Productivity and Technical Change: Measurement and Testing*

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Abstract

This paper considers two specifications, namely, the time trend (TT) and general index (GI) of technical change. These models are extended to accommodate the TFP growth accounting relationship in to the econometric model. We also propose a formal test to determine whether the TT or the GI model is appropriate for the data.

Key words: Total factor productivity growth, Divisia index, technical change, returns to scale.

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1. Introduction

Baltagi and Griffin (1988) proposed a procedure for estimating a general index (GI) of technical change. This procedure gives a measure of total factor productivity (TFP) growth that is generally found to be close to the Divisia index (obtained directly from the data without any econometric estimation). They also found that the GI method performs better than the popular time trend (TT) model in tracking the observed TFP growth (the Divisia index). This evidence is supported by other empirical studies as well (e.g., Baltagi, Griffin and Rich (1995), Kumbhakar and Heshmati (1996), Kumbhakar, Nakamura and Heshmati (2000), among others).

TFP growth and its components (viz., technical change (TC) and scale (SC)) in parametric models are calculated using the estimated parameters of the parametric model and observed data. Sum of these components, quite often, diverges from the observed TFP growth obtained independently from the data. Theoretically, the Divisia index is the sum of TC and SC, irrespective of the functional form chosen to represent the production technology. But in practice a wide gap between the two measures is often observed (e.g., see Capalbo (1988)). This gap cannot be solely explained in terms of difference between the true and estimated parameters. This divergence problem can be avoided by adding the definition of TFP growth equation in the econometric model.[1]

In this paper we consider two extensions of the Baltagi and Griffin model. The first one is concerned with estimation of the model and the second one is related to testing the functional form (viz., the TT vs. the GI) specification. We propose a formal test to determine whether the GI model is appropriate for the data or not. We also estimate both the TT and GI models with and without the TFP growth equation appended in the cost system used in estimating the production technology.

2. Specification of Technical Change

2.a The Time Trend (TT) Model

Let the production process be specified by the dual translog cost function because it imposes minimum a priori restrictions on the underlying production technology and it

[1] Some differences might be observed due to the discrepancy between the estimated and true values of the parameters.

approximates a wide variety of functional forms. Assuming that panel data is available, the single output translog cost function can be written as

$$\ln C_{it} = \beta_0 + \sum_j \beta_j \ln P_{jit} + \beta_y \ln Y_{it} + \beta_t t + \frac{1}{2}\{\sum_j \sum_k \beta_{jk} \ln P_{jit} \ln P_{kit} + \beta_{yy}\{\ln Y_{it}\}^2 + \beta_{tt} t^2\} + \sum_j \beta_{jy} \ln P_{jit} \ln Y_{it} + \sum_j \beta_{jt} \ln P_{jit}\, t + \beta_{yt} \ln Y_{it}\, t, \tag{1}$$

where $\beta_{jk} = \beta_{kj}$, $\sum_j \beta_j = 1$, $\sum_j \beta_{jk} = 0 \;\forall\; k$, $\sum_j \beta_{jy} = 0$, and $\sum_j \beta_{jt} = 0$. The first restriction is due to symmetry and the rest follows from the fact that the cost function is homogeneous of degree one in input prices. C is the total cost, P_j is the jth ($j = 1, \ldots, J$) input price and Y is the output. The subscripts i and t denote respectively, the firm and time periods. The time variable t in the cost function represents shifts in the production technology.

