Alternative Approaches to Commercial Property Price Indexes for Tokyo

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Discussion Paper 14-6, School of Economics, The University of British Columbia, Vancouver, Canada, V6T 1Z1.

Abstract

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 of the country and related price indexes for the land and structure components of a commercial property are required in the Income Accounts of the country if the Multifactor Productivity of the Commercial Property Industry is calculated as part of the System of National Accounts. 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 REITs. The problems associated with the decomposition of asset value into land and structure components are addressed.

Key Words


Journal of Economic Literature Classification Numbers


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1. Introduction

In this paper, we will use quarterly data on the performance of 50 Real Estate Investment Trusts (REITs) that have single location commercial offices 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 expenditures on the property and we also use an exogenous construction price index that is relevant 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 2, we briefly describe our data set.

In section 3, we construct our first (overall) price index that requires only information on assessed 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.²

In section 4, 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. Basically, assumptions are made about the form of depreciation which may not be correct but they still seem to serve a useful purpose.

In section 5, 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 REIT assessed values in place of selling prices.

In sections 6 and 7, 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.

² This index is an assessed value counterpart to a repeat sales index, which also suffers from the same conceptual problems.
In section 6, 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 7, we generalize this model to allow for changing geometric depreciation rates as the building ages.

Section 8 concludes.

2. The Tokyo REIT Data

This paper uses published information on the Japanese Real Estate Investment Trust (REIT) market in the Tokyo area.\(^3\) 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 value of the property; CE, the quarterly capital expenditures made on the property during the quarter; L, the area of the land plot in square meters (m\(^2\)); S, the total floor area of the structure in m\(^2\) 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 units of measurement for these financial variables is in millions of yen. The basic descriptive statistics for the above variables are listed in Table 1 below.\(^5\)

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

Thus over the sample period, the sample average assessed value of the properties was approximately 4985 million yen, the average structure area was 5925 m\(^2\), the average lot size was 1106 m\(^2\), the average age of the structure was 84 quarters or 21 years and the average quarterly capital expenditure was about 6 million yen.

There were fairly high correlations between the V, S and L variables. The correlations of the selling price 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

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\(^3\) REIT data were supplied by MSCI-IPD, Japan. The authors thank Toshiro Nishioka and Hideaki Suzuki for their assistance. And see Shimizu et al (2013) in details.

\(^4\) The REITs were chosen so that each REIT consisted of a single commercial property located somewhere in Tokyo. The assessed values are reported at the end of each quarter. However, the actual assessments take place either during the quarter or prior to it. We will regard the published assessed values as approximations to the true market values of the property as of the beginning of the relevant quarter.

\(^5\) 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.
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.6

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 Index for Tokyo.7 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 4 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).8

3. The Asset Value Price Index for Commercial Properties in Tokyo

Denote the estimated asset value for a property of REIT n (hereafter, REIT n) during quarter t by V_{tn} for t = 1,...,22 and n = 1,...,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.9 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} = 1; P_{tn} = V_{tn} for t = 1,...,22 and n = 1,...,50. The asset value price index for period t for this group of REITs is the following Lowe (1823)10 index:

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

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 Chart 1 in the following section and the series is listed in Table A1 in the Appendix.

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6 See Diewert, de Haan and Hendriks (2011a) (2011b) for evidence on this multicollinearity problem for house prices using Dutch data.
7 This index, denoted as P_{St}, 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_{St}. The quarterly values were constructed from the Monthly Commercial Construction Cost index for Tokyo for reinforced concrete buildings.
8 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 m². Since construction prices in 2011 were very close to construction prices in 2007, in section 4 we will assume that the construction cost of a new commercial office was approximately 300,000 yen per m² at the start of our sample period.
9 We are also ignoring changes in the amenities around the property over the sample period.
10 A Lowe index is a fixed basket price index where the quantity basket remains fixed over the sample period.
This index is very much analogous to a repeat sales index,\textsuperscript{11} except instead of using actual sales of properties, we use the assessed values for the properties that are supplied by professional assessors.

