

## ALTERNATIVE APPROACHES TO COMMERCIAL PROPERTY PRICE INDEXES FOR TOKYO

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The paper studies the problems associated with the construction of price indexes for commercial properties that could be used in the System of National Accounts. Property price indexes are required for the stocks of commercial properties in the balance sheets and related price indexes for the land and structure components of a commercial property are required in the balance sheet accounts for the calculation of the Multifactor Productivity of the Commercial Property Industry. The paper uses a variant of the builder's model that has been used to construct Residential Property Price Indexes. Geometric depreciation rates are estimated for commercial offices in Tokyo using assessment data for REIT. The problems associated with the decomposition of property value into land and structure components are addressed. The problems associated with depreciating capital expenditures on buildings and with measuring the loss of asset value due to early retirement of the structure are also addressed.

**JEL Codes:** C2, C23, C43

**Keywords:** commercial property price indexes, System of National Accounts, balance sheets, methods of depreciation, land and structure price indexes

### I. INTRODUCTION

In this paper, we will use quarterly data on the performance of 50 Real Estate Income Trusts (REITs) that have single location commercial office buildings in Tokyo. The period covered is the first quarter of 2007 through the second quarter of 2012 or 22 quarters in all. We will make use of the quarterly assessed value information that is required for REIT properties and treat these end of quarter assessed property values as approximations to the beginning of the quarter market value of the properties. In addition to assessed value information, we also have information on the age of the building, the floor space area of the structure and the area of the land plot. We also have data on some other characteristics of the property but for this paper, we will only use information on assessed values, age of structure, floor space area, land space area and two other variables: quarterly capital

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expenditures on the property and an exogenous construction price index for the construction of new office buildings in Tokyo.

Our goal is to obtain not only an overall *commercial property price index* for this group of 50 properties but to have a decomposition of the overall index into structure and land components. This decomposition is required in order to construct industry balance sheets and to measure the Total Factor Productivity of a commercial building.

In section II, we briefly describe our data set.

In section III, we construct our first (overall) price index that requires only information on assessed or appraised values of the properties. This index is conceptually flawed because it does not take into account depreciation of the building or capital expenditures that have been made to the property. However, as we shall see, this very simple index does provide a useful approximation to a more accurate index.<sup>1</sup>

In section IV, we develop an overall price index and component subindexes for capital expenditures, the basic structure and the land area of the properties using the same type of techniques that national income accountants use to construct estimates of the capital stock. “Reasonable” assumptions about the form of structure depreciation are required in order to implement this method.

In section V, we try out the traditional approach to hedonic regressions where the logarithm of the selling price of a property is the dependent variable and the various characteristics of the property are used as explanatory variables. For our hedonic regressions, we use property assessed values in place of selling prices.

In sections VI and VII, we move away from the traditional hedonic regression approach and use assessed value as the dependent variable (in place of the logarithm of assessed value) and we are able to decompose overall value into separate land and structure components. In section VI, we use a geometric model of structure depreciation where there is only one constant over time depreciation rate that is estimated by the hedonic regression. In section VII, we generalize this model to allow for changing geometric depreciation rates as the building ages.

The models described in sections VI and VII provide a decomposition of the assessed value of a commercial property into the sum of a land plot value plus the value of the structure. However, our sample of properties includes only properties where the same structure continued to exist throughout the sample period. Our models capture the decline in structure value throughout the sample period but they do not capture the (unanticipated) depreciation of structures that are prematurely demolished during the sample period. This unanticipated decline in structure asset value needs to be estimated separately. In section VIII, we show how this can be done with the help of historical data on the demolition of commercial office structures in Japan.

Section IX concludes.

<sup>1</sup>This index is an assessed value counterpart to a repeat sales index, which also suffers from the same conceptual problems.

TABLE 1  
DESCRIPTIVE STATISTICS FOR THE VARIABLES

Name	No. of Obs.	Mean	Std. Dev	Minimum	Maximum
V	1100	4984.8	3417.8	984.3	18600.0
S	1100	5924.8	3568.1	2099.0	18552.0
L	1100	1106.3	718.2	294.5	3355.0
A	1100	83.9	25.2	16.7	156.7
CE	1100	6.08	11.94	0.06	85.49

## II. THE TOKYO REIT DATA

This paper uses published information on the Japanese Real Estate Investment Trust (REIT) market in the Tokyo area.<sup>2</sup> We used a balanced panel of observations on 50 REITs for 22 quarters, starting in Q1 of 2007 and ending in Q2 of 2012. The variables that were used in this paper were: V, the assessed or appraised value of the property;<sup>3</sup> CE, the quarterly capital expenditures made on the property during the quarter; L, the area of the land plot in square meters (m<sup>2</sup>); S, the total floor area of the structure in m<sup>2</sup> and A, the age of the structure in quarters. V and CE were reported in yen. In order to reduce the size of these variables, we divided by one million so the unit of measurement for these financial variables is in millions of yen. The basic descriptive statistics for the above variables are listed in Table 1.<sup>4</sup>

There were fairly high correlations between the V, S and L variables. The correlations of the appraised value V with structure and lot area S and L were 0.725 and 0.532 respectively and the correlation between S and L was 0.840. Given the large amount of variability in the data and the relatively high correlations between V, S and L, we can expect multicollinearity problems in a simple linear regression of V on S and L.<sup>5</sup>

In order to eliminate the multicollinearity problem between the lot size L and floor space area S for an individual REIT property when running hedonic regressions in later sections, we will assume that the value of a new structure in any quarter is proportional to a Construction Cost Price

<sup>2</sup>REIT data were supplied by MSCI-IPD, Japan. The authors thank Toshiro Nishioka and Hideaki Suzuki for their assistance.

<sup>3</sup>The REITs were chosen so that each REIT consisted of a single commercial property located somewhere in Tokyo. The appraised values are reported at the end of each quarter. However, the actual appraisals take place either during the quarter or the quarter prior to it. We will regard the published appraised values as approximations to the true market values of the property as of the beginning of the relevant quarter. The appraisals are made by professional appraisers who have incentives to make appraisals that are close to market values. However, there is evidence that appraised values will miss turning points in market values by a quarter or so; see Shimizu and Nishimura (2006) and Shimizu, Diewert, Nishimura and Watanabe (2013). Since our methodology requires beginning of the quarter asset values, these end of period appraised values will provide an adequate approximation to beginning of the quarter asset values.

<sup>4</sup>Additional variables were made available to us such as (quarterly) net operating income, property taxes, rentable floor space, number of basement floors, number of above ground floors and the distance to the Tokyo main station. We did not use these property characteristics in the present paper.

<sup>5</sup>See Diewert, de Haan and Hendriks (2011a,b) for evidence on this multicollinearity problem for house prices using Dutch data.

Index for Tokyo times its floor space area.<sup>6</sup> In order to approximate beginning of the quarter values for this construction cost index, we will lag the official index by one quarter. In section IV below, we also will require an estimate of construction cost per square meter for the first quarter in our sample. We obtained a starting value for construction cost at the beginning of our sample period from a commercial provider of data, Turner and Townsend (2012).<sup>7</sup>

### III. THE ASSET VALUE PRICE INDEX FOR COMMERCIAL PROPERTIES IN TOKYO

Denote the estimated asset value for REIT  $n$  during quarter  $t$  by  $V_{tn}$  for  $t = 1, \dots, 22$  and  $n = 1, \dots, 50$  where  $t = 1$  corresponds to the first quarter of 2007 and  $t = 22$  corresponds to the second quarter of 2012. If we ignore capital expenditures and depreciation of the structures on the properties, each property can be regarded as having a constant quality over the sample period.<sup>8</sup> Thus each property value at time  $t$  for REIT  $n$ ,  $V_{tn}$ , can be decomposed into a price component,  $P_{tn}$ , times a quantity component,  $Q_{tn}$ , which can be regarded as being constant over time. We can choose units of measurement so that each quantity is set equal to unity. Thus the price and quantity data for the 50 REITs has the following structure:  $Q_{tn} \equiv 1$ ;  $P_{tn} = V_{tn}$  for  $t = 1, \dots, 22$  and  $n = 1, \dots, 50$ . The *asset value price index* for period  $t$  for this group of REITs is the following Lowe (1823)<sup>9</sup> index:

$$(1) \quad P_A^t \equiv \frac{\sum_{n=1}^{50} P_{tn} Q_{tn}}{\sum_{n=1}^{50} P_{1n} Q_{1n}} = \frac{\sum_{n=1}^{50} V_{tn}}{\sum_{n=1}^{50} V_{1n}}; \quad t=1, \dots, 22.$$

Thus the asset value price index for period  $t$  is simply the total asset value for the 50 REITs in period  $t$  divided by the corresponding total asset value for sample period 1. The series  $P_A^t$  is graphed in Figure 1 in the following section and the series is listed in Table A1 in the Appendix.

This index is very much analogous to a *repeat sales index*,<sup>10</sup> except instead of using actual sales of properties, the index uses the appraised values for the properties that are supplied by professional assessors.

<sup>6</sup>This index, denoted as  $P_{SI}$  for quarter  $t$ , was constructed by the Construction Price Research Association which is now an independent agency but prior to 2012 was part of the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), a ministry of the Government of Japan. The quarterly values for this index are listed in Table A1 in the Appendix; see the listing for the variable  $P_S$ . The quarterly values were constructed from the Monthly Commercial Construction Cost index for Tokyo for reinforced concrete buildings.

<sup>7</sup>On page 20 of Turner and Townsend (2012), the 2011 construction cost for a prestige CBD office in Japan is listed as 303,800 yen per  $m^2$ . Since construction prices in 2011 were very close to construction prices in 2007, in section IV we will assume that the construction cost of a new commercial office was approximately 300,000 yen per  $m^2$  at the start of our sample period.

<sup>8</sup>We are also ignoring changes in the amenities around the property over the sample period.

<sup>9</sup>A Lowe index is a fixed basket price index where the quantity basket remains fixed over the sample period.

<sup>10</sup>The Repeat Sales Method for measuring property prices dates back to Bailey, Muth and Nourse (1963). See Shimizu, Nishimura and Watanabe (2010) for a comparison of the Repeat Sales Method and hedonic regression methods. Clapp and Giaccotto (1992) and Gatzlaff and Ling (1994) noted the structural similarity of an assessed value index to a repeat sales index in the housing context.

