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TOTAL FACTOR PRODUCTIVITY GROWTH, TECHNOLOGICAL PROGRESS AND TECHNICAL EFFICIENCY CHANGE: DIMENSIONS OF PRODUCTIVITY CHANGE IN YUGOSLAVIA, 1965–78*

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The economic theory of production has provided the analytical framework for most empirical research on productivity. The cornerstone of the theory is the production function which postulates a well-defined relationship between a vector of maximum producible outputs and a vector of factors of production. Historical analyses of total factor productivity change, whether the non-parametric index number approach or the parametric approach, identify the change in total factor productivity as the change in output levels controlling for input levels, i.e. the vertical shift of the production function. All known and usual criticisms notwithstanding, the resulting estimates have proven to be useful policy parameters. There is, however, an important weakness in the conventional approach. It does not permit the distinction between technological change and changes in the efficiency with which known technology is applied to production. More often than not, in fact, the concept of total factor productivity change is used synonymously with technological change in the productivity literature.[1]

Following Farrell's (1957) contribution to the analysis of production, substantial empirical and methodological interest has focused on the concept of a frontier or 'best practice' production function which defines for any set of observations the outer boundary of possible input–output combinations. Much of this work seeks to measure and explain variations in the total factor productivity of observations relative to the frontier. The amount by which measured total factor productivity is less than the potential, based on best practice, is conventionally defined as technical inefficiency.

Although technological change and technical efficiency share a common methodological basis in the production function, applied work in these fields has evolved largely independently. The objective of this paper is to propose a methodology that decomposes total factor productivity change into technologi-

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[1] For relevant discussions see, for example, Jorgenson and Nishimizu (1978, 1979) who proposed a methodology for bilateral total factor productivity comparisons, and applied it to aggregate as well as disaggregate United States–Japan comparisons. Caves *et al.* (1981, 1982) and Denny and Fuss (1980, 1981) have examined the property of index numbers and structure of production in multilateral or interspatial and intertemporal output, input and total factor productivity comparisons.

cal progress and changes in technical efficiency. We define technological progress as the change in the best practice production frontier, and establish its rate by direct estimation of a deterministic frontier production function.[1] We then refer to all other productivity change – for example learning by doing, diffusion of new technological knowledge, improved managerial practice as well as short run adjustment to shocks external to the enterprise – as technical efficiency change.

In studying the productivity performance of developing economies, the distinction between technological progress and changes in technical efficiency is particularly relevant. Given a level of technology, explicit resource allocation may be required to reach the 'best-practice' level of technical efficiency over time. There is accumulating evidence that the productivity gain due to such 'technological mastery' is substantial in developing economies, and may outweigh gains from technological progress. It is therefore important to know how far one is off the technological frontier at any point in time, and how quickly one can reach the frontier.

The analysis of productivity change in Yugoslavia provides a useful illustration of the distinction drawn above. Considerable attention has recently been directed at the sources of the slowdown in Yugoslav economic growth in the 1970s. (See for example Tyson (1980) and Sapir (1980).) The principal finding of this paper is that changes in technical efficiency dominated technological progress in Yugoslavia throughout the period 1965–70 and that the impact of deteriorating technical efficiency was particularly acute in the period 1970–5.

In section I of the paper we outline our methodological framework for decomposing total factor productivity growth into technological progress and changes in technical efficiency. Section II discusses specification and estimation of the deterministic frontier production function. We specify a translog production frontier, which is estimated by the programming technique of Aigner and Chu (1968) and Timmer (1970, 1971). To our knowledge this is the first empirical application of the programming approach to the estimation of a flexible functional form of the production frontier.[2] Section III presents an application of the technique to social sector panel data of Yugoslavia by industry and region for the period 1965–78, and discusses main empirical results. Section IV offers some concluding remarks including some policy implications of our results.

[1] For an excellent survey of the literature on the frontier production function see Forsund *et al.* (1980). A few applications of the frontier production function have been made to the study of technological change. Forsund and Hjalmarsson (1979) have employed a generalised Cobb-Douglas frontier to examine technological change in the Swedish dairy industry. Greene (1980*b*) has applied a frontier cost function to measure technical change in aggregate U.S. manufacturing. We know of no empirical effort, however, that examines changes in technical efficiency simultaneously with technological change, although Timmer (1970) presented a theoretical discussion of the relationship between them using Farrell's (1957) unit isoquant.

[2] Greene (1980*a*) has proposed a specification of the translog production function with a two parameter Gamma distribution which can be estimated by maximum likelihood techniques.

I. THEORETICAL FRAMEWORK

The starting point for our analysis is a functional relationship between outputs and inputs which characterises the production processes of a well-defined economic entity, for example a firm:

$$G[\mathbf{x}(s, t), \mathbf{z}(s, t); s, t] \leqslant 0, \tag{1}$$

where $\mathbf{x}$ and $\mathbf{z}$ are respectively the vector of outputs and inputs of firm s at time t. s and t appear in G to indicate the levels of marginal factor productivities of firm s at time t. For brevity of exposition, let us suppose that the output vector is separable from the input vector, and that there exists an appropriate aggregate index of output. We can then represent the production relationship as

$$x(s, t) \leqslant g[\mathbf{z}(s, t); s, t], \tag{2}$$

where $x(s, t)$ represents the index of aggregate output of firm s at time t. We assume that the usual regularity conditions are satisfied by g.

