Structure Depreciation: Cross-Sectional Variations and Their Implications on Investments*

Jiro Yoshida†

January 22, 2017

Abstract

This study analyzes the economic depreciation of real estate using data of detached housing in the U.S. and Japan and commercial real estate in Japan. The estimated property-level depreciation rate exhibits large cross-sectional variation; depreciation rates are larger for newer and denser properties located further away from the downtown area in a smaller city. Because a larger depreciation rate directly decreases appreciation returns and increases income returns, this variation in depreciation rates is a cause of variation in the observed cap rates.

This study also estimates the structure depreciation rate by adjusting for the share of structure value and survivorship biases. The structure depreciation rate varies significantly by property type and country; approximately 7% for residential properties and 10% for commercial properties in Japan in contrast with 1% for residential structures in the U.S. These large structure depreciation rates for Japan are confirmed by a separate data set of demolished buildings.

These results serve as important inputs for the analysis of real estate investment, consumer choice of housing, sustainability, and macro economy.

JEL Classification: R32; D24; E23

Keywords: capital consumption, housing, commercial real estate, hedonic analysis, survivorship bias, demolition, Japan, USA

*I thank Lorraine Spock for providing data. I gratefully acknowledge research assistance from Conor Doyle and Sergio Garate. This paper is supported by the Real Estate Research Institute.

†Smeal College of Business, The Pennsylvania State University, 368 Business Building, University Park, PA 16802, jiro@psu.edu.

I. Introduction

The economic depreciation of real estate is important in a wide range of economic analysis and decision making. First, in real estate investments, a large depreciation rate implies small appreciation returns and large income returns. Thus, the component returns can significantly vary simply due to variations in depreciation rates by country, city, urban location, building age, and property type. Because investors choose portfolios by taking into account the proportions of income and appreciation returns for the purpose of liquidity management, investor asset allocations are influenced by the cross-sectional variation in depreciation rate.

Second, in macroeconomics, structure depreciation rates are a key parameter in models of economic growth and fluctuations (e.g., Greenwood and Hercowitz, 1991; Davis and Heathcote, 2005; Davis and Nieuwerburgh, 2015). For example, depreciation rates affect the equilibrium level capital, consumption, saving, and productivity.[1] Depreciation rates are also a key input to macroeconomic statistics such as gross domestic product and inflation rates, which influence monetary and other macroeconomic policies (e.g., Ambrose, Coulson, and Yoshida, 2015).

Third, in housing economics, the depreciation rate of housing affects consumer choice, welfare, and the environmental sustainability. For example, a large depreciation rate increases the user cost and rental cost of housing. Since housing services are complementary to other goods (Davidoff and Yoshida, 2013), large depreciation makes households to spend a larger share of income on housing. Residential properties that depreciate more slowly than standard properties are traded at a premium (Yoshida and Sugiura, 2015). Larger depreciation also has an adverse environmental consequence because more frequent demolitions of structures increase CO_2 emissions.

This study has three objectives. The first objective is to demonstrate significant cross-sectional variation in the property-level depreciation rate. Because the property-level depreciation rate is directly proportional to the structure value share, the depreciation rate and the structure value share will exhibit similar variation. The urban economic theory predicts that the structure value share is affected by the city size, the location within a city, the building age, the density of a property, and other factors (e.g., Alonso, 1964; Muth, 1969; Mills, 1967; Fujita, 1989; Duranton

[1] The measurement of depreciation rates is central to understanding Japan's high saving rate (e.g., Hayashi, 1986, 1989, 1991; Hayashi, Ito, and Slemrod, 1987; Dekle and Summers, 1991; Hayashi and Prescott, 2002; Imrohoroglu, Imrohoroglu, and Chen, 2006).

and Puga, 2015). I estimate the effect of building age on property values by using data for the U.S. residential properties (Centre County, PA) and the Japanese residential and commercial properties. The estimated variation is economically significant (up to 3.5% per year) and consistent with the urban economic theory for both countries; i.e., the property depreciation rate is larger for newer and denser properties located away from the Central Business District (CBD) in a smaller city. Since depreciation rates have a direct impact on the proportions of income and appreciation returns, this result provides a new insight into the variation in real estate returns.

The second objective is to estimate the structure depreciation rate. I estimate the net depreciation rate, which is the rate after maintenance and capital expenditures are made.[2] I use two estimation methods. The first method is to adjust the property-level depreciation rate for the structure value share. For example, if the property-level depreciation rate is 1% and the structure value share is 0.2, then the implied structure depreciation rate is 5% (1%/0.2) because other components of property value do not depreciate with building age. The structure value share is estimated by the elasticity of property value with respect to the size of structure in the hedonic regression. The estimated share is significantly smaller in Japan (30%-40% at median ages) than in the U.S. (50%-70%) whereas the land value share is significantly larger in Japan (60%-70%) than in the U.S. (10%). The larger proportion of land value probably reflects the scarcity of habitable land in Japan.[3]

The second method of estimating the structure depreciation rate uses the building age information at the time of demolition. Buildings are demolished when the depreciated structure value equals the scrap value, which is implicitly determined by the owner's redevelopment decision. I make an assumption about the scrap value and estimate the average annual depreciation rate over building life. For example, if the scrap value is 10% of the original value, the average depreciation rate is 4.6% per year for a demolished 50-year old building ($-\ln 0.1/50$). Using the demolition data in Japan, I estimate the frequency distribution of depreciation rates for various property types. The mean depreciation rate is 6.2% for residential, 9.2% for industrial, 11.7% for office, 14.8% for retail, and 17.2% for hotel property. These estimates are consistent with the estimates by the first

[2]The data in this study do not include maintenance expenditures. For an estimate of gross depreciation rate of commercial real estate value in the U.S., see Geltner and Bokhari (2015).

[3]The habitable area is only approximately 30% of the national land; large part is forest, mountains, and waters. Therefore, population density is 50 times larger in Japan than in the United States.

method.

The third objective is to develop and empirically demonstrate new methods of correcting for survivorship biases in the estimation of structure depreciation rates. When the econometrician estimates depreciation rates using a sample of surviving buildings, the estimated rate is too small (Hulten and Wykoff, 1981b). Because buildings with the largest depreciation rate are demolished first, this survivorship bias does not exist for the sample of new buildings and becomes larger for the sample of older buildings. In contrast, when the econometrician uses a sample of demolished buildings, the estimated rate is too large. The observed distribution of building life span is skewed because shorter-lived buildings are more frequently demolished. The distribution is additionally distorted by the past variation in the construction volume; e.g., the econometrician will observe a larger number of 50-year old buildings in the demolished sample if the construction volume was large 50 years ago. To address the former type of biases for surviving buildings, I focus on the mean depreciation rate for relatively new buildings because the estimated rate is unbiased if no building is demolished. I additionally show a distribution of depreciation rates that is consistent with the observed survivorship bias. To address the latter type of estimation biases for demolished buildings, I correct the distribution of building life spans for the oversampling of short-lived structures and past variation in construction volume.

The proposed methods of bias correction have several advantages. First, they do not require data on both surviving and demolished buildings unlike standard methods such as the Cox proportional hazard rate model, the Kaplan-Meier estimator, and Heckman's two-step procedure. Second, the proposed methods improve the method by Hulten and Wykoff (1981b). They assume that the depreciation rate for demolished structures is zero by treating the value of demolished structures being zero. In contrast, I incorporate large depreciation rates for demolished buildings based on a distributional assumption. However, the proposed methods do not address the maintenance effect, the vintage effect, or the selection for sold properties. The current data set contains no information on maintenance and is too short to estimate the vintage effect as Coulson and McMillen (2008) do. This study can be extended if a richer and longer data set is available. The selection issue is partially mitigated because this study focuses only on traded properties.

The bias-corrected rate of structure depreciation also varies widely by country and the estimation method. The structure depreciation rate based on the price data is 6.4%-7.0% for residential properties and 9.1%-10.2% for commercial properties in Japan whereas it is 1.5% for residential properties in the U.S. These rates are consistent with those based on the demolition data in Japan. The bias corrected median life span of structures in Japan is 30-35 years for residential and 20-30 years for commercial properties. The property-type specific depreciation rate for commercial properties in Japan is 7.8% for industrial, 9.9% for office, 14.6% for hotel, and 12.6% for retail properties. Since researchers have not reached a consensus regarding the level of aggregate structure depreciation rates, the estimated rate serves as an important input for macroeconomic models.

The large depreciation rates in Japan could be caused by cultural, historical, and institutional factors. For example, a lack of reliable information about building inspections can cause adverse selection and moral hazard. In such a bad equilibrium, maintenance expenditures will be small and depreciation rates will be large. Cultural and behavioral biases can be another cause. People's perceptions about building life spans were formed on the basis of traditional structures that were vulnerable to earthquakes and fire. Although modern structures are significantly more robust to these risks, people's perceptions have not changed very much. Indeed, a rapid progress in building technologies is a major factor of large depreciation. In particular, given that approximately 20% of large earthquakes on earth occur in and around Japan (Cabinet Office of Japan, 2013), technological progress in earthquake resistance was large in the 20th century. The earthquake resistance standard in the national building code was repeatedly revised in 1950 (after Fukui earthquake), 1971 (after Tokachi earthquake), 1981 (after Miyagi earthquake), and 2000 (after Hanshin-Awaji earthquake). The proportion of structures that were directly damaged by earthquakes was not large in the national stock of structures. However, the existing buildings became obsolete relatively quickly due to the rapid progress in building technologies. Moreover, many existing buildings became out of compliance after revisions to the national building code.

The extant studies use different methods and show a wide range of estimated depreciation rate. The first method utilizes time-series or cross-sectional variations in asset prices (e.g., Hulten and Wykoff, 1981a; Coulson and McMillen, 2008; Yoshida and Sugiura, 2015; Geltner and Bokhari, 2015). A cross-sectional hedonic regression is often used because of better data availability. The second method combines the flow investment data and the real estate stock data, typically in the National Accounts (e.g., Hulten and Wykoff, 1981a; Hayashi, 1991; Yoshida and Ha, 2001; Economic and Social Research Institute, 2011). The implicit depreciation rate in the accumulation equation is estimated. The third method utilizes the data on demolished buildings. Structure depreciation rates are estimated by the building age at the time of demolition. This is more common in engineering studies. 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 Wykoff, 1981b) but 5.2%-7.2% based on the implicit rate in the National Accounts published by the Buerau of Economic Analysis (Hulten and Wykoff, 1981a; 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, Smith, Stern, and Webb, 2005; Geltner and Bokhari, 2015). The estimated rates for the U.S. residential structures fall within a relatively narrow range; they are 1.36% (Leigh, 1980), 1.89% (Knight and Sirmans, 1996), and 1.94% (Harding, Rosenthal, and Sirmans, 2007) based on asset prices.[4] Based on the National Accounts, the rate is 1.57% between 1948 and 2001 (Davis and Heathcote, 2005). The estimated rates for residential structures in Japan range from as low as 1%-2% (Seko, 1998) to 15% (Yoshida and Ha, 2001). Based on the National Accounts of Japan, the depreciation rate is 8.5%-9.9% when data between 1970 and 1989 is used (Hayashi, 1991) but the rate is 4.7% and 5.4% when newer data are used (Economic and Social Research Institute, 2011).[5] For non-residential (commercial) structures, a few available estimates based on the National Accounts are 5.7%-7.2% (Hayashi, 1991; Economic and Social Research Institute, 2011).

The remaining sections proceed as follows. In Section II, I present the conceptual framework and two methods of bias correction. Section III discusses the data and summary statistics, and Section IV outlines the empirical strategy. Sections V and VI present the empirical results. Section VII concludes.

II. Conceptual Framework

The value $V_{t,u}$ of a property of age u is determined in the real estate asset market at time t. The property value can be decomposed into three factors: structure value, land value, and any

[4] However, the effect of aging on residential rents is significanlty smaller at 0.11% to 0.36% (Lane, Randolph, and Berenson, 1988).

[5] The depreciation rate also varies by prefecture, property type, whether a property is for rental or not, and whether a property is a green building or not (Yoshida and Ha, 2001; Yoshida, Yamazaki, and Lee, 2009; Yamazaki and Sadayuki, 2010; Yoshida and Sugiura, 2015)

other factors:

$$V_{t,u} = P_t^{ES} E_u S + P_t^L L + O_t, \tag{1}$$

where S denotes the quantity of structure (i.e., square footage of floor area), E_u denotes the effectiveness of structure, P_t^{ES} denotes the price of effective structure, L denotes the quantity of land (i.e., square footage of land area), P_t^L denotes the land price, and O_t denotes the value of possible other factor.[6] Although most studies decompose the property value only into structure and land, I allow for the possibility of another component such as public goods, amenities, and infrastructure. Whether there is a significant value for such factors is an empirical question. Variables V, S, and L are observed in data but other variables are not. The economic depreciation, defined as the rate of decrease in asset value with age (Hulten and Wykoff, 1981b), occurs due to the decreasing effectiveness (or obsolescence) of structures. However, the effectiveness of an old asset may rather increase with age possibly due to renovations or increasing historic values.[7] Although the econometrician will need additional data for renovations and historic values to disentangle these factors, these data are not available for this study. Thus, the change in the effectiveness of structure (dE_u/du) is the sum of economic depreciation and the factors that augment effectiveness.

The property depreciation rate equals the negative of the partial derivative of the log property value with respect to building age. It is convenient to define the shares of structure value and land value:

$$s_{t,u} \equiv \frac{P_t^{ES} E_u S}{V_{t,u}}, \tag{2}$$

$$l_{t,u} \equiv \frac{P_t^L L}{V_{t,u}}. \tag{3}$$

Using equations (1) and (2), I obtain the following result.

Proposition 1: *The property-level depreciation rate is directly propotional to the structure value*

[6] I subsume the effectiveness of land into the factor price because it is not the primary focus of this study. I also assume that the value of other factors do not depend on building age.

[7] I include in structures all factors whose value depends on the building age. The value of land and other factors do not depend on the building age.

ratio and the structure depreciation rate: i.e.,

$$-\frac{\partial \ln V_{t,u}}{\partial u} = s_{t,u}\delta_u, \tag{4}$$

where $\delta_u \equiv -d\ln E_u/du$ denotes the instantaneous depreciation rate of structures.

Proof. Take the logarithm of both sides of equation (1). The partial derivative of $\ln V_{t,u}$ with respect to u is:

$$\begin{aligned}\frac{\partial \ln V_{t,u}}{\partial u} &= \frac{P_t^{ES} S}{V_{t,u}}\frac{dE_u}{du} \\ &= \frac{P_t^{ES} E_u S}{V_{t,u}}\frac{1}{E_u}\frac{dE_u}{du} \\ &= s_{t,u}\frac{d\ln E_u}{du} \\ &= -s_{t,u}\delta_u.\end{aligned}$$

□

Since the structure value share $s_{t,u}$ is less than one, the property depreciation rate is always smaller in absolute value than the structure depreciation rate. However, the structure value could appreciate with age after removing the inflation effect (i.e., $\delta_u < 0$) possibly due to renovations or increasing historical values.