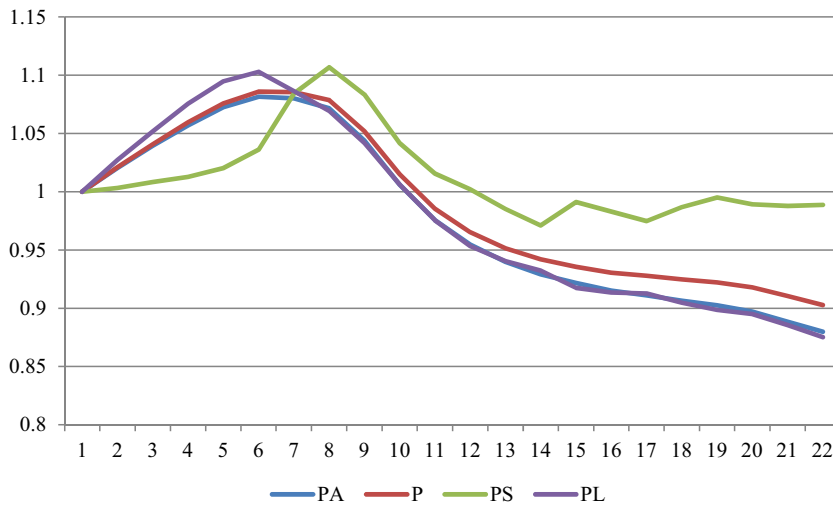


Figure 1. Asset Value Price Index  $P_A$  and Accounting Price Index  $P$ , Price of Structures  $P_S$  and Price Index for Land  $P_L$  [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

There are *three major problems* with the asset value price index:

1. The index relies on assessed values for the properties and there is some evidence that assessed values are smoother and lag behind indexes that are based strictly on sales at market values;<sup>11</sup>
2. The index does not take into account that *capital expenditures* will generally change the quality of each property over time (so that the  $Q_{tn}$  are not in fact constant) and
3. The index does not take into account *depreciation* of the underlying structure, which of course also changes the quality of each property.

The last problem mentioned above will generally impart a downward bias to the asset value indexes  $P_A^t$  defined in equation (1).<sup>12</sup> We cannot address the first problem mentioned above but in the following section, we will attempt to address problems 2 and 3 listed above.

#### IV. A NATIONAL BALANCE SHEET ACCOUNTING APPROACH TO THE CONSTRUCTION OF COMMERCIAL PROPERTY PRICE INDEXES

In this section, we will implement an approach to the construction of commercial property price indexes that is similar to the approach used by national income accountants to construct capital stock estimates.<sup>13</sup> National income accountants build up capital stock estimates for a production sector by deflating

<sup>11</sup>See for example, Shimizu and Nishimura (2006).

<sup>12</sup>Repeat sales price indexes are also subject to this downward bias due to the neglect of depreciation but this downward bias can often be negated by an upward bias due to sample selectivity problems associated with the repeat sales index. In any case, the repeat sales method is in general not very workable for the construction of a commercial property price index due to the infrequency of sales of commercial properties (and their heterogeneity).

<sup>13</sup>See Schreyer (2001, 2009) and Diewert (2005) for a detailed explanation of these techniques.

investments by asset and then adding up depreciated real investments made in prior periods. For commercial property capital expenditures and for the expenditures on the initial structure, we will more or less follow national income capital stock construction procedures. Next, we will assume that the assessed values for each property represents a good estimate for the total value of the structure and the land that the structure sits on. Once we have formed estimates for the stock values for capital expenditures and the value of the initial structure on the property, the value of land is set equal to assessed value of the property less our imputed value for the initial structure and the capital improvements made to the structure. The weakness in this approach is that one must make estimates for the structure depreciation rates based on limited information.

We postulate that the assessed asset value of REIT  $n$  in quarter  $t$ ,  $V_{tn}$ , is equal to the sum of three components:

- The *value of the land plot*  $V_{Ltn}$  for the property;
- The *value of the initial structure* on the property,  $V_{Stn}$ , and
- The *value of the cumulated (but also depreciated) capital expenditures* on the property made in prior periods,  $V_{CEtn}$ .

Thus we assume that the following asset value decomposition holds for property  $n$  in period  $t$ :<sup>14</sup>

$$(2) \quad V_{tn} = V_{Ltn} + V_{Stn} + V_{CEtn}; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22.$$

We know the assessed values,  $V_{tn}$ , on the left hand side of equation (2) and our strategy will be to determine the components of the values on the right hand side of equation (2) by making plausible assumptions about the prices and quantities involved in the right hand side values. We start off by considering the decomposition of the property land values,  $V_{Ltn}$ , into price and quantity components; i.e., we assume that the following equations hold:

$$(3) \quad V_{Ltn} = P_{Ltn}Q_{Ltn}; \quad Q_{Ltn} = L_{tn} = L_n; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22$$

where  $L_n$  (which is equal to  $L_{tn}$ ) is the area of the land plot for REIT  $n$ , which is part of our data base (and constant from period to period), and  $P_{Ltn}$  is the price of a square meter of land for REIT  $n$  in quarter  $t$  (which is not known yet).

Turn now to the value of the structure for property  $n$  in period  $t$ . If the structure is a new one, its value should be approximately equal to its cost of construction. Recall that an approximation to the cost of a square meter of new commercial property construction in quarter  $t$  is 300,000 times  $P_{St}S_{tn}$  where  $P_{St}$  is the construction price index per  $m^2$  for Tokyo for quarter  $t$  (normalized to equal one in quarter 1) and  $S_{tn} = S_n$  is the floor area for property  $n$  in period  $t$ . Upon noting that  $V_{tn}$  has been rescaled to units of million yen from a single yen, if the structure for REIT  $n$  is new in period  $t$ , then its value in millions of yen,  $V_{Stn}$ , should be approximately equal to  $0.3P_{St}S_{tn}$ . We now assume that the *quarterly geometric (or declining balance) depreciation rate* for the structure is  $\delta_S \equiv 0.005$  or

<sup>14</sup>This assumption is a strong one. In particular, we are assuming that capital expenditures immediately add to asset value, an assumption that is unlikely to hold precisely.

0.5 percent per quarter.<sup>15</sup> Thus the structure value for REIT  $n$  in quarter  $t$  (where the age of the structure in quarters at time  $t$  is  $A_{tn}$ ) should be approximately equal to:

$$(4) \quad V_{Stn} = 0.3P_{St}S_{tn}(1-\delta_S)^{A(t,n)}; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22$$

where  $A(t,n) \equiv A_{tn}$ . Thus we obtain the following decomposition of  $V_{Stn}$  into price and quantity components:

$$(5) \quad V_{Stn} = P_{Stn}Q_{Stn}; \quad P_{Stn} \equiv P_{St}; \quad Q_{Stn} \equiv 0.3S_{tn}(1-\delta_S)^{A(t,n)}; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22$$

where  $P_{St}$  is the known official construction price index for quarter  $t$  (lagged one quarter),  $S_{tn}$  is the known floor space for REIT  $n$  in quarter  $t$  (this is almost always constant across quarters),  $A(t,n)$  is the known age of REIT  $n$  in quarter  $t$  and  $\delta_S = 0.005$  is the assumed known quarterly geometric structure depreciation rate. Thus  $V_{Stn}$  can be calculated.

Finally, we need to determine the contribution of capital expenditures to REIT asset values. This is a more difficult task.<sup>16</sup> Define the capital expenditures of REIT  $n$  in quarter  $t$  as  $CE_{tn}$ . We need a deflator to convert these nominal expenditures into real expenditures. It is difficult to know precisely what the appropriate deflator should be. We will simply assume that the official structure price index,  $P_{St}$ , is a suitable deflator. Thus define *real capital expenditures* for REIT  $n$  in quarter  $t$ ,  $q_{CEtn}$ , as follows:

$$(6) \quad q_{CEtn} \equiv CE_{tn}/P_{St}; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22.$$

We know both series on the right hand side of equation (6) so the  $q_{CEtn}$  can also be determined. Now we require starting capital stocks for these capital expenditures and a geometric depreciation rate that determine how these capital expenditures are written off over time. It is difficult to determine an appropriate depreciation rate for capital expenditures since this problem has not been studied very extensively (if at all) in the literature. In section VII below, we will bring some limited econometric evidence to bear on this issue and using this evidence, we assume that the quarterly geometric depreciation rate for capital expenditures is  $\delta_{CE} = 0.10$  or 10 percent per

<sup>15</sup>Hulten and Wykoff (1981; 387) obtain annual geometric depreciation rates for office buildings in the U.S. around 1 percent for continuing structures and around 2.5 percent when premature retirement is taken into account. Other studies often obtain higher rates. Our later analysis in section VI below justifies our assumption of a 1/2 percent quarterly depreciation rate.

<sup>16</sup>Crosby, Devaney and Law acknowledge the importance of capital expenditures in explaining property value but they also point out the scarcity of research on this topic: "Other important issues are the roles of maintenance expenditure and replacement investment. . . . Thus, expenditure is central to interpreting depreciation rates but it has received little attention in much of the commercial real estate literature." Neil Crosby, Steven Devaney and Vicki Law (2012; p. 230).



quarter.<sup>17</sup> The next problem is the problem of determining the starting stock of capital expenditures for each REIT, given that we do not know what capital expenditures were before the sample period. We provide a solution to this problem in two stages. First, we generate *sample average real capital expenditures* for each REIT  $n$ ,  $q_{CEn}$ , as follows:

$$(7) \quad q_{CEn} \equiv \sum_{t=1}^{22} q_{CEtn}/22; \quad n = 1, \dots, 50.$$

Our next assumption is that each REIT  $n$  has a starting stock of capital expenditures equal to depreciated investments for 20 quarters (or five years) equal to the REIT  $n$  sample average investment,  $q_{CEn}$ , defined above by (7).<sup>18</sup> Thus the *starting stock of CE capital* for REIT  $n$  is  $Q_{CE1n}$  defined as follows:

$$(8) \quad Q_{CE1n} \equiv q_{CEn}[1-(1-\delta_{CE})^{21}]/\delta_{CE}; \quad n = 1, \dots, 50.$$

The REIT capital stocks for capital expenditures can be generated for quarters subsequent to quarter 1 using the usual geometric model of depreciation recommended by Hulten and Wykoff (1981), Jorgenson (1989) and Schreyer (2001, 2009) as follows:

$$(9) \quad Q_{CEtn} \equiv (1-\delta_{CE})Q_{CE,t-1,n} + q_{CE,t-1,n}; \quad t = 2, 3, \dots, 22; \quad n = 1, \dots, 50.$$

Note that  $Q_{CEtn}$  is now completely determined for  $t=1, \dots, 22$  and  $n = 1, \dots, 50$  and the corresponding price  $P_{St}$  is also determined. Thus an estimated value for the stock of capital expenditures of REIT  $n$  for the beginning of period  $t$ ,  $V_{CEtn}$ , can be determined by multiplying  $P_{St}$  by  $Q_{CEtn}$ ; i.e., we have:

$$(10) \quad V_{CEtn} \equiv P_{CEtn}Q_{CEtn}; \quad P_{CEtn} \equiv P_{St}; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50$$

where the  $Q_{CEtn}$  are defined by (8) and (9).

