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Technical Change and The Slowdown in Productivity Growth*

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Productivity Growth Slowdown, Total Factor Productivity *(TFP), R & D,* factor price effect, demand effect

Introduction

This paper considers the growth of productivity in the United States. It is reported that the recent slowdown in the growth of productivity in the United States has attracted considerable attention. There are two major measures of productivity growth used routinely by economists: output per man-hour and total factor productivity. The first measures productivity growth by the difference in rate of growth of an output index based on value-added in constant prices and an index of man-hours worked in a country or industry. The second measure subtracts from the first an estimate of the contribution of

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physical capital to productivity growth, based on the growth in the capital-labor ratio weighted by the smoothed share of capital inputs in factor payments. These measures suffer from difficulties in computing correctly an index based on value-added real output in a world of changing commodities and services and in measuring the quantity and quality of labor service. The *TFP* measure suffers from the additional problem of how to measure capital in general and its utilization rate, in particular.

From 1960 to 1970, real output per hour in the private sector rose at an annual rate of 3.0 percent; from 1970 to 1985, it rose at a rate of only 1.1 percent. The sharp increases in the price of oil caused by supply disruptions in 1974 and 1979 reduced productivity growth as firms substituted capital and labor for energy. The slowdown in productivity growth was exacerbated by a decline in rates of capital formation. Net investment in fixed business capital fell from 3.5 percent of GNP in the 1960s to 3.0 percent in the 1970s, and the rate of growth of capital per worker fell even more sharply, from 3.2 percent per year in the 1960s to only 1.3 percent in the 1970s. The declining of productivity can be attributed to many factors, such as a slowdown in the growth of capital accumulation and the size and composition of firms' *R & D* expenditures, changes in the composition of product, and declines in the capital utilization rate, etc. The purpose of this paper is to investigate the role of the above factors and to consider leading policy issues, e. g. Should the rate of capital accumulation be raised as a response to the slowdown? In this paper, I provide a framework for analyzing changes in total factor productivity *(TFP)* in the presence of economies of scale. I hope to demonstrate formally the positive relationship between growth in productivity and output which is found in the empirical studies by economists and researchers. The model is based on an output demand function, a variable cost function which is shifted by disembodied technical change and the stock of *R & D,* and a market clearing rule which equates output price to average variable cost plus quasi rents to *R & D*. This identifies the contribution of demand growth, real factor prices, and the stock of *R & D* to changes in the growth of total factor productivity *(TFP).*

I. Analyzing Changes in *TFP*

Since constant returns to scale are not imposed, the proper index of conventional *TFP* growth is the "quasi–Divisia" index

(1) $DTFP \equiv DQ - DF = DQ - \sum s_i DX_i$

where D denotes a rate of growth, Q is output, the X represents traditional inputs, F is total factor input, and where $s_i = P_i X_i / PQ$ is the value share of the ith input. Given the production function

(2) $Q = G(X, R, T)$

where R and T denote the stock of R & D and the technology level, differentiating with respect to time and assuming cost minimization over all inputs, results in

(3) $$DQ = \sum[(P_i X_i / Q)/MC]DX_1 + [(P_r R/Q)/MC]DR + DT$$

where MC is marginal cost and P_r is the service of R & D[1] or opportunity cost. According to Kenneth Arrow and others, we can assume that price equals current average variable cost *(AVC)* plus the unit quasi rents which accrue to past R & D. That is, $P=AVC(1+\theta)$ where θ is the ratio of current quasi rents to the level of AVC. Using the definition of the elasticity along the variable cost function $\eta = MC/AVC$, then we obtain $MC=\eta P/(1+\theta)^2$. Substituting this expression for MC into (3), we obtain the output growth equation

$$(4) \quad DQ=\eta^{-1}(1+\theta)\sum s_i DX_i + \eta^{-1}(1+\theta)s_r DR+DT$$

Obtaining $DF=\sum s_i DX_i$ from (4) and (1), the growth of TFP becomes

$$(5) \quad DTEP=\frac{(1+\theta-\eta)}{1+\theta}DQ+\frac{\eta}{1+\theta}DT+s_r DR$$

Assuming a *log*–linear per capita demand function, we obtain the equilibrium equation

$$(6) \quad DQ=\lambda+\alpha DP+\beta DY+(1-\beta)DN$$

where Y and N are income and population, and λ reflects a demand time trend.

The pricing rule implies

$$(7) \quad DP=DCV-DQ+D(1+\theta)$$

where CV represents total variable cost. The total variable cost function can be written as $CV=H(P_x, Q, R, T_c)$, where T_c is the associated technology level, and both R and T_c shift the variable cost function downward. Differentiating with respect to time, using Shephard's Lemma and the relation $DT_c=-\eta DT$, we obtain

$$(8)\quad DCV=(1+\theta)\sum s_i DP_i+\eta DQ-\Pi DR-\eta DT$$

where $\Pi=P_r R/CV$. Substituting (6), (7), (8) into (5), we obtain the reduced form expression for the growth rate of total factor productivity *(TFP)*.

$$\begin{aligned}(9)\quad DTEF=&A[\lambda+\alpha D(1+\theta)]\\ &+A\alpha(1+\theta)\sum s_i DP_i\\ &+A\beta DY+A(1-\beta)DN\\ &+s_r[1-A\alpha(1+\theta)]DR\\ &+A\eta(1-\alpha\theta)(1+\theta-\eta)^{-1}DT\end{aligned}$$

where $A=(1+\theta-\eta)[(1+\theta)(1+\alpha(1-\eta))]^{-1}$ From equation (9), we obtain

$$\begin{aligned}(10)\quad DTFP=&A\alpha(1+\theta)\sum s_i DP_i\\ &+A[\lambda+\beta DY+(1-\beta)DN]\\ &+A\alpha D(1+\theta)+s_r[1-A\alpha(1+\theta)]DR\\ &+A\eta(1-\alpha\theta)(1+\theta\,\tau\,\eta)^{-1}DT\end{aligned}$$