There are three major problems with the assessed value price index:

- 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;\textsuperscript{12}
- The index does not take into account that \textit{capital expenditures} will generally change the quality of each property over time (so that the $Q_{tm}$ are not in fact constant) and
- The index does not take into account \textit{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, $P_{At}$.\textsuperscript{13} We cannot address the first problem mentioned above but in the following section, we will attempt to address problems 2 and 3 listed above.

\textbf{4. 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.\textsuperscript{14} National income accountants build up capital stock estimates for a production sector by deflating investments by asset and then adding up depreciated real investments made in prior periods. For commercial property capital expenditures and the expenditures on the initial structure, we will more or less follow national income capital stock construction procedures. 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 relevant depreciation rates based on limited information.

\textsuperscript{11} The Repeat Sales Method for measuring property prices dates back to Bailey, Muth and Nourse (1963).

\textsuperscript{12} See Shimizu and Nishimura (2006) and Shimizu, Nishimura and Watanabe (20012) in details.

\textsuperscript{13} 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).

\textsuperscript{14} See Schreyer (2001) (2009) and Diewert (2005) for a detailed explanation of these techniques.
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 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:

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

We know the assessed values, $V_{tn}$, on the left hand side of equations (2) and our strategy will be to determine the components of the values on the right hand side of equations (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:

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

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 REIT 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 n is $300,000 \times P_{StStn}$ where $P_{St}$ is the construction price index per m² for Tokyo for quarter t (normalized to equal one in quarter 1) and $S_{tn} = S_n$ is the floor area for REIT 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 $0.3P_{StStn}$. We now assume that the quarterly geometric (or declining balance) depreciation rate for the structure is $\delta_S = 0.005$ or 0.5% per quarter. 15 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:

\[(4) \quad V_{Stn} = 0.3P_{StStn}(1-\delta_S)^{A(t,n)} ; \quad n = 1,...,50 ; \quad t = 1,...,22\]

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

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15 Hulten and Wykoff (1981) obtain annual geometric depreciation rates for office buildings in the U.S. in the 1 to 2.5% range. Other studies sometimes obtain somewhat higher rates.
(5) \[ V_{S_t} = P_{S_t}Q_{S_t} ; \quad P_{S_t} = P_{S_t}^* ; \quad Q_{S_t} = 0.3S_t(1-\delta_S)^{A(t,n)} ; \quad n = 1,\ldots,50 ; \quad t = 1,\ldots,22 \]

where \( P_{S_t} \) is the known official construction price index for quarter \( t \) (lagged one quarter), \( S_t \) 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 \( V_{S_t} \) can be calculated.

Finally, we need to determine the contribution of capital expenditures to REIT asset values. This is a more difficult task. Define the capital expenditures of REIT \( n \) in quarter \( t \) as \( C_{E_t} \). 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, \( P_{S_t} \), is a suitable deflator. Thus define real capital expenditures for REIT \( n \) in quarter \( t \), \( q_{C_{E_t}n} \), as follows:

(6) \[ q_{C_{E_t}n} = CE_{tn}/P_{S_t} ; \quad n = 1,\ldots,50 ; \quad t = 1,\ldots,22. \]

We know both series on the right hand side of (6) so the \( q_{C_{E_t}n} \) 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 7 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% per quarter.\(^{16}\) 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 \( n \), \( q_{C_{E_t}n} \), as follows:

(7) \[ q_{C_{E_t}n} = \frac{\sum_{t=1}^{22} q_{C_{E_t}n}/22}{22} ; \quad n = 1,\ldots,50. \]

Our next assumption is that each REIT \( n \) has a starting stock of capital expenditures equal to depreciated investments for 20 quarters (or 5 years) equal to the REIT \( n \) sample average investment, \( q_{C_{E_t}n} \), defined above by (7). Thus the starting stock of CE capital for REIT \( n \) is \( Q_{C_{E_t}n} \) defined as follows:

