of annual total operating expenses per net rentable area is 18,443 yen/sqm/year. We can calculate net operating income for 220 buildings in which both average rent and operating expense are available. Average net operating income per net rentable area is 46,647 yen/sqm/year.

Capital expenditures and net cash flows

Capital expenditures are drawn from 328 buildings and average annual total capital expenditures per net rentable area are 4,151 yen/sqm/year. Finally, we can calculate net cash flows for 148 buildings in which both net operating income and capital expenditures are available. Average net cash flow per net rentable area is 42,761 yen/sqm/year.

Filtering

Unit-level new rent and individual lease rates

For unit-level rent datasets, we trimmed outliers by excluding records which resulted in large residuals (top 5% and bottom 5%) using the basic regression model (5). After the trimming, number of the unit-level new rent observation is 39,332 reduced from original 43,714 observations. Number of the unit-level individual lease rates observations was originally 186,406 and is 164,723 after trimming. Then, we eliminated observations from buildings with age of over 50 years because availability of those data is limited and spline analysis using the age dummy variable may not work. After this elimination, number of the unit-level new rent observations is 36,922 and number of the unit-level individual lease rates observations is 162,559.

Operating expenses and capital expenditures

Original operating expenses and capital expenditures datasets are aggregated from every single payment record. No outliers trimming similar to rent datasets is implemented for operating expense and capital expenditures data since the trimming will result in removing large amount of expenses such as renovation works which are significant in this research.

Operating expenses mainly include maintenance costs, management fee, utility costs, insurance and other expenses related to building operations. From the original datasets, we excluded expenses such as land lease, trust costs and other exceptional expenses that are observed only in part of buildings with special conditions.

Data Collection

We use following datasets in this paper.

Unit-level data

After the elimination of outliers, we obtained two sets of unit-level rent datasets: 36,922 new rent observations from 6,097 buildings ranges from 2005 to 2016 and 162,559 individual lease rates observations from 293 buildings ranges from 2008 to 2016. Number of individual lease rates observations is larger than new rent despite individual lease rates are drawn from fewer buildings. It is because individual lease rates are recorded monthly in the unit-level data, whereas new rent data is observed sporadically when tenants move in buildings.

Building panel data

We mainly analyze building-level panel data created from the unit-level data above. Within the panel data, we obtained 19,993 new rent observations from 2005 to 2016 in 6,097 buildings and 1,930 average rent observations from 2008 to 2016 in 293 buildings. We added 1,930 sitting tenant's rents calculated separately from individual lease rates.

We also obtained 897 annual total operating expenses in 239 buildings from 2008 to 2016 in the panel data and 816 net operating income observations as well in 220 buildings calculated where both average rent and operating expenses data are given. Likewise, we added 1,965 annual total capital expenditures observations from 2005 to 2015 in 328 buildings and calculated 680 net cash flows in 148 buildings from 2008 to 2015 where both net operating income and the capital expenditures are given.

Subsample data

For the subsample analysis to compare age profile of large buildings and small buildings, we created large building subset and small building subset of building panel data. The large building subset includes 7,486 new rent observations from 2005 to 2016 in 2,447 buildings and 620 average rent and sitting tenant's rent observations from 2008 to 2016 in 2,447 buildings. The small building subset includes 2,762 new rent observations from 2005 to 2016 in 2,450 buildings and 230 average rent and sitting tenant's rent observations from 2008 to 2016 in 2,450 buildings.

For the subsample analysis to compare age profile of large tenants and small tenants, we created large tenant subset and small tenant subset of unit-level individual lease rates data. The large tenant subset includes 39,469 rent observations from 2005 to 2016in 190 buildings and the small tenant subset includes 39,496 rent observations from 2005 to 2016in 129 buildings.

Result

New Rents

Table 3 shows the estimation result for newly contracted rents based on the building panel. Columns (1) and (2) show the result of baseline models (equation (5)). The average annual depreciation rate for newly contracted rents is 0.78%. This rent depreciation rate is significantly smaller than the property value depreciation rate estimated by the existing studies. For example, Yoshida (2017) estimates a property-level depreciation rate of 1.1% for all ages and 5.3% for the initial 5 years. The estimated coefficients on other variables are as expected. The annual rent per square meter is 0.15% higher for a 1% larger building, 2.2% lower for a 1-minute distant location from the nearest train station, approximately 4% higher if a building had a significant renovation.

Panel A of Figure 1 depicts the spline rent function corresponding to column (2). The estimated model is evaluated at the mean value of floor area, distance, and renewal status. The city is set to Chiyoda-ward, and year is set to 2016. The depreciation rate is large at the beginning and gradually decreases. The rent depreciation nearly stops when a building becomes 40 years old, and rents exhibit some appreciation after 40 years. This age profile is qualitatively similar to that for property prices (e.g., Geltner and Bokhari, 2015, and Yoshida, 2017).

Columns (3) and (4) of Table 3 and Panel B of Figure 1 show the estimation result of equation (6) when we control for cohort effects. The average annual depreciation rate becomes larger and 0.84%. The spline function exhibits much steady depreciation in new rents with less curvature. In particular, newly contracted rents continually decreases after 30 years, and there is no appreciating segment after 40 years old. The typical age profile for old buildings is caused by the cohort effect.

Table 4 and Figure 2 show the estimation result of equation (5) based on the leasing unit panel. Because of the larger number of observations, the estimation tends to be more precise even after controlling for building clusters in standard errors. The result is consistent with the result based on the building panel.

Table 5 and Figure 3 show the estimation result of equation (5) when we divide the building sample into two: smallest 25% and largest 25% in the gross floor area. Large office properties may exhibit a different age profile from small properties because there may be unobserved differences in the property owner characteristics, the tenant characteristics, leasing strategies, the quality of structure, and micro-level location. The new rent depreciation rate is slightly larger for smaller buildings; 0.90%/year for the small building sample and 0.83%/year for the large building sample. However, since the rent level is significantly higher for large buildings, the JPY amount of rent decrease is larger for large buildings (Figure 3). Smaller buildings are more sensitive to a marginal increase in the gross floor area, less sensitive to the distance from the nearest station, and less sensitive to significant renovations.

Rents for Sitting Tenants

Table 6 shows the estimation result regarding the rent for sitting tenants. With a traditional lease contract in Japan, tenants are generally more protected by the law than the landlord regarding the lease termination and rent revision at renewal. For example, the landlord needs to provide just cause to reject a sitting tenant's request to renew a lease. The landlord also generally cannot increase rents significantly to catch up with the fast appreciating marginal rent in the market. As a result, we expect a different age profile of rents for sitting tenants.

Under the standard lease contract, especially if the move-in date is before 2000, the tenant can terminate the contract anytime with 6 month notice, but the landlord is virtually unable to even refuse a lease renewal. It is also customary that the landlord change rents only moderately for the existing tenant due to possible legal costs. Thus, there is an upward stickiness in property rents in Japan.

The annual depreciation rate is smaller and 0.42%. Panel A of Figure 4 exhibit non-uniform depreciation in rents with some bumps between 5 and 15 years and 35 and 40 years. To see if these bumps are caused by cohort effects, we include cohort fixed effects. The age coefficients are less precisely estimated because of a smaller sample size than for the new rent sample. However, the bumps are significantly reduced. Thus, these non-uniform depreciation seems to be an artifact of cohort effects. Regarding other variables, sitting tenants' rents are less sensitive to the building size, location, and a recent renovation. This result may imply that sitting tenants are more likely to be infra-marginal and paying rents based on suboptimal choices or some idiosyncratic factors.

To gain more insights, we estimate equation (5) separately for small and large buildings. Table 7 and Figure 5 show the result. Since the sample sizes drop significantly, we do not obtain any conclusive result. However, it seems that small buildings experience larger depreciation than larger buildings. Since the landlord of a smaller office building has a smaller bargaining power against tenants, this result may suggest that the sitting tenant rents are more significantly affected by individual negotiations between the landlord and the tenant.

Average Rents

Table 8 and Figure 6 show the estimation result regarding the average rent. The average rent is the basis for the building-level cash flows and the property value. Since the average rent is a mixture of newly contracted rents and sitting tenant rents, the estimation result is consistent with both of the previous results. The spline function exhibits bumps as for sitting tenants' rents, but cohort effects reduce of these bumps. The annual average depreciation rate is 0.53%, which is smaller than the rate for new rents and larger than the rate for sitting tenant rents. The leasing unit panel regressions (Table 9 and Figure 7) demonstrate the same result with an increased precision with more observations. The average depreciation rate is 0.68% after controlling for cohort effects. These estimated rates are significantly smaller than the rate of property value depreciation (e.g., 1.1% by Yoshida, 2017). This discrepancy is partly caused by the difference in sample characteristics. Our data include larger buildings than Yoshida's (2017) sample. Since smaller buildings exhibit a larger depreciation rate (Table 10 and Figure 8), our estimate is naturally smaller. However, even for the sample of small buildings, the average depreciation rate is 0.73. Thus, the sample difference is not a major reason for the discrepancy. This result suggests that a large component of the property value depreciation stems from a short life of structure.

Table 11 and Figure 9 show the result for subsamples. The Large25% sample shown in columns (1) and (2) contains the tenants that occupy the largest proportion of the building floor area. The Small25% sample shown in columns (3) and (4) contains the tenants with the smallest proportion. The rent depreciation rate is larger for the tenants with large proportions (0.65% and significant) than for the tenants with small proportions (0.08% and insignificant). The spline functions in depicted in Figure 9 show more specific age profiles. Although there are some irregular bumps and dips, we do not observe a significant rent depreciation for less significant tenants. The tenant that occupies a significant proportion of a building has a stronger bargaining power and tends to successfully renegotiate on a new preferential rent at a lease renewal. Thus, the depreciation result can also be interpreted by a significant tenant's bargaining power.

Operating Expenses

Table 12 shows the estimation result regarding operating expenses. There is much larger cross-sectional variation in operating expenses than in rents. For example, the adjusted R-squared is only 0.09. As a result, none of the estimated coefficients is statistically significant. Figure 10 also exhibits wide confidence intervals. Although the point estimate is a small negative number: -0.64%/year for the baseline case (column (1)), the estimated age coefficient is not statistically significant. When we control for cohort effects, the point estimate is a large negative number (-0.026), but it is still not statistically significant. Overall, the operating expenses do not exhibit a large increase or decrease by aging.

Net Operating Income

Table 13 shows the estimation result regarding net operating income (NOI). Since NOI is the basis for property valuation, the deprecation rate of NOI can be directly compared with the property value depreciation rate. The estimated age profile of NOI is also noisy. For this estimation, we use a JPY value of net operating income because it is sometimes negative. The point estimate is -182 JPY/sq.mr/year. Since the average NOI is 46,647 JPY, the depreciation rate is approximately 0.4% per year. This rate is even smaller than the rate for the average rent. In contrast, when we control for cohort effects, the estimated coefficient becomes positive 878 JPY. This number approximately corresponds to 1.8% per year. Figure 11 depicts this upward-sloping spline rent function with respect to age. This increasing NOI is the result of a large decrease in operating expenses (Figure 10). This result is counter-intuitive and requires further investigation.

Capital Expenditures

Table 14 shows the estimation result regarding capital expenditures. Although capital expenditures are not large on average, they generally increase as a building ages. The average annual increase is 2.4% in the baseline model. However, there is large cross-sectional variation in capital expenditures; the adjusted R-squared is 0.05 for the baseline model and 0.09 for the spline model. Figure 12 also shows large time-series variation. Capital expenditures significantly increase until 20 years old and remain large until 30 years old. After 30 years, expenditures decrease for 10 to 15 years. This time-series pattern is consistent with the anecdotal evidence that a building typically needs a significant renovation after 10 to 20 years. When we control for cohort effects, standard errors significantly increase and the age coefficient becomes insignificant. However, the point estimate in the baseline model and the spline function are consistent with the baseline case.

Net Cash Flow

Table 15 and Figure 13 show the estimation result regarding net cash flow (NCF) after capital expenditures. The NCF is also the basis for the property valuation. Since NCF also sometimes takes negative values, we estimate the level of NCF. The estimated age coefficient is -234 JPY per year. Based on the average NCF of 42,761JPY per year, the percentage depreciation is 0.6% per year. This depreciation rate is larger than the NOI depreciation rate because of increasing capital expenditures, but it is significantly smaller than the property value depreciation rate. When we control for cohort effects, NCF exhibits an upward-sloping age profile as NOI does. This is due to a noisy yet large negative effect of age on operating expenses. Since there is no good economic explanation of a decreasing operating expenses and increasing NCF, more investigation is needed.