For any observed combination of output and inputs of a firm, the inequality in (2) holds when the observed firm is not employing its inputs with the productivity level of 'best practice' at the observed input mix. Denoting by $\hat{s}$, $\hat{t}$, and $\hat{x}$ the potential or best practice productivity and output levels, we can rewrite (2) for an 'interior firm' operating at less than the best practice:

$$\begin{aligned} x(s, t) &= g[\mathbf{z}(s, t); s, t] \\ &< g[\mathbf{z}(s, t); \hat{s}, \hat{t}] = \hat{x}(s, t). \end{aligned} \tag{3}$$

g is assumed to be well-defined over s and t; and it represents our presumption that a firm possesses good technological or economic reasons in operating away from its potential frontier.

Let us define the potential level of total factor productivity relative to the actual observed level of total factor productivity for this firm as the minimum possible factor of reduction in potential output that can be produced with the observed inputs employed at the actual productivity levels:

$$e(s, t)\,\hat{x}(s, t) = g[\mathbf{z}(s, t); s, t], \quad (0 \leqslant e \leqslant 1). \tag{4}$$

An alternative definition for $e(s, t)$ is the maximum factor of increase in actual output that can be produced with the observed input employed at the potential productivity levels:[1]

$$x(s, t)/e(s, t) = g[\mathbf{z}(s, t); \hat{s}, \hat{t}]. \tag{5}$$

These two definitions are equivalent within our framework, and e is reduced to an output level comparison between x and $\hat{x}$ at the observed input mix $\mathbf{z}(s, t)$:

$$e(s, t) = x(s, t)/\hat{x}(s, t). \tag{6}$$

From the first equality of (3), the rate of change of total factor productivity observed for the firm s is

$$\dot{g}(\mathbf{z}, s, t) = \dot{x}(s, t) - g_{\mathbf{z}}(s, t)\,\dot{\mathbf{z}}(s, t), \tag{7}$$

[1] These definitions are due to Malmquist (1953). See Caves *et al.* (1981, 1982) for discussion of Malmquist index in productivity comparisons.

where $g_{\mathbf{z}}(s, t)$ is the vector of output elasticities of each component of $\mathbf{z}$, and the dot over variables denotes logarithmic time derivatives. But from (5), we can rewrite (7) as

$$\dot{g}(\mathbf{z}, s, t) = \dot{g}(\mathbf{z}, \hat{s}, \hat{t}) + \dot{e}(s, t) + [g_{\mathbf{z}}(\hat{s}, \hat{t}) - g_{\mathbf{z}}(s, t)]\,\dot{\mathbf{z}}(s, t). \tag{8}$$

In equation (8), the rate of technological change of the 'best practice' frontier, $\dot{g}(\mathbf{z}, \hat{s}, \hat{t})$, represents in a sense the 'true' rate of technological progress. Over any given set of firms the frontier production function provides information on the subset of firms which define the technological state of the art. Its movement over time, however, must not be confused with changes in the relative efficiency with which known techniques are employed. These effects are captured by $\dot{e}(s, t)$ in equation (8). As we have defined it, $\dot{e}(s, t)$ represents the rate at which any observed firm is moving toward or away from the best practice frontier. We can refer to $\dot{e}$ as the rate of technical efficiency change in the sense discussed in the introduction.[1] Finally, at any given level of inputs, an interior firm's effort to reach its potential output may entail changes in output elasticities. The last component of observed total factor productivity change in (8) represents this. Thus, equation (8) represents a decomposition of the conventional measure of total factor productivity change into three components: technological progress, technical efficiency change, and output elasticity differences between the frontier and the interior.

The relationship between our decomposition of total factor productivity change and the conventional approach is illustrated for a simplified case in Fig. 1. g_1 and g_2 represent linear homogeneous, Cobb-Douglas frontier production functions with Hicks neutral technical progress between periods 1 and 2. Points A and C are the observed levels of output x_1, x_2 (in logarithms) at time 1 and 2 with corresponding potential levels $\hat{x}_1$, $\hat{x}_2$ at points a and c.[2] The line segment AB represents the projection of the input contribution to the change in output, based upon the actual output elasticities of the interior firm.[3] The distances Aa and Cc are e_1 and e_2, respectively.

The conventional measure of total factor productivity change is BC, the change in output net of the input contribution to that change, $A'B$. The usual interpretation is that BC represents the increase in output due in some sense to technological progress. Our method posits that the contribution of technological progress is given directly by the displacement of the frontier production function, bc. If the observed firm had employed the best practice technologies embodied in g_1 and g_2, the difference between its potential outputs $a'c$ and the amount of the change attributable to the increase in input, $a'b$, would equal bc. The increase in output predicted from the frontier production function is BC'

[1] By definition, $\dot{e}$ for a firm that sustains best-practice over time must be zero. For others it will be positive (negative) as the firm experiences a decreasing (increasing) gap between its potential to actual productivity levels. Of course it is possible for a firm to be on the frontier at one time period and off it at another. In such cases $\dot{e}$ will take on the value and sign appropriate to the direction of movement relative to the shifting frontier.

[2] All variables in the text referring to Fig. 1 will be defined in logarithms unless specifically noted. The reader may think of x as output per capita and z as capital labour ratio.

[3] AB is drawn parallel to g_1. We assume the equality between actual and potential output elasticities of z for brevity of exposition.

(equals bc). In Fig. 1, this is less than the actual change BC. The distance $C'C$ is the change in output attributed to technical efficiency gain, $\dot{e}$. The observed production point has moved closer to the frontier in period 2 than in period 1.