Now that the asset values  $V_{tn}$ ,  $V_{Stn}$  and  $V_{CEtn}$  have all been determined, the price of land for REIT  $n$  in quarter  $t$ ,  $P_{Ltn}$ , can be determined residually using equations (2) and (3):

$$(11) \quad P_{Ltn} \equiv [V_{tn} - V_{Stn} - V_{CEtn}]/L_n; \quad n = 1, \dots, 50; \quad t = 1, \dots, 22.$$

The above material shows how to construct estimates for the price of land, structures and capital expenditures for each REIT  $n$  for each quarter  $t$  ( $P_{Ltn}$ ,  $P_{Stn}$  and  $P_{CEtn}$ ) and the corresponding quantities ( $Q_{Ltn}$ ,  $Q_{Stn}$  and  $Q_{CEtn}$ ). Now use this price and quantity information in order to construct *quarterly value aggregates*

<sup>17</sup>After 20 quarters or five years, only 12 percent of an initial real investment in capital expenditures contributes to asset value; after 40 quarters or 10 years, only 1.5 percent of an initial real investment in capital expenditures contributes to asset value.

<sup>18</sup>The smallest age of structure in our sample is four years and so virtually all structures in our sample are at least five years old.



(over all 50 REITs in our sample) for the properties and for the land, structure and capital expenditure components; i.e., make the following definitions:<sup>19</sup>

$$V^t \equiv \sum_{n=1}^{50} V_{tn}; \quad V_L^t \equiv \sum_{n=1}^{50} V_{Ltn}; \quad V_S^t \equiv \sum_{n=1}^{50} V_{Stn}; \quad V_{CE}^t \equiv \sum_{n=1}^{50} V_{CEtn}; \quad t = 1, \dots, 22. \quad (12)$$

We form aggregate overall and component price and quantity indexes using chained Fisher (1922) ideal indexes.<sup>20</sup> In order to define these indexes, it is necessary to define Laspeyres and Paasche indexes and their chain link components. We will indicate how this is done when constructing aggregate land price indexes for the group of 50 REITs for each quarter. Define the *Laspeyres chain link land index* going from quarter  $t-1$  to quarter  $t$ ,  $P_{L, Land}^{t-1, t}$ , as follows:

$$(13) \quad P_{L, Land}^{t-1, t} \equiv \sum_{n=1}^{50} P_{Ltn} Q_{L, t-1, n} / \sum_{n=1}^{50} P_{L, t-1, n} Q_{L, t-1, n}; \quad t = 2, 3, \dots, 22.$$

The above chain links are used in order to define the *overall Laspeyres land price indexes*,  $P_{L, Land}^t$ , as follows:

$$(14) \quad P_{L, Land}^1 \equiv 1; \quad P_{L, Land}^t \equiv P_{L, Land}^{t-1} P_{L, Land}^{t-1, t}; \quad t = 2, 3, \dots, 22;$$

Thus the Laspeyres price index starts out at 1 in period 1 and then we form the index for the next period by updating the index for the previous period by the chain link indexes defined by (13). A similar procedure is used in order to define the sequence of *Paasche chained indexes* for land,  $P_{P, Land}^t$ . First define the *Paasche chain link land index* going from quarter  $t-1$  to quarter  $t$ ,  $P_{P, Land}^{t-1, t}$ , as follows:

$$(15) \quad P_{P, Land}^{t-1, t} \equiv \sum_{n=1}^{50} P_{Ltn} Q_{Ltn} / \sum_{n=1}^{50} P_{L, t-1, n} Q_{Ltn}; \quad t = 2, 3, \dots, 22.$$

The above chain links are used in order to define the overall Paasche land price indexes,  $P_{P, Land}^t$ , as follows:

$$(16) \quad P_{P, Land}^1 \equiv 1; \quad P_{P, Land}^t \equiv P_{P, Land}^{t-1} P_{P, Land}^{t-1, t}; \quad t = 2, 3, \dots, 22.$$

Once the sequences of Laspeyres and Paasche land price indexes,  $P_{L, Land}^t$  and  $P_{P, Land}^t$ , have been constructed, the *Fisher ideal land price index* for quarter  $t$ ,  $P_{F, Land}^t$ , is defined as the geometric mean of the corresponding Laspeyres and Paasche indexes; i.e., define

$$(17) \quad P_{F, Land}^t \equiv \left[ P_{L, Land}^t P_{P, Land}^t \right]^{1/2}; \quad t = 1, \dots, 22.$$

<sup>19</sup>These aggregate value series are listed in the Appendix in Table A1.

<sup>20</sup>Laspeyres, Paasche and Fisher indexes are explained in much more detail in Fisher (1922) and in the 2004 *Consumer Price Index Manual*. The Fisher indexes have very good axiomatic and economic properties.

The Fisher chained price indexes for structures and capital expenditures,  $P_{F,S}^t$  and  $P_{F,CE}^t$ , are constructed in an entirely analogous way, except that the REIT micro price and quantity data on land,  $P_{Ltn}$  and  $Q_{Ltn}$ , are replaced by the corresponding REIT micro price and quantity data on structures,  $P_{Stn}$  and  $Q_{Stn}$ , or on capital expenditures,  $P_{CEtn}$  and  $Q_{CEtn}$ , in equations (13)–(17).

Finally, an *overall chained Fisher property price index*,  $P_F^t$ , can be constructed in the same way except that the summations in the numerators and denominators of (13) and (15) above sum over 150 separate price components (all of the  $P_{Ltn}$ ,  $P_{Stn}$  and  $P_{CEtn}$ ) instead of just 50 price components. The Fisher price indexes  $P_F^t$ ,  $P_{F,Land}^t$ ,  $P_{F,S}^t$ , and  $P_{F,CE}^t$  are listed in Table A1 in the Appendix, except that we dropped the subscript F; i.e., in what follows, denote these series by  $P^t$ ,  $P_L^t$ ,  $P_S^t$ , and  $P_{CE}^t$  respectively.

The price series  $P^t$ ,  $P_L^t$ ,  $P_S^t$ , and  $P_{CE}^t$  can be used to deflate the corresponding aggregate value series defined above by (12),  $V^t$ ,  $V_L^t$ ,  $V_S^t$ , and  $V_{CE}^t$ , in order to form *implicit quantity or volume indexes*; i.e., define the following aggregate quantity indexes:

$$Q^t \equiv V^t/P^t; \quad Q_L^t \equiv V_L^t/P_L^t; \quad Q_S^t \equiv V_S^t/P_S^t; \quad Q_{CE}^t \equiv V_{CE}^t/P_{CE}^t; \quad t = 1, \dots, 22. \tag{18}$$

$Q^t$  can be interpreted as an estimate of the real stock of assets across all 50 REITs at the beginning of quarter  $t$ ,  $Q_L^t$  is an estimate of the aggregate real land stock used by the REITs<sup>21</sup> and  $Q_{CE}^t$  is an estimate of the real stock of capital improvements made by the REITs since they were constructed.<sup>22</sup>

Because the price of structures for each REIT is proportional to the exogenous official construction price index for Tokyo, the aggregate structure price index,  $P_S^t$ , defined above as a Fisher index turns out to equal the official price index,  $P_{St}$  defined earlier.<sup>23</sup> Similarly, the Fisher price index of capital expenditures,  $P_{CE}^t$ , defined above also turns out to equal the official index,  $P_{St}$ . Thus the fairly complicated construction of the Fisher implicit quantity indexes that was explained above can be replaced by the following very simple shortcut equations:

$$Q_S^t = V_S^t/P_{St}; \quad Q_{CE}^t = V_{CE}^t/P_{St}; \quad t = 1, \dots, 22. \tag{19}$$

The asset value (or repeat sales) overall price index,  $P_A^t$ , is graphed in Figure 1 above along with the overall commercial property price index  $P^t$ , where the method used to construct  $P^t$  might be termed a “national accounts” method for constructing a capital stock price index. We also show the “national accounts” land price index  $P_L^t$  and the official structures construction cost price index  $P_S^t$

<sup>21</sup>This remains constant over time since the quantity of land used by each REIT remained constant over time.

<sup>22</sup>The four implicit quantity series defined by (18) are also listed in Table A1 of the Appendix.

<sup>23</sup>The chained Laspeyres and Paasche price indexes for structures are also equal to the official index (and so are the corresponding fixed base indexes). Since the quantity of land is fixed for each REIT, the chained (and fixed base) Laspeyres and Paasche land price indexes are also equal to the chained Fisher land price indexes.

which we have used as a price deflator for both capital expenditures and the estimated value of the structure.<sup>24</sup>

It can be seen that the asset value price index  $P_A^t$  defined in the previous section is consistently below the more accurate economic accounting index  $P^t$  and the gap widens over time.<sup>25</sup> In our Japanese sample of commercial properties, our estimated average land value divided by total property value turned out to be 74.7 percent; i.e., approximately 75 percent of the property value is due to land value. In the U.S., the land to property value ratio is very much less so that the bias in the asset value price index would be correspondingly much larger since it is the neglect of structure depreciation that causes the differences in  $P^t$  and  $P_A^t$ .<sup>26</sup> The movements in the price of structures,  $P_S^t$ , versus the price of land,  $P_L^t$ , are also of some interest. It appears that land prices peaked in period 6 (Q2-2008) while construction prices peaked somewhat later in period 8 (Q4-2008). Land prices continued to fall steadily after Q2-2008, ending up at 0.8752. Structure prices fell from Q8-2008 until Q2-2010 and remained more or less steady until the end of the sample period to end up at 0.9887.

In the following sections, we will construct alternative price indexes using hedonic regression techniques rather than using assumptions about depreciation rates (and the form of depreciation) along with assessed value information.