Conclusion

This is the first comprehensive study on the age profile of newly contracted rents, rents for sitting tenants, the average rents, operating expenses, net operating income, capital expenditures, and net cash flows for office properties. We use the proprietary data of a major property management firm about Tokyo office market and find: (1) The average annual rent depreciation rate (i.e., the aging effect) is 0.8% for new leases, 0.4% for leases by sitting tenants, and 0.5% on average; (2) the rent function is more convex in age than the logarithmic function; (3) Smaller buildings tend to experience larger rent depreciation; (4) A tenant that occupies a larger proportion of building experiences larger rent depreciation; (5) Operating expenses depreciate annually at 0.6%; (6) Net operating income (NOI) depreciates annually at 0.4%; (7) Capital expenditures generally increase over time; and (8) Net cash flows (NCF) depreciates at 0.6% per year. The level of the depreciation rate is much smaller for rents and cash flows than for property values. This study is the first step toward understanding the link among the rent depreciation, the economic life of buildings, and the property depreciation.

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Tables

Variable	Short name	Unit	Description
BLDG_ID	BLDG_ID	-	Unique ID for the building
YEAR	YEAR	-	Year of observation
NEW_RENT	NR	JPY/sqm year	New contract rent per net rentable area per annum
AVG_RENT	AR	JPY/sqm year	Average rent per net rentable area per annum
SIT_RENT	SR	JPY/sqm year	Calculated sitting tenants rent per net rentable area per annum
CAPEX	CP	JPY/sqm year	Annual total of capital expenditures per net rentable area per annum
OPEX	OP	JPY/sqm year	Annual total of operating expenditures per net rentable area per annum (excl. land lease, deposit and trust cost)
net operating income	NOI	JPY/sqm year	Calculated from AVG_RENT and OPEX
net cash flows	NCF	JPY/sqm year	Calculated from NOI and CAPEX
GFA	GFA	sqm	Gross floor area
NRA	NRA	sqm	Net rentable area
HEIGHT	HEIGHT	-	Number of floors above ground
DISTANCE	DISTANCE	m	Walking distance to the nearest station
MINUTES	MINUTES	minutes	Walking minutes to the nearest station
AGE	AGE	years	Age of the building
AGE_INT	AGE_INT	years	Interger value (floor) of age
COMPLETION_YEAR	CPL_YEAR	-	Year the building built
COHORT	COHORT	-	Decennary floor value of COMPLETION_YEAR
RENEWAL	RNW	-	Dummy variable to indicate renovation
RENEWAL_YEAR	RNW_YEAR	-	Year renovated
DEMOLITION	DML	-	Dummy variable to indicate demolition
DEMOLITION_YEAR	DML_YEAR	-	Year demolitioned

Table1: Definition of variables

Variable	N	mean	sd	median	min	max
BLDG_ID	21,415	7,143.753	7,250.650	4,629.000	1.000	36,294.000
YEAR	21,415	2,011.268	3.323	2,011.000	2,005.000	2,016.000
NEW_RENT	19,993	64,177.906	22,696.630	58,080.002	22,143.001	254,100.010
AVG_RENT	1,930	63,350.561	17,225.231	60,169.777	32,514.430	165,010.293
SIT_RENT	1,930	67,934.411	17,599.644	65,066.088	32,670.001	157,894.326
CAPEX	1,965	4,151.942	9,280.731	1,767.917	2.264	222,806.522
OPEX	897	18,443.338	12,426.174	16,637.749	295.432	164,039.653
NOI	816	46,647.814	20,518.152	45,775.612	-118,565.427	141,168.308
NCF	680	42,760.880	21,948.160	41,369.957	-127,933.144	141,015.083
GFA	21,415	12,374.030	27,971.174	4,196.562	285.289	379,447.920
NRA	21,415	7,326.374	14,760.149	2,911.008	115.008	182,443.993
HEIGHT	21,345	10.310	6.154	9.000	2.000	60.000
DISTANCE	21,415	288.529	156.170	267.375	1.764	1,177.446
MINUTES	21,415	4.960	2.442	4.633	0.000	23.683
AGE	21,415	22.725	10.704	22.000	1.000	50.000
COMPLETION_YEAR	21,415	1,988.543	10.448	1,990.000	1,956.000	2,015.000
RENEWAL	21,415	0.164	0.371	0.000	0.000	1.000
RENEWAL_YEAR	4,266	2,005.124	7.414	2,006.000	1,964.000	2,017.000
DEMOLITION	21,415	0.032	0.175	0.000	0.000	1.000
DEMOLITION_YEAR	561	2,013.879	2.345	2,014.000	2,002.000	2,017.000

Table2: Descriptive Statistics (Building Panel)

Dependent Variable: Log new rent	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	0.153***	0.145***	0.144***	0.144***
	(65.34)	(63.59)	(62.72)	(62.83)
MINUTES	-0.0235***	-0.0220***	-0.0220***	-0.0219***
	(-22.52)	(-22.20)	(-22.18)	(-22.18)
RNW	0.0472***	0.0377***	0.0361***	0.0356***
	(7.41)	(6.09)	(5.81)	(5.74)
AGE	-0.00783***		-0.00840***	
	(-32.79)		(-9.32)	
_cons	10.04***	10.19***	10.33***	10.32***
	(462.26)	(447.81)	(162.59)	(161.63)
AgeFE(1yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	19993	19993	19993	19993
adj. R^2	0.722	0.738	0.738	0.739

Table 3: Regression Result (Building Panel: New Rent – Cohort Analysis)

Dependent Variable: Log new rent	(1) Baseline - Linear	(2) Baseline - Spline
GFA_LOG	0.150***	0.144***
	(58.61)	(56.92)
MINUTES	-0.0239***	-0.0222***
	(-18.86)	(-18.72)
RNW	0.0477***	0.0391***
	(6.61)	(5.59)
AGE	-0.00784***	
	(-27.50)	
_cons	10.07***	10.16***
	(411.00)	(384.75)
AgeFE(1yr)	No	Yes
YearFE	Yes	Yes
CityFE	Yes	Yes
N	36922	36922
adj. R^2	0.736	0.751

Table 4: Regression Result (Unit Panel: New Rent)

Dependent Variable: Log new rent	(1) Large25% - Linear	(2) Large25% - Spline	(3) Small25% - Linear	(4) Small25% - Spline
GFA_LOG	0.143***	0.137***	0.156***	0.159***
	(29.58)	(29.36)	(4.70)	(4.89)
MINUTES	-0.0265***	-0.0238***	-0.0233***	-0.0225***
	(-15.31)	(-14.39)	(-11.09)	(-10.74)
RNW	0.0571***	0.0445***	0.0412*	0.0335*
	(5.46)	(4.40)	(2.51)	(2.03)
AGE	-0.00826***		-0.00901***	
	(-21.44)		(-16.68)	
_cons	10.22***	10.34***	10.01***	10.03***
	(198.23)	(212.89)	(42.02)	(42.11)
AgeFE(1yr)	No	Yes	No	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	7486	7486	2762	2762
adj. R^2	0.728	0.744	0.565	0.581

Table 5: Regression Result (Building Panel: New Rent – Subsample Analysis)

Dependent Variable: Log sitting tenant's rent	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	0.117***	0.112***	0.114***	0.112***
	(9.03)	(9.96)	(9.80)	(10.00)
MINUTES	-0.0155***	-0.0104*	-0.0117*	-0.0108*
	(-3.40)	(-2.33)	(-2.58)	(-2.39)
RNW	-0.0125	-0.0140	-0.0140	-0.0136
	(-0.41)	(-0.49)	(-0.49)	(-0.47)
AGE	-0.00421**		-0.00504	
	(-3.26)		(-1.20)	
_cons	10.39***	10.34***	10.44***	10.21***
	(101.45)	(104.26)	(46.08)	(46.57)
AgeFE(1yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	1930	1930	1930	1930
adj. R^2	0.480	0.527	0.531	0.534

Table 6: Regression Result (Building Panel: Sitting Tenant's Rent – Cohort Analysis)

Dependent Variable: Log sitting tenant's rent	(1) Large25% - Linear	(2) Large25% - Spline	(3) Small25% - Linear	(4) Small25% - Spline
GFA_LOG	0.117**	0.112**	-0.0380	-0.194
	(2.90)	(2.84)	(-0.18)	(-1.01)
MINUTES	-0.0259***	-0.0230**	-0.0106	-0.0110
	(-3.62)	(-3.20)	(-1.01)	(-1.16)
RNW	-0.0332	-0.0140	-0.202	-0.291***
	(-0.68)	(-0.28)	(-2.02)	(-4.60)
AGE	-0.00321		-0.00673	
	(-1.39)		(-1.77)	
_cons	10.46***	10.47***	11.48***	12.52***
	(28.99)	(29.99)	(7.67)	(9.02)
AgeFE(1yr)	No	Yes	No	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	620	620	230	230
adj. R^2	0.581	0.598	0.612	0.665

Table 7: Regression Result (Building Panel: Sitting Tenant's Rent – Subsample Analysis)

Dependent Variable: Log average rent	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	0.113***	0.110***	0.109***	0.108***
	(8.25)	(8.87)	(8.93)	(8.98)
MINUTES	-0.0197***	-0.0151***	-0.0164***	-0.0153***
	(-4.76)	(-3.73)	(-4.05)	(-3.69)
RNW	-0.0227	-0.0264	-0.0260	-0.0264
	(-0.77)	(-0.93)	(-0.92)	(-0.93)
AGE	-0.00530***		-0.00422	
	(-4.35)		(-1.14)	
_cons	10.46***	10.42***	10.45***	10.39***
	(98.10)	(98.47)	(49.66)	(50.25)
AgeFE(1yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	1930	1930	1930	1930
adj. R^2	0.520	0.550	0.555	0.554

Table 8: Regression Result (Building Panel: Average Rent – Cohort Analysis)

Dependent Variable: Log rent	(1) Baseline - Linear	(2) Baseline - Spline	(3) Initial Control - Linear	(4) Initial Control - Spline
GFA_LOG	0.109***	0.110***	0.109***	0.111***
	(7.09)	(8.89)	(7.85)	(9.92)
MINUTES	-0.0228***	-0.0183***	-0.0214***	-0.0168***
	(-4.79)	(-4.31)	(-4.83)	(-4.34)
RNW	-0.0189	-0.0149	-0.00876	-0.00600
	(-0.62)	(-0.57)	(-0.32)	(-0.26)
AGE	-0.00583***		-0.00677***	
	(-4.05)		(-5.07)	
_cons	10.52***	10.50***	10.68***	10.59***
	(89.68)	(94.88)	(81.13)	(89.32)
AgeFE(1yr)	No	Yes	No	Yes
InitialYrFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	162559	162559	162559	162559
adj. R^2	0.525	0.571	0.637	0.681

Table 9: Regression Result (Unit Panel: Average Rent – Control Initial Year)

Dependent Variable: Log average rent	(1) Large25% - Linear	(2) Large25% - Spline	(3) Small25% - Linear	(4) Small25% - Spline
GFA_LOG	0.114**	0.113**	-0.113	-0.315
	(2.71)	(2.78)	(-0.61)	(-1.67)
MINUTES	-0.0303***	-0.0284***	-0.0115	-0.0120
	(-4.85)	(-4.50)	(-1.60)	(-1.69)
RNW	-0.0381	-0.0275	-0.112	-0.191*
	(-0.86)	(-0.62)	(-1.15)	(-2.40)
AGE	-0.00537*		-0.00725	
	(-2.27)		(-1.92)	
_cons	10.59***	10.60***	12.02***	13.38***
	(28.38)	(29.98)	(8.96)	(9.82)
AgeFE(1yr)	No	Yes	No	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	620	620	230	230
adj. R^2	0.641	0.660	0.611	0.645

Table 10: Regression Result (Building Panel: Average Rent – Subsample Analysis)