Conventional measures of total factor productivity change cannot distinguish between technological progress and changes in technical efficiency, yet the two are analytically distinct and may have quite different policy implications. Technological progress, as we define it, is the consequence of innovation or

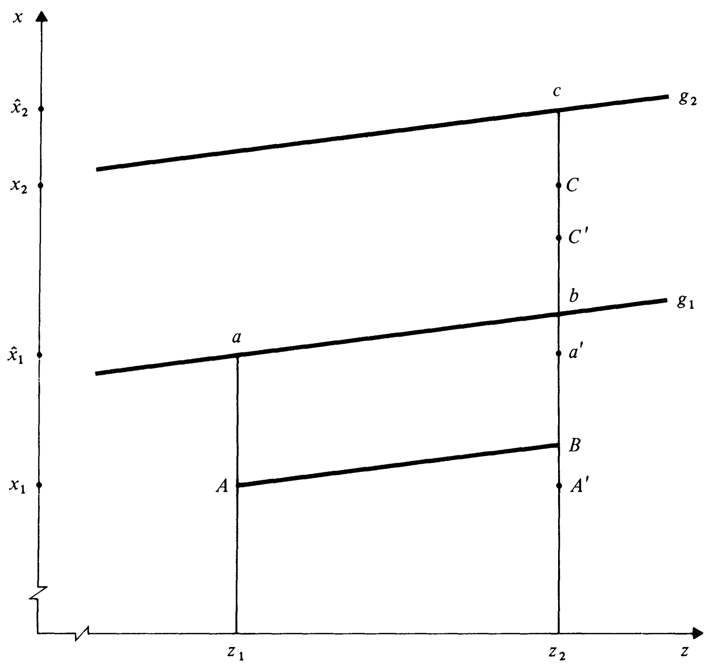

Fig. 1. Alternative interpretations of productivity change.

adoption of new technology by best practice firms. Total factor productivity change, however, is the sum of the rate of technological progress and changes in technical efficiency. High rates of technological progress can co-exist with deteriorating technical efficiency – perhaps due to failures in achieving technological mastery or due to short-run cost-minimising behaviour in the face of quasi-fixed vintage capital – and thus with low or the often observed negative overall rates of total factor productivity change. On the other hand, relatively low rates of technological progress can co-exist with rapidly improving technical efficiency. Policy actions intended to improve the rate of total factor productivity growth might be badly misdirected if focused on accelerating the rate of innovation for example in circumstances where the cause of lagging total factor productivity change is a low rate of mastery or diffusion of best practice technology.

II. SPECIFICATION AND ESTIMATION OF FRONTIER PRODUCTION FUNCTIONS

In the estimation of frontier production models, the conventional approach has been to impose rather strong restrictions on the properties of the technology. Most empirical estimates of the production frontier have employed variants of the Cobb-Douglas form (Timmer (1971), Forsund and Hjalmarsson (1979)) which despite its many attractive properties remains quite restrictive in its ability to approximate the nature of factor substitution possibilities and the characteristics of technological change. Flexible functional forms of the production function impose relatively fewer *a priori* restrictions on the structure of production. One such flexible form which has been frequently used in recent empirical literature is the transcendental logarithmic form (Christensen *et al.* 1971, 1973), which is a second-order Taylor-series approximation to a twice-differentiable arbitrary production function.[1]

We can write the translog production function corresponding to (3) as:

$$\ln x(s, t) = \alpha_0(s, t) + \sum_m \alpha_m(s, t) \ln z_m(s, t) + \tfrac{1}{2} \sum_m \sum_n \beta_{mn} \ln z_m(s, t) \ln z_n(s, t), \tag{9}$$

where

$$\alpha_0(s, t) = \alpha_0(s) + \alpha_t(s)\, t + \tfrac{1}{2}\beta_{tt}(s)\, t^2, \tag{10}$$

$$\alpha_m(s, t) = \alpha_m(s) + \beta_{mt}(s)\, t. \tag{11}$$

The output elasticity of each factor input is:

$$\frac{\partial \ln x(s, t)}{\partial \ln z_m(s, t)} = \alpha_m(s) + \beta_{mt}(s)\, t + \sum_n \beta_{mn} \ln z_n(s, t), \quad (m = 1, \ldots, N). \tag{12}$$

All differences in marginal factor productivities across (s, t) are assumed to be captured in $\{\alpha_m\}$ and $\{\beta_{mt}\}$; thus the structure of factor substitution possibilities described by $\{\beta_{mn}\}$ is invariant across (s, t). The rate of total factor productivity change is the change in output with respect to time holding all factor inputs constant:

$$\frac{\partial \ln x(s, t)}{\partial t} = \alpha_t(s) + \beta_{tt}(s)\, t + \sum_m \beta_{mt}(s) \ln z_m(s, t). \tag{13}$$

For the subset of firms who perform the 'best-practice' at different points in time, the translog frontier production function is

$$\ln \hat{x}(s, t) = (\hat{\alpha}_0 + \hat{\alpha}_t t + \tfrac{1}{2}\hat{\beta}_{tt} t^2) + \sum_m (\hat{\alpha}_m + \hat{\beta}_{mt} t) \ln z_m(s, t) + \tfrac{1}{2} \sum_m \sum_n \hat{\beta}_{mn} \ln z_m(s, t) \ln z_n(s, t), \tag{14}$$

for which the frontier equivalent of (12) and (13) also applies.

For the frontier firms, we can interpret the technological progress coefficients as follows: $\hat{\alpha}_t$ is the rate of technological progress at a frontier point around

[1] The structure of production specified by a chosen functional form directly implies the property of index numbers used to measure output, inputs, and productivity. See Diewert (1976), Caves *et al.* (1981, 1982), Denny and Fuss (1980, 1981) for detailed discussion of various index number properties and the structure of production.

which the Taylor-series expansion approximates tne frontier. Under normal economic conditions, it should be non-negative; $\hat{\beta}_{tt}$ is the rate of change of technological progress, and takes on a positive, negative, or zero value depending on whether there is acceleration, deceleration or constancy of the rate of technological progress; $\hat{\beta}_{mt}$ is the change in the output elasticity of each factor input over time, so that it takes on a positive, negative, or zero value depending on whether the bias of technological change is m-th factor using, m-th factor saving, or neutral.

