（京都学園大学経済学部論集　第14巻 第2号　2004年12月　1頁～19頁）

Article

An Empirical Study of Complementarity between Natural and Human-made Capital — The Case of Japanese Economy

Toyokazu NAITO

Department of Economics
Kyoto Gakuen University

Abstract

A proposition by ecological economists that natural capital and human-made capital are complements rather than substitutes, is examined by estimating the cross-price elasticities of demand for inputs used in the Japanese new construction sector. Quinquennial benchmark and annual input-output tables of the Japanese economy are used to define natural capital such as wood input and human-made capital such as non-wood inputs. A profit function approach is applied to derive unconditional input demands and product supply for estimation. As a flexible functional form, translog is employed to analyze the input relationships appearing on elasticity estimates. Results show that estimates of unconditional cross-price elasticities are all negative, suggesting that wood and non-wood inputs may be gross complements, rather than substitutes, proving that natural capital and human-made capital are complements.

Keywords Complementarity, Ecological economics, Flexible functional forms, Human-made capital, Natural capital, Profit function, Substitutability

1. Introduction

There is a proposition that natural capital (natural resources) and human-made capital are complements rather than substitutes.1) This proposition is asserted by specialists in the of field ecological economics, the relatively new discipline of economics which addresses the relationships between ecosystems and economic systems (Daly 1996 and Costanza et al. 1997). On the other hand, the standard assumption of neoclassical economics has been that factors of production are highly substitutable, hence the flow of natural resources (and the stock of natural capital that yields that flow) is substitutable with human-made capital.[2]

If factors of production are substitutes rather than complements, then there can be no limiting factors. Hence, the productivity of human-made capital is not limited by a lack of natural capital, so that we can continue to accumulate human-made capital even if natural capital is depleted. However, if the complementarity theory proposed by ecological economists is valid, then the productivity of human-made capital is limited by the decreasing supply of the complementary natural capital. If this is the case, sustainability of resources pose a significant problem to our present society. It is therefore important to resolve the issue of complementarity versus substitutability on empirical grounds.

In this paper, the complementarity proposition is examined empirically using data on new construction projects in Japan. The study especially estimates the cross-price elasticities of demand for inputs used in the new construction sector in Japan. The input factors used in new construction projects are of two kinds: (1) wood inputs such as timber and wooden products, and (2) non-wood inputs such as ceramic, stone, and clay; metal products; other industrial products; labor; and services. The wood inputs are natural capital and the non-wood inputs are human-made capital. Hence, the estimated cross-price elasticities of demand for inputs show whether natural capital and human-made capital are compliments or substitutes. The study uses

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1) The natural capital is defined as the available endowment of land and resources including air, water, soil, forests, fisheries, minerals, and ecological life-supports systems that make economic activity, and indeed life itself possible (Harris 2002).

2) For example, the total complementarity of the Leontief model is one of exception.

quinquennial benchmark and annual input-output tables of Japanese economy as the source for cost and/or net revenue shares and input use indexes for broad categories of inputs to the construction industry. The result is a richer, more internally consistent data set allowing a more detailed representation of the various input categories used in new construction.

For the estimation, the study employs a profit function approach to derive unconditional input demands and product supply for estimation. The application of a profit function approach derives a comprehensive and internally consistent system of input demand and product supply relationships for estimation. The profit function approach reveals unconditional input demand behavior-output is allowed to adjust to price changes. This approach has a considerable advantage in comparison with cost function approach, which derives the estimated parameters of the factor demand functions, yielding constant output elasticities. Appropriately applied, these approaches can yield information on technical substitution. However, because output is not held constant in reality, and because the output effect may be important in overall materials use responses to price changes, the profit function approach is the more appropriate one for predictive and policy analytic purposes. As a flexible functional form, the study employs translog forms, which were estimated both with and without curvature constraints.