Dependent Variable: Log rent	(1) Large25% - Linear	(2) Large25% - Spline	(3) Small25% - Linear	(4) Small25% - Spline
GFA_LOG	0.0959***	0.0892***	0.142***	0.140***
	(7.44)	(7.04)	(5.04)	(7.26)
MINUTES	-0.0186*	-0.0160*	-0.0209*	-0.0220**
	(-2.52)	(-2.17)	(-2.46)	(-2.90)
RNW	0.00434	-0.0321	-0.0597	-0.00695
	(0.09)	(-0.81)	(-1.19)	(-0.19)
AGE	-0.00647***		-0.000793	
	(-3.42)		(-0.38)	
_cons	10.64***	10.71***	10.19***	10.03***
	(72.73)	(71.08)	(46.13)	(57.21)
AgeFE(1yr)	No	Yes	No	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	39469	39469	39496	39496
adj. R^2	0.558	0.601	0.621	0.670

Table 11: Regression Result (Unit Panel: Average Rent – Subsample Analysis)

Dependent Variable: Log OpEx	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	0.0579	0.0526	0.0675	0.0586
	(1.19)	(1.07)	(1.45)	(1.24)
MINUTES	-0.0110	-0.00965	-0.00526	-0.0107
	(-0.64)	(-0.55)	(-0.30)	(-0.61)
RNW	-0.00685	-0.0184	-0.00438	0.00796
	(-0.06)	(-0.15)	(-0.04)	(0.07)
AGE	-0.00635		-0.0263	
	(-1.55)		(-1.56)	
_cons	9.232***	9.040***	10.14***	9.901***
	(22.26)	(17.41)	(14.19)	(14.51)
AgeFE(1yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	897	897	897	897
adj. R^2	0.086	0.090	0.112	0.105

Table 12: Regression Result (Building Panel: Opex– Cohort Analysis)

Dependent Variable: NOI	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	8168.4**	7770.8**	7493.2***	7374.6**
	(3.13)	(3.27)	(3.39)	(3.33)
MINUTES	-1232.8*	-1010.7	-1050.8*	-942.1
	(-2.29)	(-1.79)	(-1.98)	(-1.69)
RNW	-2517.2	-1835.5	-2594.2	-2256.3
	(-0.74)	(-0.54)	(-0.79)	(-0.67)
AGE	-182.6		877.8*	
	(-1.35)		(2.03)	
_cons	-559.9	-1990.2	-40708.9	-42532.0
	(-0.03)	(-0.10)	(-1.58)	(-1.62)
AgeFE(1yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	816	816	816	816
adj. R^2	0.383	0.401	0.426	0.416

Table 13: Regression Result (Building Panel: NOI– Cohort Analysis)

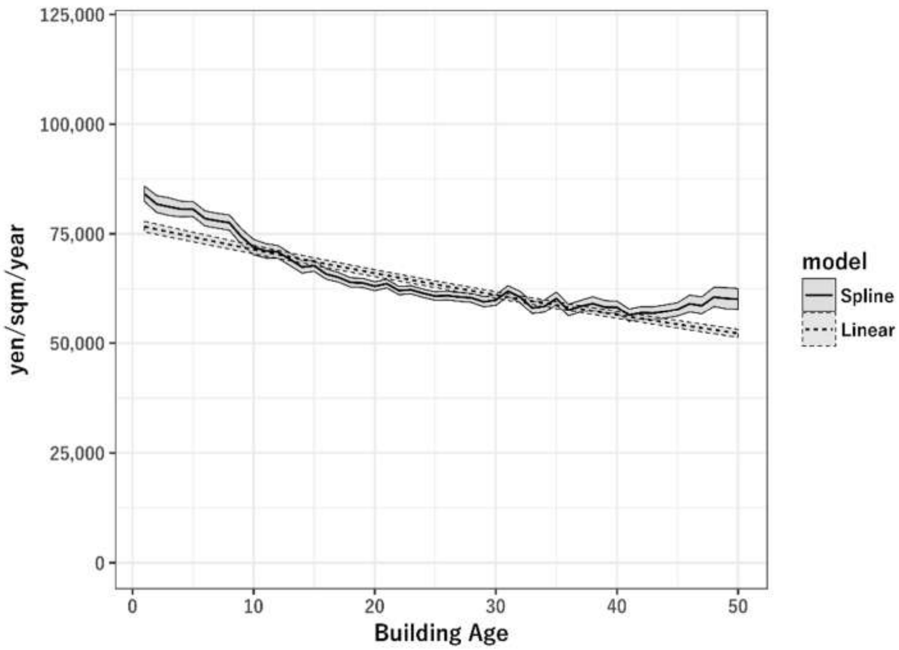
Dependent Variable: Log CapEx	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	-0.0110	0.00973	0.0224	0.0103
	(-0.18)	(0.19)	(0.43)	(0.20)
MINUTES	-0.00158	-0.0325	-0.0282	-0.0326
	(-0.06)	(-1.36)	(-1.15)	(-1.36)
RNW	0.112	0.226	0.181	0.217
	(0.68)	(1.47)	(1.14)	(1.39)
AGE	0.0238***		0.0285	
	(3.60)		(1.24)	
_cons	6.608***	5.424***	5.754***	5.959***
	(12.17)	(6.83)	(5.51)	(5.26)
AgeFE(5yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	1965	1965	1965	1965
adj. R^2	0.045	0.122	0.090	0.121

Table 14: Regression Result (Building Panel: CapEx– Cohort Analysis)

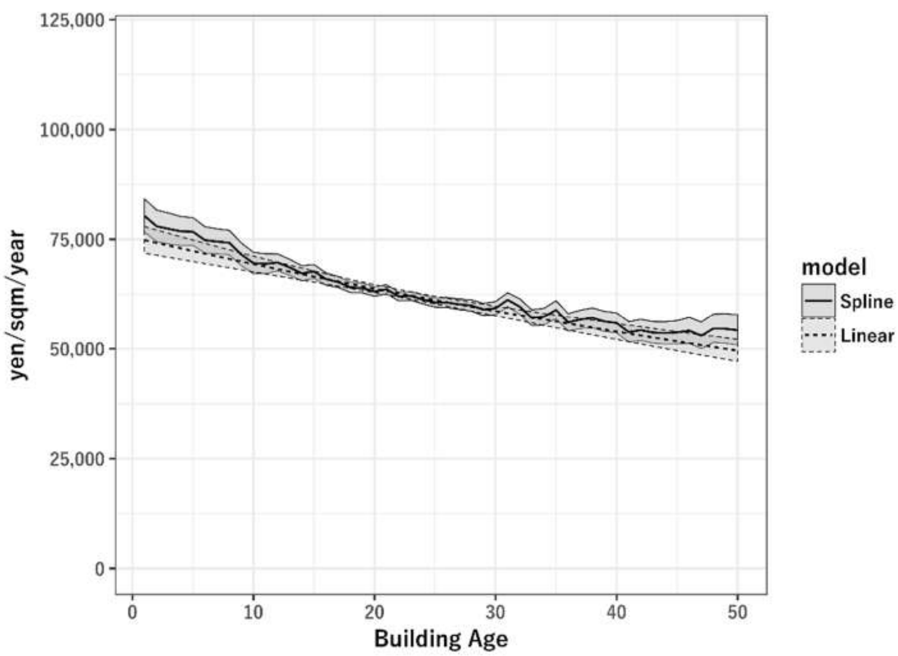
Dependent Variable: NCF	(1) Baseline - Linear	(2) Baseline - Spline	(3) Cohort Control - Linear	(4) Cohort Control - Spline
GFA_LOG	8303.1**	8035.6**	7623.9**	7572.7**
	(2.82)	(3.06)	(3.05)	(3.14)
MINUTES	-984.4	-670.3	-774.3	-617.5
	(-1.83)	(-1.14)	(-1.42)	(-1.06)
RNW	-5452.9	-5729.7	-6010.4	-5484.3
	(-1.39)	(-1.53)	(-1.64)	(-1.49)
AGE	-273.6*		764.8	
	(-2.00)		(1.55)	
_cons	-8205.3	-3112.2	-47596.6	-48020.7
	(-0.38)	(-0.14)	(-1.65)	(-1.76)
AgeFE(5yr)	No	Yes	No	Yes
CohortFE	No	No	Yes	Yes
YearFE	Yes	Yes	Yes	Yes
CityFE	Yes	Yes	Yes	Yes
N	680	680	680	680
adj. R^2	0.327	0.365	0.371	0.383

Table 15: Regression Result (Building Panel: NCF– Cohort Analysis)

Figures



Panel A: Baseline



Panel B: With Cohort Fixed Effects

Figure 1: Age Profile (Building Panel: New Rent)

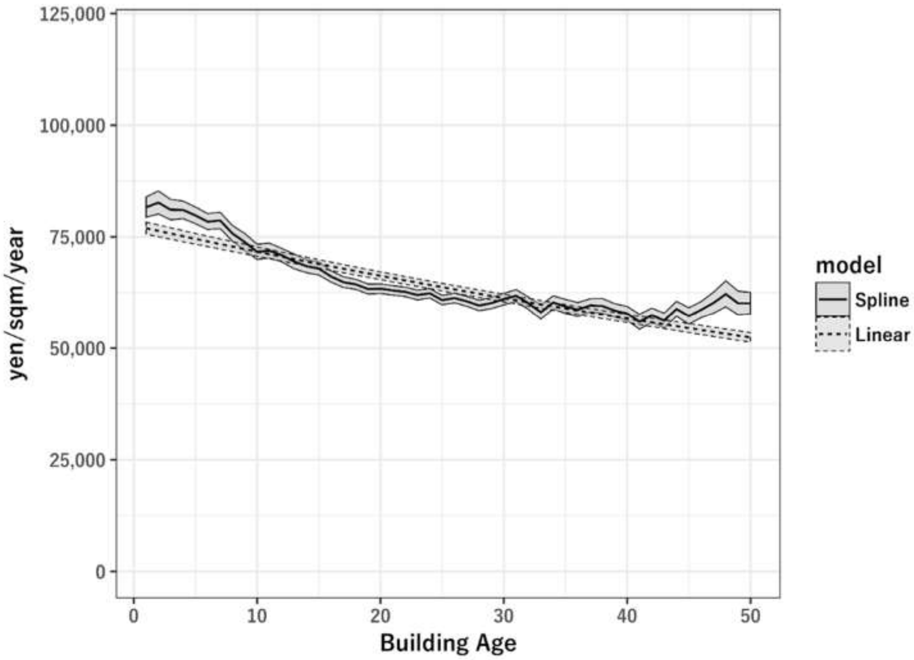
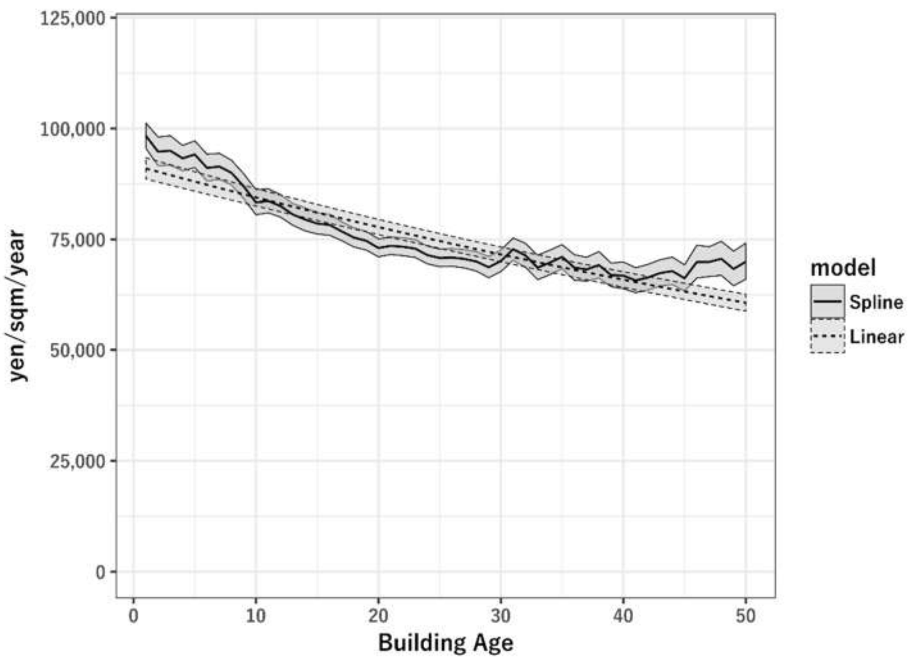
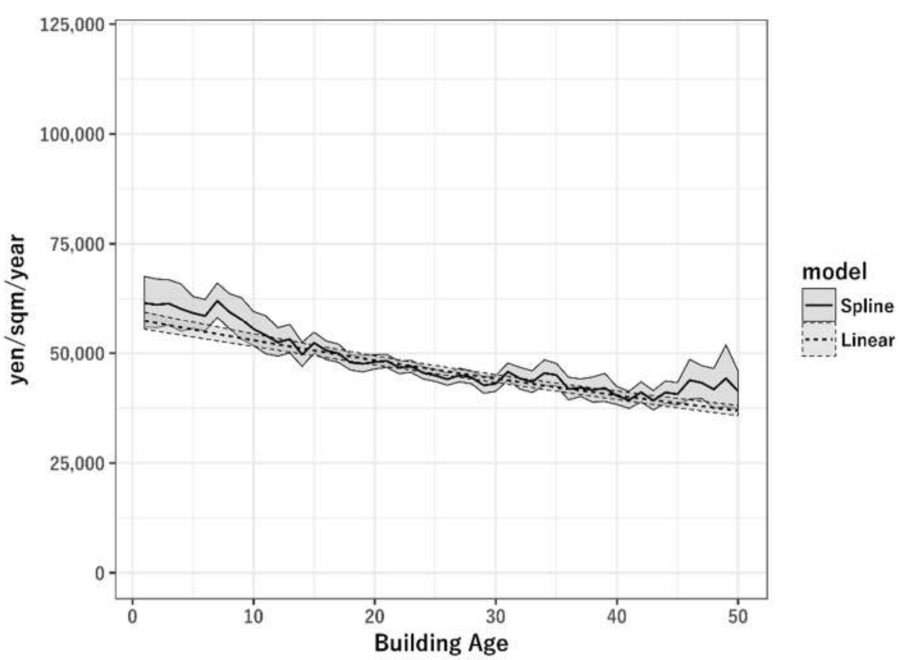