## V. TRADITIONAL HEDONIC REGRESSION APPROACHES TO INDEX CONSTRUCTION

Most hedonic commercial property regression models are based on the *time dummy approach* where the log of the selling price of the property is regressed on either a linear function of the characteristics or on the logs of the characteristics of the property along with time dummy variables.<sup>27</sup> In this section, instead of using selling prices for commercial properties, we will use the quarterly assessed values for the properties. The time dummy method does not generate decompositions of the asset value into land and structure components and so it is not suitable when such decompositions are required but the time dummy method can be used to generate overall property price indexes, which can then be compared with the overall price indexes  $P_A^t$  and  $P^t$  that were described in the previous two sections.

Recall that  $V_{tn}$  is the assessed value for REIT  $n$  in quarter  $t$ ,  $L_{tn} = L_n$  is the area of the plot,  $S_{tn} = S_n$  is the floor space area of the structure and  $A_{tn}$  is the age of the structure for REIT  $n$  in period  $t$ . In the time dummy linear regression defined below by (20), we have replaced  $V_{tn}$ ,  $L_{tn}$  and  $S_{tn}$  by their logarithms,

<sup>24</sup> $P_A^t$ ,  $P^t$ ,  $P_S^t$ , and  $P_L^t$  are listed as PA, P, PS and PL in Figure 1.

<sup>25</sup>From Table A1 in the Appendix, we see that  $P_A^{22} = 0.8798$  and  $P^{22} = 0.9027$ . This translates into an approximate (geometric) downward bias in the asset value price index of about 0.5 percentage points per year, which is fairly significant.

<sup>26</sup>Since the asset value price index is a variant of the repeat sales index that is frequently used to construct property price indexes, we expect that these repeat sales indexes also have substantial downward biases compared to indexes that take structure depreciation into account.

<sup>27</sup>This methodology was developed by Court (1939; 109–111) as his Hedonic Suggestion Number Two.

$\ln V_{tn}$ ,  $\ln L_{tn}$  and  $\ln S_{tn}$ .<sup>28</sup> Our first time dummy hedonic regression model is defined for  $t = 1, \dots, 22$  and  $n = 1, \dots, 50$  by the following equations:<sup>29</sup>

$$(20) \quad \ln V_{tn} = \alpha + \alpha_t + \beta \ln L_{tn} + \gamma \ln S_{tn} + \delta A_{tn} + \varepsilon_{tn}$$

where  $\alpha_1, \dots, \alpha_{22}$ ,  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$  are 26 unknown parameters to be estimated and the  $\varepsilon_{tn}$  are independently distributed normal error terms with mean 0 and constant variance. The  $\alpha_t$  are the quarter  $t$  time coefficients which shift the hedonic surface during each quarter,  $\alpha$  is a constant term,  $\gamma$  and  $\beta$  are parameters which adjust the asset value for the size of the lot and the floor space area respectively and  $\delta$  is a parameter which adjusts the asset value for the age of the structure (essentially a depreciation parameter). We expect  $\beta$  and  $\gamma$  to be positive and  $\delta$  to be negative. The time dummy variables associated with the  $\alpha_t$  and the constant term  $\alpha$  are linearly dependent and so we need to impose a normalization on the parameters in order to identify the remaining parameters. We choose the following normalization:

$$(21) \quad \alpha_1 = 0.$$

This normalization makes the overall commercial property price index equal to 1 in the first period.

The ordinary least squares estimates for the 25 remaining parameters in Model 1 are listed in Table A2 of the Appendix. For later reference, we note that the log likelihood for Model 1 was  $-583.955$  and the (pseudo)  $R^2$  (the square of the correlation coefficient between the dependent variable and the corresponding predicted variable) was  $0.6339$ . The estimated coefficient associated with the log of land area was  $\beta = -0.1713$  (which is the wrong sign for this parameter) while the coefficient for the log of the structure area was  $\gamma = 1.1264$  with a  $t$  statistic equal to  $25.9$ . The estimated age coefficient was  $\delta = 0.0020$ , which is also the wrong sign for this parameter ( $t$  statistic equal to  $3.9$ ). The results for Model 1 were not very encouraging.

The overall commercial property price indexes for Model 1,  $P_1^t$ , are defined as the exponentials of the estimated time coefficients  $\alpha_t$ :

$$(22) \quad P_1^t \equiv \exp[\alpha_t]; \quad t=1, \dots, 22,$$

The resulting overall commercial property price indexes generated by Hedonic Model 1, the  $P_1^t$ , are graphed in Figure 2 below and are listed in Table A4 of the Appendix. We will discuss these estimated price indexes after we have presented the results for our second “traditional” hedonic regression model.

Our second time dummy hedonic regression model is defined for  $t = 1, \dots, 22$  and  $n = 1, \dots, 50$  by the following equations which introduce a dummy variable  $\omega_n$  for each property  $n$ :

$$(23) \quad \ln V_{tn} = \alpha + \alpha_t + \beta \ln L_{tn} + \gamma \ln S_{tn} + \delta A_{tn} + \omega_n + \varepsilon_{tn}$$

<sup>28</sup>This led to a better fitting regression model based on a higher pseudo  $R^2$ .

<sup>29</sup>The hedonic regression models defined by (20) and (23) can be set up as linear regression models by defining suitable dummy variables for the  $\alpha_t$  and  $\omega_n$  parameters that appear in these equations.

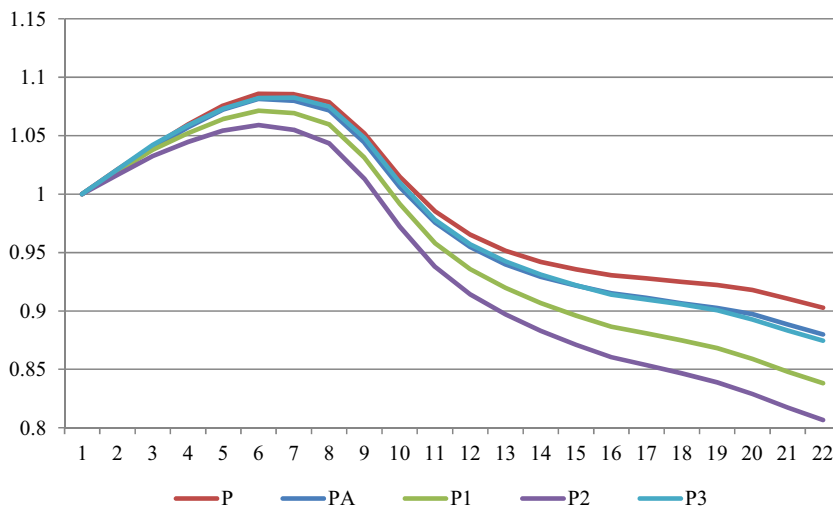


Figure 2. Accounting Price Index P, Asset Value Price Index P<sub>A</sub> and Hedonic Price Indexes P<sub>1</sub>, P<sub>2</sub> and P<sub>3</sub> [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

where  $\alpha_1, \dots, \alpha_{22}, \omega_1, \dots, \omega_{50}, \alpha, \beta, \gamma$  and  $\delta$  are 76 unknown parameters to be estimated and the  $\varepsilon_{tn}$  are independently distributed normal error terms with mean 0 and constant variance. The linear regression model defined by equations (23) is the same as the model defined by equations (20) except that we have now added 50 additional property dummy variables where  $\omega_n$  is the parameter which shifts the hedonic surface when the dependent variable is the logarithm of property value for property n. It is well known that not all parameters can be identified in this model. Since  $L_{tn} = L_n$  and  $S_{tn} = S_n$  (so that the floor area and land areas of each REIT in our sample are constant over our sample period), it can be seen that the effects of the  $\beta \ln L_{tn}$  and  $\gamma \ln S_{tn}$  terms in (23) can be absorbed into the REIT specific parameters  $\omega_n$ . Thus we set  $\beta = \gamma = 0$ . As was the case with (20), the dummy variables associated with the  $\alpha_t$  and the constant term  $\alpha$  are also linearly dependent, so as before, we set  $\alpha_1 = 0$ . However, the dummy variables associated with  $\alpha, \alpha_2, \dots, \alpha_{22}$  when combined with the dummy variables associated with  $\omega_1, \dots, \omega_{50}$  are also linearly dependent so to eliminate this linear dependence, we set  $\alpha = 0$ . Finally, it turns out that the age variable  $A_{tn}$  is also linearly dependent on the dummy variables associated with  $\alpha_2, \dots, \alpha_{22}$  and  $\omega_1, \dots, \omega_{50}$ . In order to eliminate this linear dependence in the regression model, we could set  $\delta = 0$ . However, if we replace  $A_{tn}$  by the logarithm of  $A_{tn}$ , this leads to a regression model where all of the parameters are identified. Thus our *second linear regression model* is the following one which has 72 independent parameters:<sup>30</sup>

$$(24) \quad \ln V_{tn} = \alpha_t + \omega_n + \delta \ln A_{tn} + \varepsilon_{tn}; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50.$$

Equations (24) and (21) define Hedonic Model 2. The  $\alpha_t$  parameters explain how, on average, the property values of the REIT sample shift over time and the

<sup>30</sup>We still impose the normalization (21) on the parameters in (24); i.e., we set  $\alpha_1 = 0$ .

REIT specific parameters, the  $\omega_n$ , reflect the effect on REIT value of the size of the structure and the size of the land plot as well as any locational characteristics that can be attributed to each REIT. The  $\delta$  parameter reflects the effects of aging of the structure on property value (we would expect this parameter to be negative: the value of the structure should decline as it ages).<sup>31</sup>

The ordinary least squares estimates for the 72 parameters in Model 2 are listed in Table A3 of the Appendix. The log likelihood for Model 2 was 1687.33, a massive increase from the Model 1 log likelihood which was  $-583.955$ . The Model 2 pseudo  $R^2$  between the dependent variable and the corresponding predicted variable was 0.9941, a big increase over the Model 1  $R^2$  which was 0.6339. The estimated coefficients for Model 2 have relatively small standard errors and high statistics. However the estimated age coefficient for this model was a huge  $\delta = 0.2896$  (with a standard error of 0.0476 and t statistic equal to 6.1), which is the wrong sign for this parameter.

The *overall commercial property price indexes* for Model 2,  $P_2^t$ , were defined as the exponentials of the estimated time coefficients  $\alpha_t^*$ :

$$(25) \quad P_2^t \equiv \exp[\alpha_t^*]; \quad t=1, \dots, 22.$$

The  $P_2^t$ , are graphed in Figure 2 above and are listed in Table A4 of the Appendix.