Four components are: 1) factor price effect, $A\alpha(1+\theta)\sum s_i DP_i$; 2) demand effect, $A[\lambda+\beta DY+(1-\beta)DN]$; 3) *R & D* effect, $A\alpha D(1+\theta)+s_r[1-A\alpha(1+\theta)]DR$; and 4) disembodied technical change, $A\eta(1-\alpha\theta)$

$(1+\theta\tau\eta)^{-1}DT.$

The underlying model is an equilibrium model in which there is cost minimization over all inputs, the level of R & D is adjusted until it earns the normal rate of return in the form of quasi rents, and the market clears. Because market clearing is imposed, each separate component reflects both the direct impact on TFP of the factor in question and its indirect effect via induced changes in the output price.

The important parameters in (9) are the price and income elasticities of demand and the cost elasticity of the variable cost function. We can consider two special cases. First, if demand is completely inelastic ($\alpha = 0$), shifts in the cost function due to real factor price change ($\sum s_i DP_i$) have no effect on output, and hence none on TFP. Second, if marginal cost pricing prevails ($\eta = 1+\theta)^2$, then equation (9) collapses to $DTFP = s_r DR + DT$, which is the standard result when TFP is defined over conventional inputs only.

Ⅱ. Future Empirical Application

As a future study, I intend to apply this model to U. S. manufacturing industries for the period 1958–1986. In this application of the model, the deceleration in demand is taken as the main factor behind the slowdown in TFP growth. The application requires three parameters, the variable cost elasticity and the price and income elasticities of product demand. Given these parameters the producer can then compute the factor price, demand and R & D effects, and retrieve the technical change effect as a residual using equation (10). Discrete approximations to the Divisia indices in (10) are used. Annual data on gross value-added, capital, labor, and energy for the period 1958–86 are available from various public and private research institutes in the United States. For example, data on output in current and constant prices are available from the Interindustry Economics Division of the Bureau of Economics Analysis (BEA) for the manufacturing sectors and from Bureau of Labor Statistics (BLS) for nonmanufacturing sectors.

I hope to illustrate empirically the utility of this framework for analyzing changes in *TFP* and for clarifying the leading factors in the recent decline of *TFP* growth in American manufacturing.

Footnotes:

1) One alternative is to restrict cost minimization to the conventional inputs and let *R & D* earn a different net rate of return. The service price *P* would then represent the associated gross rate of return.
2) $P = MC$ provided $\eta = 1 + \theta > 1$, i. e., if there are decreasing returns along the variable cost function. This reflects the fact that since $P > AVC$ by a variable markup, $P = MC$ can occur only if $MC > AVC$.

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〔抄　訳〕

生産性の鈍化と技術進歩

生産性を測定する場合にこれまで多くの経済学者達によって労働者の一人当り生産量と総要素生産性の二つの方法がとられてきた。前者では価格一定のもとでの生産物の付加価値と労働者の労働時間指数の差をもちいて生産性を測定するのに対して，後者では資本労働比率の伸び率をもとに生産性の伸びに物的資本の貢献度を前者から差し引くことからもとめられる。しかしながらその測定は常に変化している商品やサービスの実質的な付加価値にもとづいて正確な指数をはじきだすことが困難であるとともに，後者においてはさらに資本の効用率をいかに測定するかが難しい問題になってくる。

本研究の目的は米国の生産性の伸び率を後者の方法を使って分析しようとするものである。今日のアメリカ経済における生産性の伸び率の鈍化の要因として，資本力の低下，*R & D* のストックの減少，資本稼動率の減少などがあげられる。この研究のモデルにおいて，規模の経済における総要素生産性（*TFP*）の伸び率について次の式を導きだし，４つの要因について分析する：

$$
\begin{aligned}
DTFP = {} & A\alpha(1+\theta)\textstyle\sum s_i DP_i \\
& + A[\lambda + \beta DY + (1-\beta)DN] \\
& + A\alpha D(1+\theta) + s_r[1 - A\alpha(1+\theta)]DR \\
& + A\eta(1-\alpha\beta)(1+\theta\tau\eta)^{-1}DT
\end{aligned}
$$

１）要素価格効果，$A\alpha(1+\theta)\sum s_i DP_i$;　２）需要効果，$A[\lambda+\beta DY+(1-\beta)DN]$;　３）*R & D* 効果，$A\alpha D(1+\theta)+s_r[1-A\alpha(1+\theta)]DR$;　４）技術進歩の変化，$A\eta(1-\alpha\beta)(1+\theta\tau\eta)^{-1}DT$. に分解，分析をはかるものである。このモデルは，全ての投入に対し費用極小化の均衡モデルであり，*R & D* はある程度の収益が見込まれる水準まで調節

される。このモデルにおける重要なパラメータは需要の価格弾力性と所得弾力性および可変費用関数の費用弾力性である。

この研究の最終的な目的はこのモデルを米国の製造業の実証分析に応用して，1658－86年のアメリカ経済を，1958－65，1966－70，1971－75,1976－80，1981－86の段階に分けてその生産性の実態を明らかにすることである。

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