Figure 2: Age Profile (Unit Panel: New Rent)

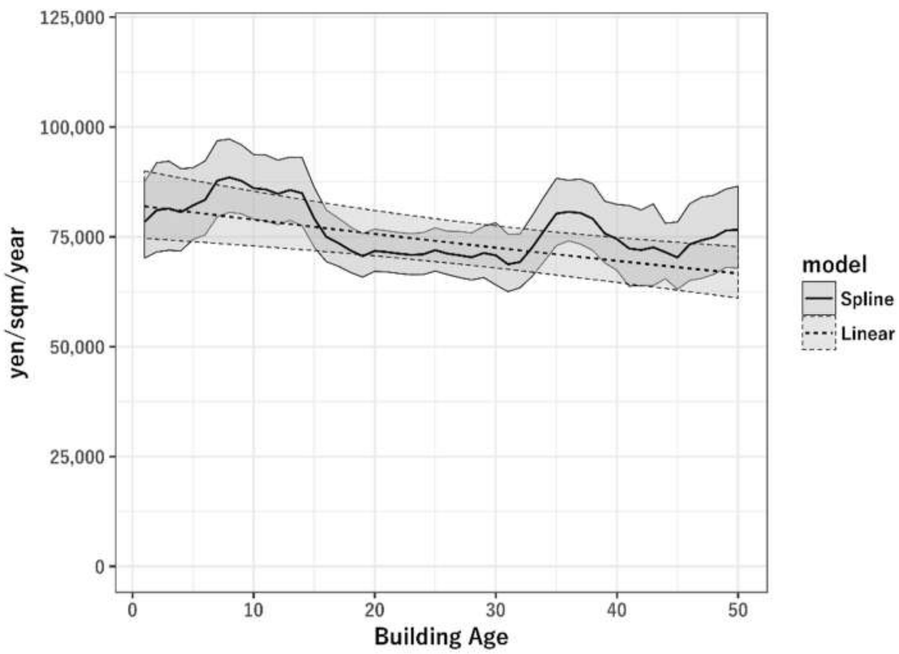


Panel A: Large 25%

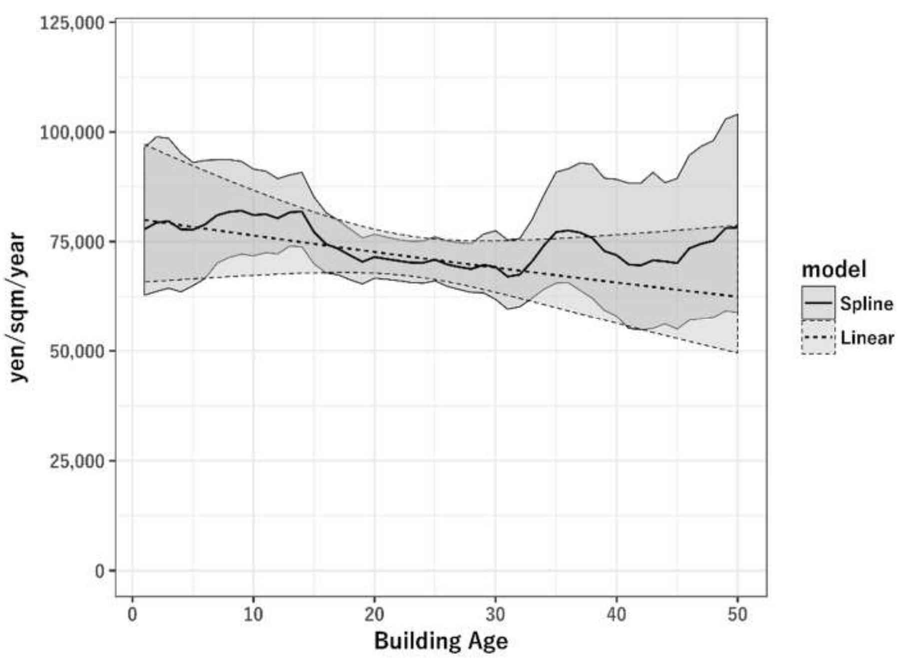


Panel B: Small 25%

Figure 3: Age Profile (Building Panel: New Rent)

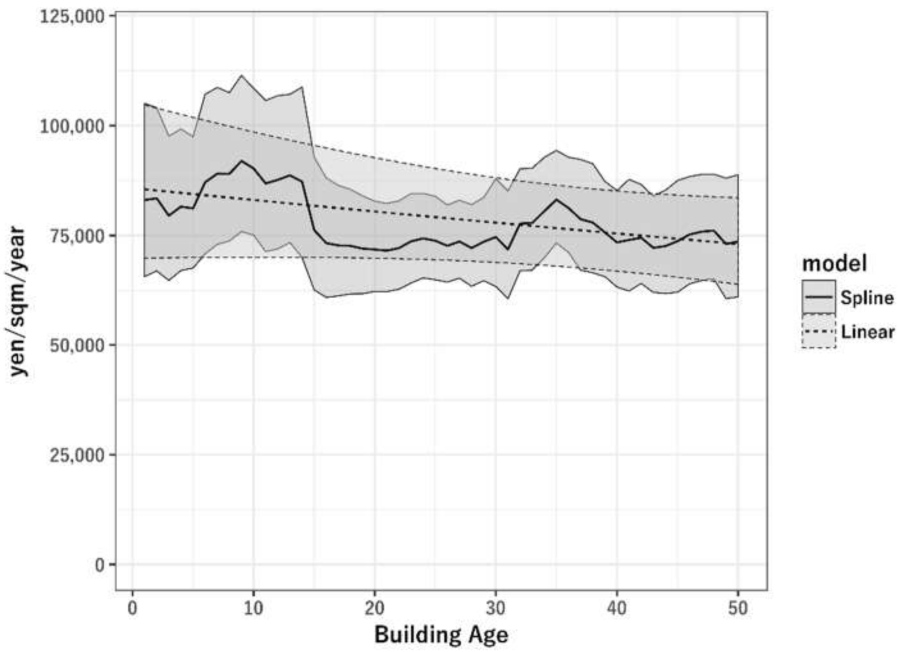


Panel A: Baseline

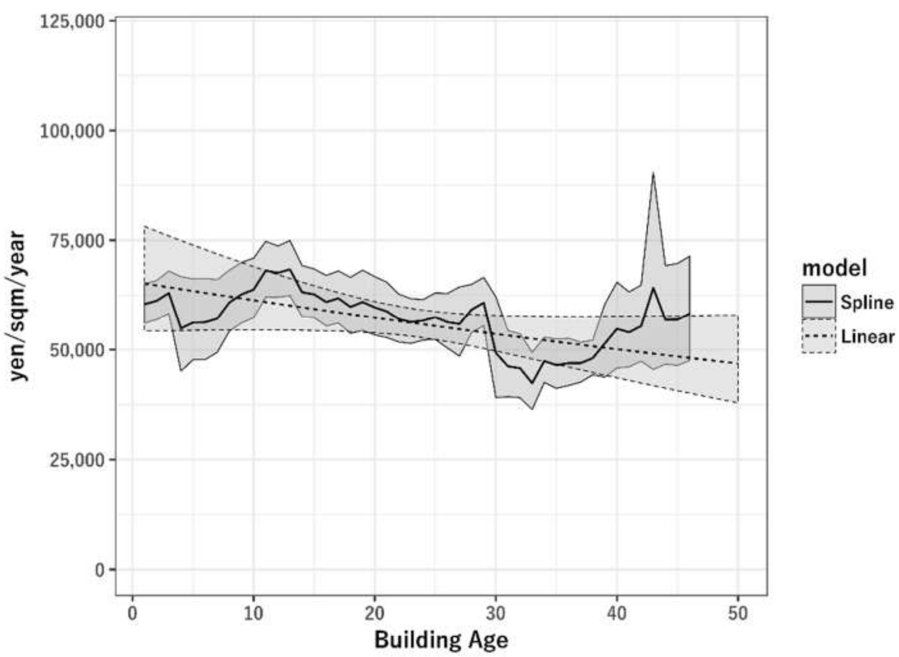


Panel B: Control Cohort Fixed Effect

Figure 4: Age Profile (Building Panel: Sitting Tenant's Rent)