From the above cost function one can compute technical change (TC_TT) which is defined as the percentage change in the total cost over time, *ceteris paribus*,

$$TC\_TT_{it} = -\partial \ln C_{it}/\partial t = -[\beta_t + \beta_{tt} t + \sum_j \beta_{jt} \ln P_{jit} + \beta_{yt} \ln Y_{it}]. \tag{2}$$

One can measure returns to scale, RTS_TT from

$$RTS\_TT_{it} = 1/\theta\_TT_{it}, \tag{3}$$

where

$$\theta\_TT_{it} = \partial \ln C_{it}/\partial \ln Y_{it} = \beta_y + \beta_{yy} \ln Y + \sum_j \beta_{jy} \ln P_{jit} + \beta_{yt} t. \tag{4}$$

Finally using the definition of TFP growth (the Divisia index) it can shown that

$$T\dot{F}P \equiv \dot{Y} - \sum_j S_j \dot{x}_j = TC\_TT + (1 - \theta\_TT)\dot{Y}, \tag{5}$$

where $S_j = P_j x_j / C$ is the cost share of the jth input. TFP growth is thus decomposed into a technical change (TC) and a scale (SC) component. These components are calculated using the estimated parameters of the cost function and data.

2.b The General Index (GI) Model

The translog cost function incorporating the general index can be written as

$$\ln C_{it} = \beta_0 + \sum_j \beta_j \ln P_{jit} + \beta_y \ln Y_{it} + \beta_a\, A(t) + \frac{1}{2}\, \{ \sum_j \sum_k \beta_{jk} \ln P_{jit} \ln P_{kit} + \beta_{yy} \{\ln Y_{it}\}^2 + \beta_{aa}\, A(t)^2 \} + \sum_j \beta_{jy} \ln P_{jit} \ln Y_{it} + \sum_j \beta_{jt} \ln P_{jit}\, A(t) + \beta_{yt} \ln Y_{it}\, A(t), \tag{6}$$

where $A(t)$ is the index of technical change. The above function differs from the formulation used in Baltagi and Griffin (1988) in the sense that we included the $A(t)^2$ term explicitly. Baltagi and Griffin (1988) replaced t and t^2 by a general $A(t)$ function. However, they did not include the $A(t)^2$ term because this was estimated using time dummies and the square of time dummies are the time dummies themselves. We show that it is possible to include the $A(t)^2$ term explicitly in the translog function. By doing so we get the GI model from the TT model when t is replaced by $A(t)$ (as stated in Baltagi and Griffin (1988, page 26)). Another reason for doing this is that the translog function is a second order approximation, and therefore inclusion of all the square terms is preferred.

Analogous to the time trend model, technical change in the general index model (TC_GI) is defined as

$$\begin{aligned} TC\_GI_{it} = &-\{A(t) - A(t-1)\}\{\beta_a + \frac{1}{2}\,\beta_{aa}\{A(t) + A(t-1)\}\} \\ &- \{A(t) - A(t-1)\}\{\sum_j \beta_{jt} \ln P_{jit} + \beta_{yt} \ln Y_{it}\} \end{aligned} \tag{7}$$

which is (7) is both firm and time-specific.

Finally returns to scale, RTS_GI, is obtained from

$$RTS\_GI_{it} = 1/\theta\_GI_{it}, \tag{8}$$

where

$$\theta\_GI_{it} = \partial \ln C_{it}/\partial \ln Y_{it} = \beta_y + \beta_{yy} Y + \sum_j \beta_{jy} \ln P_{jit} + \beta_{yt} A(t), \tag{9}$$

and TFP growth from

$$\dot{TFP} = TC\_GI + (1 - \theta\_GI)\dot{Y}. \tag{10}$$

3. Estimation, Testing and Results

We use a panel data (see Kumbhakar, Nakamura and Heshmati (2000) for details) for 72 firms in the Japanese chemical industry for the period of 1968 to 1987 to estimate the TT and GI models specified in the preceding section, using capital, labor and materials as inputs. The cost function, two cost share equations (labor and capital), and the TFP growth equation ((5) for the TT model and (10) for the GI model) constitute the cost system in both the TT and the GI models. We label these models as TT_e and GI_e. Since the TFP growth is decomposed into TC and SC components, the sum of TC and SC should be close to the observed TFP growth. This is the reason why equation (5) (for the TT model) and (10) (for the GI model) are included in estimation (see Gollop and Roberts (1981) for a somewhat similar procedure). We append classical error terms in all the equations. Both full information maximum likelihood (FIML) and nonlinear iterative seemingly unrelated (NLITSUR) regression procedures are used. Since the results are very similar, we report the results based on the FIML estimates.