When the property value changes with building age, the structure value share also changes.

Proposition 2: *The structure value share increases (decreases) with building age if and only if the property value increases (decreases) with building age.*

Proof. Take a partial derivative of the structure value share with respect to the building age in equation (2).

$$\begin{aligned}\frac{\partial s_{t,u}}{\partial u} &= \frac{P_t^{ES} S dE_u/du}{V_{t,u}} - \frac{\left(P_t^{ES} E_u S\right)\left(P_t^{ES} S dE_u/du\right)}{V_{t,u}^2} \\ &= \left(1 - \frac{P_t^{ES} E_u S}{V_{t,u}}\right)\frac{P_t^{ES} S dE_u/du}{V_{t,u}} \\ &= \left(1 - s_{t,u}\right)\frac{\partial \ln V_{t,u}}{\partial u}.\end{aligned}$$

Since the first term $(1 - s_{t,u})$ is positive, I obtain: $sgn\,(\partial s_{t,u}\,/\partial u) = sgn\,(d \ln E_u\,/du)$. □

When estimating depreciation rates and the structure value share using the actual data, an econometrician can only observe the nominal value of a property and the quantities of structure and land. Using these observable variables, I estimate the shares of structure value and land value by calculating the elasticity of property value with respect to the quantities of structure and land:

$$\frac{\partial \ln V_{t,u}}{\partial \ln S} = \frac{\partial V_{t,u}}{\partial S}\frac{S}{V_{t,u}} = \frac{P_t^{ES} E_u S}{V_{t,u}} = s_{t,u}, \tag{5}$$

$$\frac{\partial \ln V_{t,u}}{\partial \ln L} = \frac{\partial V_{t,u}}{\partial L}\frac{L}{V_{t,u}} = \frac{P_t^{L} L}{V_{t,u}} = l_{t,u}. \tag{6}$$

I use these elasticities to estimate the structure depreciation rate δ_u on the basis of equation (4).

This method has an advantage over another popular method of estimating the structure value share. For example, Yoshida, Yamazaki, and Lee (2009) and Geltner and Bokhari (2015) estimate the land value share by taking the ratio of the value of old properties to the value of new properties, and subtract the land value share from one. There are several implicit assumptions in this method. First, the structure value must be approximately zero for old properties. This may not be the case when historical values are attached to structures. Second, the structure value share must equal one minus the land value share. This may not be the case if there is the third factor with a fixed value.

In the next three sections, I discuss how the structure value share, property-level depreciation rates, and income returns varies by location (II.A) and how to correct for biases in estimating the structure depreciation rate from price data (II.B) and from demolition data (II.C).

A. *Cross-Sectional Variation in Property Depreciation Rates*

The structure value share varies by location in the urban economic theory. In particular, the monocentric city model of urban land use predicts that the structure value share varies by city size (e.g., population) and urban location (e.g., distance to the CBD) for several reasons. For example, Duranton and Puga (2015) summarize the following predictions of the basic monocentric city model. First, for newly developed properties, land prices decline as one moves away from the CBD. Since the unit cost of structures is by and large constant within a city, the property value also exhibits a declining price gradient. Second, the density of construction declines as one moves away from the CBD. Since the physical land ratio increases and the land price decreases with distance, whether the land value share decreases with distance depends on these competing effects. In spatial equilibrium, the land value share equals the ratio of the percentage decline in the property price to the percentage decline in the land price with distance. Third, the differential land price between the CBD and the edge of the city should be proportional to the city population and the unit commuting cost.

Because the structure value share impacts the property depreciation rate in equation (4), the above predictions of the monocentric city model imply that the property depreciation rate also varies by (1) building age, (2) city size, (3) unit commuting cost in a city, (4) distance to the CBD, and (5) physical density. Furthermore, the proportions of income and appreciation returns will also vary by these factors. To see the effect of property-level depreciation rates on income returns, recall an equilibrium relation between rents and the user cost of real estate (e.g., Poterba, 1984): $R = V\,(r + m - g + d)$, where R is rents, V is property value, r is the after-tax cost of capital, m is the rate of operating expenses including property tax, g is the market-wide appreciation rate, and d is the property-level depreciation rate. A rearranged equation demonstrates that the equilibrium income return is directly affected by the property-level depreciation rate: $(R - Vm)\,/V\; = r - g + d$. Thus, as property-level depreciation rates vary by five factors described above, income returns (i.e., cap rates) also vary in the same direction and appreciation returns vary in the opposite direction. A stylized fact is that cap rates tend to be higher in suburban locations and in smaller cities. Although cap rates also depend on r and g in addition to d, this stylized fact is consistent with the predicted variation in property-level depreciation rates. In this study, I empirically analyze factors (1), (2), (4), and (5).

B. Bias Corrections: Case of Price Data

The structure depreciation rate that is estimated from the average of property depreciation rate for the observed properties of age u is by equation (4):

$$\bar{\delta_u} = -\frac{\partial \ln V_{t,u}}{\partial u}\frac{1}{s_{t,u}}. \tag{7}$$

However, this estimate is biased due to survivorship when structures are heterogeneous and demolished in the descending order of depreciation rates. The observed structures that remain in the market have small depreciation rates. To crystallize the idea, assume that the depreciation rate for building i, δ^i, is constant and uniformly distributed on $\left[\delta^L, \delta^H\right]$ at the time of construction. The initial mean depreciation rate δ equals $\left(\delta^H + \delta^L\right)/2$. Assume further that building i is demolished when the structure value $P^{Si}_{t,u}S$ becomes smaller than a scrap value: $\ln P^{Si}_{t,u}S - \ln P^{Si}_{t,0}S \leq \zeta$, where $\zeta < 0$ is the natural logarithm of the scrap value relative to the new structure value. The age of a demolished structure is: $u^i = -\zeta/\delta^i \in \left(-\zeta/\delta^H, -\zeta/\delta^L\right)$. Thus, the proportion of surviving buildings (survival ratio) of age u is:

$$r_u = \begin{cases} 1 & \text{if } u < -\frac{\zeta}{\delta^H} \\ \dfrac{-\frac{\zeta}{u} - \delta^L}{\delta^H - \delta^L} & \text{if } u \in \left(-\frac{\zeta}{\delta^H}, -\frac{\zeta}{\delta^L}\right) \end{cases} \tag{8}$$

The mean depreciation rate for the surviving structures is:

$$\bar{\delta_u} = \begin{cases} \dfrac{\delta^H + \delta^L}{2} & \text{if } u < -\frac{\zeta}{\delta^H} \\ \dfrac{-\frac{\zeta}{u} + \delta^L}{2} & \text{if } u \in \left(-\frac{\zeta}{\delta^H}, -\frac{\zeta}{\delta^L}\right) \end{cases} \tag{9}$$

Although the structure depreciation rate does not change over time, the mean depreciation rate of the structures that remain in the market decreases from $\left(\delta^H + \delta^L\right)/2$ to δ^L. One approach to obtain an unbiased estimate is to use the observed mean depreciation rate for relatively new structures ($u < -\zeta/\delta^H$). The other approach is to take into account the mean depreciation rate of the structures that were already demolished but would be u years old: $\left(-\zeta/u + \delta^H\right)/2$ for $u \in \left(-\zeta/\delta^H, -\zeta/\delta^L\right)$. The original mean structure depreciation rate can be recovered by the weighted average rate for the surviving and demolished structures:

$$\delta = r_u \bar{\delta_u} + (1 - r_u)\frac{-\frac{\zeta}{u} + \delta^H}{2}. \tag{10}$$

A benefit of this method over other standard methods of dealing with survivorship biases (e.g., the Cox proportional hazard rate model, the Kaplan-Meier estimator, and Heckman's two-step procedure) is that it does not require the detailed information on the demolished structures. It is common that data are available only for the surviving structures. The proposed method does not need those data by imposing a structure in the distribution of depreciation rates. However, the specific formulas (8), (9), and (10) depend on the distributional assumption.

The proposed method is somewhat similar to the method proposed by Hulten and Wykoff (1981b) in that both methods take a weighted average for the surviving and demolished structures, there is an important difference. They take the weighted average of structure values by assuming that the value of demolished structures is always zero. Thus, they implicitly assume that the change in the value of demolished structures is zero. In contrast, I recover the mean depreciation rate if all structures existed by taking the weighted average of depreciation rates. In other words, the method in this study incorporates large depreciation rates of demolished structures.

C. Bias Corrections: Case of Demolition Data

Consider the model characterized by equations (8) and (9). There is a one-to-one relationship between a depreciation rate δ^i and the age at demolition u^i (i.e., building life): $u^i = -\zeta / \delta^i$. Suppose the initial depreciation rate is drawn from a continuous probability density function $f(\delta^i)$ on the support $[\delta^L, \delta^H]$. Then the corresponding life span is distributed on $[-\zeta / \delta^H, -\zeta / \delta^L]$. At any time t, a full range of depreciation rates (and life spans) are observed in the sample of demolished structures.

However, since structures with a short life (i.e., a large depreciation rate) are frequently demolished, the demolition sample overrepresents these short-lived structures. If the market is in a steady state in the sense that the total amout of structures is constant over time, the frequency of demolition is inversely proportional to life span and directly proportional to depreciation rate. This causes the selection bias in the observed rate of depreciation in the demolition sample. This bias can be corrected by multiplying the probability density function of observed depreciation rate $g(\delta)$ by $u(\delta)$ and normalize it so that its integral equals unity:

$$g^*(\delta) \equiv \frac{g(\delta)u(\delta)}{\int_{\delta^L}^{\delta^H} g(\theta)u(\theta)d\theta}. \tag{11}$$

When the construction volume changes over time, let C_u denote the construction volume for age u. Then, in the time t sample of demolished structures, the frequency of age u is proportional to C_u. This causes the second bias in the observed depreciation rate in a demolition sample. This bias can be corrected by multiplying the probability density function and normalizing it. Thus, the density function corrected for both biases is:

$$g^{**}(\delta) \equiv \frac{g(\delta)u(\delta)C_{u(\delta)}^{-1}}{\int_{\delta^L}^{\delta^H} g(\theta)u(\theta)C_{u(\theta)}^{-1}d\theta}. \tag{12}$$

III. Data

This study uses three different data sets. The first data set contains transactions of single-family housing in Centre County, PA in the United States. The data is taken from the Multiple Lisiting Service (MLS) data between 1996 and 2015. Centre County comprises the State College Metropolitan Statistical Area where the Pennsylvania State University's main campus is located. The population was 153,990 in the 2010 Census. Although it is a college town, it has a well-balanced industry structure, which approximately represents the national average. For example, the largest value of location quotient is only 1.33 for real estate, rental and leasing.[8]

Table I shows the descriptive statistics. The average home price is \$215,723, which approximately equals the national average during the sample period. The average characteristics of houses are 30 years old, 2,000 square feet of floor area, 36,000 square feet of lot size, and 6.5 miles from the CBD. Houses typically have 2 stories, a parking structure, a fireplace, Vinyl exterior, and a basement.

The second data set contains transactions of the Japanese residential and commercial properties between 2005 and 2007 compiled by Yoshida, Yamazaki, and Lee (2009). The original source is the Transaction Price Information Service (TPIS) obtained from the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT). The MLIT generates its data by combining three data sources. First, the registry data are obtained from the Ministry of Justice (MOJ) on transactions of raw land, built property, and condominiums. The MOJs registry information includes location, plot number, land use type, area, dates of receipt and contract, and the name and address of the new owner. Second, property buyers fill out the MLIT survey on the transaction price, property size, and reason for the transaction. Third, real estate appraisers conduct a field survey on each property

[8]The location quotient is the ratio of an industrys share of regional employment to its share of national employment. See `www.bls.gov/cew/cewlq.htm`.

to record the information necessary to perform an appraisal, such as building height, frontal road, distance from the nearest railway station, site shape, and land use. The TPIS is the only source of transaction price data and is regarded as the most reliable price data by real estate appraisers. Since the data set contains a rich set of real estate characteristics, hedonic models have a significant explanatory power.

Table II shows the descriptive statistics of major variables used in the empirical analysis. I divide the sample to Tokyo and Non-Tokyo to characterize large and small cities. I removed outliers in terms of the number of stories, sales price, price per floor area, floor area, lot size, age, and the distance to the CBD. The number of residential transactions is 12,624 and 53,938 for Tokyo and elsewhere, respectively. The number of commercial transactions is 2,184 and 7,413, respectively. The average transaction price for residential real estate is 66 million yen for Tokyo and 32 million yen for outside Tokyo. The average price is significantly larger for commercial real estate: 345 million yen for Tokyo and 213 million yen for outside Tokyo. The average age of structures is 10-13 years for residential and 21-22 years for commercial real estate. The average floor area is approximately 127 m^2 for residential and 550 m^2 for commercial real estate. Residential properties typically have one- or two-story wooden structures and are located in a residential zoning area with low floor-to-area ratio (FAR). Commercial properties typically have non-wooden structures of 4-story or higher and are located in a commercial zoning area with a large FAR near a train station. Most sites have a regular shape and face public roads.

The third data set is the demolition statistics constructed from two data sources. The first data source is the Annual Survey on Capital Expenditures and Disposals of Private Enterprises in the system of National Accounts of Japan. This survey is conducted by the Cabinet Office of Japan since 2005 and considered one of a few reliable statistics of asset demolition. In the most recent survey, 13,524 firms reported their actual capital expenditures and disposals. The statistics include the number of demolished structures by ten age groups for single-family housing, apartment, factory, warehouse, office, hotel, restaurant, and retail. I use surveys between 2005 and 2014, which contain 1,351 residential, 15,782 industrial, 8,531 office, 383 hotel, and 6,141 retail properties. The second data source is buildings construction started (construction starts) from the Annual Survey on Construction Statistics conducted by the MLIT. This survey is based on the mandated construction registration information and goes back to 1951. The construction volume in the past is used to correct for estimation biases.