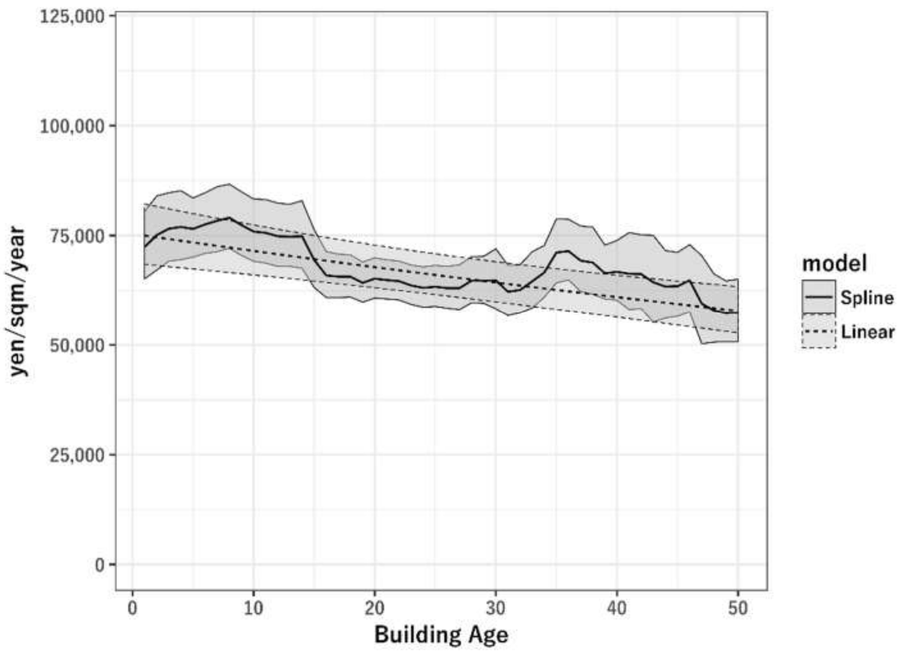


Panel A: Large 25%

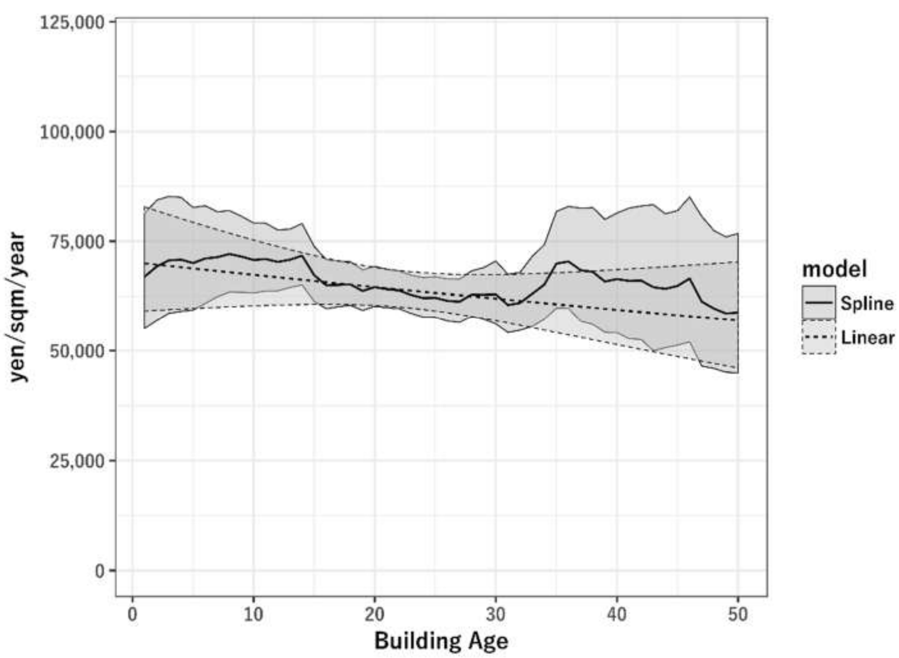


Panel B: Small 25%

Figure 5: Age Profile (Building Panel: Sitting Tenant's Rent)

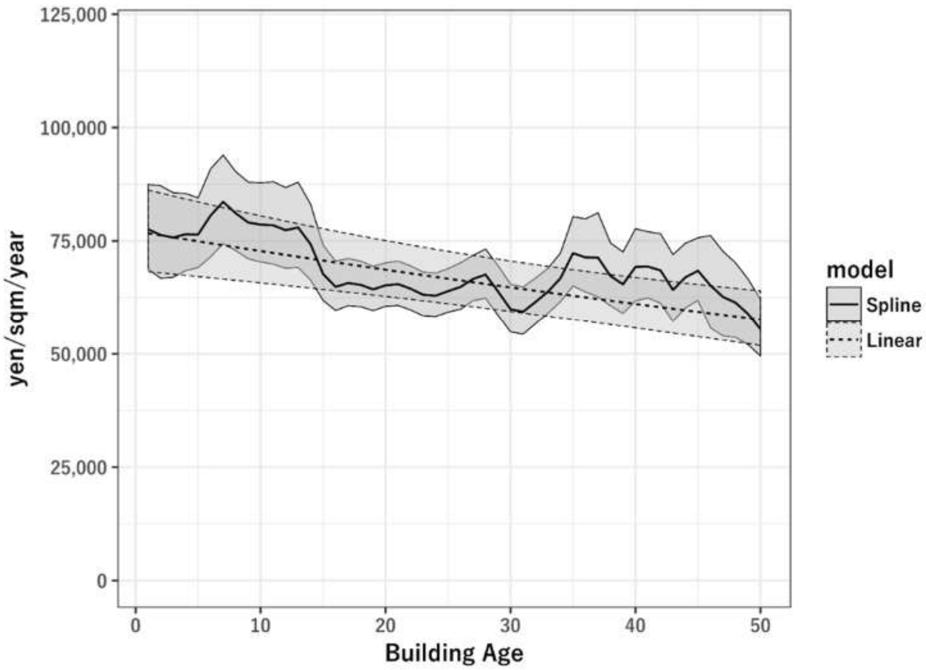


Panel A: Baseline

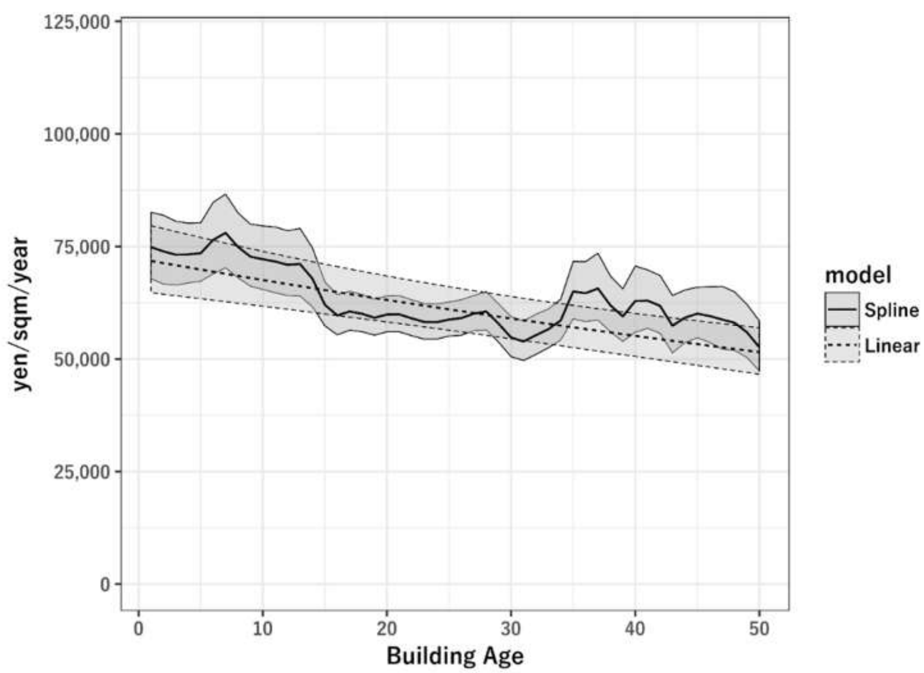


Panel B: Control Cohort Fixed Effects

Figure 6: Age Profile (Building Panel: Average Rent)

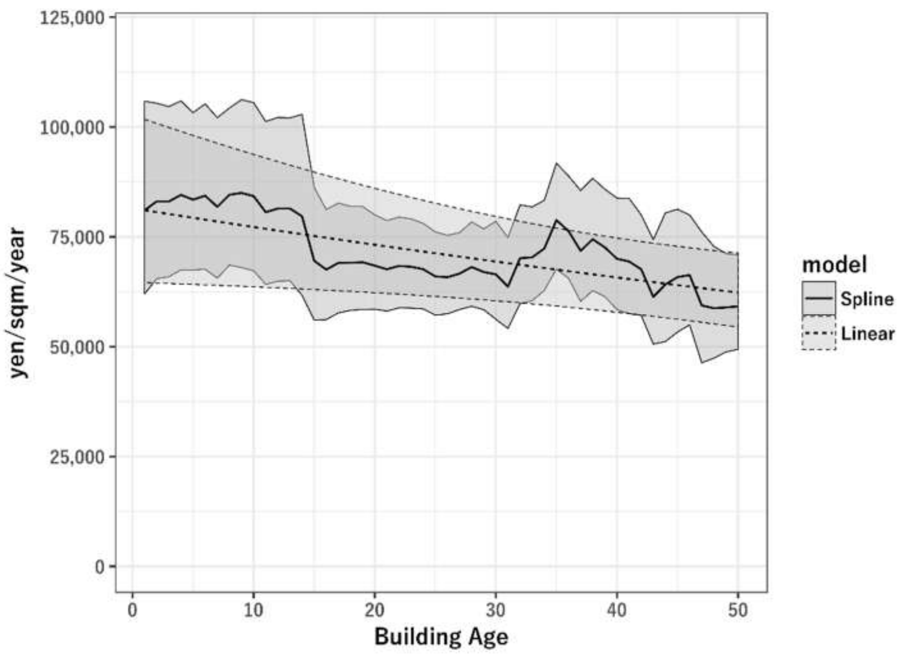


Panel A: Baseline

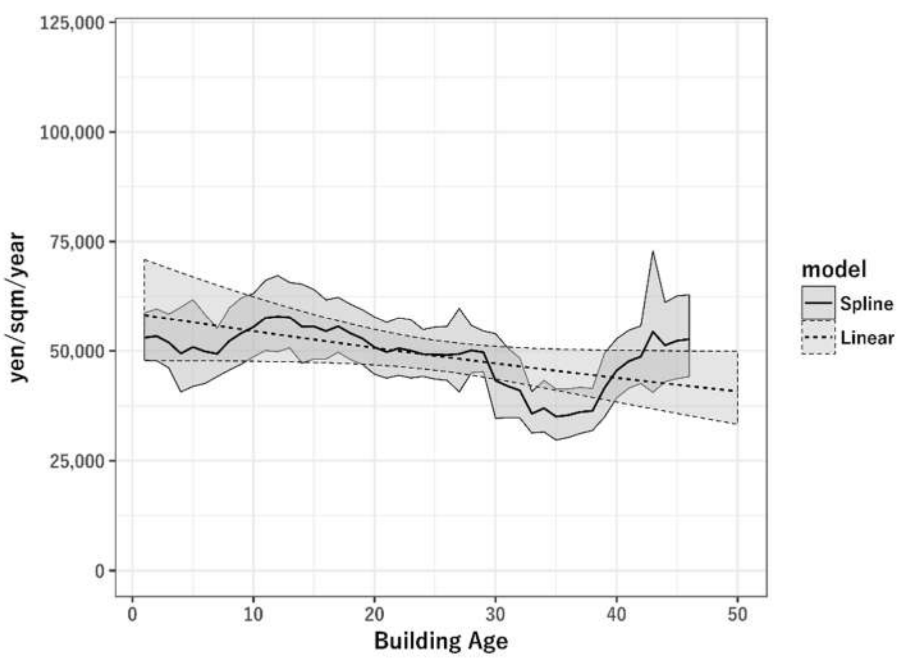


Panel B: Control Move-In Year

Figure 7: Age Profile (Unit Panel: Average Rent)

