Nonparametric Test for Translog Specification of Production Function in Japanese Manufacturing Industry

Y. Konishi[a] **and Y.Nishiyama**[b]

[a] *Graduate School of Economics, Nagoya University*

[b] *Graduate School of Environmental Studies, Nagoya University,Huro-cho Chikusa Nagoya, 464-8601 Japan*

Abstract: Beginning with a series of pioneering work by Cobb and Douglas, estimation of production function has been one of the main issues in empirical economics and econometrics in various aspects. The functional form they used is called Cobb-Douglas production function. It is later generalized to so-called translog production function which has a more flexible form to describe the relation between the output and input levels. It is also analytically convenient for obtaining factor demand functions or cost function so that it has been widely used in both macroeconomic and microeconomic empirical studies. However, it is well known that statistical analysis leads to incorrect conclusions in general if the specified parametric model is wrong. This paper tests for the translog specification of production function for Japanese manufacturing industry. We apply the nonparametric misspecification test by Hong and White [1995]. It is a consistent test having nontrivial power against local alternatives. We test the null hypothesis of translog specification using cross section data of Japanese manufacturing firms listed in Tokyo Stock Exchange market. We also test the Cobb-Douglas specification by the same method.

Keywords: Translog production function; Nonparametric specification test; Japanese manufacturing indutry

1. INTRODUCTION

Production technology of a firm or an economy is characterized by its production function (or cost function alternatively) so that if one would like to investigate economic aspects associated with producer's behaviour, we need to study the production function. Beginning with a series of pioneering work by Cobb and Douglas [1928, 1948] and Douglas [1927, 1934], estimation of production function has been one of the main issues in empirical economics and econometrics. The production function they consider has the form,

$$Y = AK^{\alpha}L^{\beta} \quad (1.1)$$

where Y, K, L indicate the output level, capital and labour inputs respectively and A, α, β are parameters determining the production technology. If $\alpha + \beta = 1$, this production technology is said to be constant returns to scale. Taking the logarithm, we obtain

$$\log Y = \log A + \alpha \log K + \beta \log L \,. \quad (1.2)$$

(1.1) or equivalently (1.2) is called the Cobb-Douglas production function. Christensen, Jorgenson and Lau [1973] consider an extension of the Cobb-Douglas production function to the following more general and flexible functional form.

$$\log Y = \alpha_0 + \alpha_K \log K + \alpha_L \log L + \frac{1}{2}\alpha_{KK}(\log K)^2 + \frac{1}{2}\alpha_{LL}(\log L)^2 + \alpha_{KL}\log K \log L$$

(1.3)

They call it the transcendental logarithmic (translog) production function.

Production function estimation itself could be of direct interest, but it is often the case that we are more interested in some other economic quantities associated with production functions. For example, researchers studying economic growth may like to quantitatively determine the technological progress, while labour economists may be interested in effects of human capital to productivity. Public economists may wish to measure the marginal effect of social capital stock. Either Cobb-Douglas or translog function has been employed for these purposes and used to estimate the production function. Solow [1957] looks at the constant term of the Cobb-Douglas production function to calculate the total factor productivity (TFP). Recent developments on this are in Romer [1986], Lucas [1988], Mankiw, Romer and Weil [1992] and Benhabib and Spiegel [1994] among others.

They have influenced the subsequent research in empirical macro economic studies. Temple [1999] gives a detailed survey about the new growth theory and the empirical work based on it. There is a considerable number of studies focusing on the comparison of productivity among countries or industries using mainly the translog production function, e.g. Jorgenson and Nishimizu [1978]. There are some research on productivity in Japan or its comparison with other countries as in e.g. Jorgenson, Kuroda and Nishimizu [1987]. There is also a vast number of studies on the effects of human capital and social capital stock.

To the best of our knowledge, Nerlove [1963] is the first empirical study which uses cross section data of individual firms to investigate production techonology. He estimates Cobb-Douglas cost function using 145 observations on American electric generating companies to analyze U.S. electric power industry, while Christensen and Greene [1976] and others extend it to employ the translog form.