This paper is organized as follows. Section 2 summarizes the background of the complementarity proposition by Daly. Section 3 describes the empirical model employed in the study and the flexible functional form of translog. Section 4 presents data (quinquennial benchmark and annual input-output tables) used in this study. In section 5, the estimation results are reported. The final section concludes the study.

2. Complementarity Proposition

Herman E. Daly, a leading ecological economist, puts forward a complementarity proposition, i.e., that natural capital (natural resources) and human-made capital are complements rather than substitutes. This proposition is in contradiction of the traditional Neoclassical Economics viewpoint. In the neoclassical theorists' assumptions, factors of production are highly substitutable (although there is a perfect complementarity of the Leontief model); hence the flow of natural resources (and the stock of natural capital that yields that flow) is substitutable by human-made capital.

Daly (1999 and 1996) shows the three basic reasons behind this proposition. First, he argues by assuming the opposite and shows it is absurd. If human-made capital were a near perfect substitute for natural capital, then the reverse is also true, i.e., natural capital would be a near perfect substitute for human-made capital. However, if this were true, there would have been no reason to accumulate human-made capital in the first place, since we would have been already endowed by nature with a near perfect substitute, namely, natural capital. But historically, we humans did begin to accumulate human-made capital long before natural capital was depleted. This activity is an apparent contradiction. In fact, we needed human-made capital to make effective use of the natural capital (this is what we mean by complementarity). Next, Daly presents the defining condition of complementarity. Human-made capital is itself a physical transformation of natural resources that derives from originally natural capital, so that human-made capital itself requires natural capital. In other words, producing more of the human-made capital requires more of the very input being substituted for (natural capital).

Finally, Daly points out that there are two different roles in production ("material cause" and "efficient cause"), and that these two roles are not substitutable. Human-made capital is an agent of the transformation of the resource flow from raw material inputs into product outputs. The natural resource flow (natural capital stock) is the "material cause" of production; on the other hand, the human-made capital stock that transforms raw material inputs into product output is the "efficient cause" of production. Thus, he concludes that we cannot substitute efficient cause for material cause, likening it to the impossibility of building the same wooden house with half the lumber no matter how many extra power saws or carpenters we try to substitute.

Daly argues that if the comprimentarity proposition is accepted, "strong sustainability" is ultimately the relevant concept for our environmental and natural resource policy, although even "weak sustainability" would be an improvement over current practice.3) He argues farther that if the natural and human-made capitals are complements rather than substitutes, then the productivity of human-made capital is more and more limited by the decreasing supply of complementary natural capital. Therefore, our investment at the present time must shift from human-made capital accumulation toward natural resource preservation and restoration (investing more in natural capital). Furthermore, technology should be aimed at increasing the productivity of natural capital more than human-made capital.

Taking into account Daly's view of the comprimentarity proposition, it might be considered appropriate to examine it empirically. In so doing, the next section provides an empirical model for factor substitutions in house construction.

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3) Strong sustainability is the view that natural and human-made capitals are generally not substitutable and, therefore, natural capital levels should be maintained. Weak sustainability is the view that natural capital depletion is justified as long as it is compensated for with increases in human-made capital; assumes that human-made capital can substitute for most types of natural capital. (Harris 2002)

3. Empirical Model

The objective of the present study is to estimate changes in the quantities of various inputs used in the new house construction sector in Japan when the prices of these inputs change. At a minimum, this entails estimating demand equations for the several inputs. Since it is concerned with identifying total input use responses and not simply the technical substitution characteristics of production, as might be represented by elasticities of substitution, unconditional demand functions are required. Thus a profit function approach is employed, rather than a cost function analysis, so that demand relations will reflect input use responses due both to changes in relative prices and the level of output.