IV. Empirical Strategy

I analyze five samples for (1) residential properties in Centre County, PA, USA, (2) residential properties in Tokyo, (3) residential properties outside Tokyo in Japan, (4) commercial properties in Tokyo, and (5) commercial properties outside Tokyo in Japan. For each sample, I estimate the following hedonic model:

$$\begin{aligned}\ln V_{ijt} =& a_0 + f(A_i, \ln S_i, \ln L_i, D_i)\\ &+ a_2 \ln S_i + a_3 (\ln S_i)^2 + a_4 \ln L_i + a_5 (\ln L_i)^2 + a_6 D_i + a_7 D_i^2 + a_8 D_i^3\\ &+ a_9 \ln S_i \times \ln L_i + a_{10} \ln S_i \times D_i + a_{11} \ln L_i \times D_i\\ &+ X_i b + N_j + Q_t + \epsilon_{it}, \qquad (13)\end{aligned}$$

where V_{ijt} denotes the price of property i located in district j traded in time t, $\ln S_i$ denotes the log floor area, L_i denotes the log lot size, D_i denotes the distance, $f(A_i, \ln S_i, \ln L_i, D_i)$ denotes a function of building age A_i and its interaction terms with the above variables, and ϵ_{it} denotes the error term. The location fixed effects N_j are school districts for Centre County, wards and cities for Tokyo, and prefectures for the other part of Japan. The time fixed effects Q_t are years for Centre County and quarters for Japan.[9] The vector X_i includes a rich set of property characteristics: For Centre County, the number of bathrooms, building style, parking, heating system, exterior finish, and basement; for Japan, the site shape, street type, rental or non-rental, structure type, the number of stories, zoning, the FAR restriction, the building coverage ratio restriction for Japan. Tables I and II show the descriptive statistics of major variables.

The translog function with respect to land and structure provides flexibility in the estimation (See Rosen, 1978). The marginal effects of the log floor area $(\partial \ln V_{ijt} / \partial \ln S_i)$ and the log lot size $(\partial \ln V_{ijt} / \partial \ln L_i)$ represent the structure value share and the land value share, respectively (equations (5) and (6)). I use these shares to estimate the structure depreciation rate (equation (7)).

[9] The coefficients on Q_t form a hedonic price index (e.g., Ito and Hirono, 1993; Yoshida, Yamazaki, and Lee, 2009), but it is not a focus of the present study.

The property depreciation rate is measured by the marginal effect of building age ($\partial f / \partial A_i$). I first estimate the non-parametric function $f(A_i)$ without interaction terms. To include interaction terms, I use a step function of age groups as a parametric counterpart of this function. Specifically, I estimate:

$$f(A_i, \ln S_i, \ln L_i, D_i) = \sum_g a_{1,g}\mathbb{I}_g + a_{1,g,s}\mathbb{I}_g \times \ln S_i + a_{1,g,l}\mathbb{I}_g \times \ln L_i + a_{1,g,d}\mathbb{I}_g \times D_i, \qquad (14)$$

where $\mathbb{I}_g$ is an indicator function for the 5-year or 10-year age group g. I also estimate the following parametric models to directly obtain the annual depreciation rate:

$$f(A_i) = a_1 A_i, \qquad (15)$$

$$f(A_i, \ln S_i, \ln L_i, D_i) = \sum_g a_{1,g} A_i \mathbb{I}_g + a_{1,s} A_i \ln S_i + a_{1,l} A_i \ln L_i + a_{1,d} A_i D_i. \qquad (16)$$

In particular, the additional interaction term with distance can be important because of a correlation between distance and building age. The new houses were actively developed around the city center a century ago but at more distant locations in later years as the city size grew. Figure 13 in Appendix A depicts how the active development areas changed over time.

V. The Cross-Sectional Variation in Property Depreciation Rates

A. Japan

Figures 1 through 4 depict the estimated depreciation profiles for residential and commercial properties in Japan. Panel (a) shows the nonparametric estimate of relative prices for different ages. The graph is truncated at 50 years old because the number of older properties is small and standard errors are very large. The depreciation profile in Japan exhibits both similarities and differences compared with that for the United States. First, the functional form is generally similar until 50 years old. In particular, property values level off by 50 years old. However, unlike in the U.S., the depreciation rate is very small for the first few years before it increases and remains high for the subsequent 15 years. Overall, the total depreciation is large in Japan; for example, residential property values depreciate by half in Tokyo and 55% in smaller cities. Commercial property values depreciate by 40% after 30 years in Tokyo and by 50% after 35 years outside Tokyo.

Table III shows the estimated annual depreciation rate based on a linear and pairwise linear functions for building ages (equations 15 and 16). The average depreciation rate is 1.6% in Tokyo and 2.3% outside Tokyo for residential properties (columns 1 and 5) whereas it is 1.1% in Tokyo and 1.6% outside Tokyo for commercial properties (columns 3 and 7). Based on the pairwise linear function, the property depreciation rate gradually decreases. For example, for residential properties in Tokyo (column 2), the rate is 3.1% for the first 5 years but 1.1% between 46 and 50 years. The initial depreciation rate is even larger for commercial properties in Tokyo: 5.3% for the first 5 years.

Depreciation rates are larger for residential properties and properties outside Tokyo than for commercial properties and properties in Tokyo. There are also significant cross-sectional variations in depreciation by distance and the physical density. Table V and Figures 1 through 4 summarize the results. Panel (b) of these figures shows the variation by the distance to the nearest station.[10] Property value depreciates less significantly at the central locations. Property values at the central locations even exhibit appreciation after 40 years outside Tokyo (Figures 2b and 4b). Qualitatively, for residential properties in Tokyo (Figure 1b), the relative price is 59.5% of the new value after 40 years if distance is 140 meters but 39.4% if distance is 3500 meters. The implied annual depreciation rate is 1.30% for the close location but 2.33% for the distant location; the difference is 1.03 percentage points (column 2 of Table V).[11] This result explains why real estate agents in Japan conjecture that property values tend to be sustained at a better location near a station. It is because the depreciating component is small at a good location if it is not the only reason.

Panels (c) and (d) depict significant variations by the physical density of properties. A large density is represented by a large log floor area and a small log lot size. A high-density property with a large floor area or a small lot size significantly depreciates in value, ceteris paribus. (See also Table III.) In contrast, the economic depreciation is small for a low-density property. Remarkably,

[10]The distance to the nearest station is a relevant measure in Japan. In Tokyo, train and subway stations serve as local commercial centers and commuting hubs connected to multiple city centers. The network of railways and subways is so dense that the median distance to the nearest station is only 830 meters for residential properties and 320 meters for commercial properties. Outside Tokyo, although train stations are not necessarily located in the CBD, alternative commercial centers are often formed around stations. The errors in the distance variable may be attenuating the estimated coefficients and decreasing the statistical significance.

[11]The same result is confirmed in column 1 of Table III by a negative and statistically significant coefficient on the interaction term between age and distance.

for both residential and commercial properties in Tokyo, there is no significant depreciation over 50 years for a property at the 99 percentile in the lot size (Figures 1d and 3d). The implied annual depreciation rate over 40 years for residential properties in Tokyo is 2.83% and -0.70% for the 1 and 99 percentiles in the lot size, respectively (Column 2 of Table V). The difference of 3.53% in depreciation rates will make a large impact on investment returns. The variation in floor area also creates a similarly large variation in depreciation rate. For example, the average annual depreciation rates over 40 years are 0.79% and 3.34% for the 1 and 99 percentiles in the floor area, respectively, for residential properties in Tokyo. The result for residential properties outside Tokyo (Figures 2c and 2d), commercial properties in Tokyo (Figures 3c and 3d), and commercial properties outside Tokyo (Figures 4c and 4d) are qualitatively the same. The differences in depreciation rates between 1 and 99 pecerntiles in floor area and lot size are all economically and statistically significant (Columns 3, 4, and 5 of Table V).

Figure 5 depicts the decomposed property value. The shaded areas represent the estimated value of land and structure relative to the new property value, which is normalized to one. I estimate the value shares of structure and land on the basis of Equations (5) and (6) by calculating the marginal effects on the property value for each age group while holding the property characteristics constant at the sample mean. The land value is approximately constant over different building ages after controlling for quality and location. The value share of land for new properties is 36.0% for residential properties in Tokyo (Panel (a)), 24.2% for residential properties outside Tokyo (Panel (b)), 47.9% for commercial properties in Tokyo (Panel (c)), and 54.3% for commercial properties outside Tokyo (Panel (d)). In general, the land value share is greater in Tokyo than outside and for commercial properties than residential properties. I use the structure value share to estimate the structure depreciation rate in the next section.

B. Centre County, U.S.A.

Table IV and Figure 6 summarize the estimation result for Centre County. Figure 6a shows the relative prices of properties of various ages based on the nonparametric estimation of the age function. Property prices continuously depreciate until 50 years old and then level off around 75% of the new property price. They depreciate again after 70 years old although standard errors become larger due to a smaller number of observations. The estimated annual depreciation rate is shown in

Table IV. Based on the linear age funciton in equation (15), the average property depreciation rate is 0.4% per year. However, the property depreciation rate decreases with age when the pairwise linear function in equation (16) is estimated (column 2). The annual depreciation rate is 1.2% for properties newer than 10 years old but 0.2% for properties older than 71 years old.

Figure 6b shows the variation in depreciation rate by the distance to the CBD. This figure depicts the marginal effect of age group dummies evaluated at the mean values of other variables. The use of age groups corresponds to the step function (14). The exponential of the marginal effect represents the relative property price. Properties located farther away from the CBD (24.93 miles) significantly depreciate in value. For example, the marginal effect of -0.62 for 61-70 years old corresponds to a 46% depreciation in value. In contrast, properties located near the CBD (0.56 miles) depreciate less. This variation is summarized in column 1 of Table V. On the basis of the marginal effect for 40 year-old properties, the average annual log depreciation rate is 0.56% for the CBD and 1.06% for the distant location. This result indicates that the appreciation return to a residential property is larger (and the income return is smaller) for the central location by 0.50% than for the 25-mile distant location.

Figure 6c shows the variation by the log floor area when other variables are fixed at the mean values. Thus, this variation is caused by the physical density of properties. Properties with a low density (1 percentile in the floor area) depreciate at a significantly smaller rate than properties with a high density (99 percentile in the floor area) until 60 years old. The difference is insignificant after 60 years old. Moreover, the depreciation profiles are very different by the physical density. For low density properties, the depreciation is not statistically significant until 40 years old and becomes significant thereafter. In contrast, for high density properties, the initial depreciation is very large until 40 years old; the property value after 40 years is approximately 60% of the new property value. The difference in the annual depreciation rate is close to 1.16% between a high-density property and a low-density property (Table V). However, prices somewhat recover after 40 years.

This price increase after 40 years old is caused by an increase in the effectiveness of structures (i.e., $\partial E_u / \partial u > 0$) .[12] In particular, based on Figures 6b and 6c, the property value appreciation after 40 years old is mainly driven by the high-density properties located relatively close to the

[12]Note that the cause is not the land price appreciation at prime locations where older properties tend to exist because the correlation between building age and distance is controlled for.

CBD. Other types of properties constantly depreciate in value with age. On the basis of the theoretical model, the value appreciation for old properties can be caused either by increasing prices of the effective structure (P^{ES}) or the increasing effectiveness of structure (E_u). However, it is not plausible that the price of deteriorated structures significantly increases only for high-density properties in downtown areas. Rather, it seems more natural that the effectiveness of structure gradually increases after 40 years due to the increasing value of renovation options or historic qualities particularly for high-density properties located in the downtown area. However, separating out these appreciating factors is not possible from the data of this study.

Figure 6d shows the variation by the log lot size. This variation is negatively associated with the physical density but not significant. This small variation is reasonable given a relatively small land value (7% of the property value). A small share of land is also estimated by Epple, Gordon, and Sieg (2010). Figure 7 depicts the decomposed property value. I estimate the value shares of structure and land on the basis of equations (5) and (6) by calculating the marginal effects on the property value for each age group while holding the property characteristics constant at the sample mean. The shaded areas represent the estimated value of land and structure relative to the new property value. The land value is approximately 7% of the new property value and relatively constant over different age groups. However, the structure share decreases sharply until 50 years old and then increases until 80 years old. The increase in the structure value share can be caused by the increasing historical value, major renovations, and the option value of future renovation.

Another important result is that the sum of land and structure values is significantly smaller than the property value. In other words, the estimated shares of land and structure values do not add up to one. Since the value shares are estimated by the elasticity of property value with respect to scale, a smaller sum of land and structure shares implies decreasing returns to scale. The implied returns to scale are approximately 0.8 for new properties and 0.5 for 50-year old properties.

C. An Alternative Estimation of the Structure Value Share

One of the possible reasons for a small sum of structure and land shares is the underestimation of the structure value share. The value shares are estimated by the change in the property value caused by a small change in floor area and lot area (Equations 5 and 6) while the property characteristics are held constant. However, for a larger change in floor area, the building characteristics will also change. For example, a larger house tends to have a separate parking garage and fireplace. Thus, I estimate an alternative measure of the structure value share by changing the building characteristics with the floor area. Specifically, when I estimate the effect of an increase in floor area on the property value, I take into account the change in the mean building characteristics.

Figure 8 depicts the result. Panel (a) shows the relation between the floor area and property value when the property characteristics depend on floor area. However, I fix the building age at the mean age (approximately 30 years) to isolate the effect of building age. The slope of the graph is steeper when characteristics are allowed to change. In other words, the effect of a change in the floor area on the property value is larger with the size-dependent characteristics because of the indirect effect through changes in building characteristics.

Panel (b) shows the percentage in crease in the property value for a large change in the floor area. The building characteristics may not significantly change for a small increase in size, but can change significantly for a larger increase in size. The graph exhibits convexity although the curvature does not appear to be large. Panel (c) depicts the estimated value share of structure when the change in the building characteristics is taken into account. For a small change in the building size, the estimates are reasonably close to each other (approximately 30%) with or without variations in building characteristics. However, the difference becomes significant for a larger change in the building size. Based on the average effect of a large increase in size, the structure value share is 35% when building characteristics are fixed, but 55% when they are allowed to change. The correction is approximately 20%.

Figure 9 depicts the decomposition of depreciating property values on the basis of the alternative measure of structure value share. For a house with the average size (Panel (b)), the land value share is 7% and the structure value share is 91%. The sum of land and structure value shares is approximately one, which is larger than in Figure 7. However, the structure value share is significantly smaller for ages around 30 and 60. In other words, the size of structures affects a smaller proportion of the total property value for older houses. For example, the size determines only 58% of the value of 40-year old houses even after accounting for the size-dependent building features. The result is qualitatively similar to the one for larger houses (Panel (c)). However, for smaller houses (Panel (a)), the structure value share is small.

VI. Bias-Corrected Rates of Structure Depreciation

This section empirically demonstrates two bias adjustment methods that I propose. The first method (Section II.B) is applied to the property depreciation rate estimated by hedonic regressions of traded real estate prices. The second method (Section II.C) is applied to the demolition statistics.

A. Asset Price Approach

I estimate the bias-corrected rate of structure depreciation by using equations 7 and 10. The data for this exercise are summarized in Tables VII and VI. For the annual property depreciation rate, I use the estimate of the pairwise linear function (16) (Tables IV and III). The structure value share is taken from the result depicted in Figures 5 and 7. To calculate survival ratio, I set the lower bound of structure depreciation rate as half of the initial depreciation rate. For Japan, I set the the lower and upper bounds such that the implied survival rates approximately match the demolition data (column 5 of Table VI). Note that these upper and lower bounds affect the variances but not the mean depreciation rate. The scrap value of structure is 20% of the original value: $\zeta = \ln 0.2$.