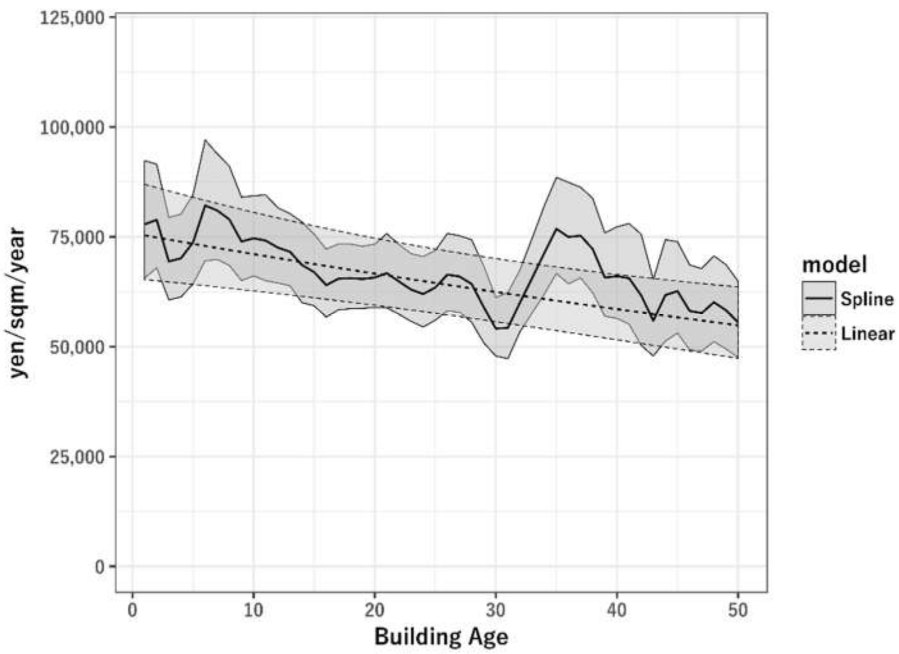


Panel A: Large 25%

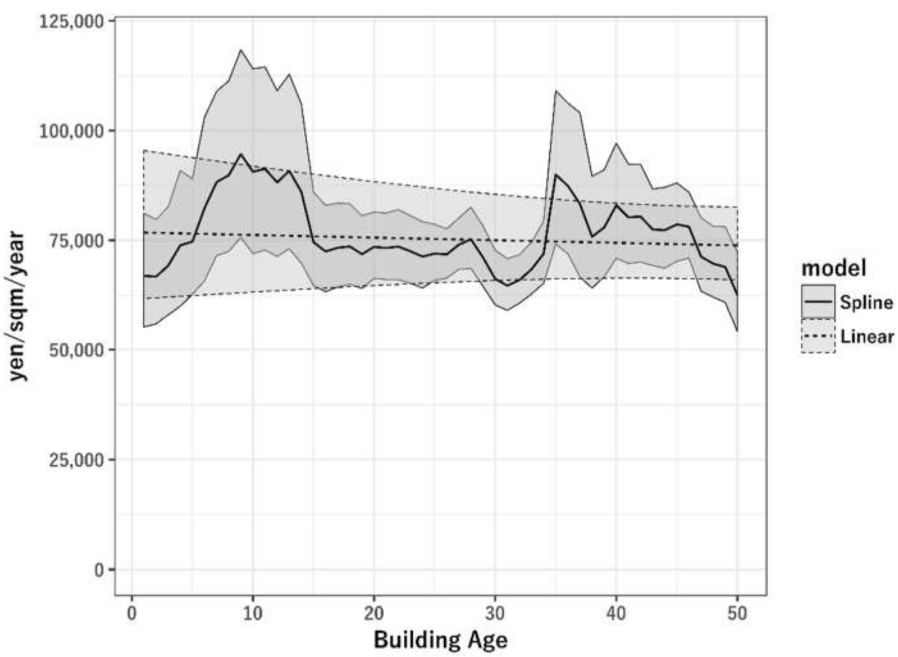


Panel B: Small 25%

Figure 8: Age Profile (Building Panel: Average Rent)



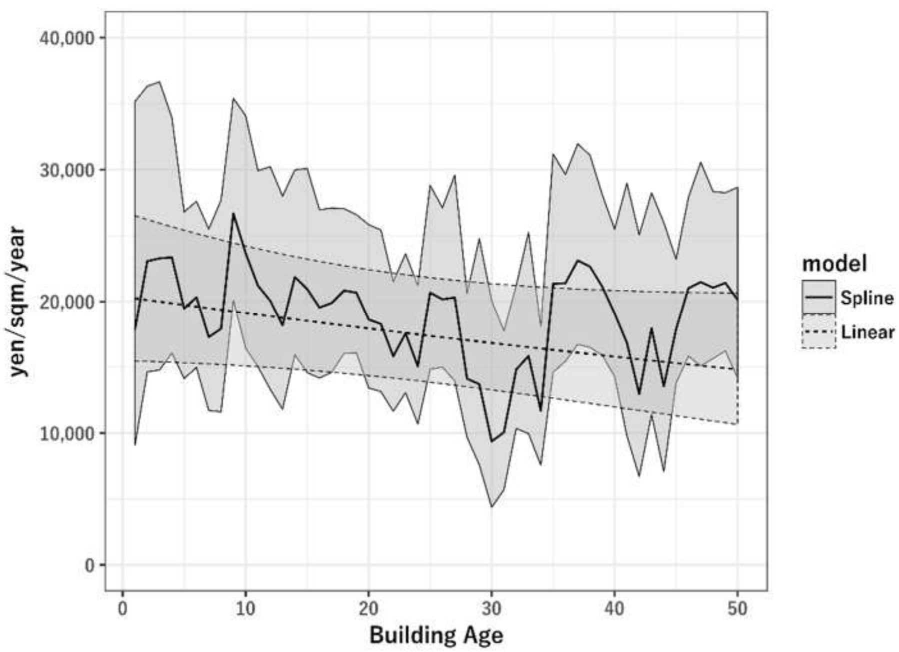
Pael A: Large 25%



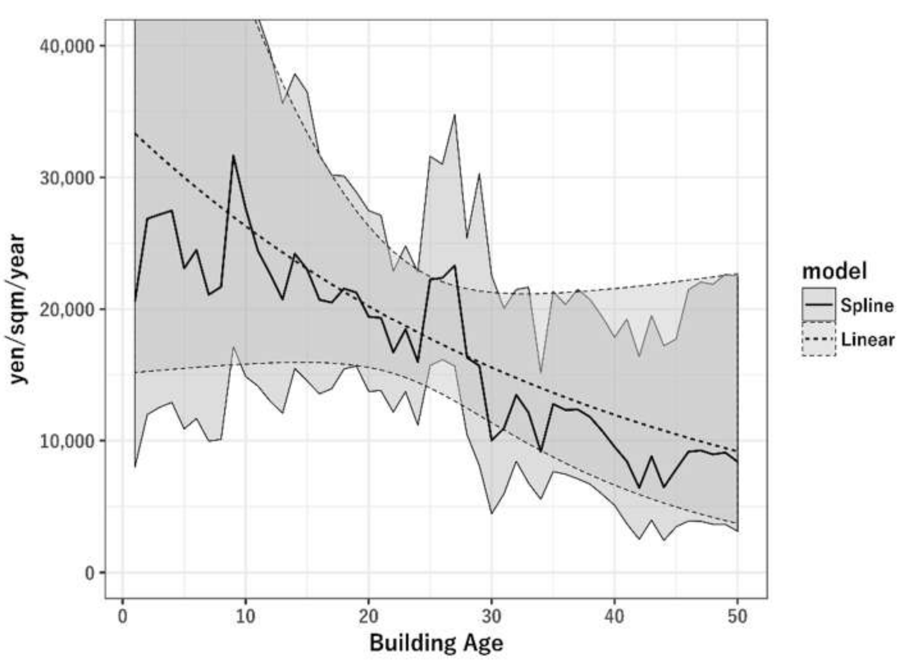
c

Panel B: Small 25%

Figure 9: Regression Result (Unit Panel: Average Rent)



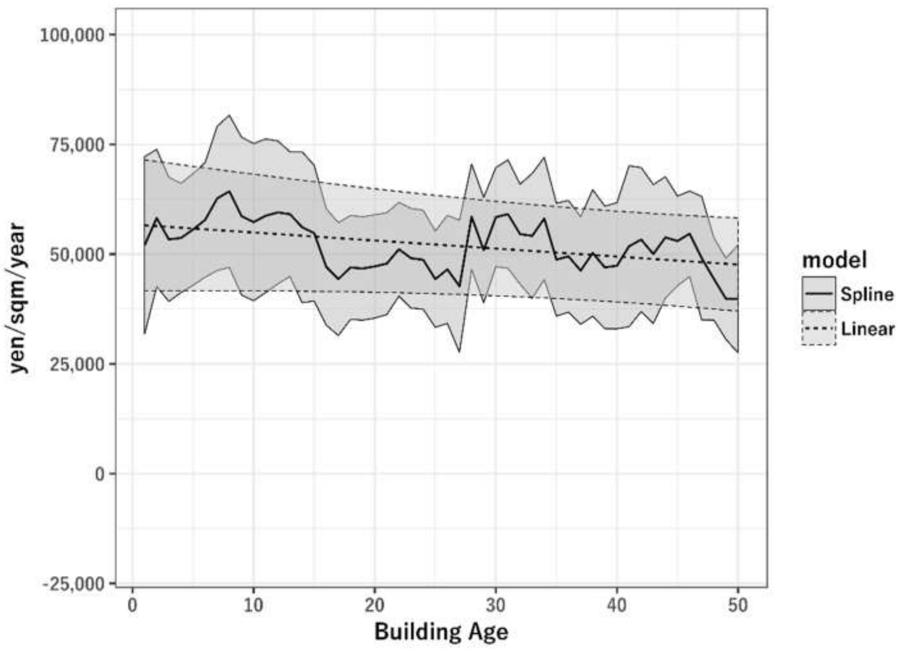
Panel A: Baseline



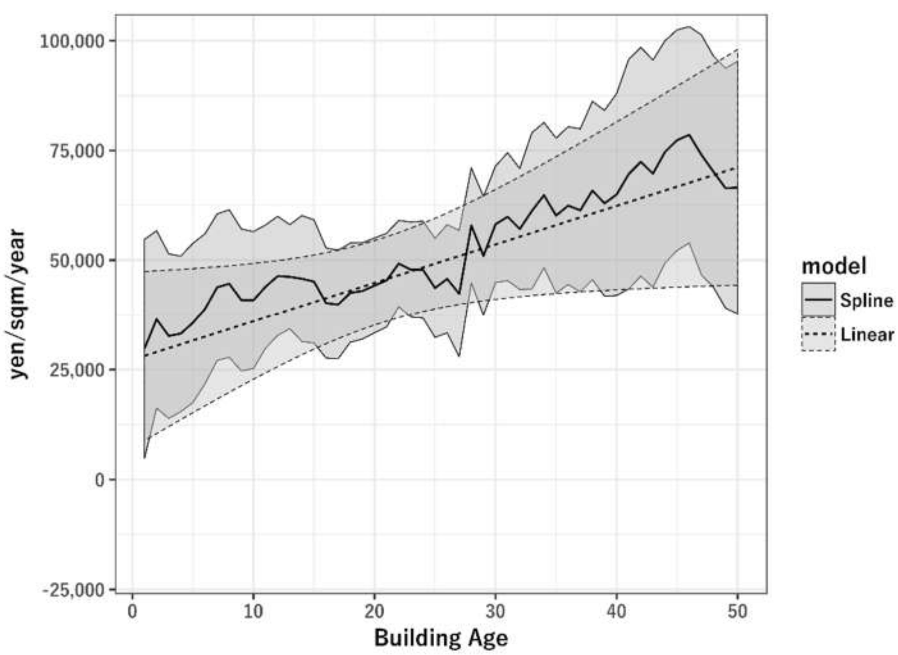
Panel B:

Panel B: Control Cohort Fixed Effect

Figure 10: Age Profile (Building Panel: Opex)

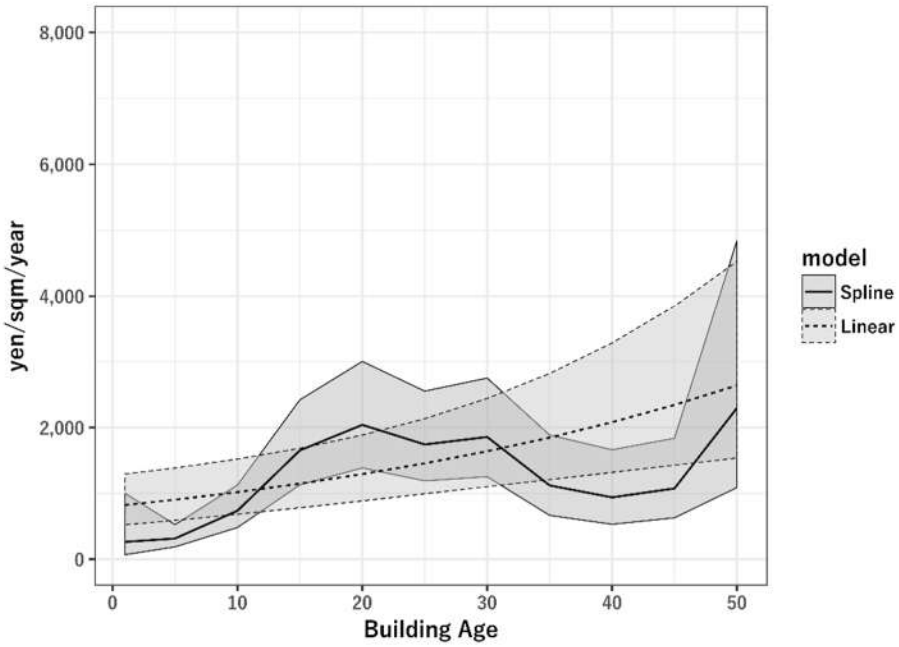


Panel A: Baseline

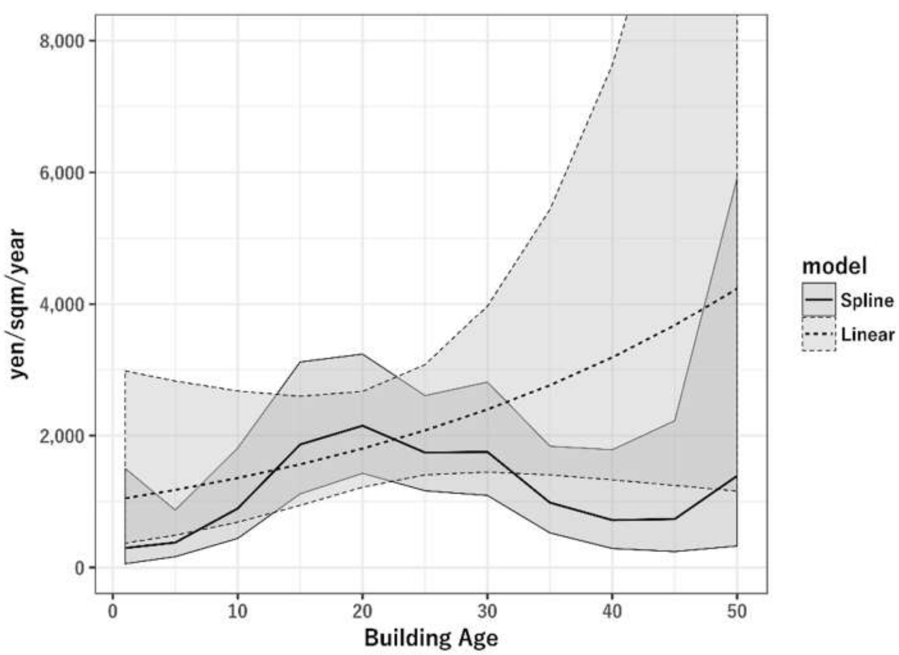


Panel B: Control Cohort Fixed Effect

Figure 11: Age Profile (Building Panel: NOI)