Three general approaches to the estimation of frontier production functions are found in the literature. These may be characterised as deterministic, probabilistic, and stochastic estimation techniques. (For a thorough recent survey of the estimation problem and an empirical application see van den Broek *et al.* (1980).) The deterministic approach utilises the whole sample of observations but constrains all observed points in output space to lie on or below the frontier. Although this technique corresponds most closely to the theoretical concept of the frontier as an outer boundary on the production set, empirically it is sensitive to errors in observations. The probabilistic and stochastic approaches basically attempt to reduce the sensitivity of the estimated frontier to truly random errors. The probabilistic approach (Timmer, 1971) accomplishes this by allowing a pre-specified percentage of the most efficient observations to lie above the frontier. Stochastic frontiers (Aigner *et al.* (1977), Meeusen and van den Broek (1977), van den Broek *et al.* (1980)) specify both an efficiency distribution and pure random variations in the error structure of the estimated frontier. In the present context we have chosen to estimate a deterministic frontier by restricting the observed points in output–input space to lie on or below the production surface. Hence, we specify a one-sided error added to (14) such that it enforces the on-or-below the frontier constraint.

Although it is possible to estimate the parameters of the production frontier by single equation methods, recent applications of the translog form have employed joint estimation of the production function and the set of factor share equations (12) to obtain more precise estimates. Use of the system of share equations, however, is usually predicted on the assumption of profit maximisation in competitive product and factor markets which leads to equality between observed factor income shares and output elasticities. There is a substantial body of evidence to indicate that this equality does not hold in the case of self-managed enterprises in the Yugoslav social sector. (See, for example, Sapir (1980) and Tyson (1979).) It is therefore impossible to know if the estimated parameters are those of the production frontier or a spurious set arising out of mis-specification of the input share equations. For this reason we are constrained to use a single equation method to estimate the production frontier.

Choice of a procedure to estimate the parameters of the production frontier depends crucially on the assumption made with regard to the distribution of the errors. If one is willing to impose a specific disturbance model, procedures have been suggested for the maximum likelihood estimation of the production function parameters (Schmidt (1976), Greene (1980*a*)). The statistical properties of the maximum likelihood estimators are not straightforward in all cases, however, and there is little guidance as to the appropriate specification of the distribution of the errors (Schmidt (1976), van den Broek *et al.* (1980)). An alternative is to minimise the sum of the deviations from the frontier, subject to the constraint that all observations lie on or below the frontier (Aigner and Chu (1968), Timmer (1971), Forsund and Hjalmarrsson (1979)). Given this specification the estimation procedure we adopt is an application of linear programming.

The objective function to be minimised is linear in the unknown parameters:

$$\begin{aligned}\min: \sum_{t=1}^{T}\sum_{s=1}^{S} [(\hat{\alpha}_0+\hat{\alpha}_t t+\tfrac{1}{2}\hat{\beta}_{tt}t^2)+\sum_m (\hat{\alpha}_m+\hat{\beta}_{mt}t)\ln z_m(s,t)\\ +\tfrac{1}{2}\sum_m\sum_n \hat{\beta}_{mn}\ln z_m(s,t)\ln z_n(s,t)-\ln x(s,t)]. \qquad (15)\end{aligned}$$

The constraints of the model are imposed by the restrictions on the observations securing the observed input–output combinations to lie on or below the frontier:

$$\begin{aligned}(\hat{\alpha}_0+\hat{\alpha}_t t+\tfrac{1}{2}\hat{\beta}_{tt}t^2)+\sum_m (\hat{\alpha}_m+\hat{\beta}_{mt}t)\ln z_m(s,t)\\ +\tfrac{1}{2}\sum_m\sum_n \hat{\beta}_{mn}\ln z_m(s,t)\ln z_n(s,t) \geqslant \ln x(s,t), \quad (s=1,\ldots,S;\\ t=1,\ldots,T). \quad (16)\end{aligned}$$

We assume that the translog frontier is characterised by constant returns to scale, and therefore impose the following restrictions:

$$\begin{aligned}\sum_m \hat{\alpha}_m &= 1,\\ \sum_m \hat{\beta}_{mn} &= 0, \quad (n=1,\ldots,N), \qquad (17)\\ \sum_m \hat{\beta}_{mt} &= 0.\end{aligned}$$

In addition to differentiability, we maintain monotonicity and concavity to be the minimum irreducible properties of the frontier. The translog frontier is neither monotonic nor concave for any arbitrary set of its domain. To impose monotonicity, we restrict $\{\hat{\alpha}_m\}$ and $\{\hat{\alpha}_t\}$ to be non-negative. These are necessary but not sufficient conditions for monotonicity, so that we also restrict the output elasticity of each factor input and the rate of technological progress to be non-negative:

$$\begin{aligned}\hat{\alpha}_m+\hat{\beta}_{mt}t+\sum_n \hat{\beta}_{mn}\ln z_n(s,t) &\geqslant 0, \quad (m=1,\ldots,N),\\ \hat{\alpha}_t+\hat{\beta}_{tt}t+\sum_m \hat{\beta}_{mt}\ln z_m(s,t) &\geqslant 0. \qquad (18)\end{aligned}$$

Under monotonicity and constant returns to scale, the necessary and sufficient conditions for concavity can be expressed as the non-positivity of own share elasticities (see Lau (1978)). Thus, we impose concavity on the frontier by the restriction, $\{\beta_{mm}\} \leqslant 0$ for $m = 1, \ldots, N$.