Figure 10 depicts the estimation result. Downward-sloping dashed lines are property depreciation rates estimated by hedonic regressions whereas the thick solid lines are the bias corrected structure depreciation rates for each age group. The property depreciation rates are smaller than the structure depreciation rates due to both the effect of structure value share and a survivorship bias. In the United States, the structure depreciation rate is small and decreasing with age; the initial depreciation rate is 1.8%, but the rate for old buildings is 0.3%. Because the building life is relatively long, the survivorship bias is not large. Furthermore, since the structure value share is large in Centre County, PA, its effect is also small.

In contrast, the structure depreciation rate is much larger in Japan. For residential properties, the initial depreciation rate is 5.8% in Tokyo and 6.7% outside Tokyo. These rates tend to increase with age and become 7.7% in Tokyo and 7.3% outside Tokyo. For commercial properties, the initial depreciation rate is 10.8% in Tokyo and 9.8% outside Tokyo. These rates do not change much with age and become 10.0% and 9.1%, respectively, after 50 years. The median age group is 26-35 years for residential properties and 16-25 years for commercial properties. At the median age, the bias-corrected aggregate structure depreciation rate is 6.4% for residential properties in Tokyo, 7.0%

for residential properties outside Tokyo, 10.2% for commercial properties in Tokyo, and 9.1% for commercial properties outside Tokyo. These rates fall in the range of the lowest estimate by Seko (1998) and the highest estimate by Yoshida and Ha (2001). These rates are also significantly larger than those in the United States.

B. Demolition Approach

The sample of demolished structures is another source of information for depreciation rates. Since the life span of a structure is directly associated with its depreciation rate, one can infer the depreciation rate by measuring the building age at the time of demolition. However, there are obvious biases because the sample of demolished structures do not represent the entire population of structures. The first is a selection bias that fast depreciating structures are more frequently observed in the sample of demolished structures. The second bias is that historical changes in construction volume affect the age distribution of demolished buildings. For example, a construction boom that occurred several decades ago would naturally increases the frequency of the corresponding ages in the current demolition sample.

Figure 11 depicts the cumulative distribution of building age at demolition. The ten age groups in the data are on the horizontal axis. Panel (a) shows unadjusted distributions by property type. Residential real estate has the longest life and retail real estate has the shortest life. The observed median life is quite short: 30-40 years for residential, 20-25 years for industrial, 15-20 years for office, 10-15 years for hotel, and 5-10 years for retail. However, by adjusting for frequency and construction volume, the cumulative distribution function tends to be shifted to the right (Panels b and c). The median life corrected for both biases (Panel c) is 40-50 years for residential, 25-30 years for industrial and office, 15-20 years for hotel, and 20-25 years for retail.

Figure 12 depicts the probability mass function for depreciation rates. The discrete depreciation rates on the horizontal axis correspond to ten age groups. Panels (a), (b), and (c) are discrete analogues of density functions $g(\delta)$, $g^{*}(\delta)$, and $g^{**}(\delta)$, respectively. By comparing Panel (a) with Panel (c), it is clear that probability masses are shifted toward smaller depreciation rates. The shift is most clearly seen for residential and retail. The residential distribution is extremely skewed to the right after correcting for biases. The unadjusted retail distribution is skewed to the left but the adjusted distribution is more symmetrical.

Table VIII presents the mean and median depreciation rate with and without bias corrections by Equation (12). Since these rates depend on the assumption of scrap value, I examine three cases of scrap value. First, bias corrections are significant in magnitude. For example, when the scrap value equals 0.15, the unadjusted mean depreciation rate for residential real estate is 9.64% whereas the bias-corrected rate is 6.20%. The unadjuted rates are unreasonably large; e.g., 28.82% for retail. Second, the bias-corrected mean depreciation rate is consistent with the rate estimated by the asset price approach when the scrap value equals 0.15 or 0.2. For example, when the scrap value is 0.15, the mean rate is 6.2% for residential and 9.2-17.2% for commercial real estate. Although there are no reliable statistics for scrap values, this scrap value seems reasonable.

VII. Conclusion

This study estimates real estate depreciation rates both at the property-level and teh structure-level. The outcome of this study has several important implications. First, the cross-sectional variation in the property depreciation rate has an important implication on real estate investments and the housing economics. Second, the bias corrected structure depreciation rate serves as an important input to macroeconomics models.

The result is qualitatively summarized as follows. The property depreciation rate decreases with age and is always smaller than the structure depreciation rate due to the effect of the non-depreciating land component and a survivorship bias. The property depreciation rate is larger for newer and denser properties located away from the CBD in a smaller city. The structure depreciation rate is larger in Japan than in the U.S. and larger for commercial properties than for residential properties.

References

Alonso, William, 1964, *Location and Land Use; Toward a General Theory of Land Rent* (Harvard University Press: Cambridge, MA).

Ambrose, Brent W., N. Edward Coulson, and Jiro Yoshida, 2015, The repeat rent index, *Review of Economics and Statistics*.

Cabinet Office of Japan, 2013, White paper on disaster management, Discussion paper.

Coulson, N. Edward, and Daniel P. McMillen, 2008, Estimating time, age and vintage effects in housing prices, *Journal of Housing Economics* 17, 138 – 151.

Davidoff, Thomas, and Jiro Yoshida, 2013, Estimating consumption substitution between housing and non-housing goods using macro data, Working paper.

Davis, Morris, and Jonathan Heathcote, 2005, Housing and the business cycle, *International Economic Review* 46, 751–784.

Davis, Morris A., and Stijn Van Nieuwerburgh, 2015, Chapter 12 - housing, finance, and the macroeconomy, in J. Vernon Henderson Gilles Duranton, and William C. Strange, ed.: *Handbook of Regional and Urban Economics*, vol. 5 of *Handbook of Regional and Urban Economics* . pp. 753 – 811 (Elsevier).

Dekle, Robert, and Lawrence H. Summers, 1991, Japan's High Saving Rate Reaffirmed, NBER Working Papers 3690 National Bureau of Economic Research, Inc.

Duranton, Gilles, and Diego Puga, 2015, Chapter 8 - urban land use, in J. Vernon Henderson Gilles Duranton, and William C. Strange, ed.: *Handbook of Regional and Urban Economics*, vol. 5 of *Handbook of Regional and Urban Economics* . pp. 467 – 560 (Elsevier).

Economic and Social Research Institute, 2011, Outline of the 2005 revision to the national account (in japanese), Discussion paper Cabinet Office of Japan.

Epple, Dennis, Brett Gordon, and Holger Sieg, 2010, A new approach to estimating the production function for housing, *American Economic Review* 100, 905–24.

Fisher, Jeffrey D., Brent C Smith, Jerrold J. Stern, and R. Brian Webb, 2005, Analysis of Economic Depreciation for Multi-Family Property, *Journal of Real Estate Research* 27, 355–370.

Fujita, Masahisa, 1989, *Urban Economic Theory* . No. 9780521346627 in Cambridge Books (Cambridge University Press).

Geltner, D., and S. Bokhari, 2015, The nature and magnitude of commercial buildings capital consumption in the united states, Working paper MIT Center for Real Estate.

Greenwood, Jeremy, and Zvi Hercowitz, 1991, The Allocation of Capital and Time over the Business Cycle, *Journal of Political Economy* 99, 1188–214.

Harding, John P., Stuart S. Rosenthal, and C.F. Sirmans, 2007, Depreciation of housing capital, maintenance, and house price inflation: Estimates from a repeat sales model, *Journal of Urban Economics* 61, 193 – 217.

Hayashi, Fumio, 1986, Why Is Japan's Saving Rate So Apparently High?, in *NBER Macroeconomics Annual 1986, Volume 1* NBER Chapters . pp. 147–234 (National Bureau of Economic Research, Inc).

——— , 1989, Japan's Saving Rate: New Data and Reflections, NBER Working Papers 3205 National Bureau of Economic Research, Inc.

——— , 1991, Measuring Depreciation For Japan: Rejoinder to Dekle and Summers, NBER Working Papers 3836 National Bureau of Economic Research, Inc.

——— , Takatoshi Ito, and Joel Slemrod, 1987, Housing Finance Imperfections and Private Saving: A Comparative Simulation Analysis of the U.S. and Japan, NBER Working Papers 2272 National Bureau of Economic Research, Inc.

Hayashi, Fumio, and Edward C. Prescott, 2002, The 1990s in Japan: A Lost Decade, *Review of Economic Dynamics* 5, 206–235.

Hulten, Charles, and Frank C. Wykoff, 1981a, The Measurement of Economic Depreciation, in Charles Hulten, ed.: *Depreciation, Inflation, and the Taxation of Income from Capital* . pp. 81–125 (The Urban Institute, Washington, D.C.).

Hulten, Charles R., and Frank C. Wykoff, 1981b, The estimation of economic depreciation using vintage asset prices, *Journal of Econometrics* 15, 367 – 396.

Imrohoroglu, Selahattin, Ayse Imrohoroglu, and Kaiji Chen, 2006, The Japanese Saving Rate, *American Economic Review* 96, 1850–1858.

Ito, Takatoshi, and Keiko Nosse Hirono, 1993, Efficiency of the Tokyo Housing Market, *Monetary and Economic Studies* 11, 1–32.

Knight, John R., and C.F. Sirmans, 1996, Depreciation, maintenance, and housing prices, *Journal of Housing Economics* 5, 369 – 389.

Lane, Walter F., William C. Randolph, and Stephen A. Berenson, 1988, Adjusting the cpi shelter index to compensate for effect of depreciation, *Monthly Labor Review* pp. 34–37.

Leigh, Wilhelmina A., 1980, Economic depreciation of the residential housing stock of the united states, 1950-1970, *The Review of Economics and Statistics* 62, 200–206.

Mills, Edwin S., 1967, An aggregative model of resource allocation in a metropolitan area, *The American Economic Review* 57, 197–210.

Muth, Richard F., 1969, *Cities and housing; the spatial pattern of urban residential land use* (niversity of Chicago Press: Chicago, IL).

Poterba, James M., 1984, Tax subsidies to owner-occupied housing: An asset-market approach, *The Quarterly Journal of Economics* 99, pp. 729–752.

Rosen, Harvey S., 1978, Estimating Inter-city Differences in the Price of Housing Services, *Urban Studies* 15, 351–355.

Seko, Miki, 1998, *Tochi to jutaku no keizai bunseki* (Sobunsha: Tokyo, Japan).

Yamazaki, F., and T. Sadayuki, 2010, An estimation of collective action cost in condominium reconstruction: The case of japanese condominium law, Working Paper REAL 12-T-05 The Regional Economics Applications Laboratory, University of Illinois.

Yoshida, Atsushi, and Chun Ha, 2001, Todofuken betsu jutaku stokku no suikei, *Kikan Jutaku Tochi Keizai* 39, pp. 18–27.

Yoshida, Jiro, and Ayako Sugiura, 2015, The effects of multiple green factors on condominium prices, *The Journal of Real Estate Finance and Economics* 50, 412–437.

Yoshida, J., R. Yamazaki, and J. E. Lee, 2009, Real estate transaction prices in japan: New findings of time-series and cross-sectional characteristics, *AsRES-AREUEA Conference Proceedings*.

	$N = 13,803$			
SELECTED VARIABLES	Mean	SD	Min	Max
Price	215,723	106,719	20,000	875,000
Log Price	12.17	0.482	9.903	13.68
Building Age	29.82	23.63	0	100
# of Bedrooms	3.448	0.723	1	10
# of Bathrooms	1.984	0.747	1	6
Floor Area (sq.ft.)	2,008	694.3	792	4,552
Log Floor Area	7.548	0.338	6.675	8.423
Lot Size (sq.ft.)	36,246	77,124	3,920	871,200
Log Lot Size	9.867	0.900	8.274	13.68
Style: 2 Stories	0.385	0.487	0	1
Style: Ranch	0.300	0.458	0	1
Parking: Yes	0.886	0.318	0	1
Parking: Attached	0.557	0.497	0	1
Parking: Detached	0.109	0.311	0	1
Heating: Forced Air Heating	0.342	0.474	0	1
Heating: Baseboard	0.252	0.434	0	1
Heating: Heat Pump	0.180	0.384	0	1
Heating: Hot Water	0.171	0.376	0	1
Fireplace: Yes	0.786	0.410	0	1
Fireplace: Wood	0.306	0.461	0	1
Exterior: Vinyl	0.549	0.498	0	1
Exterior: Brick	0.343	0.475	0	1
Exterior: Aluminum	0.164	0.371	0	1
Basement: Full	0.671	0.470	0	1
Basement: Partial	0.131	0.337	0	1
City: State College	0.648	0.478	0	1
City: Bald Eagle	0.0477	0.213	0	1
City: Bellefonte	0.191	0.393	0	1
City: Penns Valley	0.0501	0.218	0	1
City: Philipsburg-Osceola	0.0324	0.177	0	1
Direction: North	0.628	0.483	0	1
Direction: East	0.511	0.500	0	1
Distance to CBD	6.534	5.996	0.335	29.97
Year of Transaction	2,007	5.064	1,996	2,015

Table I: Descriptive Statistics (Centre County, PA, USA)

	Tokyo				Outside Tokyo			
	Residential		Commercial		Residential		Commercial	
	N = 12,624		N = 2,184		N = 53,938		N = 7,413	
SELECTED VARIABLES	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Property Value (million yen)	66.3	96.8	345.4	747.1	31.7	37.4	213.3	499.8
Log Property Value	17.70	0.711	18.83	1.257	17.01	0.742	18.24	1.317
Building Age	10.47	13.38	21.77	13.54	13.19	13.67	22.17	12.95
Floor Area (sq. meter)	126.6	117.4	549.6	666.5	127.2	92.71	583.3	779.9
Log Floor Area	4.667	0.495	5.764	1.032	4.724	0.429	5.795	1.035
Lot Size (sq. meter)	116.9	85.89	166.6	157.5	179.1	133.4	302.1	393.8
Log Lot Size	4.600	0.521	4.811	0.745	5.005	0.579	5.222	0.930
Distance to Station (meter)	996.2	685.6	419.0	347.2	1,591	1,087	829.2	1,028
Site Width (meter)	7.622	6.318	9.882	6.050	10.50	8.175	12.95	10.41
Rectangular shaped site	0.31	0.46	0.32	0.47	0.34	0.47	0.33	0.47
Private road	0.31	0.46	0.05	0.21	0.18	0.38	0.02	0.15
Number of Stories	2.390	0.649	4.633	2.464	2.127	0.546	3.955	2.415
Wooden structure	0.83	0.37	0.19	0.39	0.82	0.38	0.23	0.42
Regulation: Coverage Ratio (%)	56.22	9.283	78.70	5.180	57.42	9.090	76.05	8.026
Regulation: Floor Area Ratio (%)	178.0	84.65	472.7	156.3	166.8	66.61	393.8	168.2