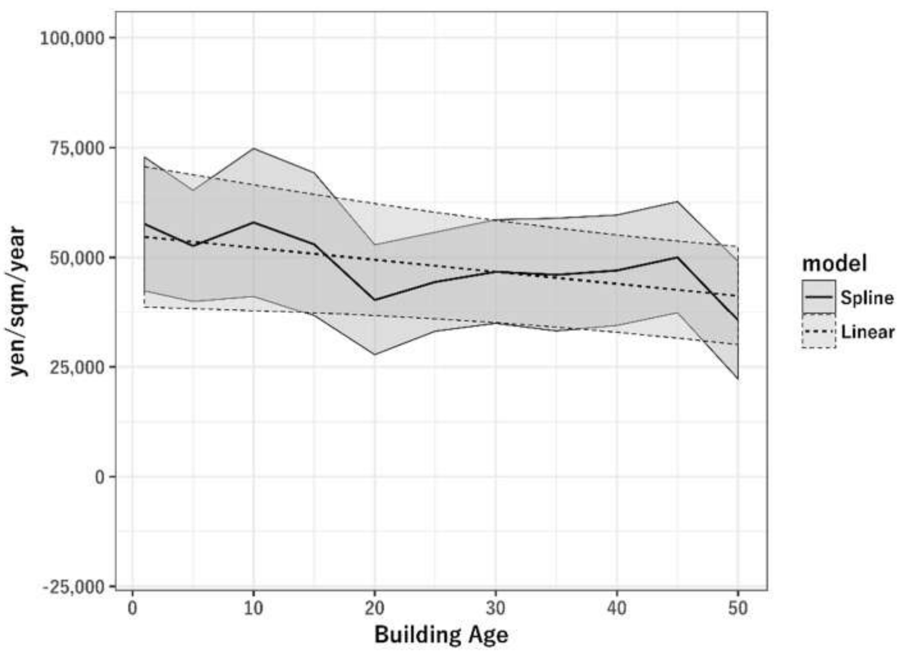


Panel A: Baseline

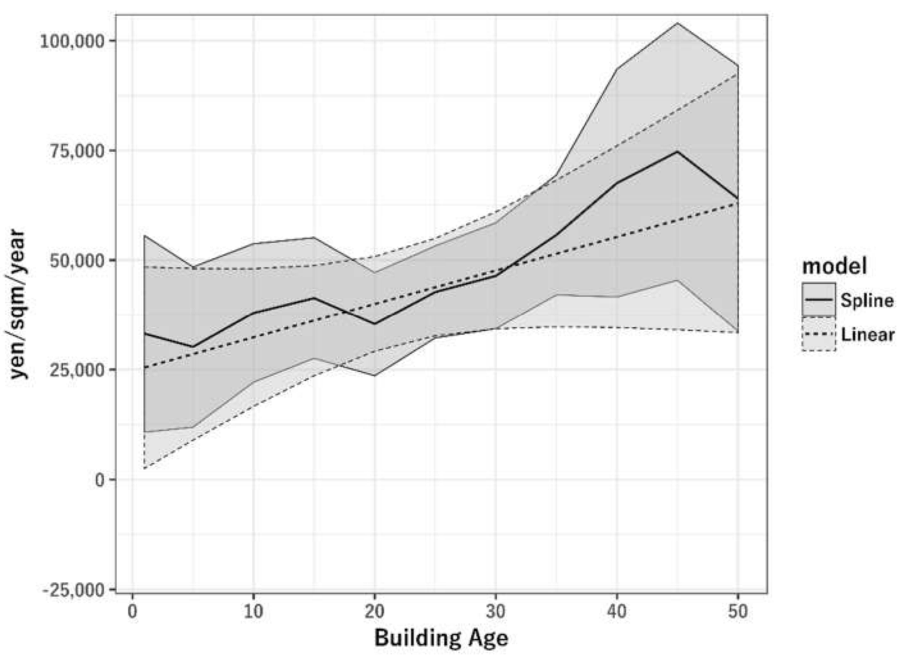


Panel B: Control Cohort Fixed Effect

Figure 12: Age Profile (Building Panel: CapEx)



Panel A: Baseline



Panel B: Control Cohort Fixed Effect

Figure 13: Age Profile (Building Panel: NCF)

Appendix

variable	n	mean	sd	median	min	max
BLDG_ID	36,922	6,369.237	6,871.577	4,003.000	1.000	36,294.000
YEAR	36,922	2,011.378	3.384	2,011.000	2,005.000	2,016.000
RENT	36,922	66,822.118	24,094.449	61,710.002	22,143.001	235,950.009
GFA	36,922	18,134.907	38,361.822	5,108.430	1,000.066	379,447.920
NRA	36,922	10,483.288	20,332.871	3,527.240	115.008	182,443.993
HEIGHT	36,868	11.508	7.778	9.000	2.000	60.000
DISTANCE	36,922	288.369	153.649	268.741	1.764	1,177.446
MINUTES	36,922	4.992	2.452	4.667	0.000	23.683
AGE	36,922	22.512	10.687	21.888	1.002	50.995
COMPLETION_YEAR	36,922	1,988.941	10.438	1,990.000	1,956.000	2,015.000
RENEWAL	36,922	0.180	0.384	0.000	0.000	1.000
RENEWAL_YEAR	8,157	2,005.635	7.289	2,007.000	1,964.000	2,017.000
DEMOLITION	36,922	0.027	0.161	0.000	0.000	1.000
DEMOLITION_YEAR	826	2,014.048	2.283	2,015.000	2,002.000	2,017.000

Table A.1: Descriptive Statistics (Unit Panel – New rent)

variable	n	mean	sd	median	min	max
BLDG_ID	162,559	5,240.821	5,755.332	2,928.000	64.000	28,280.000
YEAR	162,559	2,012.035	2.508	2,012.000	2,008.000	2,016.000
RENT	162,559	66,748.051	20,686.037	63,525.002	21,780.001	199,650.007
GFA	162,559	14,192.325	25,293.322	5,346.182	379.636	102,604.955
NRA	162,559	9,604.682	17,788.329	3,529.587	360.859	83,655.898
HEIGHT	161,297	10.492	5.398	9.000	2.000	34.000
DISTANCE	162,559	289.284	151.322	270.536	1.764	826.353
MINUTES	162,559	4.883	2.317	4.517	0.000	13.550
AGE	162,559	21.680	9.842	21.251	1.002	50.998
COMPLETION_YEAR	162,559	1,990.342	9.801	1,991.000	1,957.000	2,015.000
RENEWAL	162,559	0.233	0.423	0.000	0.000	1.000
RENEWAL_YEAR	42,196	2,006.098	7.023	2,007.000	1,964.000	2,016.000
DEMOLITION	162,559	0.035	0.184	0.000	0.000	1.000
DEMOLITION_YEAR	4,858	2,014.318	1.126	2,014.000	2,010.000	2,016.000

Table A.2: Descriptive Statistics (Unit Panel – Individual lease rates)

variable	n	mean	sd	median	min	max
BLDG_ID	19,993	7,181.301	7,322.821	4,624.000	1.000	36,294.000
YEAR	19,993	2,011.286	3.325	2,011.000	2,005.000	2,016.000
NEW_RENT	19,993	64,177.906	22,696.630	58,080.002	22,143.001	254,100.010
GFA	19,993	12,825.984	28,777.285	4,238.016	1,000.066	379,447.920
NRA	19,993	7,567.573	15,178.037	2,956.826	115.008	182,443.993
HEIGHT	19,960	10.416	6.277	9.000	2.000	60.000
DISTANCE	19,993	287.718	155.149	267.164	1.764	1,177.446
MINUTES	19,993	4.960	2.439	4.650	0.000	23.683
AGE	19,993	22.850	10.759	22.000	1.000	50.000
COMPLETION_YEAR	19,993	1,988.437	10.502	1,990.000	1,956.000	2,015.000
RENEWAL	19,993	0.165	0.371	0.000	0.000	1.000
RENEWAL_YEAR	4,008	2,005.087	7.510	2,006.000	1,964.000	2,017.000
DEMOLITION	19,993	0.030	0.170	0.000	0.000	1.000
DEMOLITION_YEAR	487	2,013.973	2.358	2,014.000	2,002.000	2,017.000

Table A.3: Descriptive Statistics (Building Panel – New rent subset)

variable	n	mean	sd	median	min	max
BLDG_ID	1,930	6,196.670	6,086.017	3,959.000	64.000	28,280.000
YEAR	1,930	2,012.030	2.507	2,012.000	2,008.000	2,016.000
AVG_RENT	1,930	63,350.561	17,225.231	60,169.777	32,514.430	165,010.293
GFA	1,930	7,253.015	12,394.405	3,967.107	379.636	102,604.955
NRA	1,930	4,841.285	8,014.342	2,791.835	360.859	83,655.898
HEIGHT	1,912	9.167	3.757	9.000	2.000	34.000
DISTANCE	1,930	302.273	160.010	279.733	1.764	826.353
MINUTES	1,930	5.028	2.410	4.658	0.000	13.550
AGE	1,930	21.172	9.741	21.000	1.000	50.000
COMPLETION_YEAR	1,930	1,990.859	9.658	1,992.000	1,959.000	2,015.000
RENEWAL	1,930	0.181	0.385	0.000	0.000	1.000
RENEWAL_YEAR	398	2,006.206	5.955	2,007.000	1,964.000	2,016.000
DEMOLITION	1,930	0.039	0.193	0.000	0.000	1.000
DEMOLITION_YEAR	65	2,014.308	1.435	2,014.000	2,010.000	2,016.000

Table A.4: Descriptive Statistics (Building Panel – Average rent subset)

variable	n	mean	sd	median	min	max
BLDG_ID	1,930	6,196.670	6,086.017	3,959.000	64.000	28,280.000
YEAR	1,930	2,012.030	2.507	2,012.000	2,008.000	2,016.000
SIT_RENT	1,930	67,934.411	17,599.644	65,066.088	32,670.001	157,894.326
GFA	1,930	7,253.015	12,394.405	3,967.107	379.636	102,604.955
NRA	1,930	4,841.285	8,014.342	2,791.835	360.859	83,655.898
HEIGHT	1,912	9.167	3.757	9.000	2.000	34.000
DISTANCE	1,930	302.273	160.010	279.733	1.764	826.353
MINUTES	1,930	5.028	2.410	4.658	0.000	13.550
AGE	1,930	21.172	9.741	21.000	1.000	50.000
COMPLETION_YEAR	1,930	1,990.859	9.658	1,992.000	1,959.000	2,015.000
RENEWAL	1,930	0.181	0.385	0.000	0.000	1.000
RENEWAL_YEAR	398	2,006.206	5.955	2,007.000	1,964.000	2,016.000
DEMOLITION	1,930	0.039	0.193	0.000	0.000	1.000
DEMOLITION_YEAR	65	2,014.308	1.435	2,014.000	2,010.000	2,016.000