We estimate one parameter in $A(t)$ for each t. That is, the parameters in $A(t)$ are obtained from $\lambda_t\, DT_t$ where DT are the year dummies and λ_t are the associated parameters. However, we need to impose some normalizing restrictions since all the λ_t parameters cannot be identified. These identifying restrictions are $\lambda_1 = 1, \lambda_2 = 2$, and $\lambda_3 = 3$ (instead of $\beta_a = \beta_{aa} = 1$ and $\lambda_1 = 0$ used in Baltagi and Griffin).[2] Thus, if $\lambda_t = t$ for $t = 4, \ldots, T$ then the GI model reduces to the TT model. Thus we specify the null hypothesis as

$$H_0 : \lambda_t = t \;\forall\; t = 4, \ldots, T$$

which imposes $T - 3$ linear restrictions on the λ parameters. These restrictions are tested using the LR test. The LR test overwhelmingly rejects the null at the 5% level of significance (the LR statistic = 522.16 and $\chi^2_{17,.05} = 27.59$).

[2] Note that these identifying restrictions affect neither the value of the loglikelihood function nor the estimates of RTS, TT and other features of the technology. These normalizations make the comparison between the TT and GI models straightforward.

We also estimated the original version of the TT and GI models used by Baltagi and Griffin (i.e., the above system of equations are estimated without the TFP growth equations built into the system). We label these models as TT_o and GI_o. Note that the TFP growth equation does not contain any additional parameters. That is the number of parameters in both sets of models (i.e., TT_e, TT_o and GI_e, GI_o) are the same. We test additional flexibility of the GI model by imposing the above restrictions (i.e., $\lambda_t = t$ for $t = 4, \ldots, T$). The null hypothesis is strongly rejected at the 5% level of significance (LR = 152.86, and $\chi^2_{17,.05} = 27.59$).

Thus, in both cases (i.e., whether TFP growth equation is appended or not) the TT model is rejected in favor of the GI model. Consequently, one can argue that the GI model is better than the TT model not because it traces the path of actual TFP growth better or can identify the downturns in TFP growth more accurately than its competitor, but because the TT model specification is rejected by the data using a formal statistical test.

We calculate TFP indices from $TFP_t = TFP_{t-1}(1 + T\dot{F}P_t)$ using $TFP_{1968} = 100$. The results are reported in Figures 1(a) and 1(b). In Figure 1(a) we plot TFP indices derived from the Divisia, $T\dot{F}P_{GI_0}$ and $T\dot{F}P_{GI_e}$. All three indices are very close to each other, and TFP indices based on both the extended and original models (labeled by the subscripts e and o) trace the Divisia TFP index quite well. This is, however, not the case for the TFP indices derived from the TT models, as shown in Figure 1(b). The TFP index deviates from the Divisia index substantially, in some years, even for the TT_e model in which the TFP growth equation is used as an extra equation in estimation. Part of the reason for large fluctuations in TFP growth in the TT models is that technical change is somewhat smoother by construction. The GI models, on the other hand, are designed to handle large year-to-year fluctuations in technical change by estimating one parameter for each year in the $A(t)$ function.

In Table 1 we report (for selected time intervals) average TFP growth (the Divisia) rates, predicted values of TFP growth and its components (TC and SC) for the GI_e and TT_e as well as the GI_o and TT_o models. We find that the major reason for dissimilar patterns of TFP growth predicted by the TT and GI models is due to differences in the estimates of both technical change and scale economies. Scale components are found to be much smaller relative to the TC components in the GI models. It is just the opposite for the TT models.