Table II: Descriptive Statistics (Japan)

Dependent Variable:	Tokyo				Outside Tokyo			
Log transaction price	Residential		Commerical		Residential		Commerical	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Building age	-0.016***		-0.011***		-0.023***		-0.016***	
	(0.000)		(0.001)		(0.000)		(0.001)	
$\times\mathbb{I}(1-5 \text{ years})$		-0.031***		-0.053***		-0.044***		-0.048***
		(0.004)		(0.013)		(0.002)		(0.010)
$\times\mathbb{I}(6-10 \text{ years})$		-0.021***		-0.036***		-0.036***		-0.028***
		(0.001)		(0.008)		(0.001)		(0.004)
$\times\mathbb{I}(11-15 \text{ years})$		-0.020***		-0.031***		-0.033***		-0.029***
		(0.001)		(0.003)		(0.001)		(0.002)
$\times\mathbb{I}(16-20 \text{ years})$		-0.019***		-0.022***		-0.029***		-0.025***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(21-25 \text{ years})$		-0.016***		-0.021***		-0.025***		-0.024***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(26-30 \text{ years})$		-0.014***		-0.019***		-0.024***		-0.023***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(31-35 \text{ years})$		-0.014***		-0.016***		-0.021***		-0.020***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(36-40 \text{ years})$		-0.013***		-0.010***		-0.018***		-0.016***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(41-45 \text{ years})$		-0.013***		-0.009***		-0.016***		-0.015***
		(0.001)		(0.002)		(0.000)		(0.001)
$\times\mathbb{I}(46-50 \text{ years})$		-0.011***		-0.008***		-0.014***		-0.012***
		(0.001)		(0.002)		(0.001)		(0.001)
× Log Floor Area (demeaned)		-0.008***		-0.005***		-0.009***		-0.004***
		(0.001)		(0.002)		(0.001)		(0.001)
× Log Lot Size (demeaned)		0.012***		0.008***		0.008***		0.003***
		(0.001)		(0.002)		(0.000)		(0.001)
× Distance		-0.000***		-0.000***		-0.000***		-0.000***
		(0.000)		(0.000)		(0.000)		(0.000)
Other variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Location fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-quarter fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	12,624	12,624	2,184	2,184	53,938	53,938	7,413	7,413
Adjusted R-squared	0.816	0.826	0.836	0.844	0.679	0.698	0.795	0.800

Table III: Regression Result (Japan)

This table presents the key estimation result of equation (13) for Tokyo (columns 1-4) and outside Tokyo (columns 5-8), for both residential (columns 1,2,5,6) and commerical (columns 3,4,7,8) with age functions (15) (columns 1, 3, 5, 7) and (16) (columns 2, 4, 6, 8). $\mathbb{I}(\cdot)$ denotes an indicator variable for each age group. White's heteroskedasticity-robust standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

Dependent Variable: Log transaction price	(1) Linear	(2) Pairwise linear with interactions
Building Age	-0.004***	
	(0.000)	
$\times \mathbb{I}(1-10 \text{ years})$		-0.012***
		(0.001)
$\times \mathbb{I}(11-20 \text{ years})$		-0.010***
		(0.000)
$\times \mathbb{I}(21-30 \text{ years})$		-0.007***
		(0.000)
$\times \mathbb{I}(31-40 \text{ years})$		-0.006***
		(0.000)
$\times \mathbb{I}(41-50 \text{ years})$		-0.005***
		(0.000)
$\times \mathbb{I}(51-60 \text{ years})$		-0.004***
		(0.000)
$\times \mathbb{I}(61-70 \text{ years})$		-0.003***
		(0.000)
$\times \mathbb{I}(71-80 \text{ years})$		-0.002***
		(0.000)
$\times \mathbb{I}(81-90 \text{ years})$		-0.002***
		(0.000)
$\times \mathbb{I}(91-100 \text{ years})$		-0.002***
		(0.000)
$\times$ Log Floor Area (demeaned)		-0.000
		(0.000)
$\times$ Log Lot Size (demeaned)		-0.000
		(0.000)
$\times$ Distance		-0.000***
		(0.000)
Other variables	Yes	Yes
Location fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Observations	13,803	13,803
Adjusted R-Squared	0.841	0.852

Table IV: Regression Result (Cenre County, PA)

This table presents the key estimation result of equation (13) for Centre County with age functions (15) (column 1) and (16) (column 2). $\mathbb{I}(\cdot)$ denotes an indicator variable for each age group. White's heteroskedasticity-robust standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

		Residential		Commerical	
	Centre County	Tokyo	Outside Tokyo	Tokyo	Outside Tokyo
	(1)	(2)	(3)	(4)	(5)
Distance Measure					
1 percentile	0.0056	0.0130	0.0180	0.0103	0.0163
	(0.0004)	(0.0009)	(0.0005)	(0.0019)	(0.0011)
99 percentile	0.0106	0.0233	0.0260	0.0285	0.0255
	(0.001)	(0.0025)	(0.0011)	(0.0054)	(0.0039)
Difference	0.0050	0.0103	0.0081	0.0183	0.0092
Floor Area					
1 percentile	0.0012	0.0079	0.0123	-0.0012	0.0122
	(0.0007)	(0.0011)	(0.0006)	(0.0037)	(0.0023)
99 percentile	0.0128	0.0334	0.0370	0.0334	0.0251
	(0.0006)	(0.0026)	(0.0014)	(0.0052)	(0.0032)
Difference	0.0116	0.0255	0.0247	0.0347	0.0128
Lot Size					
1 percentile	0.0075	0.0283	0.0304	0.0268	0.0195
	(0.0005)	(0.0015)	(0.0009)	(0.004)	(0.0026)
99 percentile	0.0053	-0.0070	0.0064	-0.0050	0.0150
	(0.0012)	(0.0019)	(0.001)	(0.0057)	(0.0039)
Difference	-0.0021	-0.0353	-0.0240	-0.0318	-0.0045

Table V: Variation in the Implied Annual Depreciation Rate

This table presents the average annual log depreciation rate over 40 years that is implied by Figures 6 and 1. The depreciation rates are contrasted between the 1 percentile and 99 percentile in distance, floor area, and lot size. In parentheses are White's heteroskedasticity-robust standard errors computed by the delta method.

Age Group	Property Depreciation Rate	Structure Value Ratio	Structure Depreciation Rate without Correction (Eq. 11)	Survival Rate (Eq. 12)	Structure Depreciation Rate with Correction (Eq. 14)
(a) Residential Properties, Tokyo. Assumptions: $\zeta = \ln 0.2, \delta^L = 0.005, \delta^H = 0.111$					
5	0.031	0.519	0.058	1.000	0.058
10	0.021	0.476	0.049	1.000	0.049
15	0.020	0.433	0.056	1.000	0.056
20	0.019	0.390	0.045	0.866	0.052
25	0.016	0.347	0.042	0.674	0.058
30	0.014	0.304	0.045	0.551	0.063
35	0.014	0.261	0.047	0.466	0.065
40	0.013	0.218	0.062	0.404	0.071
45	0.013	0.175	0.050	0.357	0.066
50	0.011	0.132	0.086	0.319	0.077
(b) Residential Properties, Outside Tokyo. Assumptions: $\zeta = \ln 0.2, \delta^L = 0.005, \delta^H = 0.130$					
5	0.044	0.718	0.067	1.000	0.067
10	0.036	0.671	0.054	1.000	0.054
15	0.033	0.625	0.055	1.000	0.055
20	0.029	0.579	0.044	0.738	0.061
25	0.025	0.532	0.046	0.574	0.069
30	0.024	0.486	0.044	0.469	0.071
35	0.021	0.440	0.042	0.397	0.071
40	0.018	0.393	0.049	0.344	0.074
45	0.016	0.347	0.054	0.304	0.075
50	0.014	0.301	0.049	0.272	0.073
(c) Commerical Properties, Outside Tokyo. Assumptions: $\zeta = \ln 0.2, \delta^L = 0.02, \delta^H = 0.197$					
5	0.053	0.429	0.108	1.000	0.108
10	0.036	0.403	0.129	1.000	0.129
15	0.031	0.377	0.086	0.728	0.107
20	0.022	0.351	0.062	0.520	0.102
25	0.021	0.324	0.052	0.405	0.101
30	0.019	0.298	0.062	0.331	0.106
35	0.016	0.272	0.059	0.280	0.105
40	0.010	0.245	0.061	0.243	0.105
45	0.009	0.219	0.041	0.214	0.101
50	0.008	0.193	0.034	0.192	0.100
(d) Commerical Properties, Outside Tokyo. Assumptions: $\zeta = \ln 0.2, \delta^L = 0.02, \delta^H = 0.176$					
5	0.048	0.477	0.098	1.000	0.098
10	0.028	0.456	0.058	1.000	0.058
15	0.029	0.436	0.071	0.824	0.086
20	0.025	0.415	0.058	0.589	0.089
25	0.024	0.395	0.054	0.458	0.092
30	0.023	0.375	0.056	0.375	0.094
35	0.020	0.354	0.066	0.317	0.098
40	0.016	0.334	0.047	0.275	0.092
45	0.015	0.313	0.049	0.243	0.093
50	0.012	0.293	0.042	0.217	0.091

Table VI: Bias-Corrected Rate of Structure Depreciation (Japan)

This table presents the bias correction in the estimation of the structure depreciation rate based on equations 7 and 10.

Age Group	Property Depreciation Rate	Structure Value Ratio	Structure Depreciation Rate without Correction (Eq. 11)	Survival Rate (Eq. 12)	Structure Depreciation Rate with Correction (Eq. 14)
10	0.012	0.699	0.018	1.000	0.018
20	0.010	0.607	0.016	1.000	0.016
30	0.007	0.476	0.015	1.000	0.015
40	0.006	0.433	0.014	1.000	0.014
50	0.005	0.478	0.010	1.000	0.010
60	0.004	0.560	0.007	1.000	0.007
70	0.003	0.725	0.004	1.000	0.004
80	0.002	0.866	0.002	1.000	0.002
90	0.002	0.783	0.003	1.000	0.003
100	0.002	0.733	0.002	0.948	0.003

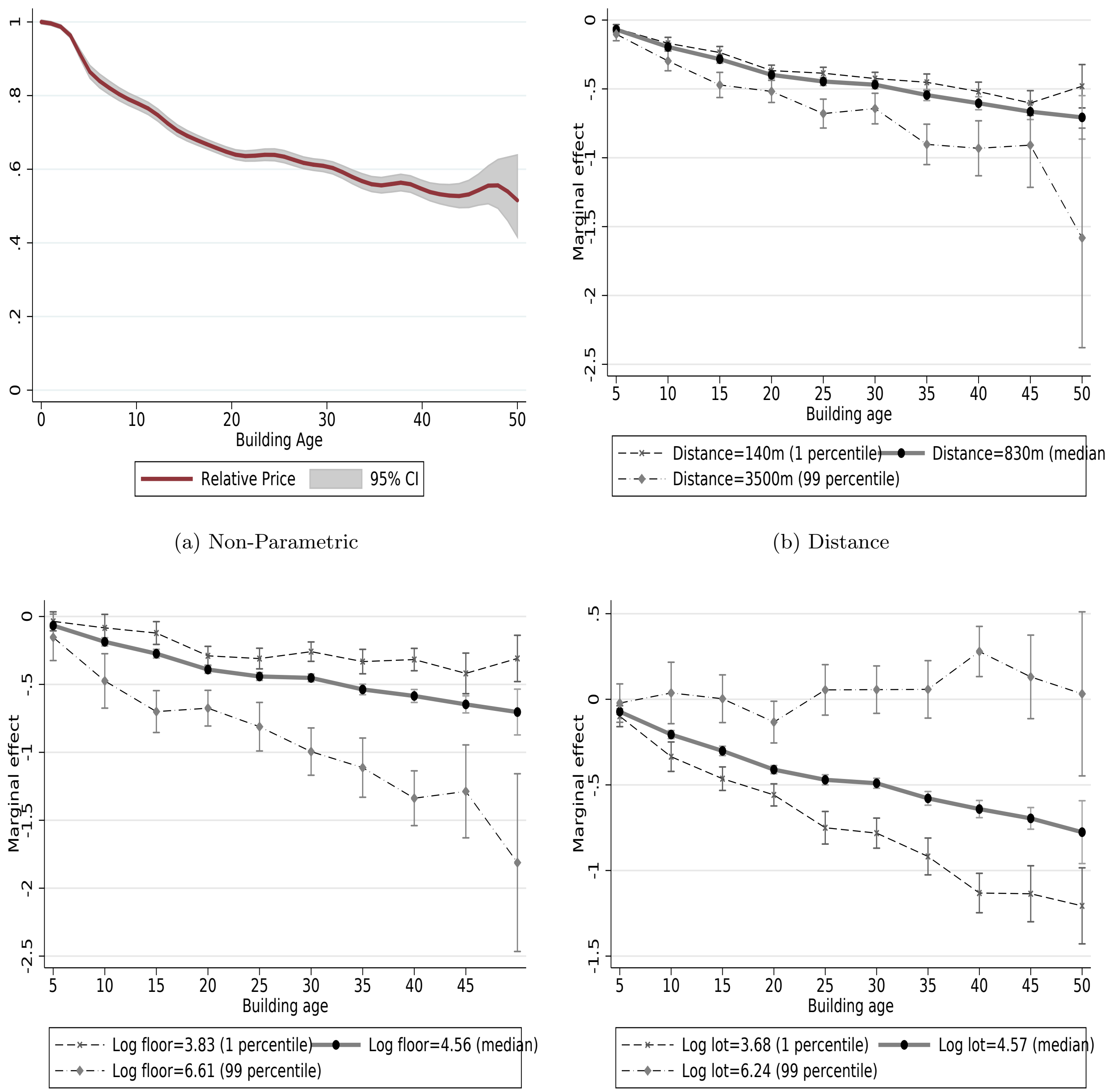
Table VII: Bias-Corrected Rate of Structure Depreciation (Centre County, PA)

This table presents the bias correction in the estimation of the structure depreciation rate based on equations 7 and 10. Assumptions are: $\zeta = \ln 0.2$, $\delta^L = 0.009$, $\delta^H = 0.027$

	Scrap Value: 0.1		Scrap Value: 0.15		Scrap Value: 0.2	
	Mean	Median	Mean	Median	Mean	Median
Bias-Corrected Rate						
Residential	0.0753	0.0512	0.0620	0.0422	0.0526	0.0358
Industrial	0.1117	0.0837	0.0920	0.0690	0.0781	0.0585
Office	0.1422	0.0837	0.1171	0.0690	0.0994	0.0585
Hotel	0.2092	0.1316	0.1724	0.1084	0.1462	0.0920
Retail	0.1797	0.1023	0.1481	0.0843	0.1256	0.0715
Unadjusted Rate						
Residential	0.1170	0.0658	0.0964	0.0542	0.0818	0.0460
Industrial	0.1766	0.1023	0.1455	0.0843	0.1234	0.0715
Office	0.2408	0.1316	0.1984	0.1084	0.1683	0.0920
Hotel	0.2531	0.1842	0.2085	0.1518	0.1769	0.1288
Retail	0.3498	0.1842	0.2882	0.1518	0.2445	0.1288

Table VIII: Demolition-Based Estimate of Structure Depreciation Rate

This table presents the mean and median rate of structure depreciation that is estimated from demolition statistics. The frequency and construction volume biases are corrected.