Table A.5: Descriptive Statistics (Building Panel – Sitting tenant's rent subset)

variable	n	mean	sd	median	min	max
BLDG_ID	897	6,765.276	6,168.419	4,752.000	64.000	29,626.000
YEAR	897	2,012.030	2.777	2,012.000	2,007.000	2,016.000
OPEX	897	18,443.338	12,426.174	16,637.749	295.432	164,039.653
GFA	897	8,845.612	15,119.343	4,597.620	285.289	102,604.955
NRA	897	5,790.548	9,185.391	3,159.636	247.207	83,655.898
HEIGHT	885	9.410	4.563	9.000	2.000	34.000
DISTANCE	897	291.745	167.372	258.107	1.764	826.353
MINUTES	897	4.918	2.621	4.383	0.000	13.550
AGE	897	21.377	9.971	21.000	1.000	50.000
COMPLETION_YEAR	897	1,990.653	10.038	1,991.000	1,962.000	2,015.000
RENEWAL	897	0.191	0.393	0.000	0.000	1.000
RENEWAL_YEAR	194	2,007.598	3.469	2,007.000	1,997.000	2,015.000
DEMOLITION	897	0.035	0.183	0.000	0.000	1.000
DEMOLITION_YEAR	31	2,013.677	1.869	2,014.000	2,009.000	2,016.000

Table A.6: Descriptive Statistics (Building Panel – Operating expenses subset)

variable	n	mean	sd	median	min	max
BLDG_ID	816	6,529.971	6,041.674	4,635.000	64.000	28,280.000
YEAR	816	2,012.216	2.621	2,012.000	2,008.000	2,016.000
NOI	816	46,647.814	20,518.152	45,775.612	-118,565.427	141,168.308
GFA	816	9,114.828	15,707.373	4,621.554	447.405	102,604.955
NRA	816	5,943.487	9,526.132	3,238.744	360.859	83,655.898
HEIGHT	810	9.427	4.671	9.000	2.000	34.000
DISTANCE	816	292.315	166.367	258.107	1.764	826.353
MINUTES	816	4.923	2.604	4.383	0.000	13.550
AGE	816	21.526	10.041	21.000	1.000	50.000
COMPLETION_YEAR	816	1,990.690	10.152	1,991.000	1,962.000	2,015.000
RENEWAL	816	0.188	0.391	0.000	0.000	1.000
RENEWAL_YEAR	174	2,007.632	3.365	2,007.000	1,998.000	2,014.000
DEMOLITION	816	0.029	0.169	0.000	0.000	1.000
DEMOLITION_YEAR	24	2,014.167	1.373	2,014.000	2,010.000	2,016.000

Table A.7: Descriptive Statistics (Building Panel – Net operating income subset)

variable	n	mean	sd	median	min	max
BLDG_ID	1,965	5,717.500	5,609.426	3,901.000	64.000	28,028.000
YEAR	1,965	2,010.322	3.079	2,010.000	2,005.000	2,015.000
CAPEX	1,965	4,151.942	9,280.731	1,767.917	2.264	222,806.522
GFA	1,965	6,950.130	11,645.153	3,940.727	379.636	102,604.955
NRA	1,965	4,644.850	7,297.863	2,791.835	182.479	83,655.898
HEIGHT	1,930	9.082	3.704	9.000	2.000	34.000
DISTANCE	1,965	301.368	165.258	279.733	1.764	826.353
MINUTES	1,965	5.012	2.486	4.600	0.000	13.550
AGE	1,965	19.979	9.712	20.000	1.000	50.000
COMPLETION_YEAR	1,965	1,990.343	9.518	1,991.000	1,962.000	2,014.000
RENEWAL	1,965	0.169	0.375	0.000	0.000	1.000
RENEWAL_YEAR	399	2,005.742	5.502	2,006.000	1,989.000	2,016.000
DEMOLITION	1,965	0.049	0.216	0.000	0.000	1.000
DEMOLITION_YEAR	93	2,013.301	2.141	2,014.000	2,007.000	2,016.000

Table A.8: Descriptive Statistics (Building Panel – Capital expenditures subset)

variable	n	mean	sd	median	min	max
BLDG_ID	680	6,495.610	5,760.976	4,685.000	64.000	25,943.000
YEAR	680	2,011.471	2.205	2,011.000	2,008.000	2,015.000
NCF	680	42,760.880	21,948.160	41,369.957	-127,933.144	141,015.083
GFA	680	9,099.501	15,802.248	4,722.793	447.405	102,604.955
NRA	680	5,925.518	9,443.013	3,286.479	360.859	83,655.898
HEIGHT	676	9.385	4.735	9.000	2.000	34.000
DISTANCE	680	290.185	169.051	252.717	1.764	826.353
MINUTES	680	4.894	2.651	4.333	0.000	13.550
AGE	680	21.341	10.278	21.000	1.000	50.000
COMPLETION_YEAR	680	1,990.129	10.318	1,991.000	1,962.000	2,014.000
RENEWAL	680	0.188	0.391	0.000	0.000	1.000
RENEWAL_YEAR	148	2,007.608	3.321	2,007.000	1,998.000	2,014.000
DEMOLITION	680	0.035	0.185	0.000	0.000	1.000
DEMOLITION_YEAR	24	2,014.167	1.373	2,014.000	2,010.000	2,016.000

Table A.9: Descriptive Statistics (Building Panel – Net cash flows subset)

Variable	n	mean	sd	median	min	max
BLDG_ID	7,868	4,809.814	5,460.328	3,097.000	1.000	30,451.000
YEAR	7,868	2,011.041	3.334	2,011.000	2,005.000	2,016.000
NEW_RENT	7,486	77,516.895	26,133.769	72,600.003	25,410.001	254,100.010
AVG_RENT	620	68,835.619	20,398.239	64,950.259	32,514.430	165,010.293
SIT_RENT	620	74,119.117	20,262.225	70,785.003	34,485.001	157,894.326
CAPEX	630	4,146.808	8,035.783	1,918.541	2.281	98,847.033
OPEX	336	20,049.555	14,900.866	17,863.997	295.432	164,039.653
NOI	305	51,497.238	25,638.274	50,904.315	-118,565.427	141,168.308
NCF	252	48,308.633	26,344.021	47,878.262	-67,220.076	141,015.083
GFA	7,868	28,788.401	41,236.230	11,910.281	5,961.950	379,447.920
NRA	7,868	16,461.376	21,435.117	7,941.752	829.521	182,443.993
HEIGHT	7,865	13.853	8.844	10.000	2.000	60.000
DISTANCE	7,868	297.704	166.012	277.509	1.764	1,177.446
MINUTES	7,868	5.166	2.662	4.800	0.000	23.683
AGE	7,868	21.572	11.863	21.000	1.000	50.000
COMPLETION_YEAR	7,868	1,989.469	11.827	1,990.000	1,958.000	2,015.000
RENEWAL	7,868	0.222	0.416	0.000	0.000	1.000
RENEWAL_YEAR	2,109	2,005.413	6.766	2,006.000	1,964.000	2,016.000
DEMOLITION	7,868	0.034	0.182	0.000	0.000	1.000
DEMOLITION_YEAR	246	2,013.947	2.245	2,014.000	2,002.000	2,017.000

Table A.10: Descriptive Statistics (Building Panel – Large 25% buildings subset)

Variable	n	mean	sd	median	min	max
BLDG_ID	2,954	12,809.923	9,150.872	10,968.000	27.000	36,281.000
YEAR	2,954	2,011.953	3.341	2,013.000	2,005.000	2,016.000
NEW_RENT	2,762	50,708.371	13,073.130	49,005.002	22,143.001	127,050.005
AVG_RENT	230	54,813.395	10,854.133	54,450.002	36,019.331	91,448.080
SIT_RENT	230	58,802.119	11,077.211	57,528.035	39,911.345	93,734.282
CAPEX	243	3,655.986	6,580.416	1,518.597	9.442	49,954.124
OPEX	94	15,951.962	9,397.950	13,471.801	1,920.681	79,552.728
NOI	85	39,534.165	11,348.848	37,365.510	-9,161.533	63,054.690
NCF	70	36,041.528	13,036.054	35,516.038	-5,410.371	58,741.438
GFA	2,954	1,309.436	175.207	1,312.397	1,000.066	1,606.612
NRA	2,954	969.294	272.042	933.884	115.008	4,427.967
HEIGHT	2,930	7.872	1.786	8.000	2.000	13.000
DISTANCE	2,954	281.113	148.014	262.534	3.404	910.910
MINUTES	2,954	4.752	2.255	4.533	0.033	15.800
AGE	2,954	24.331	9.631	24.000	1.000	50.000
COMPLETION_YEAR	2,954	1,987.622	8.973	1,989.000	1,961.000	2,015.000
RENEWAL	2,954	0.074	0.261	0.000	0.000	1.000
RENEWAL_YEAR	257	2,005.455	8.924	2,007.000	1,969.000	2,016.000
DEMOLITION	2,954	0.018	0.134	0.000	0.000	1.000
DEMOLITION_YEAR	40	2,014.350	2.202	2,014.000	2,007.000	2,017.000

Table A.11: Descriptive Statistics (Building Panel – Small 25% buildings subset)

Variable	n	mean	sd	median	min	max
BLDG_ID	39,469	5,713.380	5,846.768	3,579.000	64.000	28,280.000
YEAR	39,469	2,011.782	2.473	2,012.000	2,008.000	2,016.000
RENT	39,469	64,412.198	18,916.882	60,984.002	29,040.001	156,090.006
LEASE_AREA	39,469	493.449	545.874	386.612	17.157	17,836.297
GFA	39,469	7,157.320	7,177.219	4,913.388	528.231	81,692.889
NRA	39,469	4,846.580	4,684.018	3,374.942	369.421	39,063.007
HEIGHT	39,296	9.125	2.643	9.000	2.000	32.000
DISTANCE	39,469	305.232	150.517	274.076	26.964	774.581
MINUTES	39,469	5.106	2.230	4.667	0.450	12.383
AGE	39,469	22.109	9.419	21.588	1.002	50.998
COMPLETION_YEAR	39,469	1,989.639	9.316	1,990.000	1,959.000	2,015.000
RENEWAL	39,469	0.216	0.411	0.000	0.000	1.000
RENEWAL_YEAR	9,524	2,004.461	8.121	2,006.000	1,964.000	2,016.000
DEMOLITION	39,469	0.083	0.276	0.000	0.000	1.000
DEMOLITION_YEAR	2,828	2,014.097	1.116	2,014.000	2,010.000	2,016.000

Table A.12: Descriptive Statistics (Unit Panel – Large 25% tenants subset)

Variable	n	mean	sd	median	min	max
BLDG_ID	39,496	3,742.822	4,980.700	2,094.000	138.000	25,076.000
YEAR	39,496	2,012.333	2.488	2,013.000	2,008.000	2,016.000
RENT	39,496	72,877.362	24,610.931	68,970.003	29,040.001	199,650.007
LEASE_AREA	39,496	477.674	547.367	270.793	2.116	3,339.587
GFA	39,496	31,486.305	38,258.824	11,685.190	447.405	102,604.955
NRA	39,496	21,807.666	28,176.093	7,925.024	360.859	83,655.898
HEIGHT	39,316	12.728	7.651	10.000	3.000	34.000
DISTANCE	39,496	266.111	154.676	239.294	1.764	826.353
MINUTES	39,496	4.534	2.419	4.183	0.000	13.550
AGE	39,496	24.582	10.557	23.650	1.002	50.998
COMPLETION_YEAR	39,496	1,987.695	10.525	1,989.000	1,959.000	2,010.000
RENEWAL	39,496	0.385	0.487	0.000	0.000	1.000
RENEWAL_YEAR	16,572	2,006.749	6.081	2,008.000	1,964.000	2,014.000
DEMOLITION	39,496	0.013	0.112	0.000	0.000	1.000
DEMOLITION_YEAR	499	2,014.559	1.056	2,015.000	2,011.000	2,016.000

Table A.13: Descriptive Statistics (Unit Panel – Small 25% tenants subset)