From viewing Figure 2, it can be seen that our accounting based overall commercial property price index,  $P^t$ , shows the least amount of deflation over the sample period, ending up at an index value of 0.9027. The simple asset value price index,  $P_A^t$ , lies below  $P^t$ , ending up at 0.8798. Our first traditional log value hedonic regression model generated the index  $P_1^t$  which ended up at 0.8382 while the second model  $P_2^t$  ended up even lower at 0.8066. These large downward biases for Models 1 and 2 are due to the fact that the estimated coefficient  $\delta$  for the age variable was positive in both regressions rather than the expected negative coefficients; i.e., as the structure ages, other factors held constant, we would expect asset value to fall. Thus Models 1 and 2 do not perform well for our particular application.

It is of interest to rerun Model 2 after setting the age parameter  $\delta$  equal to 0, which results in Model 3. It turns out that Model 3 is identical to the *Country Product Dummy regression model* that was originally introduced by Summers (1973) in the context of making international comparisons between countries.<sup>32</sup> The  $R^2$  for Model 3 turned out to be 0.9939 and the log likelihood was 1667.89, a drop of about 20 from the previous Model 2. We constructed the resulting Commercial Property Price index  $P_3^t$  in the usual way (use the counterparts to equations (23) above).<sup>33</sup> The index values for  $P_3^t$  are listed in Table A4 and the series is graphed on Figure 2 above.

<sup>31</sup>The problem is that the parameter  $\delta$  will be an imperfect indicator of the effects of structure aging, due to the fact that the age variable (before transformation) will be subject to a multicollinearity problem in our original specification. We attempt to solve this problem by taking a nonlinear transform of the age variable in order to negate the exact multicollinearity but this solution does not really solve the problem.

<sup>32</sup>In the original Country Product Dummy (CPD) model, the two categories were countries and commodities. In our present context, the two categories are REITs and time. In the time series context, the CPD model also has an application as the Time Product Dummy (TPD) model.

<sup>33</sup>We did not list the coefficient estimates in the Appendix for Model 3.

It can be seen that  $P_3^t$  is virtually identical to the asset value series  $P_A^t$ . This is perhaps not too surprising since the two indexes simply aggregate up the individual REIT asset prices into an overall price index; the form of aggregation is somewhat different but the basic ingredients are the same. Of course, the problem with both  $P_A^t$  and  $P_3^t$  is that they make no allowance for structure depreciation (or for capital expenditures) and thus both of these indexes will generally have a downward bias relative to an index that takes structure depreciation into account.

There are two major problems with traditional log value hedonic regression models applied to property prices:

- These models often do not generate reasonable estimates for structure depreciation, and
- These models essentially allow for only *one factor* that shifts the hedonic regression surface over time (the  $\alpha_t$ ) when in fact, there are generally *two major shift factors*: the price of structures and the price of land. Unless these two price factors move in a proportional manner over time, the usual hedonic approach will not generate accurate overall price indexes.

In the following section, we will estimate two alternative hedonic regression models that will address the above two difficulties.

## VI. THE BUILDER'S MODEL APPLIED TO COMMERCIAL PROPERTY ASSESSED VALUES

The *builder's model* for valuing a commercial property postulates that the value of a commercial property is the sum of two components: the value of the land on which the structure sits plus the value of the commercial structure.<sup>34</sup>

In order to justify the model, consider a property developer  $n$  who builds a structure on a particular property that is ready for commercial use at the beginning of quarter  $t$ . The total cost of the property after the structure is completed will be equal to the floor space area of the structure, say  $S_{tn}$  square meters, times the building cost per square meter,  $\beta_t$  say, plus the cost of the land, which will be equal to the land cost per square meter,  $\gamma_{tn}$  say, times the area of the land site,  $L_{tn}$ . Thus if REIT  $n$  has a new structure on it at the start of quarter  $t$ , the value of the property,  $V_{tn}$ , should be equal to the sum of the structure and land value,  $\beta_t S_{tn} + \gamma_{tn} L_{tn}$ .<sup>35</sup> Note that as in section 3 above, we assume that the building cost price  $\beta_t$  depends on time only and not on the location of the building. On the other hand, the property prices  $\gamma_{tn}$  will generally depend on both the time period  $t$  and the location of the property which is indexed by  $n$ .

<sup>34</sup>This model has been applied to residential property sales by de Haan and Diewert (2011), Diewert, de Haan and Hendriks (2011a) (2011b) and Diewert and Shimizu (2015) except that straight line or piecewise linear depreciation was used as the depreciation model for the structure whereas in the present paper, we will use geometric depreciation models. In the following section, we will estimate a more complex geometric depreciation model where the depreciation rates change as the building ages. Geometric depreciation models have the advantage that the implied structure asset values that the models generate always remain positive whereas piece-wise linear depreciation models can generate negative asset values.

<sup>35</sup>Other papers that have suggested hedonic regression models that lead to additive decompositions of property values into land and structure components include Clapp (1980), Francke and Vos (2004), Gyourko and Saiz (2004), Bostic, Longhofer and Redfearn (2007), Davis and Heathcote (2007), Francke (2008), Koev and Santos Silva (2008), Statistics Portugal (2009), Diewert (2010, 2011) and Rambaldi, McAllister, Collins and Fletcher (2010).



The above model applies to new structures. But it is likely that a similar model applies to older structures as well. Older structures will be worth less than newer structures due to the depreciation of the structure. Assuming that we have information on the age of the structure  $n$  at time  $t$ , say  $A_{tn} \equiv A(t,n)$  and assuming a *geometric depreciation model*, a more realistic hedonic regression model is the following *basic builder's model*:

$$(26) \quad V_{tn} = \beta_t S_{tn} [e^\phi]^{A(t,n)} + \gamma_{tn} L_{tn} + \varepsilon_{tn}; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50$$

where the parameter  $e^\phi$  is defined to be  $1 - \delta$  and  $\delta$  in turn is defined as the quarterly depreciation rate for the structure.<sup>36</sup> Note that (26) is now a nonlinear regression model (whereas all of the regression models in the previous section were linear in the unknown parameters).<sup>37</sup> There are two problems with the model defined by (26):

- We have only 22 times 50 observations (1100 observations in all) on  $V$  but there are 1100 land price parameters  $\gamma_{tn}$  to be estimated,
- The above model does not take into account the capital expenditures that were made in order to improve the structure after its initial construction.

We deal with the second problem by subtracting our section III estimated period  $t$  capitalized value of capital expenditures estimate  $V_{CEtn}$  from total asset value  $V_{tn}$  in order to obtain a new dependent variable. Then we will use a hedonic regression to decompose  $V_{tn} - V_{CEtn}$  into structure and land components. We deal with the first problem by applying the Country Product Dummy methodology to the land component on the right hand side of equations (26) above; i.e., we set

$$(27) \quad \gamma_{tn} = \alpha_t \omega_n; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50.$$

We also set the new structure prices for each quarter  $t$ ,  $\beta_t$ , equal to a single price of structure in quarter 1, say  $\beta$ , times our official construction cost index  $P_S^t$  described in earlier sections. Thus we have:

$$(28) \quad \beta_t = \beta P_S^t; \quad t = 1, \dots, 22.$$

Replacing  $V_{tn}$  by  $V_{tn} - V_{CEtn}$  and substituting (27) and (28) into equations (26) leads to the following nonlinear regression model:

$$(29) \quad V_{tn} - V_{CEtn} = \beta P_S^t S_{tn} [e^\phi]^{A(t,n)} + \alpha_t \omega_n L_{tn} + \varepsilon_{tn}; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50.$$

This nonlinear regression has one unknown structure price  $\beta$ , one unknown  $\phi$  (where  $\delta = 1 - e^\phi$  and  $\delta$  is the quarterly geometric depreciation rate), 22 unknown  $\alpha_t$  (the overall land price series for our sample) and 50 unknown  $\omega_n$  (which reflect the relative discount or premium in the land price for REIT  $n$

<sup>36</sup>Note that  $\delta = 1 - e^\phi$ .

<sup>37</sup>We used the nonlinear option in Shazam to estimate the nonlinear regressions in this section and the OLS option to estimate the linear regressions in the previous section; see White (2004).

relative to other REITs). This is a total of 74 parameters but not all of the  $\alpha_t$  and  $\omega_n$  can be identified so we impose the normalization (21),  $\alpha_1 = 1$ . Thus there are 73 independent parameters to be estimated with 1100 degrees of freedom.

Shazam had no trouble estimating the unknown parameters.<sup>38</sup> At first glance, the results appeared to be satisfactory. The pseudo  $R^2$  between the observed variables and the predicted variables turned out to be 0.9943 and the log likelihood was  $-7658.84$ . The estimated  $\phi$  parameter turned out to be  $-0.00454$  and the corresponding quarterly depreciation rate was 0.00453, which is very close to our assumed rate of 0.005 that was used in section III. The land price series (the estimated  $\alpha_t$  ended up at  $\alpha_{22} = 0.8754$ ) turned out to be very similar to our accounting generated land price series  $P_L^t$  listed in Table A1 (which ended up at  $P_L^{22} = 0.8752$ ). However, the estimated  $\beta$  coefficient turned out to be 0.1524, which is far below our estimated cost of construction for the first period in our sample which is around 0.3. Thus we decided to set  $\beta$  equal to 0.3 and rerun the nonlinear regression model defined by equations (29) (and  $\alpha_1 = 1$ ). Call the resulting hedonic regression model, *Model 4*. The  $R^2$  between the observed variable and the predicted variable for this model turned out to be 0.9943 and the log likelihood was  $-7659.58$ , a very small drop in log likelihood of about 1.2 points due to the fact that we now set  $\beta = 0.3$  rather than estimate it as in the previous regression. Thus the cost in terms of fit and log likelihood of imposing this parameter constraint appears to be small. The estimated  $\phi$  parameter turned out to be  $-0.00515$  and the corresponding quarterly depreciation rate was 0.00514, which is very close to our assumed rate of 0.005 that was used in section III. The land price series for Model 4 is denoted by  $P_{L4}^t \equiv \alpha_t^*$  and it is graphed in Figure 3 below and listed in Table A4 in the Appendix. The Model 4 land prices turned out to be very similar to our accounting generated land price series  $P_L^t$  listed in Table A1.