(8) \[ Q_{C_{E_t}n} = q_{C_{E_t}n}[1 - (1-\delta_{CE})^{21}]/\delta_{CE} ; \quad n = 1,\ldots,50. \]

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) \[ Q_{C_{E_t}n} = (1-\delta_{CE})Q_{C_{E,t-1,n}} + q_{C_{E,t-1,n}} ; \quad t = 2,3,\ldots,22 ; \quad n = 1,\ldots,50. \]

\(^{16}\) After 20 quarters or 5 years, only 12% of a initial real investment in capital expenditures contributes to asset value; after 40 quarters or 10 years, only 1.5% of a initial real investment in capital expenditures contributes to asset value.
Note that $Q_{CEtn}$ is now completely determined for $t = 1, \ldots, 22$ and $n = 1, \ldots, 50$ 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:

$$V_{CEtn} = P_{CEtn}Q_{CEtn}; \quad P_{CEtn} = P_{St},$$

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):

$$P_{Ltn} \equiv \frac{V_{tn} - V_{Stn} - V_{CEtn}}{L_n}; \quad n = 1, \ldots, 50; \quad t = 1, \ldots, 22.$$

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 (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:17

$$V_t \equiv \sum_{n=1}^{50} V_{tn}; \quad V_{L}^t \equiv \sum_{n=1}^{50} V_{Ltn}; \quad V_{S}^t \equiv \sum_{n=1}^{50} V_{Stn}; \quad V_{CE}^t \equiv \sum_{n=1}^{50} V_{CEtn}; \quad t = 1, \ldots, 22.$$

We form aggregate overall and component price and quantity indexes using chained Fisher (1922) ideal indexes.18 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 $t$, $P_{L,\text{Land}}^{t-1,t}$, as follows:

$$P_{L,\text{Land}}^{t-1,t} = \frac{\sum_{n=1}^{50} P_{Ltn}Q_{L,t-1,n}/\sum_{n=1}^{50} P_{L,t-1,n}Q_{L,t-1,n}}{\sum_{n=1}^{50} P_{Ltn}Q_{L,t-1,n}}; \quad t = 2, 3, \ldots, 22.$$

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

$$P_{L,\text{Land}}^t = 1; \quad P_{L,\text{Land}}^{t-1} = P_{L,\text{Land}}^{t-1} P_{L,\text{Land}}^{t-1,t}; \quad t = 2, 3, \ldots, 22.$$

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

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17 These aggregate value series are listed in the Appendix in Table A1.
18 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.
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:

\[
(15) \quad P_{P,Land}^{t-1,t} = \frac{\sum_{n=1}^{50} P_{Ltn} Q_{Ltn}}{\sum_{n=1}^{50} P_{L,t-1,n} Q_{Ltn}} ; \quad t = 2, 3, ..., 22.
\]

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

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

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

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

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, \( P^t \), 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 \( P^t \), \( P_{F,Land}^t \), \( P_{F,S}^t \) 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), \( \tilde{V}, \tilde{V}_{L}, \tilde{V}_{S} \) and \( \tilde{V}_{CE} \), in order to form implicit quantity or volume indexes; i.e., define the following aggregate quantity indexes:

\[
(18) \quad Q^t \equiv \frac{\tilde{V}^t}{P^t} ; \quad Q_{L}^t \equiv \frac{\tilde{V}_{L}}{P_{L}^t} ; \quad Q_{S}^t \equiv \frac{\tilde{V}_{S}}{P_{S}^t} ; \quad Q_{CE}^t \equiv \frac{\tilde{V}_{CE}}{P_{CE}^t} ; \quad t = 1, ..., 22.
\]

\( Q^t \) 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 and \( Q_{CE}^t \) is an estimate of the real stock of capital improvements made by the REITs since they were constructed.