We estimate the frontier gross production function by sector where factor inputs are capital, labour, and material inputs. Gross output and material input series are in constant producer prices of 1972. Capital input series are net capital stocks at replacement cost in 1972 prices. Labour input series are the number of persons employed. For each of twenty-six social sectors of Yugoslavia, our panel data consist of a 1965–78 time series by eight regional cross sections, where the regions are six republics (Bosnia, Croatia, Macedonia, Montenegro, Serbia, Slovenia) and two autonomous provinces (Kosovo and Vojvodina). A description of data sources is given in the Appendix.

A short note on normalisation is required here. Recall that the translog production function is a second-order Taylor-series approximation to an arbitrary production function. Choice of a normalisation point around which the Taylor-series is expanded becomes important, since we know that the sum of the early terms in the series provides a good approximation in the neighbourhood of the chosen normalisation point. In the present context the normalisation point should represent a production point that closely approximates the frontier, and therefore the choice of the normalisation point with respect to our regional dimension is an important issue. In this respect, we choose the Republic of Slovenia as it is generally considered to be the most developed region in Yugoslavia.

The estimated translog frontier parameters for each sector are presented in Table 2 in the Appendix. The rate of technological progress for each region in each sector is computed by combining these frontier parameters with observed input levels as in (13) for each year, and taking simple averages of consecutive pairs. The level of technical efficiency as defined in (6) can be obtained as the antilog of the slack variables in our linear programming constraints (16). The rate of change in technical efficiency is approximated by taking the log differences of successive time periods. We then compute the rate of total factor productivity change as the rate of technological progress plus the rate of change in technical efficiency. Therefore, our total factor productivity change estimates for Yugoslavia are not adjusted for the effect due to difference between unobserved interior output elasticities and estimated frontier elasticities (see equation (8)).

III. EMPIRICAL RESULTS

The most important finding of this paper is that the change in technical efficiency dominated technological progress in their relative importance in sectoral total factor productivity growth of Yugoslavia. Table 1 presents our results in terms of average annual rates of total factor productivity change, technological progress and technical efficiency change based on the translog frontier estimates for twenty-six social sectors (columns (1), (2) and (3)). In Table 1, the sectors are classified according to the average signs of these three estimates for the period 1965–78. These average annual growth rates are also presented for three sub-periods corresponding roughly to Yugoslav Economic Plan periods. One half of the sectors (groups I and II) show no technological progress estimated at the frontier. The other half (groups III, IV and V) show technological

Table 1

Classification of Economic Activities by Nature of Total Factor Productivity Change: Yugoslavia Social Sector, 1965–78

	1965–78					1965–70				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
I	+	0	+							
Printing and publishing	0·67	0·00	0·67	−0·62	0·05	0·14	0·00	0·14	−0·11	0·03
Chemical products	0·10	0·00	0·10	0·55	0·65	−0·09	0·00	−0·09	1·03	0·94
Petroleum and gas*	0·56	0·00	0·56	−1·85	−1·29	0·55	0·00	0·55	−1·15	−0·60
Shipbuilding	0·18	0·00	0·18	−1·55	−1·37	4·88	0·00	4·88	−2·49	2·39
Electricity	1·87	0·00	1·87	−1·00	0·87	3·67	0·00	3·67	−1·07	2·59
II	−	0	−							
Agriculture	−0·08	0·00	−0·08	0·95	0·87	−1·63	0·00	−1·63	2·01	0·38
Construction	−0·46	0·00	−0·46	0·33	−0·13	0·45	0·00	0·45	1·35	1·80
Food processing	−0·57	0·00	−0·57	0·01	−0·56	−0·09	0·00	−0·09	0·07	−0·02
Tobacco	−1·60	0·00	−1·60	−2·26	−3·86	0·72	0·00	0·72	−5·78	−5·06
Textile products	−0·17	0·00	−0·17	0·00	−0·17	−0·56	0·00	−0·56	0·58	0·02
Lumber and Wood products	−0·60	0·00	−0·60	0·55	−0·05	−0·20	0·00	−0·20	0·98	0·78
Ferrous metals*	−0·19	0·00	−0·19	−0·71	−0·90	0·20	0·00	0·20	−0·49	−0·29
Trade and Catering†	−0·81	0·00	−0·81	−2·24	−3·05	−0·19	0·00	−0·19	−3·61	−3·80
III	+	+	+							
Forestry	1·21	0·43	0·78	−1·01	0·20	2·75	0·52	2·23	−1·21	1·54
Coal and coal products*	1·87	1·58	0·29	−3·14	−1·27	3·95	2·21	1·73	−4·39	−0·44
Rubber products	4·70	0·56	4·13	−5·43	−0·73	2·55	0·47	2·05	−2·95	−0·40
Metal products‡	0·54	0·31	0·23	−0·22	0·32	0·48	0·40	0·08	0·29	0·77
Miscellaneous Mfg.	3·88	0·37	3·51	−4·12	−0·24	9·62	0·35	9·62	−5·10	4·52
Transport and Communications	1·94	0·81	1·12	−2·16	−0·22	4·45	0·91	3·54	−3·19	1·26
IV	+	+	−							
Paper products	0·48	0·67	−0·20	−0·46	0·02	0·72	1·06	−0·33	−0·31	0·41
Leather products	0·07	0·22	−0·15	−0·82	−0·75	0·38	0·20	0·18	−0·78	−0·40
Non-metallic minerals*	2·20	3·39	−1·19	−1·75	0·45	3·03	3·98	−0·96	−1·11	1·92
Electrical machinery	0·25	0·28	−0·03	0·09	0·34	0·15	0·39	−0·23	1·12	1·27
V	−	+	−							
Building materials§	−0·05	0·06	−0·10	0·85	0·80	0·68	0·09	0·59	1·82	2·50
Non-ferrous metals*	−0·70	1·44	−2·14	−0·51	−1·21	0·00	1·22	−1·22	−0·36	−0·36
Arts and Crafts‖	−0·32	0·75	−1·06	0·01	−0·31	0·55	0·53	0·02	−4·03	−3·48