4. Conclusions

In this paper we considered two extensions in modeling technical change proposed by Baltagi and Griffin (1988). First, we built in the TFP growth equation in the system of equations in both the time trend and the general index models. Second, we suggested a test to determine which of the models (TT vs. GI) is appropriate for the data. A panel data on 72 Japanese chemical firms observed for 20 years is used to estimate both the TT and GI models. The test result shows that the GI model is most appropriate for the data. A similar test on the models excluding the TFP growth equation also supports the GI specification. These test results give an additional degree of confidence in using the GI models and results derived therefrom. Given that the data shows wide fluctuations in the observed TFP growth, it is expected that the GI specification that is designed to handle year-to-year fluctuation will outperform the TT model.

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Table 1: TFP growth decomposition under alternative models

	Time Trend Model							General Index Model					
	Extended				Original			Extended			Original		
Year	Divisia	TC	SC	$\dot{TFP}_{TTe}$	SC	TC	$\dot{TFP}_{TTo}$	SC	TC	$\dot{TFP}_{GIe}$	SC	TC	$\dot{TFP}_{GIo}$
1969-72	1.864	1.633	-0.140	1.493	0.828	0.168	0.995	0.332	0.383	0.715	0.157	0.509	0.666
1973-76	0.338	0.420	0.115	0.534	0.242	0.375	0.616	0.146	0.996	1.142	0.090	0.989	1.079
1977-80	-0.896	0.308	0.290	1.162	0.088	0.500	0.588	0.030	-0.160	-0.130	0.016	0.134	0.150
1981-84	2.026	0.613	0.467	1.080	0.291	0.647	0.937	0.152	1.912	2.063	0.076	1.826	1.902
1985-87	2.105	0.655	0.725	1.380	0.251	0.870	1.120	0.098	1.464	1.562	0.039	1.433	1.472

Figure 1(a): TFP Index (GI Models)

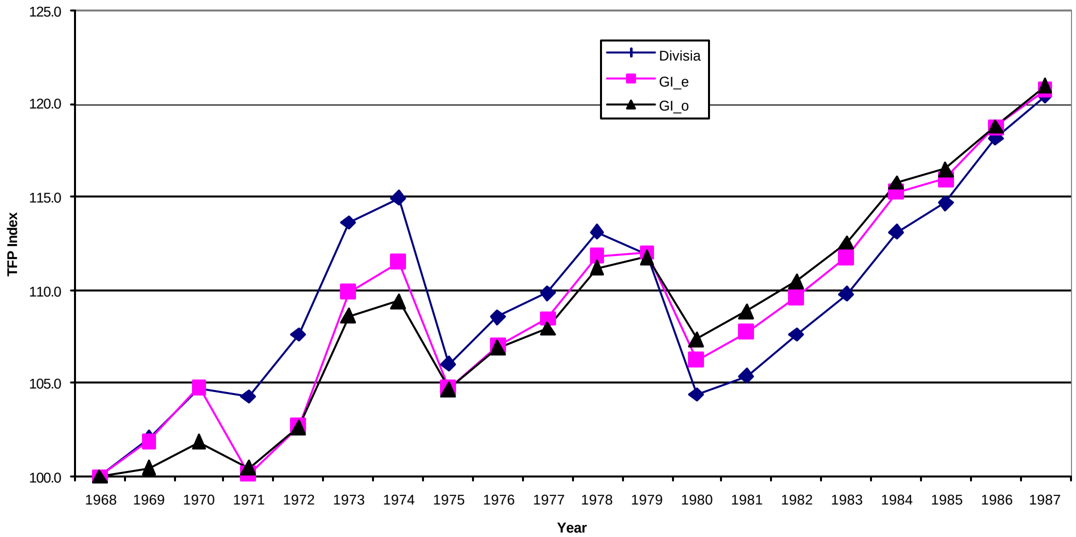

Figure 1(b): TFP Index (TT Models)