We need to explain how our new land price series  $P_{L4}^t$  can be combined with our structures (and capital expenditures) price series  $P_S^t$ . Denote the estimated Model 4 parameters as  $\beta^*, \alpha_1^* \equiv 1, \alpha_2^*, \dots, \alpha_{22}^*, \phi^*$  and  $\omega_1^*, \dots, \omega_{50}^*$ . We can break up the fitted value on the right hand side of equation (29) for observation  $tn$  into a *fitted structures component*,  $V_{S4tn}^*$ , and a *fitted land component*,  $V_{L4tn}^*$ , for  $n = 1, \dots, 50$  and  $t = 1, \dots, 22$  as follows:

$$(30) \quad V_{S4tn}^* \equiv \beta^* P_S^t S_{tn} [e^{\phi^*}]^{A(t,n)};$$

$$(31) \quad V_{L4tn}^* \equiv \alpha_t^* \omega_n^* L_{tn}.$$

Now form structures and capital expenditures aggregate (over all REITs),  $V_{S4tn}^*$ , by adding up the fitted structure values  $V_{S4tn}^*$  defined by (30) and the capital expenditures capital stocks  $V_{CEtn}$  that were defined by equations (10) in section 4 for each quarter:

$$(32) \quad V_{S4t}^* \equiv \sum_{n=1}^{50} [V_{S4tn}^* + V_{CEtn}]; \quad t = 1, \dots, 22.$$

<sup>38</sup>It was necessary to define two sets of dummy variables (one set of dummy variables for the time periods and one set for the REITs) and then interact these dummy variables in order to set up the nonlinear regression. This was a straightforward exercise.

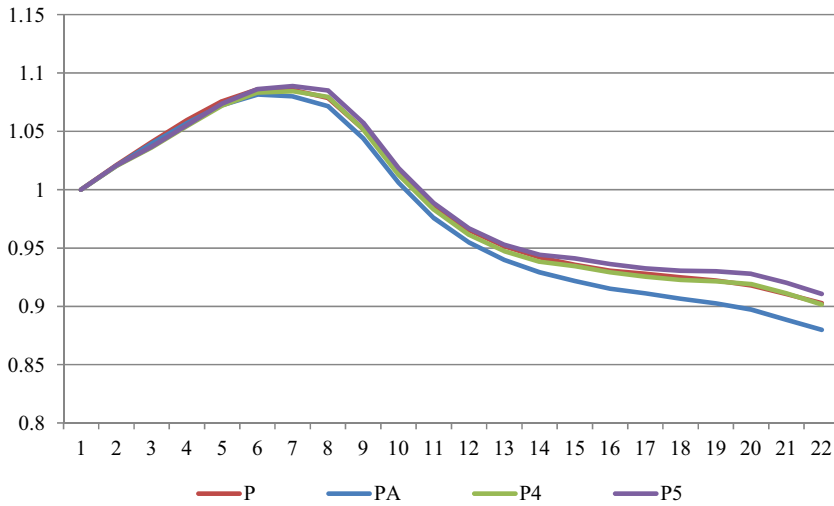


Figure 3. Accounting Method Price Index P, Asset Value Index P<sub>A</sub> Builder's Model Price Indexes P<sub>4</sub> and P<sub>5</sub> [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

In a similar fashion, form a land value aggregate (over all REITs),  $V_{L4t}^*$ , by adding up the fitted land values  $V_{L4tn}^*$  defined by (31) for each quarter t:

$$(33) \quad V_{L4t}^* \equiv \sum_{n=1}^{50} V_{L4tn}^*; \quad t = 1, \dots, 22.$$

Now define the *period t aggregate structure* (including capital expenditures) *quantity* or volume,  $Q_{S4t}^*$ , by (34) and the *period t aggregate land quantity* or volume,  $Q_{L4t}^*$ , by (35):

$$(34) \quad Q_{S4t}^* \equiv V_{S4t}^*/P_S^t; \quad t = 1, \dots, 22;$$

$$(35) \quad Q_{L4t}^* \equiv V_{L4t}^*/P_{L4}^t; \quad t = 1, \dots, 22.$$

Thus for each period t, we have two prices,  $P_S^t$  and  $P_{L4}^t$ , and the corresponding two quantities,  $Q_{S4t}^*$  and  $Q_{L4t}^*$ . We form an overall commercial property price index,  $P_4^t$ , by calculating the chained Fisher price index of these two price components.<sup>39</sup> This overall index  $P_4^t$  is graphed in Figure 3 above along with our accounting method overall index  $P^t$  and the asset value price index,  $P_A^t$ .

<sup>39</sup>Our method for aggregating over REITs can be viewed as an application of Hicks' Aggregation Theorem; i.e., if the prices in a group of commodities vary in strict proportion over time, then the factor of proportionality can be taken as the price of the group and the deflated group expenditures will obey the usual properties of a microeconomic commodity. "Thus we have demonstrated mathematically the very important principle, used extensively in the text, that if the prices of a group of goods change in the same proportion, that group of goods behaves just as if it were a single commodity" J. R. Hicks (1946; 312–313). Our REIT structure (and capital expenditure) prices move in a proportional manner over time for all REITs, where each REITs' structure prices are proportional to the exogenous construction price index. Our REIT land prices also move in a manner that is proportional to the movements in the  $\alpha_t$  because we have forced this movement by our choice of functional form in the regression model.

From Figure 3, it can be seen that our accounting method overall commercial property price index series,  $P^t$ , is extremely close to the builder's model hedonic regression approach index  $P_4^t$  that was just explained in this section. The geometric depreciation rate for capital expenditures is exactly the same (10 percent per quarter by assumption) in both models and the geometric depreciation rates for the main structure are almost identical in both models but the method of land price aggregation is different in the two approaches so the close correspondence between the two methods is a bit surprising. The asset value price index,  $P_A^t$ , lies well below  $P^t$  and  $P_4^t$  and the price index  $P_5^t$  lies a bit above  $P^t$  and  $P_4^t$ . The index  $P_5^t$  will be explained in the following section.

### VII. THE BUILDER'S MODEL WITH GEOMETRIC DEPRECIATION RATES THAT DEPEND ON THE AGE OF THE STRUCTURE

The age of the structures in our sample of Tokyo commercial office buildings ranges from about four years to 40 years. One might question whether the quarterly geometric depreciation rate does not change as the structure on the property ages. Thus in this section, we experimented with a model that allowed for different rates of geometric depreciation every 10 years. However, we found that there were not enough observations of "young" buildings to accurately determine separate depreciation rates for the first and second age groups so we divided observations up into three groups where the change in the depreciation rates occurred at ages (in quarters) 80 and 120, observations where the building was 0 to 80 quarters old, 80 to 120 quarters old and over 120 quarters old. Thus we found that 550 observations fell into the interval  $0 \leq A_{tn} \leq 80$ , 424 observations fell into the interval  $80 < A_{tn} \leq 120$  and 126 observations fell into the interval  $120 < A_{tn} \leq 160$ . We label the three sets of observations that fall into the above three groups as groups 1–3. For each observation  $n$  in period  $t$ , we define the three *age dummy variables*,  $D_{tnm}$ , for  $m = 1, 2, 3$  as follows:<sup>40</sup>

$$\begin{aligned}
 D_{tnm} &\equiv 1 \text{ if observation } tn \text{ has a building whose age belongs to group } m, \\
 &\equiv 0 \text{ if observation } tn \text{ has a building whose age is } \textit{not} \text{ in group } m.
 \end{aligned}
 \tag{36}$$

These dummy variables are used in the definition of the following function of age  $A_{tn}$ ,  $g(A_{tn})$ , defined as follows where the break points,  $A_1$  and  $A_2$ , are defined as  $A_1 \equiv 80$  and  $A_2 \equiv 120$ :

$$\begin{aligned}
 g(A_{tn}) &\equiv \exp\{D_{tn1}\phi_1 A_{tn} + D_{tn2}[\phi_1 A_1 + \phi_2(A_{tn} - A_1)] \\
 &\quad + D_{tn3}[\phi_1 A_1 + \phi_2(A_2 - A_1) + \phi_3(A_{tn} - A_2)]\}
 \end{aligned}
 \tag{37}$$

<sup>40</sup>Note that for each observation, the Age dummy variables sum to one; i.e., for each  $tn$ ,  $D_{tn1} + D_{tn2} + D_{tn3} = 1$ .

where  $\phi_1$ ,  $\phi_2$  and  $\phi_3$  are parameters to be estimated. As in the previous section, each  $\phi_i$  can be converted into a depreciation rate  $\delta_i$  where the  $\delta_i$  are defined as follows:

$$(38) \quad \delta_i \equiv 1 - \exp[\phi_i]; \quad i = 1, 2, 3.$$

Note that the logarithm of  $g(A)$  is a piecewise linear function of the variable  $A$ . The economic meaning of all of this is as follows: for the first 80 quarters of a building's life, the constant price quantity of the structure declines at the quarterly geometric rate  $(1 - \delta_1)$ . Then for the next 40 quarters, the quarterly geometric rate of depreciation switches to  $(1 - \delta_2)$ . Finally after 120 quarters, the quarterly geometric rate of depreciation switches to  $(1 - \delta_3)$ .

Now we are ready to define our new nonlinear regression model that generalizes the model defined by (29) and (21) in the previous section. *Model 5* is the following nonlinear regression model:

$$(39) \quad V_{tn} - V_{CEtn} = \beta P_S^t S_{tn} g(A_{tn}) + \alpha_t \omega_n L_{tn} + \varepsilon_{tn}; \quad t = 1, \dots, 22; \quad n = 1, \dots, 50$$

where  $g(A_{tn})$  is defined by (37). This nonlinear regression has one unknown structure price  $\beta$ , three unknown  $\phi_i$  (where  $\delta_i \equiv 1 - \exp[\phi_i]$  and  $\delta_i$  is a quarterly geometric depreciation rate), 22 unknown  $\alpha_t$  (the overall land price series for our sample) and 50 unknown  $\omega_n$  (which reflect the relative discount or premium in the land price for REIT  $n$  relative to other REITs). This is a total of 76 parameters but not all of the  $\alpha_t$  and  $\omega_n$  can be identified so, as usual, we impose the normalization (21),  $\alpha_1 = 1$ . Thus there are 75 independent parameters to be estimated with 1100 degrees of freedom.