	1970–5					1975–8				
	(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
I										
Printing and publishing	−0·02	0·00	−0·02	−1·16	−1·18	2·71	0·00	2·71	−0·60	2·11
Chemical products	−0·75	0·00	−0·75	0·60	−0·15	1·83	0·00	1·83	−0·33	1·50
Petroleum and Gas*	−2·85	0·00	−2·85	−0·70	−3·55	6·26	0·00	6·26	−4·92	1·34
Shipbuilding	−6·29	0·00	−6·29	3·77	−2·52	3·15	0·00	3·15	−8·88	−5·73
Electricity	1·43	0·00	1·43	−1·92	−0·49	−0·39	0·00	−0·39	0·65	0·26
II										
Agriculture	−0·48	0·00	−0·48	0·17	−0·31	3·17	0·00	3·17	0·49	3·66
Construction	−1·06	0·00	−1·06	−0·69	−1·75	−0·98	0·00	−0·98	0·32	−0·66
Food processing	−1·20	0·00	−1·20	−0·01	−1·21	−0·30	0·00	−0·30	−0·06	−0·36
Tobacco	−0·74	0·00	−0·74	−4·56	−5·30	−6·88	0·00	−6·88	7·43	0·55
Textile products	0·24	0·00	0·24	−0·58	−0·34	−0·20	0·00	−0·20	−0·02	−0·22
Lumber and Wood products	−1·60	0·00	−1·60	−0·01	−1·61	0·40	0·00	0·40	0·75	1·15
Ferrous metals*	−2·20	0·00	−2·20	0·16	−2·04	2·53	0·00	−2·53	−2·56	−0·03
Trade and Catering†	−1·37	0·00	−1·37	−1·94	−3·31	−0·90	0·00	−0·90	−0·45	−1·35
III										
Forestry	−0·54	0·41	−0·95	−0·81	−1·35	1·59	0·34	1·25	−1·04	0·55
Coal and coal products*	−1·74	1·40	−3·14	−1·03	−2·77	4·43	0·81	3·62	−4·60	−0·17
Rubber products	5·72	0·56	5·16	−6·93	−1·21	6·57	0·72	5·85	−7·06	−0·49
Metal products‡	0·56	0·29	0·27	−0·58	−0·02	0·60	0·19	−0·46	−0·46	0·14
Miscellaneous Mfg.	5·00	0·39	4·62	−4·36	0·64	−7·51	0·37	−7·94	−2·15	−9·66
Transport and Communications	−0·49	0·76	−1·25	−0·28	−0·77	1·80	0·75	1·06	−3·56	−1·76
IV										
Paper products	−0·47	0·58	−1·05	−0·28	−0·75	1·65	0·19	1·46	−0·99	0·66
Leather products	0·64	0·24	0·40	−0·78	−0·14	−1·40	0·22	−1·61	−1·14	−2·34
Non-metallic minerals*	2·30	3·21	−0·91	−2·81	−0·51	0·64	2·69	−2·05	−1·06	−0·42
Electrical machinery	−0·77	0·24	−1·01	0·03	−0·74	2·10	0·14	1·95	−1·52	0·58
V										
Building materials§	−0·75	0·05	−0·80	0·80	0·05	−0·07	0·01	−0·09	−0·70	−0·77
Non-ferrous metals*	−2·20	1·72	−3·92	−0·46	−2·66	0·62	1·34	−0·72	−0·84	−0·22
Arts and Crafts‖	0·04	0·81	−0·77	1·24	1·28	−2·36	1·00	−3·36	2·05	−0·31

Columns:

(1) Total factor productivity change [(2)+(3)].
(2) Technological progress.
(3) Technical efficiency change ($\dot{e}$).
(4) Input contribution difference due to frontier and observed factor share difference.
Equals $[g_z(\hat{s},\hat{t})-g_z(s,t)]\,\dot{\mathbf{z}}(s,t)$.
(5) Total factor productivity change (using observed factor shares).

Notes:

* Include mining activities in each category.
† Retail and Wholesale Trade and Hotels and Restaurants.
‡ Fabricated metal products, non-electrical machinery and transport equipment other than ships.
§ Stone, clay and glass products and processed construction materials.
‖ Small-scale industrial activities and services n.e.c.

progress, of which only in six sectors (the sectors in group IV and two sectors in group III) the rate of technological progress dominates technical efficiency change on average for the period 1965–78.

In order to facilitate a comparison of our method with the conventional measure of total factor productivity change we provide in column (5) of Table 1 index number estimates of average annual total factor productivity change based on factor income shares observed in our data base. The difference between our parametric frontier estimates of total factor productivity change and those derived by the index number method should equal the difference between the estimated input contributions to growth based on frontier output elasticities and interior output elasticities (the last term in equation (8)). Hence, we also provide in column (4) the magnitude of these differences, using observed factor income shares for 'interior' output elasticities. The sum of columns (2), (3) and (4) equals the index number estimate of total factor productivity change in column (5), and is therefore an exact decomposition of the index number estimate.