To specify the model, it is assumed that firms select the levels of output, x_0, and of variable inputs, $-x_i$ ($i=1, 2, ..., n$), subject to output price, p_0, input prices, p_i ($i=1, 2, ..., n$), the level of capital, k, and time-dependent technological change, t, in order to maximize profit. Duality theory demonstrates that if the indirect profit function, $\pi(p, k, t)$, defined as maximum profit obtainable at given p, k, and t, is well-behaved (monotonically increasing in the price of output and capacity and decreasing in the prices of inputs, linear homogeneous in all prices, convex in prices, and symmetric in second partial derivatives), it embodies all economically relevant information about its underlying and well-behaved production technology. Then, using Hotellings lemma, the output supply and negative input demand relationships (we do not reverse signs of the negative x_i in the following discussion) are:

$$x_i = \frac{\partial \pi(p,k,t)}{\partial p_i} \quad (i=1, 2, \ldots, n).$$

To estimate these relationships, one must find specifications for the profit function that are both well-behaved and, for my purposes, flexible. In this paper, as flexible functional form, the translog is employed. The translog model will be described in detail in the next section.

Translog model

The translog is a second order numerical approximation of the natural logarithm of a profit function about the unit vector, $p=k=t=1$. This is convenient because a unit vector of prices may be constructed at any sample point by normalizing at that point, thus assuring that the point of approximation is in the sample. The function can be written as:

$$\begin{aligned}\ln\pi(p,\ k,\ t) = {} & \alpha_0 + \sum_{i=0}^{n}\beta_i \ln p_i + \sum_{i=0}^{n}\sum_{j=0}^{n}\beta_{ij} \ln p_i \ln p_j + \sum_{i=0}^{n}\beta_{ik} \ln p_i \ln k \\ & + \sum_{i=0}^{n}\beta_{it} \ln p_i \ln t + \beta_k \ln k + \beta_t \ln t + \beta_{tt}(\ln t)^2 + \beta_{kt} \ln t \ln k \\ & + \beta_{kk}(\ln k)^2.\end{aligned}$$

Linear homogeneity and symmetry are imposed by:

$$\sum_{i=0}^{n}\beta_i = 1,\quad \sum_{i=0}^{n}\beta_{ij} = 0,\quad \sum_{i=0}^{n}\beta_{it} = 0,\quad \sum_{i=0}^{n}\beta_{ik} = 0,\quad \beta_{ij} = \beta_{ji}.$$

As specified, the translog is fully flexible in p, k, and t. But because the emphasis in this study is on substitution between variable inputs, the translog model needs only the $n+n(n-1)/2$ β_i and β_{ij} parameters required for flexibility in the variable inputs. For that reason, and to take advantage of the individual observations on input and output levels, the system of profit share equations with additive error terms, e_i is estimated:

$$\frac{\partial \ln\pi(p,\ k,\ t)}{\partial \ln p_i} = s_i = \frac{x_i p_i}{\pi} = \beta_i + \sum_{j=0}^{n}\beta_{ji}\ln p_j + \beta_{it}\ln t + \beta_{ik}\ln k + e_i$$

where s_i is the profit share for output and the negative profit shares for the variable inputs. Because the shares add to unity (and so the errors add to zero), just n of the $n+1$ share equations were estimated and the βs for the omitted equation were derived from the homogeneity restrictions. Own and cross price elasticities are:

$$\varepsilon_{ij}=\frac{\beta_{ij}}{s_i}+s_j,\ i\neq j.$$

$$\varepsilon_{ii}=\frac{\beta_{ii}}{s_i}+s_i-1.$$

The translog reduces to the Cobb-Douglas when the second-order coefficients are zero. Because the Cobb-Douglas is self-dual, (a Cobb-Douglas profit function represents a Cobb-Douglas production function), it presumably fits best when the underlying technology is, in fact, close to Cobb-Douglas. Consequently, the translog is a reasonable place to start an investigation of the substitution between inputs since it represents the "middle ground" between Leontief (no substitution) and linear (perfect substitution) technologies (Chambers 1988).