Again, Shazam had no trouble estimating the unknown parameters using the Nonlinear Regression option. The pseudo  $R^2$  between the observed variables and the predicted variables turned out to be 0.9946 and the log likelihood was  $-7633.63$ , which is a large increase in log likelihood of 26 over Model 4 for the addition of two depreciation parameters and one structure price parameter  $\beta$  that sets the level of structure prices in quarter 1. The estimated parameters are listed in Table A5 in the Appendix. The estimated  $\phi_i$  parameters turned out to be  $-0.00328$ ,  $-0.00705$  and  $-0.03623$  and the corresponding quarterly depreciation rates turned out to be  $\delta_1 = 0.00327$ ,  $\delta_2 = 0.00702$  and  $\delta_3 = 0.03558$ . Compare these rates to the single quarterly geometric depreciation rate from Model 4, which was 0.00514. Thus the new results indicate that the quarterly depreciation rate is around 0.33 percent for the first 20 years of building life, increasing to 0.70 percent for the next 10 years and then finishing its useful life with a 3.6 percent per quarter depreciation rate. The estimated  $\beta$  turned out to be 0.2963 which is very close to the assumed rate of 0.3 that we have used in earlier sections of this paper. The land price series for Model 5 is denoted by  $P_{L5}^t \equiv \alpha_t^*$  and it is graphed in Figure 4 below and listed in Table A4 in the Appendix. It can be seen that the new land price series  $P_{L5}^t$  lies a bit above the accounting land price index  $P_L^t$  and the previous builder's model land price index  $P_{L4}^t$  that was described in the previous section.

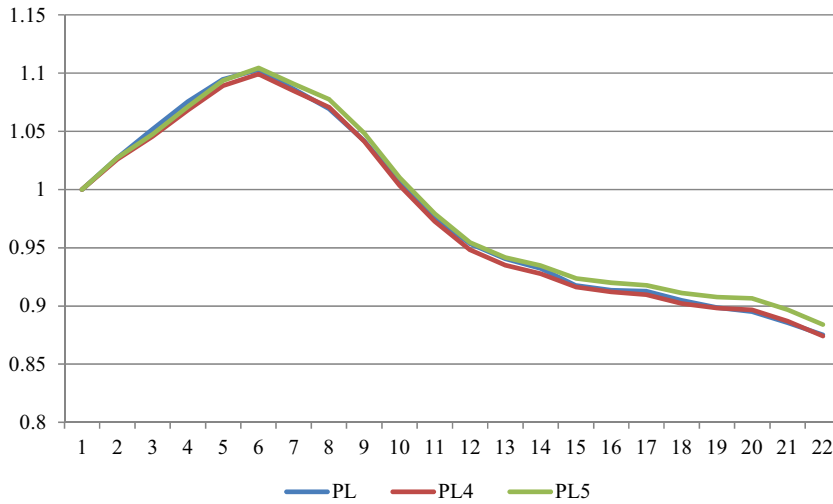


Figure 4. Accounting Method Price of Land  $P_L$ , Hedonic Regression Price Indexes for Land  $P_4$  and  $P_5$  [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Finally, we can carry out the same procedure that was used in the previous section to generate an overall commercial property price index series,  $P_5^t$ , using the fitted values that are generated by Model 5. The series  $P_5^t$  are listed in Table A4 of the Appendix and are graphed in Figure 3 in the previous section. It can be seen that  $P_5^t$  lies slightly above  $P_4^t$  and our accounting method index  $P^t$ .

### VIII. ESTIMATING DEMOLITION OR OBSOLESCENCE DEPRECIATION

The models that were described in the previous two sections are useful for national income accountants because they facilitate the accurate estimation of structure depreciation, which is required for the national accounts. The depreciation estimates that are generated by our models are *wear and tear depreciation* estimates that apply to structures that continue in existence over the sample period. However, there is another form of structure depreciation that we have not estimated; namely the loss of residual structure value that results from the *early demolition* of the structure. This problem was noticed and addressed by Hulten and Wykoff (1981)<sup>41</sup> but we will propose a somewhat different solution to the problem.

Our suggested solution to the problem of measuring the effects of the early retirement of a building will draw on the framework suggested by Komatsu, Kato and Yashiro (KKY) (1994). Their method requires the existence of data on the

<sup>41</sup>“Any analysis based only on survivors will therefore tend to overstate both the value and productivity of estimated capital stocks” Hulten and Wykoff (1981, p. 377). Wear and tear depreciation is often called *deterioration* depreciation and demolition or early retirement depreciation is sometimes called *obsolescence* depreciation. Crosby, Devaney and Law (2012, p. 230) distinguish the two types of depreciation and in addition, they provide a comprehensive survey of the depreciation literature as it applies to commercial properties.

date of construction and the date of retirement of each building in the class of buildings under consideration and for the region that is in scope.<sup>42</sup> KKY collected date of construction and date of retirement data for reinforced concrete office buildings in Japan for the reference year 1987. Thus for each age of building  $s$  (in years), they were able to calculate the number of office buildings of age  $s$  (in years),  $N_s$ , as of January 1, 1987 along with the number of office buildings of age  $s$ ,  $n_s$ , that were demolished in 1987 for ages  $s = 1, 2, \dots, 75$ . Given this information, they were able to calculate the *conditional probability*,  $\rho_s$ , that a surviving structure of age  $s$  at the beginning of the year would be demolished during 1987; i.e., they defined  $\rho_s$  as follows:

$$(40) \quad \rho_s \equiv n_s/N_s; \quad s = 1, \dots, 75.$$

Under the assumption that the conditional probabilities defined by (40) have persisted through time, KKY defined the *unconditional probability*  $\pi_s$  that a building of age  $s$  is still in existence at the beginning of the year 1987 as follows:

$$(41) \quad \pi_0 \equiv 1; \quad \pi_s \equiv \pi_{s-1}(1 - \rho_s); \quad s = 1, \dots, 75.$$

It can be seen that the series  $\pi_s$  are a building counterpart to *life expectancy tables*; i.e., the births and deaths of a population of buildings are used to construct the probability of building survival as a function of age instead of the probability of individual survival as a function of age.

Using the Japanese data for the  $\pi_s$  for 1987 that is on Figure 7 in KKY (1994, p. 8), we were able to construct (slightly smoothed) numerical estimates for their estimated survival probabilities,  $\pi_s$ . Once the probabilities of survival  $\pi_s$  have been determined, then the conditional probabilities of demolition  $\rho_s$  can be determined from the  $\pi_s$  using equations (41) above.<sup>43</sup> The resulting estimates for  $\pi_s$  and  $\rho_s$  are listed in Table A6 in the Appendix. See Figure 5 below for plots of these series.

Note that as could be expected, the conditional probabilities of demolition are very small for the first 20 years or so of building life. From 20 to 42 years, these probabilities gradually increase from 1.4 percent to about 11 percent and then the probabilities fluctuate around the 10 percent level from age 43 to 67. Finally, after age 67, the conditional probabilities of demolition increase rapidly to end up close to unity at age 75.

It is likely that the underlying probabilities of demolition are smoother than the  $\rho_s$  exhibited in Figure 5. Thus a closer approximation to these underlying probabilities could be obtained by smoothing the above estimates.<sup>44</sup> However, for our purposes in this section, the data listed in Table A6 in the Appendix and graphed above will suffice.

<sup>42</sup>Usually, land registry offices and/or municipal authorities issue building permits for the construction of new buildings and demolition permits for the tearing down of buildings. It may be difficult to classify buildings into the desired economic categories.

<sup>43</sup>Define  $\rho_0 \equiv 0$ .

<sup>44</sup>Recall that KKY (1994) carried out their life table estimation exercise for the year 1987. Ideally, the national statistical agency could carry out a similar exercise every year. Then the panel of life tables could be smoothed, leading to more accurate estimates for the underlying conditional probabilities.



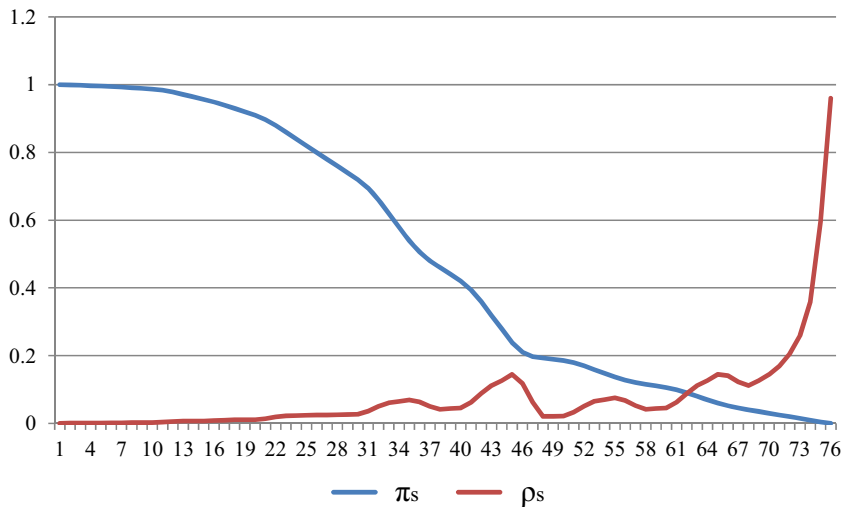


Figure 5. Unconditional Probabilities of Building Survival and Conditional Probabilities of Demolition [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

Recall that the wear and tear structure geometric depreciation rate that we estimated for our sample of continuing structures in section 6 above was about 0.5 percent per quarter. We want to form a rough idea of the possible magnitude of demolition depreciation using the information in Table A6. This component of depreciation is not included in our estimate of wear and tear depreciation.