To examine production efficiency, scale economy, and technological changes, production frontier approach is developed by Farrell [1957]. Empirical applications based on it are found in Aigner and Chu [1968] and others. The early studies assume that the frontier is deterministic. Aigner et al. [1977] extend it to a stochastic frontier model, which is mainly estimated using panel data. See Battese and Coelli [1988], Kumbhakar [1987, 1988, 1990] among others. Various extensions allowing for time- and firm-specific effects are considered in Cornwell et al. [1990], and Kumbhakar [1990, 1991]. For this kind of analysis, Cobb-Douglas and translog models are used.

Parametric models such as (1.2) and (1.3) have been widely used in a lot of empirical studies as seen in the above. However, it is well known that if the employed parametric model is incorrect in fact, statistical inferences based on it is wrong in general. In the current context, for example, if we specify the production function as the translog, but it is incorrect in fact, then TFP calculated from the estimates will be different from the true value. We, therefore, would like to test for the functional specification (1.2) and (1.3) in view that they are very commonly used. There are a number of specification tests we can use. A classical method is Ramsey's RESET test. It assumes that the regression function includes higher order powers of the null regression function under the alternative. There have been developped some nonparametric specification tests which need not specify the alternative functional form such as Bierens [1982], Bierens and Ploberger [1987], Hong and White [1995] and Hitomi [2000] among others. They are compared in Hitomi [2000] under various alternatives in small sample by Monte Carlo, and it is shown that Hong and White test has a relatively better power among well-established alternatives in small sample.

We are concerned with the production function of Japanese manufacturing firms. We test the null of (1.2) or (1.3) against the nonparametric alternative using the annual financial report of Japanese manufacturing firms listed in Tokyo Stock Exchange market, division one, for the years from 1965 to 2000. We observe that both functional forms are rejected after around 1980, while they are not rejected before then.

The following section shows preliminary results of inference on the production function based on Cobb-Douglas and Translog specification and gives some comments. Section 3 reviews some nonparametric specification methods, while Section 4 gives results of the Hong and White nonparametric specification test for the empirical data, while concluding remarks are in Section 5.

2. PRELIMINARY STATISTICAL ANALYSIS

2. 1 Estimation

We implemented cross sectional OLS regression as a preliminary study based on (1.2) and (1.3) for each year of 1965-2001. It is because we are not sure if the parameters or more generally production technology including its functional form is unchanged across time.

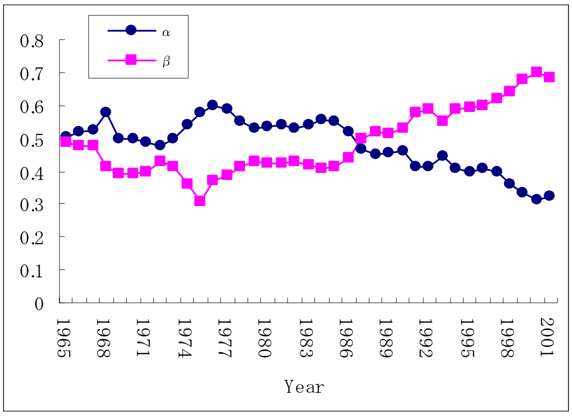

Figure 1. Coefficient estimates of Cobb-Douglas function.

Figures 1 shows the coefficient estimates of Cobb-Douglas specification (1.2). The horizontal axis is the calendar year, and circles and squares indicate estimates of α and β respectively for each year. We find the following features: [1] the parameters appear to have changed a lot during the period of 1965-2001. [2] The parameter associated with labour input has been mostly increasing since the middle of 1970's, while that associated with capital has been decreasing in the same period. [3] Labour and capital productivity show an amazing mirror image after late 1970's even though we did not assume the constant returns to scale restriction $\alpha+\beta=1$. We observe the followings for coefficient estimates of translog in Figures 2 and 3: [1] all the parameters look more or less time varying, especially α_K and α_L. [2] It appears α_K and α_L change with mirror image, but not so clear as in Cobb-Douglas estimates. [3] α_{KK} and α_{LL} co-moves, symmetrically with α_{KL}.