One key disadvantage is that, while global convexity may be imposed for positive output and negative input profit shares, the translog form appears to lose its flexibility properties under certain conditions. Global convexity requires that the matrix of cross-price coefficients, $\|\beta_{ij}\|$, be positive semidefinite (Jorgensen and Fraumeni 1981, Diewert and Wales 1987). According to Diewert and Wales, when the true elasticity of input demand is small (as suggested by past cost function studies), this restriction leads to own-price elasticity estimates that are too large (too elastic). Because the estimated β_{ij} will be small, the approach also produces cross-price elasticities that are close to the values of the factor shares.

4. Data

Basic data on construction industry expenditures for material; labor; and services inputs and the total value of output were derived from the 25 benchmark and annual input/output tables of Japanese economy developed in various years between 1965 and 2000 (MCA 1980, METI 2002, and MPHP 2004)[4]. The construction industry (the

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[4] These studies include eight benchmark tables derived from the quinquennial Cen-

output definition) and input categories were aggregated to the level of price measures for variable factors and output. Hence, the intermediate consolidated sector tables (104 tables) were used for the aggregation.

The construction industry can be consistently defined over the data set as all new construction, including residential, non-residential buildings and structures and alteration (but not repair) of these categories. Six variable input categories were identified. They were derived by aggregating I/O industries in the I/O accounts: timber and wooden products; ceramic, stone, and clay; metal products; other industrial products; compensation of employees (labor); and services. Net revenue (or profit) in the new construction sector was computed as the value of output for construction less expenditure on the six variable inputs.

Sources of price measures for variable factors and output are as follows. It was possible to find price index measures with industry definitions that were quite close to the 104 sectors of I/O industry classification used for the expenditure measures. The data used for timber and wooden products; ceramic, stone, and clay; metal products are Producer Price Index in the table of Input-Output Price Indexes of Manufacturing Industry by sector (Gross-weighted Base Indexes) in Economic Statistics Annual, Bank of Japan (RSD 1997, 1999, 2002, and 2003).

The price measure for new construction was calculated by dividing the total production output of new construction by the number of new dwelling construction. The data for other manufactured products is Producer Price Index for General Manufacturing Industry in the table of Input-Output Price Indexes of Manufacturing Industry. The data

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sus of Manufactures in 1965, 1970, 1975, 1980, 1985, 1990, 1995 and 2000 by the Management and Coordination Agency; and seventeen annual updates prepared by the Research and Statistics Department for the years 1978, 1979, 1981-1984, 1986-1989, 1991-1994, and 1996-1999.

utilized for labor came from the Cash Earning Indexes of regular employees for construction in Economic Statistics Annual Report of the Bank of Japan. Finally, the data for services is Corporate Service Price Indexes for all items average in Economic Statistics Annual, Bank of Japan.

Quantity indexes for output and inputs were developed by dividing the expenditure or gross revenue values from the I/O analysis by their respective price indexes. Considering the ratio of real value of capital stock to total sector output, capital use in new construction is not large relative to other sectors. Given the heterogeneous nature of the "new construction" industry as here defined and the likely diverse nature of capital employed, it is elected to treat capital as quasi-fixed. The "quantity" of the stock was estimated by the net constant dollar value of nonresidential private capital for the construction industry.

5. Estimation Results

The translog flexible functional form with free or imposed curvature conditions were estimated, comprising one output supply relation and six variable input demand equations. In the translog model, these are profit share equations and the services input relation is omitted. The prices of new construction output and the timber and wooden products and ceramic, stone, and clay inputs were treated as endogenous, since construction accounts for such large fractions of their total consumption. Instruments included all of the exogenous variables in the model: an interest rate variable, the annual growth rate of real GDP, the unemployment rate, the Japanese population growth rate, the all commodity producer price index, and prices lagged one year for timber and wooden products and ceramic, stone, and clay products.