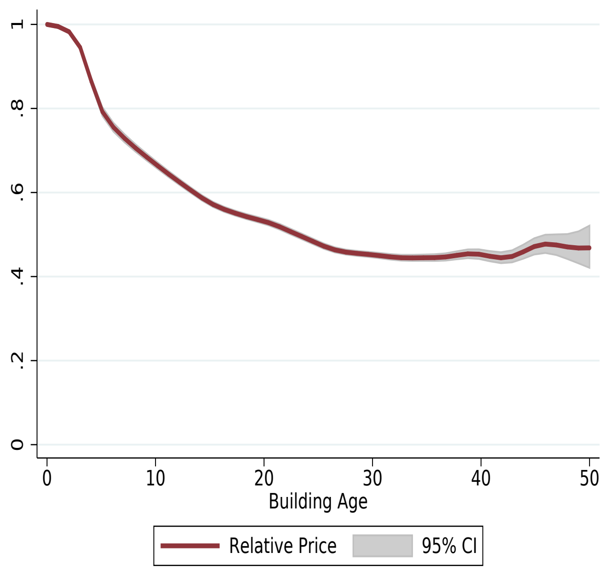
(a) Non-Parametric

(b) Distance

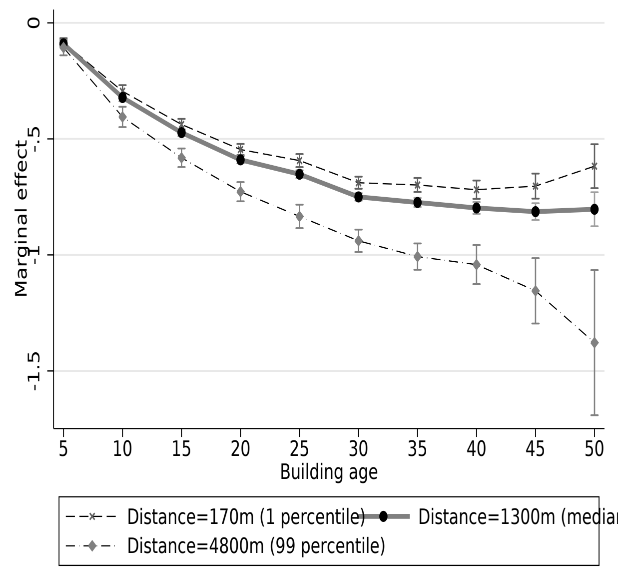
(c) Log Floor Area

(d) Log Lot Area

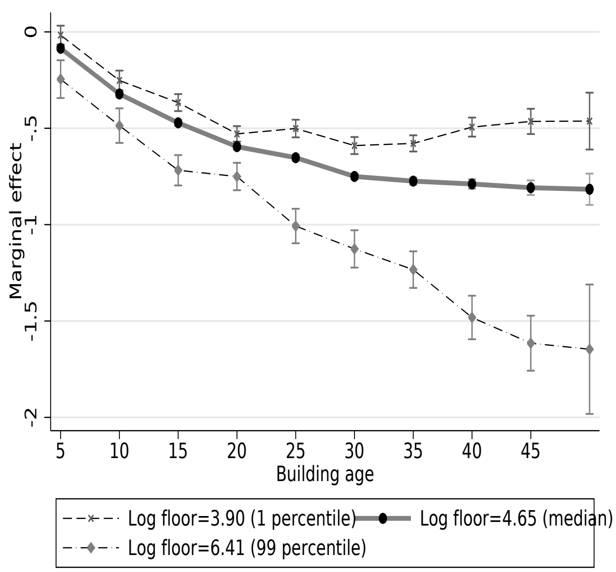
Figure 1: Property Value Depreciation (Residential, Tokyo, Japan)



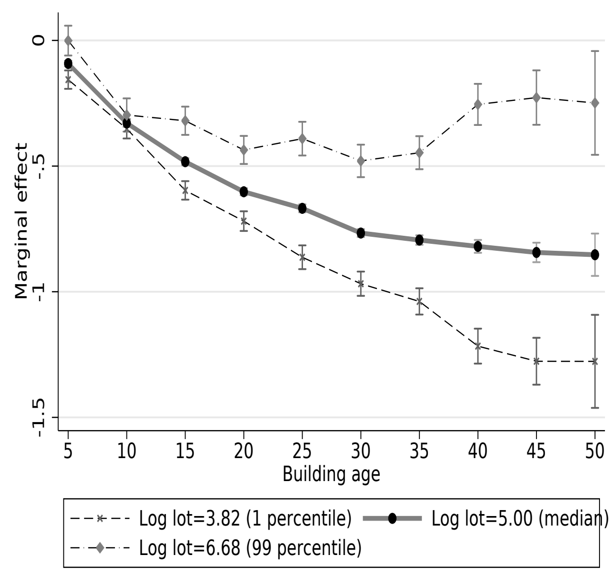
(a) Non-Parametric



(b) Distance

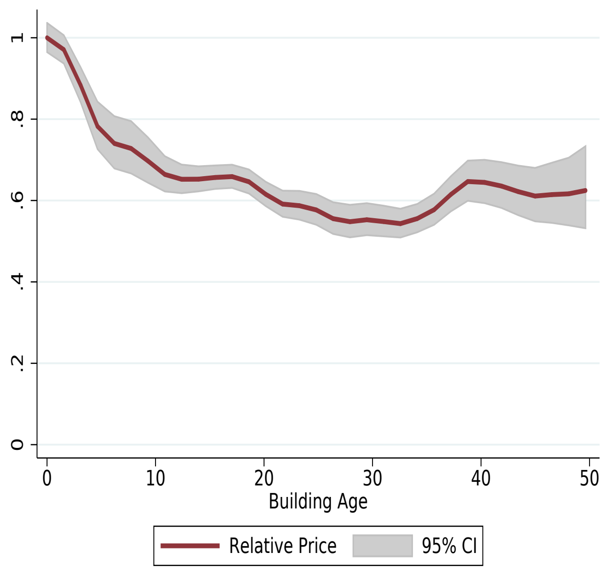


(c) Log Floor Area

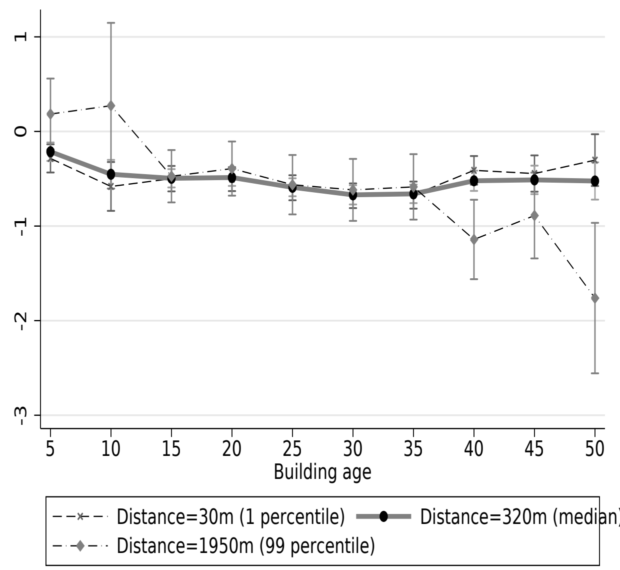


(d) Log Lot Area

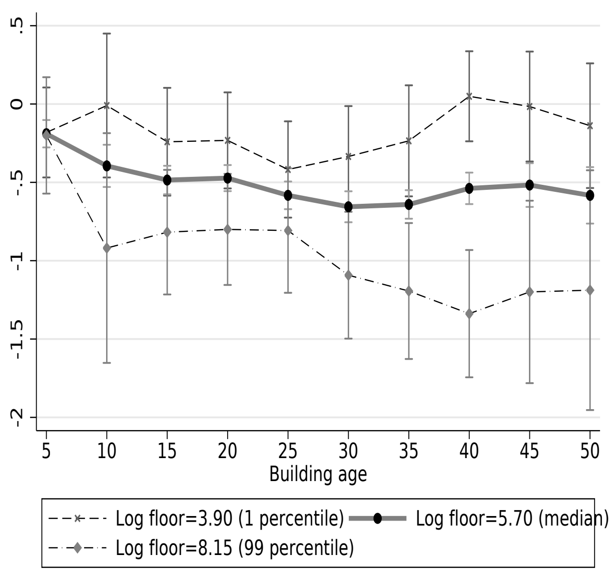
Figure 2: Property Value Depreciation (Residential, Outside Tokyo, Japan)



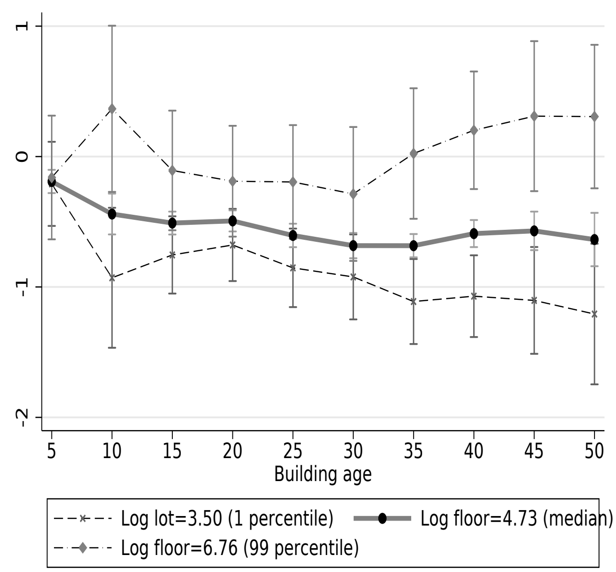
(a) Non-Parametric



(b) Distance

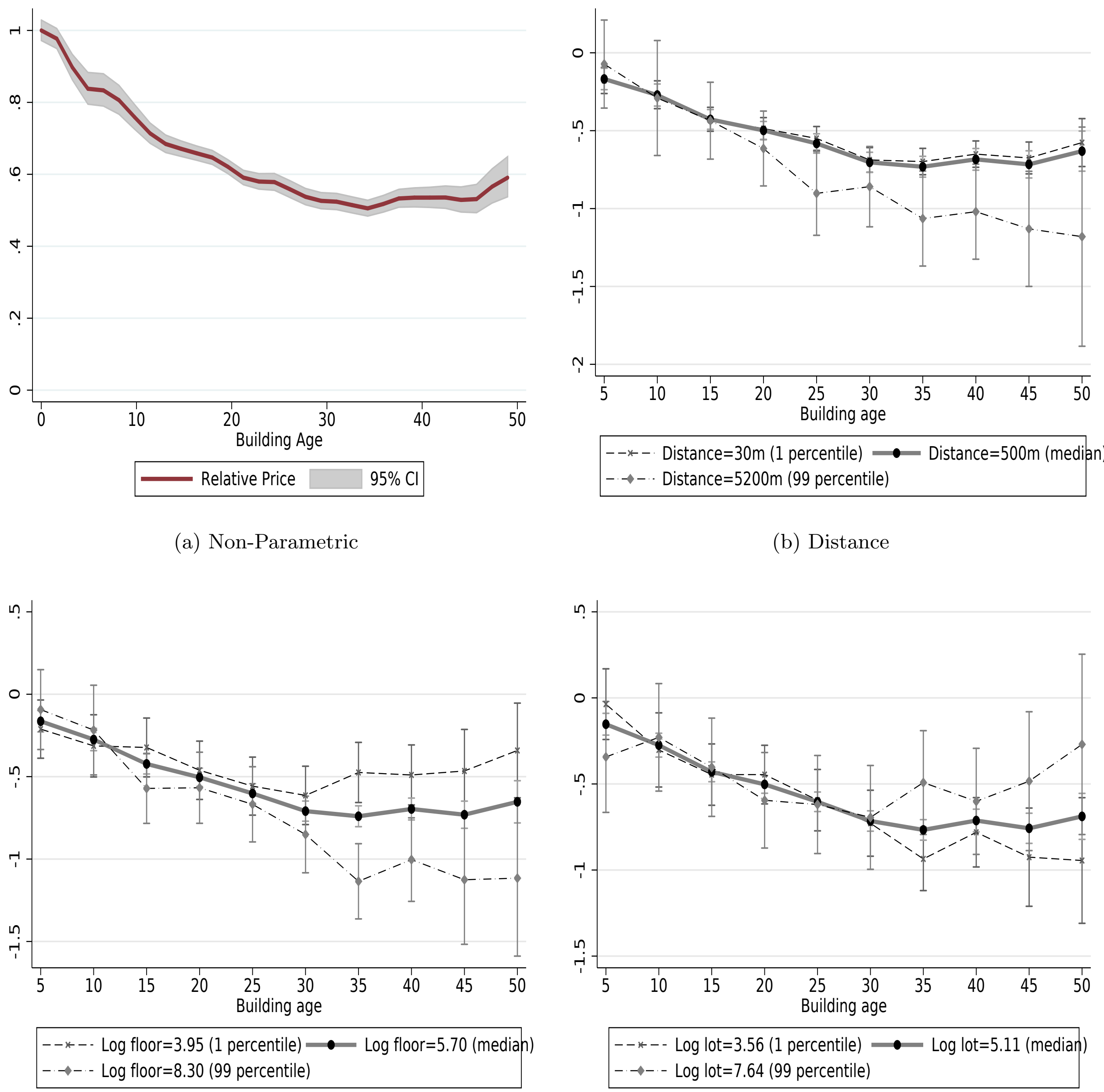


(c) Log Floor Area



(d) Log Lot Area

Figure 3: Property Value Depreciation (Commercial, Tokyo, Japan)