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

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19 This remains constant over time since the quantity of land used by each REIT remained constant over time.
20 The four implicit quantity series defined by (18) are also listed in Table A1 of the Appendix.
above as a Fisher index turns out to equal the official price index, $P_{St}$ defined earlier.\(^{21}\) 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:

\[
Q_{St}^t = \frac{V_{St}^t}{P_{St}}; \quad Q_{CE}^t = \frac{V_{CE}^t}{P_{St}}; \quad t = 1, \ldots, 22.
\]

The asset value (or repeat sales) overall price index, $P_A^t$, is graphed in Chart 1 below 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 $P_S^t$ which we have used as a price deflator for both capital expenditures and the estimated value of the structure.\(^{22}\)

![Chart 1: Asset Value Price Index $P_A$ and Accounting Price Index $P$, Price of Structures $P_S$ and Price Index for Land $P_L$](chart1.png)

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.\(^{23}\) In our Japanese sample of commercial properties, our estimated average land value divided by total property value turned out to be 74.7%; i.e., approximately 75% of the property value is due to land value. In the U.S., the land ratio is very much less so that the bias in the asset value price index would be correspondingly much larger since it is

\(^{21}\) The chained Laspeyres and Paasche price indexes for structures are also equal to the official index (and so are the corresponding fixed base indexes). And 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.

\(^{22}\) $P_A^t$, $P$, $P_S^t$ and $P_L^t$ are listed as $PA$, $P$, $PS$ and $PL$ in Chart 1.

\(^{23}\) 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 .5 percentage points per year, which is fairly significant.
the neglect of structure depreciation that causes the differences in $P_t$ and $P_A^t$.\textsuperscript{24} 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.

5. Traditional Hedonic Regression Approaches to Index Construction

Most hedonic commercial property regression models are based on the \textit{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.\textsuperscript{25} 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 2 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, $\ln V_{tn}$, $\ln L_{tn}$ and $\ln S_{tn}$.\textsuperscript{26} Our first time dummy hedonic regression model is defined for $t = 1,...,22$ and $n = 1,...,50$ by the following equations:\textsuperscript{27}

\begin{equation}
\ln V_{tn} = \alpha + \alpha_t + \beta \ln L_{tn} + \gamma \ln S_{tn} + \delta A_{tn} + \epsilon_{tn}
\end{equation}

where $\alpha_1,...,\alpha_{22}$, $\alpha$, $\beta$, $\gamma$ and $\delta$ are 25 unknown parameters to be estimated and the $\epsilon_{tn}$ 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

\textsuperscript{24} 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 a substantial downward biases compared to indexes that take structure depreciation into account.

\textsuperscript{25} This methodology was developed by Court (1939; 109-111) as his Hedonic Suggestion Number Two.

\textsuperscript{26} This led to a better fitting regression model.

\textsuperscript{27} 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 $\alpha_n$ parameters that appear in these equations.
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:

\[(21) \alpha_1 = 0.\]

This normalization makes the overall commercial 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 $R^2$ between the dependent variable and the corresponding predicted variable was 0.6339. The estimated coefficients are listed in Table A2 of the Appendix. The estimated coefficient associated with the log of land area was $\beta = -0.1713$ (which is the wrong sign for this parameter) and with the log of the structure area was $\gamma = 1.1264$ and was highly significant (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, $P_{11}$, are defined as the exponentials of the estimated time coefficients $\alpha_t$:

\[(22) P_{1t} = \exp[\alpha_t] ; \quad t = 1,\ldots,22.\]

The resulting overall commercial property price indexes generated by Hedonic Model 1, the $P_{1t}$, are graphed in Chart 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 $t = 1,\ldots,22$ and $n = 1,\ldots,50$ by the following equations:

\[(23) \ln V_{tn} = \alpha + \alpha_t + \beta \ln L_{tn} + \gamma \ln S_{tn} + \delta A_{tn} + \omega_n + \epsilon_{tn}\]