Convexity in all systems was imposed using the methods proposed by Wiley et al. (1973) in which the β_{ij} matrix is replaced by AA^T, where A is a lower triangular matrix. The elements of $A=a_{ij}$, for $i \leq j$, are estimated and the β_{ij} matrix is constructed from them. This guarantees that the matrix $\| \beta_{ij} \|$ is positive semi-definite yielding global convexity for the translog functions. All systems were estimated using nonlinear three stage least squares. Durbin Watson statistics were computed for each equation using the contiguous subset of the observations (1979-2000). Curvature conditions were evaluated for each unconstrained system at each sample point (or globally for the variants of the quadratic function) by computing the eigen values. They should all be non-negative at all sample points for global convexity to be indicated.

Coefficient estimates

Table 1 shows the coefficient estimates and their standard errors, R^2 values (simple squared correlation of actual versus fitted values), and Durbin-Watson statistics for the two functional forms, both unconstrained and constrained for convexity. An asterisk signifies that the coefficient is at least twice its standard error, a condition that is referred to loosely as "significant" in the following discussion.[5] In this study, the primarily interest is the second order terms, the β_{ij}'s.

Even though both two forms purport to be flexible, second-order approximations, there is wide variation in the apparent precision of estimation of the key second order β_{ij} coefficients. Results in the unconstrained models are 11/28 significant coefficients in the translog. The values of R^2 for two equations are not high (0.88 and 0.82), and the value of R^2 for one equation is quite low (0.20). Others are in the middle range, ranging from 0.44 to 0.51. The low R^2 is to be expected

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5) Since the usual tests using the t distribution are invalid for equation coefficients in the current estimation context (with instrumental variables, cross-equation error linkages, and nonlinear coefficients in the constrained cases) and in any event for the estimates of the elasticities, the customary t ratios are not applicable and would, at best, be asymptotically normally distributed. If the ratios of coefficients or elasticities to their standard errors were asymptotically normal, a value of 2.0 would correspond to a significance of approximately .025 in a single-tailed test and .05 in a two-tailed test.

Table 1. Coefficient estimates.

	Unconstrained							Constrained						
	Output	Wood	Stone & Clay	Metal & MP	Other Mfg	Labor	Service	Output	Wood	Stone & Clay	Metal & MP	Other Mfg	Labor	Service
β_i	*24.62	*−4.42	−0.40	−1.32	−2.90	*−12.74	−1.84	*25.30	−3.98	0.19	−0.72	−2.13	*−14.05	−3.63
	(8.65)	(1.78)	(0.76)	(1.15)	(2.69)	(3.60)	(2.78)	(9.21)	(2.17)	(1.28)	(1.64)	(2.92)	(3.90)	(4.89)
$\beta_{i,j}$	*5.74	*−1.51	−0.47	−0.15	*−1.84	−0.44	−1.33	*7.12	*−1.63	−0.51	−0.49	*−1.68	*−2.76	−0.04
Output	(2.83)	(0.39)	(0.27)	(0.38)	(0.68)	(1.12)	(0.91)	(3.12)	(0.49)	(0.36)	(0.46)	(0.74)	(1.33)	(1.14)
		*−0.38	−0.02	*0.49	*0.47	*0.59	0.36		0.40	0.05	0.17	0.47	*0.72	−0.19
Wood		(0.14)	(0.11)	(0.13)	(0.17)	(0.20)	(0.21)		(0.25)	(0.18)	(0.21)	(0.25)	(0.31)	(0.35)
Stone			−0.16	*−0.43	0.01	0.17	*0.89			0.19	−0.11	−0.09	0.02	0.46
& Clay			(0.20)	(0.15)	(0.17)	(0.22)	(0.25)			(0.22)	(0.17)	(0.22)	(0.28)	(0.31)
Metal				−0.30	0.13	−0.02	0.30				0.26	0.25	0.34	−0.42
& MP				(0.24)	(0.18)	(0.25)	(0.30)				(0.30)	(0.26)	(0.31)	(0.38)
Other					0.37	*1.01	−0.15					*0.76	*0.94	−0.66
Mfg					(0.29)	(0.30)	(0.31)					(0.36)	(0.39)	(0.44)
						*−2.07	0.78						*1.31	−0.56
Labor						(0.64)	(0.53)						(0.77)	(0.69)
							−0.85							1.41
Service							(0.61)							(0.89)
β_{ik}	*−4.35	*1.08	0.27	0.15	*1.09	1.01	0.75	*−5.27	*1.08	0.19	0.24	0.88	*2.56	0.34
Capital	(1.65)	(0.25)	(0.16)	(0.23)	(0.41)	(0.69)	(0.54)	(1.82)	(0.32)	(0.23)	(0.28)	(0.45)	(0.79)	(0.77)
β_{it}	*3.29	*−0.84	−0.25	−0.19	*−0.90	−0.35	−0.76	*4.68	*−0.76	0.01	−0.19	−0.53	*−2.58	−0.62
Time	(1.56)	(0.25)	(0.17)	(0.22)	(0.39)	(0.71)	(0.54)	(1.75)	(0.32)	(0.24)	(0.28)	(0.44)	(0.80)	(0.81)
Eq. R^2	0.478	0.512	0.877	0.442	0.202	0.815	—	0.396	0.439	0.733	0.216	0.312	0.687	—
DW	1.06	1.19	1.60	1.36	0.754	1.16	—	1.09	1.51	0.803	0.86	0.858	1.28	—