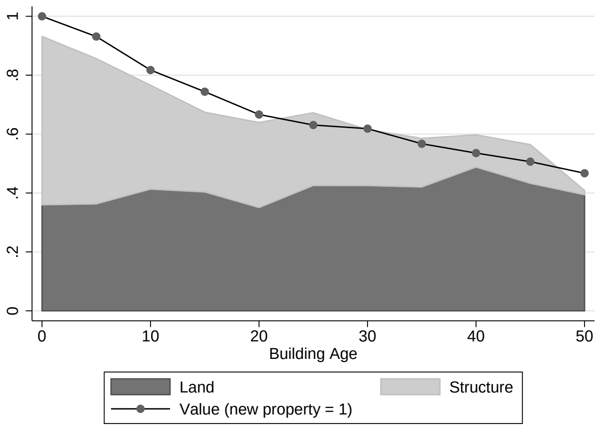
(a) Non-Parametric

(b) Distance

(c) Log Floor Area

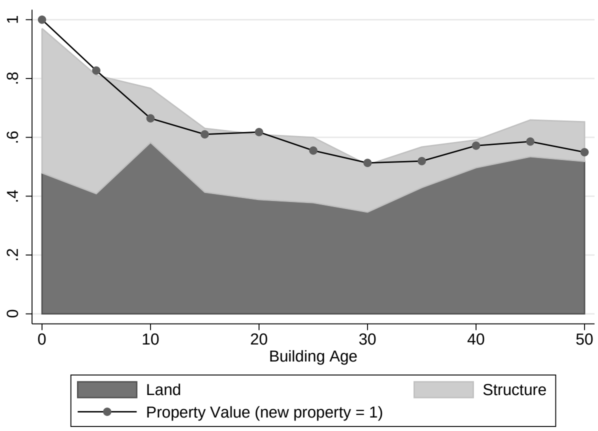
(d) Log Lot Area

Figure 4: Property Value Depreciation (Commercial, Outside Tokyo, Japan)



(a) Residential, Tokyo

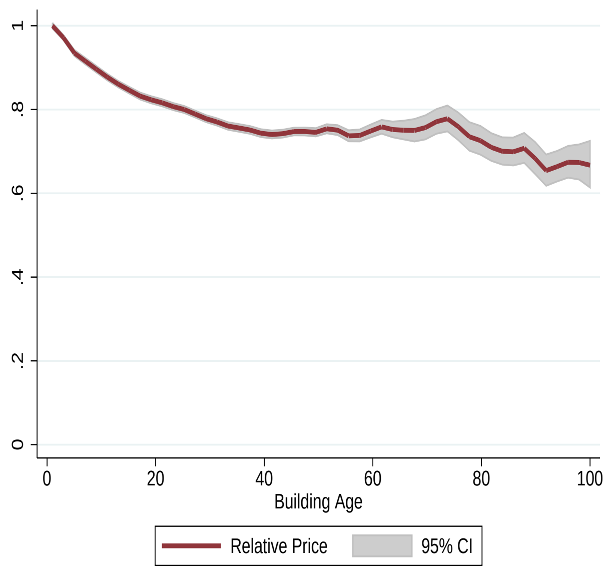
(b) Residential, Outside Tokyo



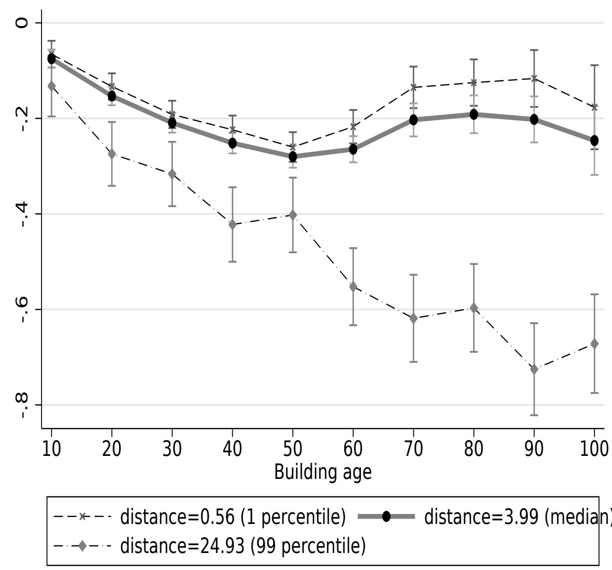
(c) Commercial, Tokyo

(d) Commercial, Outside Tokyo

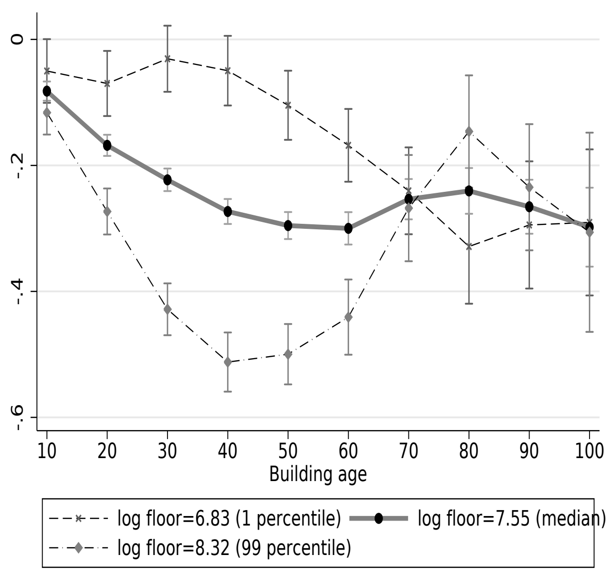
Figure 5: Decomposition of Property Value (Japan)



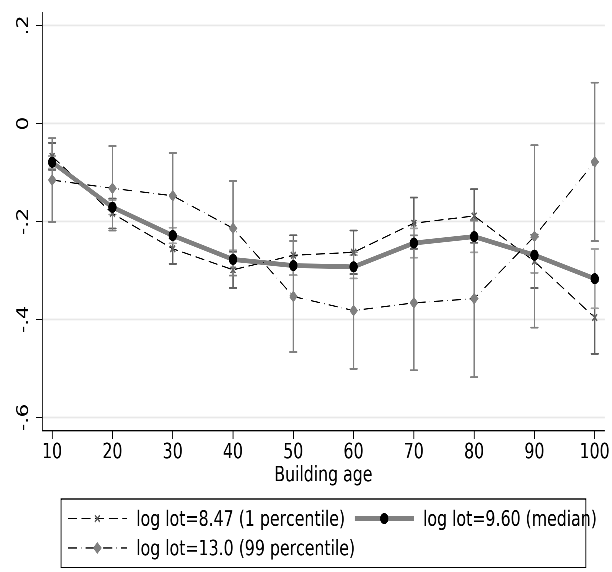
(a) Non-Parametric



(b) Distance



(c) Log Floor Area



(d) Log Lot Area

Figure 6: Property Value Depreciation (Residential, Centre County, PA)

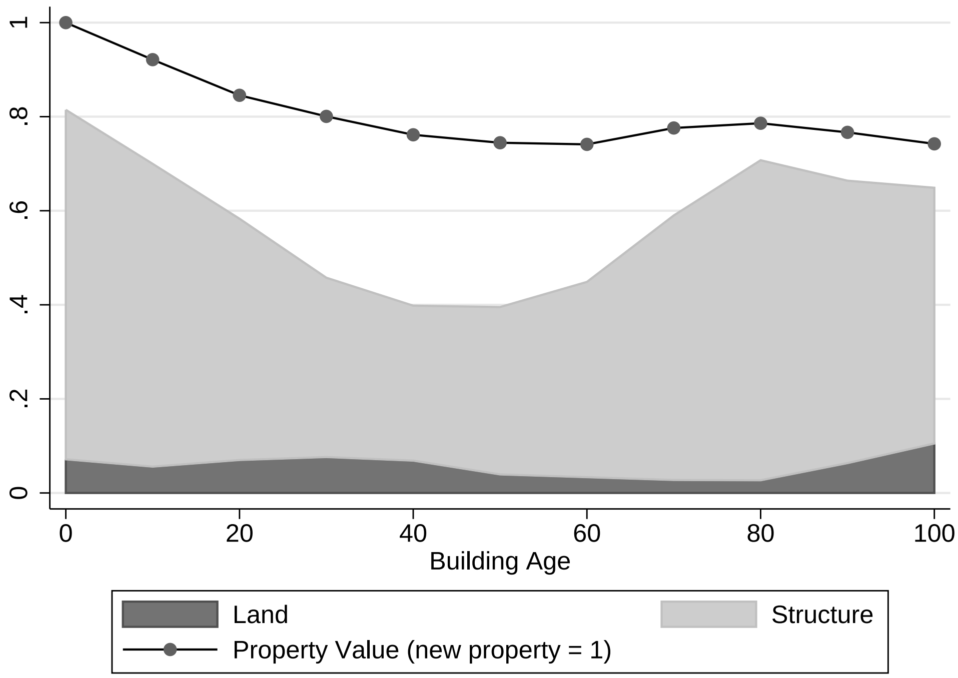
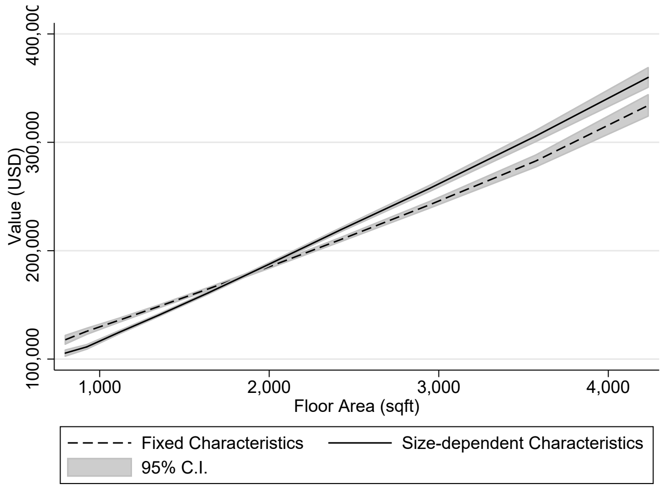
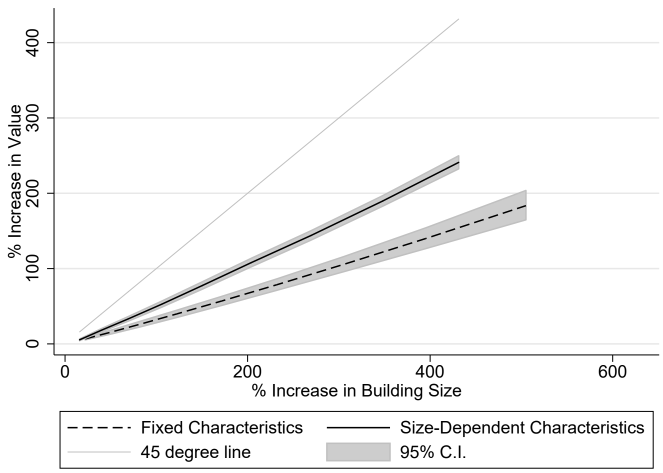


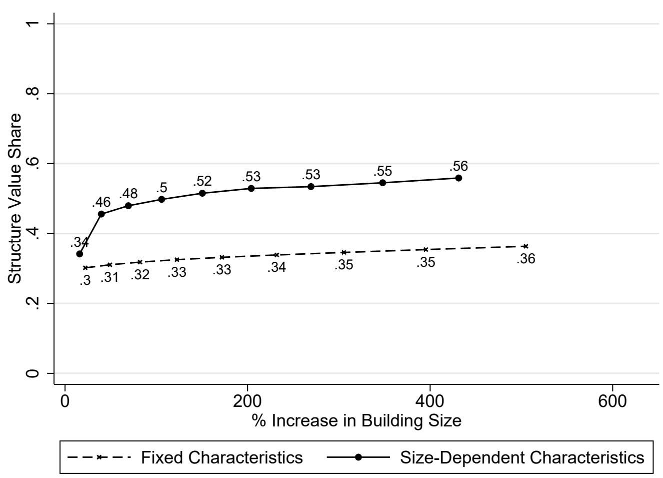
Figure 7: Decomposition of Property Value (Residential, Centre County, PA)



(a) Foor Area and Property Value

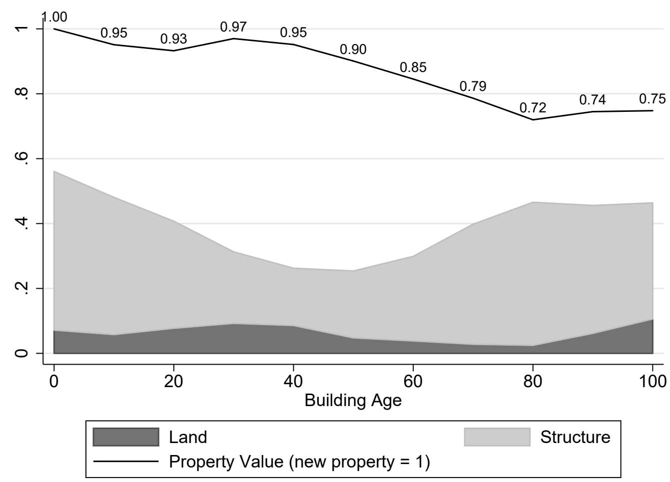


(b) Non-Marginal Change in Floor Area

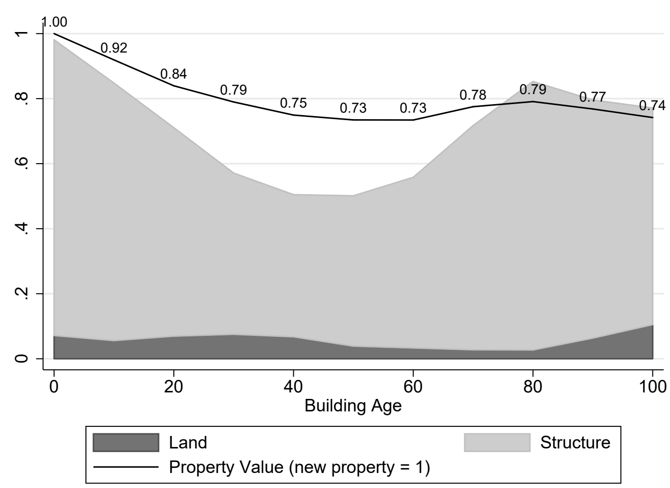


(c) Structure Value Share

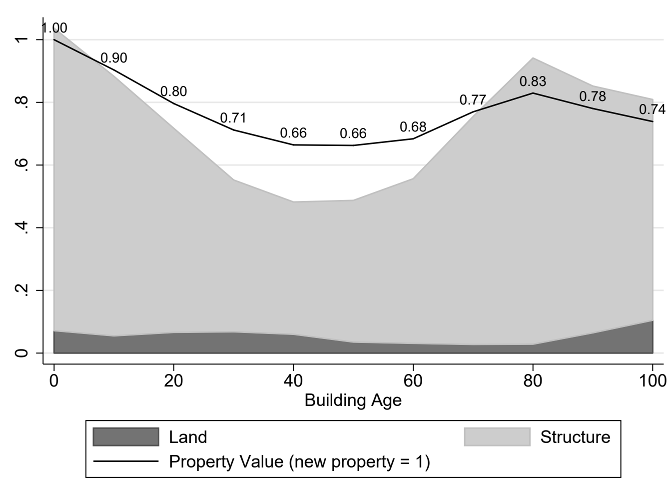
Figure 8: The Effct of Large Changes in Floor Area (Residential, Centre County, PA)