where $\alpha_1,\ldots,\alpha_{22}, \omega_1,\ldots,\omega_{50}$, $\alpha$, $\beta$, $\gamma$, and $\delta$ are 76 unknown parameters to be estimated and the $\epsilon_{tn}$ 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 REIT dummy variables where $\omega_n$ is the parameter which shifts the hedonic surface when the dependent variable is the logarithm of property value for REIT $n$. As before, 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). However, 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 area of each REIT in our sample is 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 \( \alpha_t = 0 \). However, the dummy variables associated with \( \alpha \), \( \alpha_2, \ldots, \alpha_{22} \) when combined with the dummy variables associated with \( \omega_1, \ldots, \omega_{50} \) 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 \( \alpha_2, \ldots, \alpha_{22} \) and \( \omega_1, \ldots, \omega_{50} \). 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:

\[
(24) \ln V_{tn} = \alpha_t + \omega_n + \delta \ln A_{tn} + \epsilon_{tn} ; \quad t = 1, \ldots, 22 ; n = 1, \ldots, 50.
\]

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 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).

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 \( R^2 \) 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 \( T \) 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 \( \alpha_t \):

\[
(25) P_2^t = \exp[\alpha_t] ; \quad t = 1, \ldots, 22.
\]

The \( P_2^t \), are graphed in Chart 2 below and are listed in Table A4 of the Appendix.

\[\text{We still impose the normalization (21) on the parameters in (24); i.e., we set } \alpha_t = 1.\]

\[\text{The problem is that the parameter } \delta \text{ will be an imperfect indicator of the effects of structure aging, due to the fact that the age variable (before transformation) will be subject to a multicollinearity problem in our original specification. We attempt to solve this problem by taking a nonlinear transform of the age variable in order to negate the exact multicollinearity but this solution does not really solve the problem.}\]
From viewing Chart 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, $P_A$, lies below $P_t$, ending up at 0.8798. Our first traditional log value hedonic regression model generated the index $P_1$ which ended up at 0.8382 while the second model $P_2$ 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 fail 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.\(^{30}\) 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 $P_3$ in the usual way (use the counterparts to equations (23) above).\(^{31}\) The index values for $P_3$ are listed in Table A4 and the series is graphed on Chart 2 above. It can be seen that $P_3$ is virtually identical to the asset value series $P_A$. 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 $P_A$ and $P_3$ is that they make no allowance for structure

\(^{30}\) 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.

\(^{31}\) We did not list the coefficient estimates in the Appendix for Model 3.
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 additional hedonic regression models that will attempt to deal with the above two difficulties.

6. The Builder’s Model Applied to Commercial Property Assessed Values

The builder’s model for valuing a residential property postulates that the value of a residential property is the sum of two components: the value of the land which the structure sits on plus the value of the residential structure.  

In order to justify the model, consider a REIT 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, $\beta_t S_{tn} + \gamma_{tn} L_{tn}$.  

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 $n$.

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

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32 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 (2013) except that straight line or piece-wise linear depreciation was used as the depreciation model for the structure whereas in the present paper, we will use geometric depreciation models.

the depreciation of the structure. Assuming that we have information on the age of the structure n at time t, say $A_{tn} = A(t,n)$ and assuming a geometric depreciation model, a more realistic hedonic regression model is the following basic builder’s model:

\begin{equation}
V_{tn} = \beta_t S_{tn} \left[e^{\phi t}A(t,n) \right] + \gamma_{tn} L_{tn} + \varepsilon_{tn}; \quad t = 1,\ldots,22; \ n = 1,\ldots,50
\end{equation}

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.\(^{34}\) 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).\(^{35}\) 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 3 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

\begin{equation}
\gamma_{tn} = \alpha_t \omega_n; \quad t = 1,\ldots,22; \ n = 1,\ldots,50.
\end{equation}

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:

\begin{equation}
\beta_t = \beta P_{S}^t; \quad t = 1,\ldots,22.
\end{equation}

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

\begin{equation}
V_{tn} - V_{CEtn} = \beta P_{S}^t S_{tn} \left[e^{\phi t}A(t,n) \right] + \alpha_t \omega_n L_{tn} + \varepsilon_{tn}; \quad t = 1,\ldots,22; \ n = 1,\ldots,50.
\end{equation}

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 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

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\(^{34}\) Note that $\delta = 1 - e^{\phi}$.