Standard errors are in parentheses. Asterisks denote that coefficient exceeds two times the standard error.

with profit shares because any variation in factor cost that is collinear with profit is eliminated in a ratio of the two. A larger proportion of the remaining variation is therefore unexplained by the regression. Durbin-Watson statistics are very low, which show the suspect of positive autocorrelation. However, they could not be corrected because the nonlinear system model estimated is too complex and the observation numbers are too small (25 observations).

Convexity

Failure to meet curvature properties invalidates inferences arising from duality theory so that elasticity estimates are suspect. Although the translog form yields correct signs for own-price elasticities for all equations (see Table 2), testing for convexity involves more than scanning own-price elasticities. Examination of the eigen values of the Hessian matrix of second price partials at each observation for each of the unconstrained model reveals that neither of the unconstrained models possesses the required curvature properties at any of the observations.

Since the coefficient estimates are random variables, so are the Hessian matrices of second partials, and it is reasonable to seek a statistical test for convexity rather than simply counting the number of observations for which the second order conditions are satisfied. Paraphrasing Morey (1986), failure to meet concavity (in the case of cost functions) conditions at one sample point could be sufficient to reject concavity over the entire region of interest while, at the other extreme, failure at every sample point might not be sufficient to reject global concavity.

The test proposed by Morey involves replacing the $N \times N$ matrix of β_{ij}'s in the profit function with combinations of coefficients from its Cholesky decomposition TDT' (in the estimation process[6]. At the point of approximation, the profit function is positive semi-definite if the elements, d_{ii}, of D (which is diagonal) are all non-negative. The null

Table 2. Unconditional Elasticities.