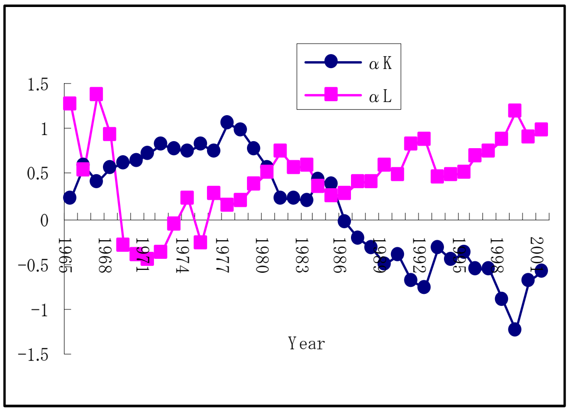

Figure 2. Coefficient estimates of translog function

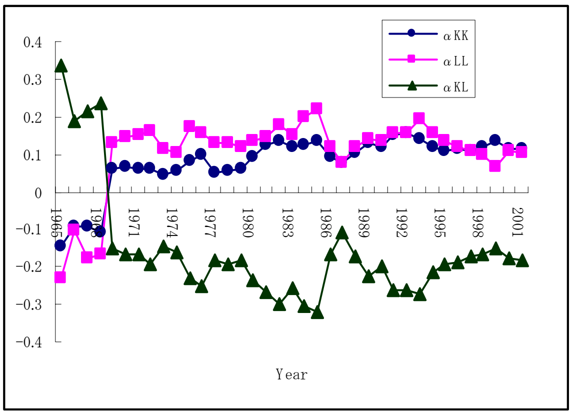

Figure 3. Coefficient estimates of translog function.

We think that these findings are quite interesting, but we do not discuss these here anymore, because estimation of production and drawing implications from it are not our primary object.

2.2 RESET test

The above observations have an important implication in our current analysis. They suggest that the production technology seems to have been changing throughout the time, so that it is natural to suppose that not only the parameters but also the functional form could be different across time. Thus, it will be inappropriate to take a standard panel model in textbooks to analyze this data because it cannot handle functional form changes across time. Therefore, in the following, we treat the data as a sequence of cross section data.

A classical specification test of regression function is the Ramsey's RESET test. Suppose y is a scalar random variable, x is a $d \times 1$ vector of random variables, and we are interested in the regression function $E(y\,|\,x)$. It tries to test if the regression function is linear in x or not. Specifically, the test is

$$H_0: \quad y = x'\beta + \varepsilon$$

against

$$H_1: \quad y = x'\beta + \alpha_1 (x'\beta)^2 + \ldots + \alpha_{P-1}(x'\beta)^P + \varepsilon$$

for some *P*. If the true regression function admits a polynomial approximation as in H_1, this test will have power.

The results of RESET test are in Table 1 (a). The second column shows test results of the Cobb-Douglas null, while the second one indicates those of the translog null. "O", "X" and "XX" mean respectively that the null hypothesis is "not rejected", "rejected at 5% size" and "rejected at 1% size". We find that both Cobb-Douglas and translog specifications are mostly appropriate in the old days before around the end of 1970's, but they are rejected after 1980. These results say that not only the parameters of production function but also its functional form is changing over time. Whichever specification we take, a structural change appears to have taken place around 1977-1979. looks to be the time of the structural change.

In Table 1 (a), we find a logical inconsistency that translog is rejected at 1% size inspite that Cobb-Douglas is not in 1979. It looks unusual because Cobb-Douglas is nested in translog model. It could possibly be because of the small sample size, but this can happen in RESET test in fact because the alternatives corresponding to Cobb-Douglas null and translog null are different so that the test with Cobb-Douglas null may not have a sufficient power.