\(^{35}\) 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).
(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.\textsuperscript{36} At first glance, the results appeared to be satisfactory. The $R^2$ between the observed variable and the predicted variable 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 3. The land price series (the estimated $\alpha_1$ ended up at $\alpha_{22} = 0.8754$) turned out to be very similar to our accounting generated land price series $P_{Lt}$ listed in Table A1 (which ended up at $P_{Lt}^{22} = 0.8752$). 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 3. The land price series for Model 4 is denoted by $P_{Lt}^4$ and it is graphed in Chart 4 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 $P_{Lt}$ listed in Table A1.

We need to explain how our new land price series $P_{Lt}^4$ can be combined with our structures (and capital expenditures) price series $P_{St}^4$. Denote the estimated Model 4 parameters as $\beta^*, \alpha_1^* = 1, \alpha_2^*, ..., \alpha_{22}^*, \phi^*$ and $\omega_1^*, ..., \omega_{50}^*$. We can break up the fitted value on the right hand side of equation (29) for observation $t_n$ into a fitted structures component, $V_{S4tn}^*$, and a fitted land component, $V_{Lt4tn}^*$, for $n = 1, ..., 50$ and $t = 1, ..., 22$ as follows:

\begin{align*}
(30) \quad V_{S4tn}^* &= \beta^* P_{St}^4 [e^{\phi^*}]^{A(t,n)}; \\
(31) \quad V_{Lt4tn}^* &= \alpha_t^* \omega_{n}^* L_{tn}.
\end{align*}

Now form structures and capital expenditures aggregate (over all REITS), $V_{S4t}^*$, 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:

\begin{align*}
(32) \quad V_{S4t}^* &= \sum_{n=1}^{50} [V_{S4tn}^* + V_{CEtn}] ; \quad t = 1, ..., 22.
\end{align*}

\textsuperscript{36} 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.
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 $t$:

\[
V_{L4t}^* = \sum_{n=1}^{50} V_{L4tn}^* ; \\
\text{t = 1,...,22.}
\]

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):

\[
Q_{S4t}^* = V_{S4t}^* / P_{S4}^* ; \\
Q_{L4t}^* = V_{L4t}^* / P_{L4}^* ;
\]

Thus for each period $t$, we have 2 prices, $P_{S4}^*$ and $P_{L4}^*$, and the corresponding 2 quantities, $Q_{S4t}^*$ and $Q_{L4t}^*$. We form an overall commercial property price index, $P_4^*$, by calculating the chained Fisher price index of these two price components. \(^{37}\) This overall index $P_4^*$ is graphed in Chart 3 below along with our accounting method overall index $P^*$ and the asset value price index, $P_A^*$.

\(\text{Chart 3: Accounting Method Price Index P, Asset Value Index, Builder's Model Price Indexes P4 and P5}\)

\(\text{P} \quad \text{PA} \quad \text{P4} \quad \text{P5}\)

\(0.87 \quad 0.92 \quad 0.97 \quad 1.02 \quad 1.07 \)

\(1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \quad 11 \quad 12 \quad 13 \quad 14 \quad 15 \quad 16 \quad 17 \quad 18 \quad 19 \quad 20 \quad 21 \quad 22\)

\(^{37}\) 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 $\alpha_i$ because we have forced this movement by our choice of functional form in the regression model.
From Chart 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 \( P_{4t} \) that was just explained in this section. The geometric depreciation rate for capital expenditures is exactly the same (10% per quarter) 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, \( P_{A1} \), lies well below \( P^1 \) and \( P_{41} \) and the price index \( P_{51} \) lies a bit above \( P^1 \) and \( P_{41} \). The index \( P_{51} \) will be explained in the following section.