	Unconstrained							Constrained						
β_{ij}, $j=$ $i=$ \	Output	Wood	Stone & Clay	Metal & MP	Other Mfg	Labor	Service	Output	Wood	Stone & Clay	Metal & MP	Other Mfg	Labor	Service
Output	*5.76	*−0.65	*−0.32	*−0.69	*−1.16	*−1.59	*−1.35	*6.00	*−0.67	*−0.33	*−0.75	*−1.13	*−1.99	*−1.13
	(0.50)	(0.07)	(0.05)	(0.07)	(0.12)	(0.20)	(0.16)	(0.55)	(0.09)	(0.07)	(0.08)	(0.13)	(0.23)	(0.21)
Wood	*9.65	−0.42	−0.19	*−1.92	*−2.04	*−3.03	*−2.05	*9.95	*−2.42	*−0.37	*−1.11	*−2.07	*−3.35	−0.63
	(1.01)	(0.36)	(0.29)	(0.35)	(0.44)	(0.53)	(0.53)	(1.28)	(0.65)	(0.47)	(0.53)	(0.65)	(0.80)	(0.90)
Stone & Clay	*7.74	−0.31	−0.57	1.13	−0.90	*−2.24	*−4.86	*7.92	−0.61	*−2.02	−0.19	−0.48	−1.58	*−3.05
	(0.69)	(0.48)	(0.84)	(0.62)	(0.72)	(0.94)	(1.06)	(0.94)	(0.77)	(0.93)	(0.73)	(0.92)	(1.19)	(1.33)
Metal & MP	*5.99	*−1.13	0.41	*−1.21	*−1.03	*−1.45	*−1.57	*6.51	*−0.65	−0.07	*−2.06	*−1.21	*−2.03	−0.49
	(0.59)	(0.20)	(0.22)	(0.36)	(0.28)	(0.37)	(0.45)	(0.71)	(0.31)	(0.26)	(0.45)	(0.39)	(0.47)	(0.58)
Other Mfg	*7.96	*−0.95	−0.25	*−0.82	*−2.28	*−2.71	*−0.95	*7.76	*−0.96	−0.13	*−0.96	*−2.74	*−2.62	−0.34
	(0.81)	(0.20)	(0.20)	(0.22)	(0.34)	(0.37)	(0.37)	(0.88)	(0.30)	(0.26)	(0.31)	(0.43)	(0.47)	(0.52)
Labor	*6.06	*−0.78	*−0.35	*−0.64	*−1.51	*−1.14	*−1.64	*7.59	*−0.86	−0.25	*−0.89	*−1.46	*−3.38	−0.75
	(0.75)	(0.14)	(0.15)	(0.16)	(0.21)	(0.43)	(0.35)	(0.88)	(0.20)	(0.19)	(0.20)	(0.26)	(0.51)	(0.46)
Service	*6.96	*−0.71	*−1.03	*−0.93	*−0.71	*−2.21	*−1.36	*5.80	−0.22	*−0.65	−0.29	−0.25	−1.01	*−3.38
	(0.81)	(0.19)	(0.22)	(0.27)	(0.28)	(0.47)	(0.54)	(1.03)	(0.31)	(0.28)	(0.34)	(0.39)	(0.62)	(0.80)

Standard errors are in parentheses. Asterisks denote that coefficient exceeds two times the standard error.

hypothesis (that the profit function is convex) is that $d_{ii} \geq 0$ for all i at all M observations. This involves $N \times M$ t-tests of the d_{ii}, suggesting a Bonferroni t-test (Lau 1978). The null hypothesis is rejected if at least one:

$$\hat{d}_{ii} < -t_{\alpha}(\infty)[VAR(\hat{d}_{ii})]^{\frac{1}{2}}$$

where $t_{\alpha}(\infty)$ is the t-value for a single test at the α significance level, and $VAR(\cdot)$ is the variance of estimated d_{ii}. The overall significance level of the test is $N \times M \times \alpha$, so the α must be set at a very small value to obtain an overall test with a reasonably small probability of falsely rejecting a true hypothesis.

In $N \times M = 150$ applications in the translog model, the test above was violated for one eigen value in seven of the observations at the overall .05 level and in 5 observations at the overall .01 level. Thus the estimated function cannot be said to be convex over the full data sample, though it may be over a small subset excluding these observations. In light of these results, all of the functional forms imposing convexity are reestimated.

Constraining for convexity decreased the precision of the estimates of the second order coefficients; from 11/28 to 8/28 significant coefficient estimates for the translog (see Table 2). They did not change sign except two cases and they remained similar in magnitude. R^2 and Durbin-Watson values were also similar across the two models.