As we discussed in Section II, it is difficult to interpret the index number estimates of total factor productivity change in Yugoslavia in view of the failure of observed income shares to reflect actual output elasticities of factor inputs. The magnitude of the differences in input contributions is as likely to reflect biases introduced by incorrect specification of the indices for factor inputs in the conventional method, as differences in the underlying structure of production between the frontier and the interior observations. For 1965–78, in seventeen of the twenty six sectors the estimated input contribution using observed shares exceeds that based on the parameters of the production frontier, and hence, our estimates of total factor productivity change exceed those derived by the conventional method. In three sectors the estimated input contributions are approximately equal, and in six sectors the estimate of total factor productivity change based on the frontier parameters is less than that based on observed shares. For the period 1965–78 we identify eleven sectors with negative average total factor productivity change by the parametric frontier method and sixteen sectors based on the index number approach. There are nine cases in which the two sets of estimates differ in sign; in seven of the nine the index number method yields a negative rate of total factor productivity change.

The additional information provided by our decomposition is most clearly illustrated by the results for those sectors showing technological progress (groups III, IV and V). Of the thirteen sectors identified in Table 1 as showing technological progress at the frontier, seven are characterised by negative total factor productivity growth during the period 1965–78 based on the index number method. In each of these cases the conventional method would yield the incorrect conclusion that technological progress had been absent in the sector. In groups IV and V technological progress is accompanied by deteriorating technical efficiency, a result which could not be inferred from the conventional approach.

Of the thirteen sectors with technological progress, four sectors (coal and coal products, transportation and communication, non-metallic minerals, and non-ferrous metals) have been priority sectors in the Yugoslav Economic Plans. Furthermore, these sectors with the exception of transportation and communication are considered to be the sectors in which Yugoslavia has natural resource-based comparative advantage. Two other sectors (metal products and electrical machinery) were industries in which substantial efforts were made to acquire foreign technology on a continuing basis (see, for example, The World Bank (1975).)

Cyclical characteristics of technical efficiency change are common across sectors, and reveal distinct differences in performance among the three periods 1965–70, 1970–5 and 1975–8.[1] The period 1965–70 is characterised by generally improving levels of technical efficiency, particularly in manufacturing. During 1970–5, on the other hand, only six sectors (five manufacturing sectors) show positive rates of technical efficiency change. Twenty sectors show deterioration in the rate of technical efficiency change between these two periods. Some recovery is observed in 1975–8. Both 1970–5 and 1975–8 were marked by quantitative restrictions on imports in the face of foreign exchange shortages, accompanied by deflation of the domestic economy under 'stabilisation' programmes. The impact of these shocks on the level of technical efficiency is apparent in most industries.

Variations in technical efficiency at the sectoral level are also attributable to problems of investment planning and implementation, lack of technical experience, and poor management and organisation particularly in co-ordinating intermediate input supply, in addition to the general impact of stabilisation policies. Four sectors in which these problems were particularly acute (wood products, electrical machinery, shipbuilding, and ferrous metals) show rapid rates of decline in the level of technical efficiency during the period 1970–5. Three manufacturing sectors which are characterised by generally improving levels of technical efficiency (metal products, chemicals, rubber products) reflect to some extent the success of explicit policy actions undertaken to improve diffusion of technical information, project implementation, and co-ordination of input supplies.

IV. CONCLUSIONS

In this paper we have proposed a method for the decomposition of total factor productivity change into two distinct elements, technical progress and changes in technical efficiency. In doing so we have brought together two largely independent lines of inquiry which have a common analytical basis in the theory of production. Our motivation was a belief, particularly in the case of developing economies, that identification of total factor productivity change with technological progress neglected an important dimension of productivity gains and losses which can be summarised as changes in the efficiency with which a known technology is applied to production.

Clearly, technological progress and technical efficiency change are not neatly separable either in theory or in practice. In our methodological approach

[1] Detailed discussion of the sectors and regional results are available in Nishimizu and Page (1982).

we define technological progress as the movement of the best practice or frontier production function over time. We then refer to all other productivity change as technical efficiency change. The distinction which we have adopted is therefore somewhat artificial, but it offers an important added dimension to the policy relevance of total factor productivity studies.

Our major empirical findings are a clear illustration of the relevance of the distinction. In an economy such as Yugoslavia which borrows technology extensively from abroad, failures to acquire and adapt technology to new international standards will be reflected in lack of technological progress at the frontier. Our findings indicate that in half of Yugoslavia's social sector industries there was no perceptible movement of the frontier during the period 1965–78. Many of these activities are mature industries, both in Yugoslavia and internationally, in which rapid movement of the frontier is not expected. In several sectors, however, the lack of technical progress is indicative of failures in investment planning and implementation to allow for acquisition of new technology. In others, the movement of the frontier reflects the success of explicit policies to facilitate the acquisition of foreign technology.

Similarly, changes in technical efficiency across plan periods and among individual sectors indicate the success or failure of a number of important dimensions of economic policy and industrial planning. Considerable attention has been focused on the question of the slowdown in economic growth in Yugoslavia in the 1970s. Our analysis indicates that the slowdown in total factor productivity growth was a consequence of both a reduction in the rate of technological progress and of a deterioration in technical efficiency. The relative magnitude of the two, however, is such that deteriorating technical efficiency change clearly dominates technological progress. Indeed the abrupt change in the pattern of technical efficiency change between two major Economic Plan periods, from moderately positive in 1965–70 to negative in 1970–5, points to a major shift in the production environment between the two.