3. NONPARAMETRIC TESTS FOR FUNCTIONAL FORM OF REGRESSION FUNCTIONS

In regression analysis, we cannot make a correct inference if we use a wrong functional form of the regression. We would like to test if a parametric regression function employed is correctly specified. One such test is the RESET test in the previous section. But its power is not so high if the specified alternative hypothesis is incorrect in fact. Godfrey et. al. (1988) point it out by some Monte Carlo studies. Specifically, this is a test for the null hypothesis of $E(\varepsilon \mid x'\beta) = 0$, not that of

$$E(\varepsilon \mid x) = 0\,, \tag{3.1}$$

which is of our interest. Since 1980's there have been developed some tests which directly check (3.1). Mostly orthogonality conditions, that disturbances have zero mean conditionally on the regressors, is tested without employing a well-specified alternative. Bierens [1982] first take this approach to propose a test of the null

$$H_0:\ P[E(y \mid x) = m(x;\,\beta)] = 1 \tag{3.2}$$

against

$$H_1:\ P[E(y \mid x) = m(x;\,\beta)] < 1 \tag{3.3}$$

given a parametric functional form of the regression such as $m(x;\,\beta) = x'\beta$. He exploits the fact that H_0 is true if and only if

$$E[\{y - m(x;\,\beta)\}\exp\{it'\Phi(x)\}] = 0$$

for any measurable function $\Phi(.)$. Thus his test statistic is

$$\int \Big| \frac{1}{n}\sum_{j=1}^{n}\{y_j - m(x_j;\,\hat{\beta})\}\exp\{it'\Phi(x_j)\}\Big|^2 dt$$

given an iid sample $(y_j,\, x_j),\ j = 1,\ldots,n$ and a consistent estimate $\hat{\beta}$ under H_0. This test is called a conditional moment (CM) test. However, this test statistic involves intractable null distribution. This idea is extended in a series of articles by Bierens and his co-authors to various data generating processes.

It is possible to construct functional form tests for (3.2) against (3.3) based on a direct comparison between residuals from parametric and nonparametric estimates for the regression function. One such approach taken by Hong and White [1995] is the following. For simplicity, denoting $m(x) \equiv E(y \mid x)$, suppose we would like to test the null of $m(x) = x'\beta$. It is easily seen that

$$E\{m(x) - x'\beta\}(y - x'\beta) = 0$$

if and only if H_0 holds. Letting $\hat{\beta}$ and $\hat{m}(.)$ be the OLS estimate of β and a series estimate of $m(.)$ respectively, they propose to test the null based on the sample analogue,

$$M_n \equiv \frac{1}{n}\sum_{j=1}^{n}\{\hat{m}(x_i) - x_j'\hat{\beta}\}(y_j - x_j'\hat{\beta})\,.$$

Their test statistic is

$$T_n = (2p_n)^{-1/2}\Big(\frac{n\,M_n}{\hat{\sigma}^2} - p_n\Big)$$

where $\hat{\sigma}^2$ is a consistent estimate for the variance of error term under H_0, and $p_n \to \infty$ as $n \to \infty$, is the number of orthogonal basis functions in the estimation of $\hat{m}(.)$. They prove $T_n \xrightarrow{d} N(0,1)$ as $n \to \infty$ under H_0. A similar test is proposed by De Jong and Bierens [1994].

Hitomi [2000] finds CM test does not have much power in small samples under certain alternatives because some moment conditions are not effectively used. He also finds that some consistent misspecification test statistics including CM, Hong and White and some others have a common structure of weighted squared sum of normalized correlation coefficients between residuals and orthonormal base functions.

Related articles include Eubank and Spiegelman [1990], Wooldridge [1992], Yatchew [1992], Gozalo [1993] and Hardle and Mammen [1993]. There is a paper which compares nonparametric and semiparametric models as Fan and Li [1996].