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6) The matrix T has the form:

$$\begin{bmatrix} 1 & 0 & \cdots & 0 \\ t_{21} & 1 & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ t_{n1} & t_{n2} & \cdots & 1 \end{bmatrix}$$

where D is:

$$\begin{bmatrix} d_{11} & 0 & \cdots & 0 \\ 0 & d_{22} & \cdots & 0 \\ \vdots & \vdots & & \vdots \\ 0 & 0 & \cdots & d_{nn} \end{bmatrix}.$$

Thus the Cholesky decomposition involves the same number of parameters as the original β_{ij}.

Unconditional Elasticities

Estimates of unconditional elasticities computed at sample period means are shown in Table 2. Standard errors are also shown in the parentheses in elasticity tables. These were obtained by approximation using numerical methods (the TEST command in SHAZAM) or the simulation method of Krinsky and Robb (1986, 1990, and 1991). The elasticities are non-linear functions of random variables. The numerical approach (TEST) uses a linear approximation around the estimated coefficient values and then computes the variance of the resulting linear function of the coefficients. See Toevs (1982) for an example of this method applied to the translog cost function.

Krinsky and Robb's simulation approach samples from the joint distribution of the coefficients, computes the elasticities (at assumed fixed values of the variables) and estimates a variance from the sample. Krinsky and Robb (1991) have shown that results are identical to the numerical approximation method (in unconstrained estimation). This approach is indicated when the elasticities are highly complex. As before, asterisks denote elasticity estimates at least twice their standard errors, which are referred to as significant.

Imposition of convexity on the model changed very little. Own price elasticities had the expected sign before convexity was imposed. All output elasticities had the expected signs; the own-price or supply elasticity was positive and output-input price elasticities were negative. The output own-price and factor demand-output price elasticities were all positive. The two cross-price elasticities for ceramic, stone, and clay, and material did not have the expected signs, which were not significant in the unconstrained model, changed to the expected signs in the constrained model. Three elasticities that were not significant in the unconstrained model turned to significant, and ten elasticities that were significant in the unconstrained model changed to insignificant in the constrained model, but were similar in magnitude.

All but two of the factor demand cross-price elasticities involving timber and wooden products were significant in the constrained model. All elasticity estimates (including significant elasticity estimates were 41/49 in the unconstrained model and 34/49 in the constrained model) were negative in the constrained model. All significant factor demand cross-price elasticities are negative, indicating gross complementarity between all inputs.

6. Conclusions

This paper examined a complementarity proposition suggested by ecological economists that natural capital (natural resources) and human-made capital are complements rather than substitutes, by empirically examining data on new construction in Japan. This proposition is explained by using house construction example as the following (Costanza et al. 1997). In the case of new house construction, we need both wood products such as timber and wooden products as well as non-wood products such as metal products. In general, metal products can be substitutable for wood products (for example, metal can be used in house frames instead of wood).

However, both wood and non-wood products play the same qualitative role in house production. In other words, both products play the role of agent of transformation of resource inputs into product house. On the other hand, both wood and metal are raw materials undergoing transformation into a house. When we come to substitution between the two different roles (agent of transformation and material undergoing transformation), the possibilities of substitution are reduced to a limited degree while that of complementarity is dominant. As Daly points out, we cannot build the same house with half the wood products no matter how many extra metal products are used.

To examine this proposition, a profit function approach was used to derive unconditional input demands and product supply. As flexible functional form, translog was employed to analyze the input relationships appearing on elasticity estimates. The translog model yielded significant estimates of unconditional cross-price elasticities for wood inputs such as timber and wooden products, and other non-wood inputs. They were all negative, indicating that wood and non-wood inputs may be gross complements, not substitutes.

This result is the same as the one in Naito (2003), which used the data for the U.S. economy between 1947 and 1987. The complementarity between natural and human-made capital are held in two developed countries at this point in time. This result has further strengthened the complementarity theory proposed by ecological economists.

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