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APPENDIX

Data on gross output and material input in current prices and labour compensation are obtained from *Statisticki Bilten* (No. 773, No. 1175), and *Drustveni Proizvod i Narodni Dohodak*. Producer price indexes for gross output and intermediate input are obtained from *Statisticki Godisnjak* (*Statistical Yearbooks of Yugoslavia*). Capital stocks in constant prices are obtained from *Statisticki Godisnal*, *Osnova Sredstra Drustvene Privred*, and worksheets provided by the Federal Statistical Office of Yugoslavia. Data on number of persons employed are obtained from *Statistical Yearbooks of Yugoslavia*. All published data sources are by the Federal Statistical Office of Yugoslavia.

Deterministic Frontier Translog Production Function Coefficients, Yugoslavia 1965–78

	Agriculture	Forestry	Con-struction	Food Processing	Tobacco	Textile products	Lumber and Wood products	Building materials	Paper products	Printing and Publishing	Chemical products	Petroleum and Gas	Coal and Coal products
α_0	7·85563	6·54696	8·92599	8·41300	6·07361	8·32452	8·05692	6·90549	7·04443	6·79953	7·94850	5·21999	7·20321
α_T	—	0·00598	—	—	—	—	—	0·00069	0·00834	—	—	—	0·01879
β_{TT}	—	−0·00046	—	—	—	—	—	−0·00009	−0·00085	—	—	—	−0·00247
α_K	0·43029	0·11588	0·01458	0·10771	0·64375	0·19241	0·02943	0·49879	0·08401	0·13425	—	0·08085	0·46080
α_L	0·33174	0·55206	0·40902	0·13320	0·12502	0·20848	0·28421	0·07888	0·23584	0·40491	0·21175	0·24981	0·73293
α_M	0·23798	0·33385	0·57641	0·75909	0·23123	0·59912	0·68636	0·42233	0·68015	0·46083	0·78825	0·66934	0·22098
β_{KK}	−0·41182	−0·22065	—	−0·15860	−0·20227	−0·39240	−0·02712	−0·24874	−0·07497	−0·09633	—	—	−0·04317
β_{LL}	−0·11690	−0·02107	−0·08496	−0·23836	−0·10986	−0·30829	−0·04175	−0·07528	−0·03563	—	−0·03593	—	—
β_{MM}	—	—	−0·09680	—	—	−0·15160	−0·07520	−0·16712	—	—	−0·03593	—	—
β_{KL}	0·26436	0·12086	−0·00592	0·19848	0·15606	0·27454	−0·00316	0·07832	0·05530	0·04817	—	—	0·02159
β_{KM}	0·14746	0·09979	0·00592	−0·03988	0·04620	0·11785	0·03028	0·17015	0·01967	0·04817	—	—	0·02159
β_{LM}	−0·14746	−0·09979	0·09088	0·03988	−0·04620	0·03375	0·04491	−0·00303	−0·01967	−0·04817	0·03593	—	−0·02159
β_{KT}	—	0·00261	—	—	—	—	—	—	−0·00175	—	—	—	0·00618
β_{LT}	—	−0·00299	—	—	—	—	—	—	0·00218	—	—	—	−0·01168
β_{MT}	—	0·00038	—	—	—	—	—	—	−0·00043	—	—	—	0·00550

	Rubber products	Leather products	Non-metallic minerals	Ferrous metals	Non-ferrous metals	Metal products	Electrical machinery	Ship-building	Miscel-laneous manu-facturing	Electricity	Trans-portation and Commu-nication	Trade and Catering	Arts and Crafts
α_0	6·39872	7·18516	6·47544	8·18623	7·60021	9·14500	7·81879	3·21268	5·72188	7·60716	8·38950	9·36949	7·21128
α_T	0·00867	0·00324	0·03593	—	0·01158	0·00404	0·00335	—	0·00901	—	0·00489	—	0·01051
β_{TT}	−0·00025	−0·00028	−0·00410	—	0·00036	−0·00065	−0·00227	—	−0·00030	—	−0·00007	—	−0·00059
α_K	0·03583	0·03938	0·32901	—	0·17727	0·07196	0·16835	0·21999	0·33052	0·11480	0·34135	0·04573	0·07067
α_L	0·72866	0·33429	0·39280	0·21053	0·12480	0·29810	0·14532	0·69772	0·35171	0·47974	0·38677	0·62464	0·30520
α_M	0·23551	0·62634	0·27819	0·78947	0·69794	0·62994	0·68633	0·08229	0·31777	0·40546	0·27188	0·32962	0·62413
β_{KK}	—	−0·00684	—	—	−0·07739	—	—	−0·08532	−0·11851	—	−0·28951	−0·11187	—
β_{LL}	—	—	−0·18526	—	—	−0·22120	—	—	−0·12105	−0·19776	—	−0·07380	—
β_{MM}	—	−0·05602	—	—	—	—	−0·11820	—	—	—	—	—	—
β_{KL}	—	−0·02459	0·09263	—	0·03869	0·11060	−0·05910	0·04266	0·11978	0·09888	−0·14475	0·09284	—
β_{KM}	—	0·03143	−0·09263	—	0·03869	−0·11060	0·05910	0·04266	−0·00127	−0·09888	0·14475	0·01904	—
β_{LM}	—	0·02459	0·09263	—	−0·03869	0·11060	0·05910	−0·04266	0·00127	0·09888	0·14475	−0·01904	—
β_{KT}	0·00717	0·00403	0·00708	—	−0·01631	0·00330	−0·00166	—	−0·00343	—	−0·01647	—	0·01167
β_{LT}	−0·00786	−0·00569	−0·02671	—	0·00688	−0·00586	0·00096	—	0·00132	—	0·01487	—	−0·00987
β_{MT}	0·00069	0·00166	0·01963	—	0·00943	0·00256	0·00071	—	0·00210	—	0·00160	—	−0·00180

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