(a) Floor Area = 924 sqft

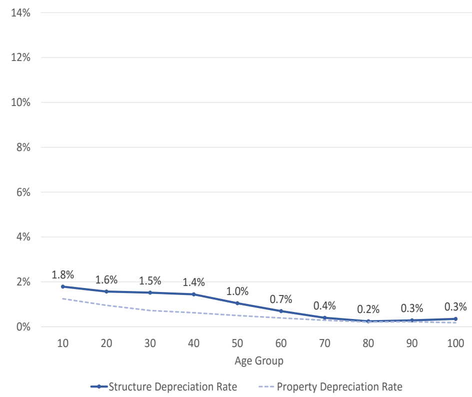


(b) Floor Area = 1,996 sqft

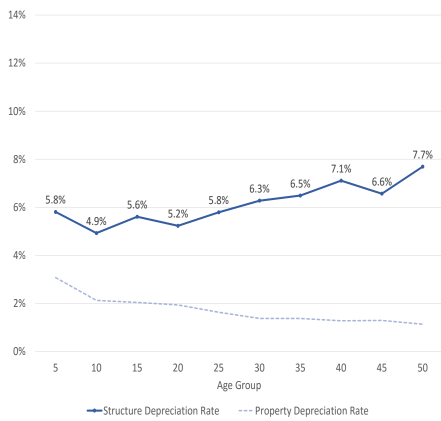


(c) Floor Area = 2,945 sqft

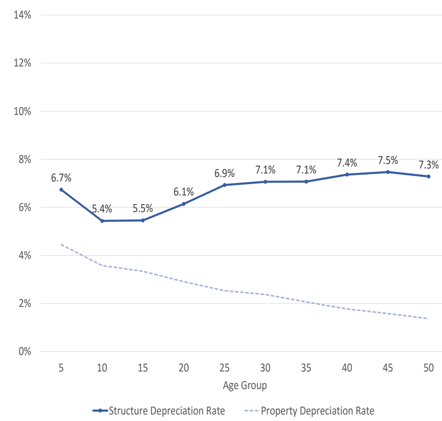
Figure 9: Alternative Estimates of Decomposed Property Value (Residential, Centre County, PA)



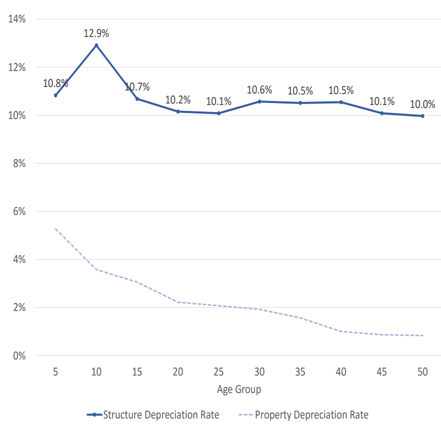
(a) Centre County, Residential



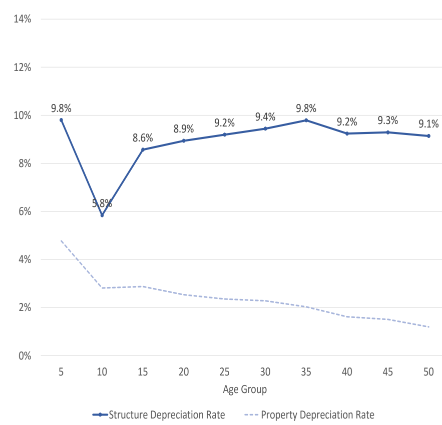
(b) Tokyo, Residential



(c) Outside Tokyo, Residential



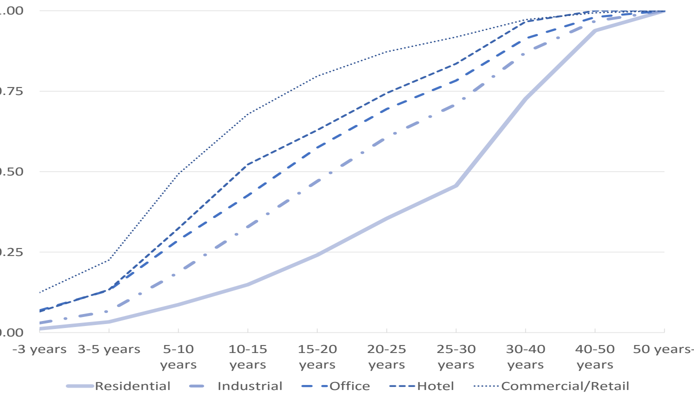
(d) Tokyo, Commercial



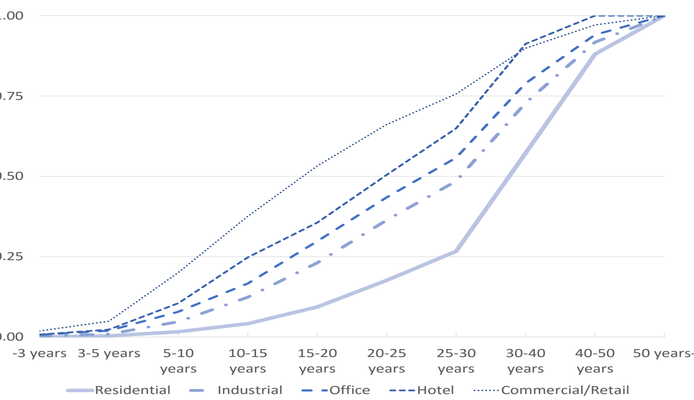
(e) Outside Tokyo, Commerical

Figure 10: Bias-Corrected Rates of Depreciation

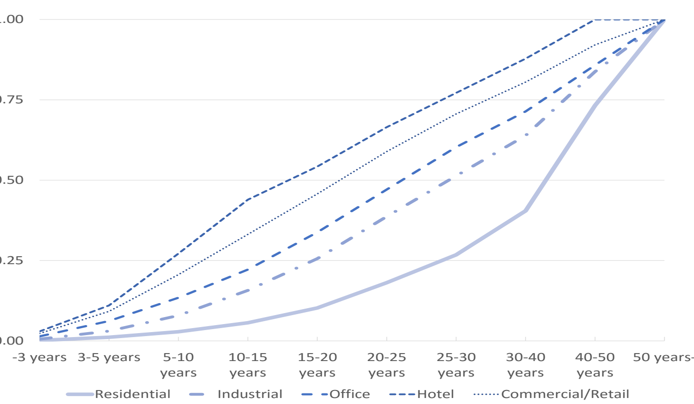
This figure depicts the estimated annual property depreciation rate and the structure depreciation rate corrected for survivorship biases based on Tables VII and VI



(a) Unadjusted

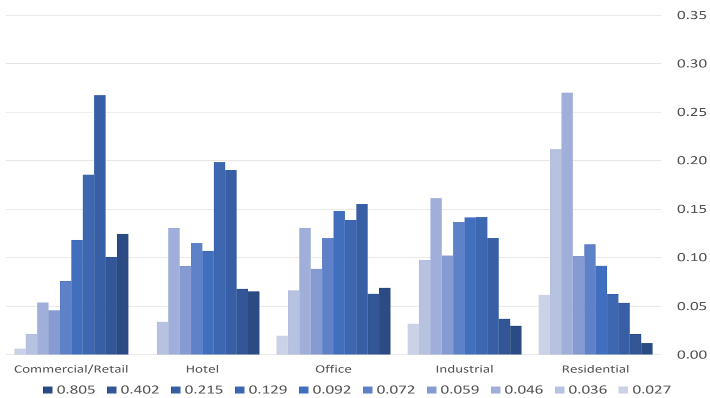


(b) Adjusted for Frequency

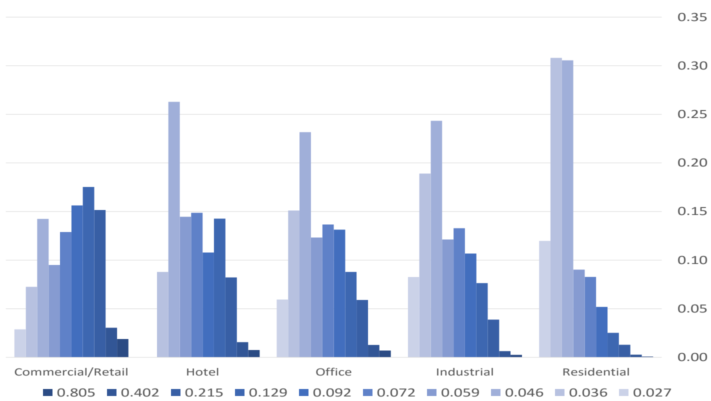


(c) Adjusted for Frequency and Construction Volume

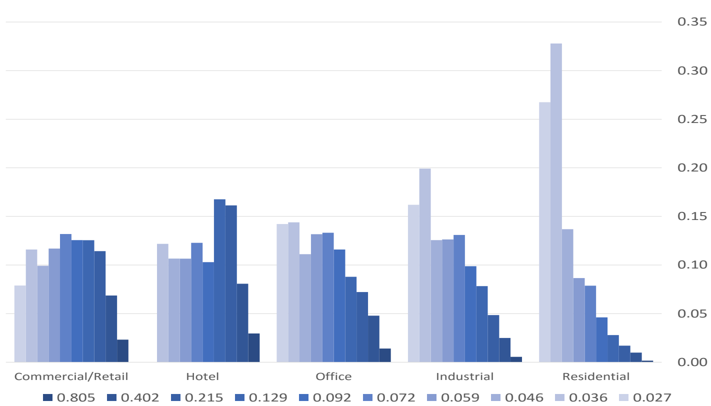
Figure 11: Cumulative Distribution of Building Age at Demolition



(a) Unadjusted



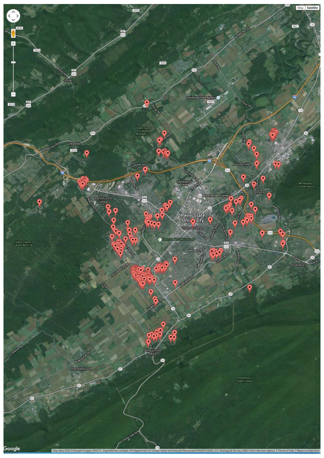
(b) Adjusted for Frequency

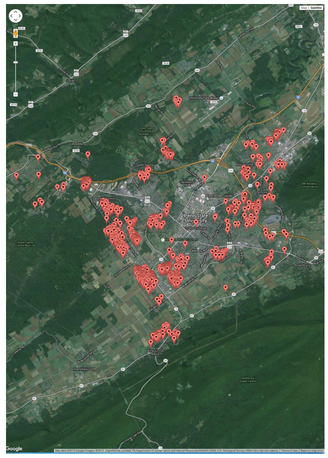


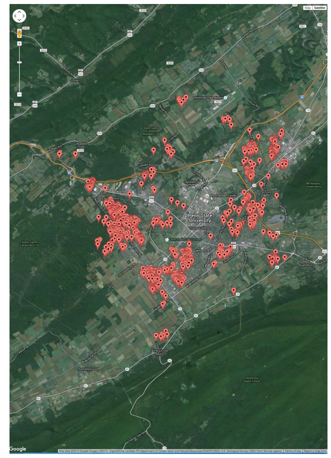
(c) Adjusted for Frequency and Construction Volume

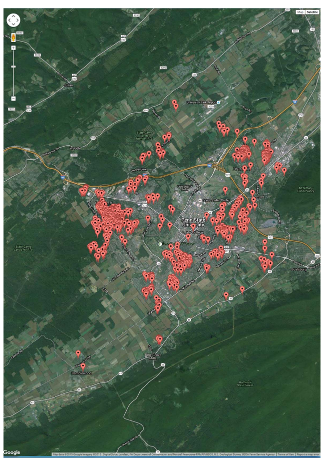
Figure 12: Distribution of Depreciation Rates

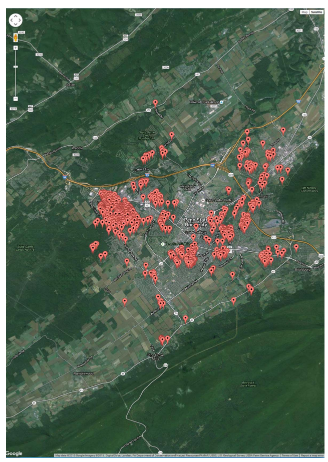
Appendix A Building Age and Location in Centre County, PA

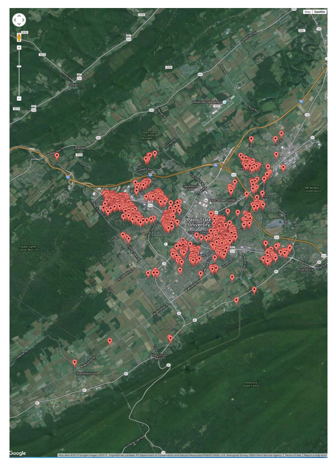

(a) 0-10 years

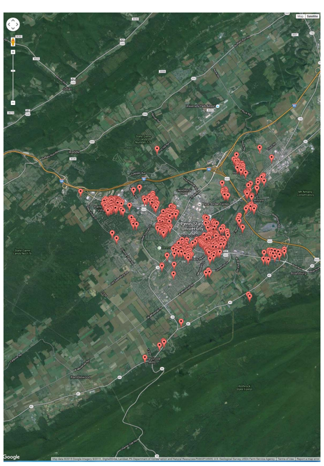

(b) 10-20 years

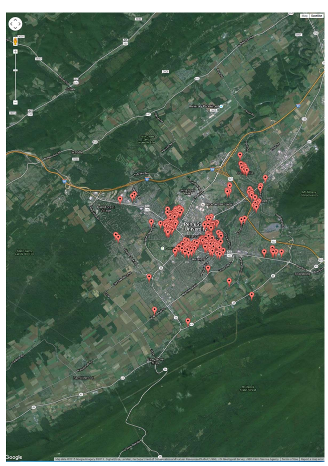

(c) 20-30 years


(d) 30-40 years


(e) 40-50 years


(f) 50-60 years


(g) 60-70 years


(h) 70-80 years

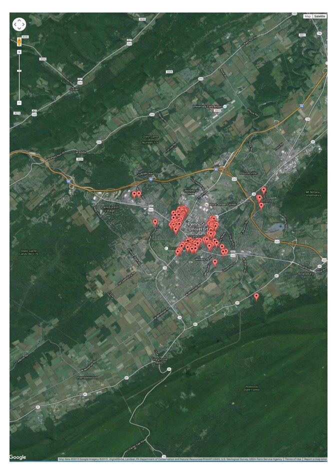

(i) 80-90 years

Figure 13: Building Age and Location