7. 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 4 years to 40 years. One might question whether the quarterly geometric depreciation rate is constant from year to year. 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 \( 0 \leq A_{tn} < 80 \), 424 observations fell into the interval \( 80 \leq A_{tn} < 120 \) and 126 observations fell into the interval \( 120 \leq A_{tn} \leq 160 \). 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:\(^{38}\)

\[
D_{tnm} = \begin{cases} 
1 & \text{if observation } tn \text{ has a building whose age belongs to group } m; \\
0 & \text{if observation } tn \text{ has a building whose age is not in group } m. 
\end{cases}
\]

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 \( A_1 = 80 \) and \( A_2 = 120 \):

\[
g(A_{tn}) = \exp \{D_{tn1} \phi_1 A_{tn} + D_{tn2} [\phi_1 A_1 + \phi_2 (A_{tn} - A_1)] + D_{tn3} [\phi_1 A_1 + \phi_2 (A_2 - A_1) + \phi_3 (A_{tn} - A_2)] \}
\]

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:

\[
\delta_i = 1 - \exp[\phi_i] \quad ; \quad i = 1,2,3.
\]

\(^{38}\) Note that for each observation, the Age dummy variables sum to one; i.e., for each \( tn \), \( D_{tn1} + D_{tn2} + D_{tn3} = 1 \). See Shimizu, Nishimura and Karato (2014) in details.
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: first 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:

\[
V_{tn} - V_{CEtn} = \beta P_S S_{tn} g(A_{tn}) + \alpha_t \omega_n L_{tn} + \epsilon_{tn}; \quad t = 1,...,22; \ n = 1,...,50
\]

where \( g(A_{tn}) \) is defined by (37). This nonlinear regression has one unknown structure price \( \beta \), 3 unknown \( \phi_i \) (where \( \delta_i = 1 - \exp[\phi_i] \) 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. The \( R^2 \) between the observed variable and the predicted variable 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% for the first 20 years of building life, increasing to 0.70% for the next 10 years and then finishing its useful life with a 3.6% 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 \( P_{L5} \) and it is graphed in Chart 4 below and listed in Table A4 in the Appendix. It can be seen that the new land price series \( P_{L5} \) lies a bit above the accounting land price index \( P_L \) and the previous builder’s model land price index \( P_{L4} \) that was described in the previous section.
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 Chart 3 in the previous section. It can be seen that $P_5^t$ lies slightly above $P_4^t$ and our accounting method index $P^t$.

8. Conclusion

Some conclusions that we may be able to 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 3 seemed to work better than indexes based on the traditional time dummy hedonic regression approach.
- The accounting method for constructing land, structure and overall property price indexes that was described in section 4 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 6 and 7.
- The methods suggested in sections 4, 6 and 7 are practical and probably could be used by statistical agencies to improve their balance sheet estimates for commercial properties.

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 presents 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% without good evidence to back up this rate.

The depreciation rates that we estimate in sections 6 and 7 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 they are fully amortized. Taking this effect into account is of course possible, but it is still an open question on how exactly should we deal with this problem.\textsuperscript{39}

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

\textsuperscript{39} Hulten and Wykoff (1981; 376-379) deal with this problem but their solution to the problem does not deal with all of the complexities of these issues.
### Appendix: Model Estimated Coefficients and Index Number Tables

#### Table A1: Aggregate Values of REIT Properties $V_t^r$ and Component Capital Expenditure Stock, Structure and Land Values $V_{CE}^r$, $V_S^r$ and $V_L^r$; Corresponding Volumes or Quantities $Q_t^r$, $Q_{CE}^r$, $Q_S^r$ and $Q_L^r$; Asset Value Price Index $P_{A}^r$, Accounting Commercial Property Price Index $P_i^r$; Price Index for Structures and Capital Expenditures $P_{CS}^r$ and Land Price Index $P_{L}^r$

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23
Table A4: Accounting Price Index $P_t$, Asset Value Index $P_{1t}$, Hedonic Model Price Indexes, $P_{i1}$ – $P_{i5}$, and Land Price Indexes $P_{1t}$, $P_{4t}$, and $P_{5t}$.

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References


Columbia, Vancouver, Canada, V6T 1Z1. Forthcoming in *Macroeconomic Dynamics*.