4. RESULTS

Among the alternative candidates, we take Hong and White [1995] test (abbreviated to HW test hereafter) following Hitomi's [2000] simulation study. Table 1 (b) shows the results of HW test. "O", "X" and "XX" mean the same as those for RESET test results in Table 1 (a). The results from the two tests are not terribly different. Cobb-Douglas is not rejected before 1978, but is rejected after 1979. The boarder is clear. We find the translog used to be a model we can employ before about 1979-1983, but not any more after 1984. The boarder appears to be just about the second oil shock. We may be able to explain these test results that Japanese firms try to adjust the structural change caused by the two shocks and change their technology suitably. We do not try to discuss in detail why this happens in this paper.

Table 1. Results of (a) RESET test and (b) HWtest.

	(a) RESET test		(b) HW test	
Year	C-D	Translog	C-D	Translog
1965	O	O	O	O
1966	O	O	O	O
1967	O	O	O	O
1968	X	O	O	O
1969	X	O	O	O
1970	XX	X	O	O
1971	O	O	O	O
1972	O	O	O	O
1973	O	O	O	O
1974	O	O	O	O
1975	O	O	O	O
1976	O	O	O	O
1977	X	O	O	O
1978	X	X	O	O
1979	X	XX	XX	X
1980	XX	XX	XX	X
1981	XX	XX	XX	O
1982	XX	XX	XX	O
1983	XX	XX	XX	O
1984	XX	XX	XX	XX
1985	XX	XX	XX	XX
1986	XX	XX	XX	XX
1987	XX	XX	XX	XX
1988	XX	XX	XX	XX
1989	XX	XX	XX	XX
1990	XX	XX	XX	XX
1991	XX	XX	XX	XX
1992	XX	XX	XX	XX
1993	XX	XX	XX	XX
1994	XX	XX	XX	XX
1995	XX	XX	XX	XX
1996	XX	XX	XX	XX
1997	XX	XX	XX	XX
1998	XX	XX	XX	XX
1999	XX	XX	XX	XX
2000	XX	XX	XX	XX
2001	XX	XX	XX	XX

O : null not rejected
X : null rejected at 5% size
XX : null rejected at 1% size

One interesting feature is that the logically inconsistent conclusion in the RESET for 1979 disappeared in HW test. In HW and other nonparametric specification tests, the alternative is the same for both Cobb-Douglas and translog nulls so that this kind of inconsistency found in RESET does not normally happen.

These results of RESET and HW tests warn us against using Cobb-Douglas or translog specification in empirical studies especially for years after 1980. We also know from them that it may not be a suitable way to estimate "macro production function" using time series data, which typically assumes that not only parameters of the production function but also its functional form does not change over time. Cobb-Douglas production function was empirically developed in 1950's, when this model fit the data well. However, the production technology seems to have been improved and that of old day form does not apply any more. To deeply investigate why and how it happened, and how we can analyze it with what kind of model are left for the future research. We believe this is an interesting finding for both economists and econometricians.

5. CONCLUDING REMARKS

We tested if Cobb-Douglas and translog specification of production function is correct or not for Japanese manufacturing industry in the period of 1965-2001. We found that they are roughly correct before 1970's, but incorrect after 1980. It warns that estimated macro or micro production functions from time series or panel data based on either functional form with fixed coefficients across time could be distorted in fact and statistical inferences based on it may be incorrect. We find it serious because most of well-established research on growth theory or human capital effects uses either of them.

Our analysis however includes some problems. Firstly, we treated the data as a sequence of cross section data, where we need to assume there exists the "production function of manufacturing industry" and we can make an inference on it using cross section data of different manufacturing firms. Investigating under which conditions it is possible and if they are satisfied are still open questions. Secondly, we limited our null hypothesis to translog function up to second order because it is most widely used, but it is possible to include higher order terms. Their inclusion could change the results. Thirdly, we employed a very simple cross section model, estimated and tested it for different years. Doubtlessly it is not the best model. It would be possible to construct a panel model which could handle time-varying functional form and/or parameters. We will be able to draw a better inference from it. Research on this direction is currently under way. Other future research possibility will be, for example, to incorporate production frontier analysis. Research for non-manufacturing industry is also currently under way.

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