Suppose that the *annual wear and tear geometric depreciation rate* is 2 percent so that we define  $\delta \equiv 0.02$ . Suppose further that investment in Tokyo office buildings has been constant for 75 years. We will normalize the annual structure investment to equal unity in constant yen units. Finally, suppose that the survival probabilities  $\pi_s$  listed in Table A6 apply to our hypothetical investment data. Thus after 75 years of steady investment, the constant yen value of the Tokyo commercial *office building stock* can be  $K$  defined as follows:

$$(42) \quad K \equiv \pi_0 + \pi_1(1-\delta) + \pi_2(1-\delta)^2 + \dots + \pi_{75}(1-\delta)^{75}.$$

The corresponding real value of *wear and tear depreciation*  $\Delta$  is defined as follows:

$$(43) \quad \Delta \equiv \delta\pi_0 + \delta\pi_1(1-\delta) + \delta\pi_2(1-\delta)^2 + \dots + \delta\pi_{75}(1-\delta)^{75} = \delta K.$$

The corresponding amount of *demolition depreciation*  $D$  is defined as each component of the surviving capital stock on the right hand side of equation (42),  $\pi_s(1-\delta)^s$ , multiplied by the corresponding conditional probability of demolition,  $\rho_s$ ; i.e., define  $D$  as follows:

$$(44) \quad D \equiv \rho_0\pi_0 + \rho_1\pi_1(1-\delta) + \rho_2\pi_2(1-\delta)^2 + \dots + \rho_{75}\pi_{75}(1-\delta)^{75}.$$

Once the surviving capital stock  $K$ , the amounts of wear and tear depreciation  $\Delta$  and demolition depreciation  $D$  have been defined, the *average wear and tear depreciation and demolition depreciation rates*,  $\delta$  and  $d$ , are defined as the following ratios:

$$(45) \quad \delta \equiv \Delta/K; \quad d \equiv D/K.$$

Of course, our assumed annual wear and tear depreciation rate of 2 percent turns out to equal the average wear and tear depreciation rate defined in (45) and the average demolition depreciation rate  $d$  turned out to equal 0.01795. Thus for the depreciation model considered in section VI above, *it is likely that demolition depreciation is almost equal to wear and tear depreciation*. Note that the sum of the two depreciation rates is approximately 3.8 percent per year.<sup>45</sup>

A similar set of calculations can be carried out for the more complex depreciation model defined in section VII above. Recall that our three *quarterly* geometric depreciation rates were estimated as follows:

$$(46) \quad \delta_1^* \equiv 0.00327; \quad \delta_2^* \equiv 0.00702; \quad \delta_3^* \equiv 0.03558.$$

We need to convert these quarterly depreciation rates into *annual rates*. Define  $\phi_i^* \equiv 1 - \delta_i^*$  for  $i = 1, 2, 3$ . Define  $\phi_i \equiv [\phi_i^*]^4$  and  $\delta_i \equiv 1 - \phi_i$  for  $i = 1, 2, 3$ . The  $\delta_i$  turned out to be the following numbers:

$$(47) \quad \delta_1 \equiv 0.01302; \quad \delta_2 \equiv 0.02779; \quad \delta_3 = 0.13490.$$

The geometric depreciation rates  $\delta_i$  defined by (47) are the annualized counterparts to the quarterly rates defined by (46). Thus for the first 20 years of building life, annual wear and tear geometric depreciation is about 1.3 percent per year, about 2.8 percent per year for the next 10 years and about 13.5 percent per year for the remaining life of the building.

A hypothetical *capital stock component* that is  $s$  years old (adjusted for wear and tear depreciation),  $K_s$ , is defined as follows:  $K_0 \equiv 1$ ;  $K_s \equiv (1 - \delta_1)K_{s-1}$  for  $s = 1, 2, \dots, 19$ ;  $K_s \equiv (1 - \delta_2)K_{s-1}$  for  $s = 20, 21, \dots, 29$  and  $K_s \equiv (1 - \delta_3)K_{s-1}$  for  $s = 30, 31, \dots, 75$ . The *aggregate constant yen capital stock* (adjusted for survival and wear and tear depreciation),  $K$ , is defined as follows:

$$(48) \quad K \equiv \pi_0 K_0 + \pi_1 K_1 + \pi_2 K_2 + \dots + \pi_{75} K_{75}.$$

*Aggregate wear and tear constant yen depreciation*,  $\Delta$ , is defined as follows:

$$(49) \quad \Delta \equiv \delta_1 \sum_{s=0}^{19} \pi_s K_s + \delta_2 \sum_{s=20}^{29} \pi_s K_s + \delta_3 \sum_{s=30}^{75} \pi_s K_s.$$

<sup>45</sup>Our method for adjusting wear and tear depreciation rates for the early retirement of assets is similar to the method suggested by Hulten and Wykoff (1981). The main difference between our suggested method and their method is that we use a building life table to form estimates of building survivor probabilities whereas Hulten and Wykoff used somewhat arbitrary assumptions to form their estimates of survivor probabilities: "Our survivor probabilities are based upon the set of retirement distributions developed by Winfrey (1935)."

Finally, *aggregate demolition depreciation D* is defined as follows:

$$(50) \quad D \equiv \sum_{s=0}^{75} \rho_s \pi_s K_s.$$

Once the surviving capital stock  $K$ , the amounts of wear and tear depreciation  $\Delta$  and demolition depreciation  $D$  have been defined, the *average wear and tear depreciation and demolition depreciation rates*,  $\delta$  and  $d$ , can again be defined by equations (45).

The annual wear and tear depreciation rate  $\delta$  for our new model turned out to equal 0.02563 and the average demolition depreciation rate  $d$  turned out to equal 0.01234. Thus for the depreciation model considered in section VII above, the “traditional” wear and tear depreciation rate is approximately 2.6 percent per year under our stationary state assumptions on building investment and the corresponding demolition depreciation rate is approximately 1.2 percent per year. Note that the sum of the two depreciation rates is approximately 3.8 percent per year, which is the same “total” depreciation rate that was generated by our section VI model for wear and tear depreciation.<sup>46</sup>

Our estimated demolition depreciation rates are only approximations to actual demolition depreciation rates. The actual rates of demolition depreciation depend on actual investments in commercial property office buildings in Tokyo for the past 75 years and this information is not available to us. However, the above calculations indicate that accounting for premature retirements of buildings adds significantly to the wear and tear depreciation rates that are estimated using hedonic regressions on continuing buildings. Thus it is important that national statistical agencies construct a data base for building births and retirements so that depreciation rates for buildings that are not retired can be adjusted to reflect the loss of building asset value that is due to premature retirement.

The analysis presented in this section does not invalidate our earlier analysis of alternative methods for constructing constant quality price indexes for commercial properties, since price indexes compare like to like and thus apply only to continuing structures. However, as a by product of our hedonic regressions in sections VI and VII, we were able to form estimates of wear and tear depreciation for buildings that remained in use. The analysis in this section simply warns the reader that wear and tear depreciation<sup>47</sup> is not the entire story: there is also a loss of asset value that results from the early retirement of a building that needs to be taken into account when constructing national income accounting estimates of depreciation.

<sup>46</sup>For comparison purposes, Hulten and Wykoff (1981, p. 387) found that their best fitting geometric model of depreciation for office buildings in the U.S. generated an estimated annual rate of 2.47 percent. This estimate includes early retirement or demolition depreciation and so is comparable to our rough estimate of 3.8 percent for Tokyo office buildings.

<sup>47</sup>What we have labeled as wear and tear depreciation could be better described as *anticipated amortization of the structure* rather than wear and tear depreciation. Once a structure is built, it becomes a fixed asset which cannot be transferred to alternative uses (like a truck or machine). Thus amortization of the cost of the structure should be proportional to the cash flows that the building generates over its expected lifetime. The pattern of cash flows generated by a commercial property can be quite volatile but market based assessed values should be able to forecast these cash flows to some degree. However, technical progress, obsolescence or unanticipated market developments can cause the building to be demolished before it is fully amortized. See Diewert and Fox (2014) for a more complete discussion of the fixity problem.

## 9. CONCLUSION

Some conclusions that we can draw from the paper are as follows:

- The traditional time dummy approach to hedonic property price regressions does not always work well. The basic problem is that there are two main drivers of property prices over time: changes in the price of land and changes in the price of structures. The hedonic time dummy method allows for only one shifter of the hedonic surface when in fact there are at least two major shifters. Moreover, the traditional approach does not lead to sensible decompositions of overall price change into land and structure component changes,
- The simple asset value price index suggested in section III seemed to work better than indexes based on the traditional time dummy hedonic regression approach,
- The national income accounting method for constructing land, structure and overall property price indexes that was described in section IV turned out to generate price indexes that were pretty close to the hedonic indexes based on the builder's model that were developed in sections VI and VII. However, this accounting method for constructing land and structure indexes for commercial properties requires an exogenous estimate of the structure depreciation rate. The hedonic regression model described in section VI shows how such a depreciation rate could be estimated,
- The methods suggested in sections IV, VI, VII and VIII are practical and could be used by statistical agencies to improve their balance sheet estimates for commercial properties and their estimates of depreciation,
- The methods described in sections IV, VI, and VII require quarterly assessed or appraised values for commercial properties where the appraisal values are made by professional appraisers and are required to approximate market values. We believe that the models presented in these sections could be successfully applied to commercial properties in other countries that have market based appraisals or market based assessments for tax purposes,
- In order to estimate demolition depreciation as in section VIII, information on the age of commercial structures when they are torn down is required.

However, there are many additional avenues that could be explored:

- We experimented with capitalizing REIT Net Operating Income into capital stock indexes but the volatility in REIT cash flows presented practical problems in implementing this method. Even after smoothing cash flows, we could not generate sensible capital stock estimates with our data set,
- We also tried to use an econometric model to determine what an appropriate quarterly depreciation rate for *capital expenditures* should be but we found that the likelihood function was very flat over a very large range of depreciation rates so we simply settled on a quarterly rate of 10 percent without completely convincing evidence to back up this rate,
- The depreciation rates that we estimate in sections VI and VII understate the actual amount of structure depreciation that takes place. Our approach is fine as far as it goes but it applies only to continuing structures. Unfortunately, structures are not all demolished at the same age: many structures still generate cash flow but yet they are demolished

before their initial cost of construction is fully amortized. We take this effect into account in section VIII and generate estimates of demolition (or premature retirement or obsolescence) depreciation.

Our overall conclusion is that constructing usable commercial property price indexes is a very challenging task; a much more difficult task than the construction of residential property price indexes.

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## SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

**Table A1:** Aggregate Values of REIT Properties  $V^t$  and Component Capital Expenditure Stock, Structure and Land Values  $V_{CE}^t$ ,  $V_S^t$  and  $V_L^t$ ; Corresponding Volumes or Quantities  $Q^t$ ,  $Q_{CE}^t$ ,  $Q_S^t$  and  $Q_L^t$ ; Asset Value Price Index  $P_A^t$ , Accounting Commercial Property Price Index  $P^t$ ; Price Index for Structures and Capital Expenditures  $P_S^t$  and Land Price Index  $P_L^t$

**Table A2:** Estimated Coefficients for Model 1

**Table A3:** Estimated Coefficients for Model 2

**Table A4:** Accounting Price Index  $P^t$ , Asset Value Index  $P_A^t$ , Hedonic Model Price Indexes,  $P_1^t - P_5^t$ , and Land Price Indexes  $P_L^t$ ,  $P_{L4}^t$  and  $P_{L5}^t$

**Table A5:** Estimated Coefficients for Model 5

**Table A6:** Unconditional Probabilities of Building Survival  $\pi_s$  and Conditional Probabilities of Demolition  $\rho_s$  as Functions of Age  $s$