Technical Change, Returns to Scale and the Productivity Slowdown

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Abstract

We provide a framework for decomposing changes in total factor productivity (TFP) in the presence of economies of scale. The traditional growth accounting framework is a special case of our model. The model is based on an output demand function, a variable (non-R&D) cost function which is shifted by disembodied technical change and a stock of R&D, and a market-clearing rule which equates output price to average variable cost plus quasi-rents to R&D. This framework identifies the contribution of demand growth, real factor prices, and the stock of R&D to changes in the growth of TFP. As an illustration, we apply the model to American manufacturing for the period 1958-1978. The evidence suggests that the deceleration in demand is a leading factor behind the slowdown in TFP growth from 1965-73 to 1973-78. Changes in real factor prices and R&D play lesser roles. By contrast, only one-quarter of the decline in TFP growth during the earlier period 1958-1965 to 1965-1973 can be attributed to these factors.

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The recent slowdown in the growth of productivity in the U.S. has attracted considerable attention. The deceleration has been attributed to many factors, including a slowdown in the growth of capital intensity and the stock of R&D, changes in the sectoral composition of output, dramatic rises in oil prices, and declines in the capital utilization rate due to sluggish demand.[1]

In this paper we provide a framework for decomposing changes in total factor productivity (TFP) in the presence of economies of scale. The traditional growth accounting framework is a special case of our model. By allowing for economies of scale, we demonstrate formally the positive relationship between growth in productivity and output which is found in the empirical studies by John Kendrick (1973), Nicholas Kaldor and others.[2] The model is based on an output demand function, a variable (non-R&D) cost function which is shifted by disembodied technical change and a stock of R&D, and a market-clearing rule which equates output price to average variable cost plus quasi-rents to R&D. This framework identifies the contribution of demand growth, real factor prices, and the stock of R&D to changes in the growth of TFP.

As an illustration, we apply the model to American manufacturing for the period 1958-1978. The preliminary evidence suggests that the deceleration in demand is a leading factor behind the slowdown in TFP growth from 1965-73 to 1973-78. Changes in real factor prices and R&D play lesser roles. By contrast, only one-quarter of the decline in TFP growth during the earlier period 1958-1965 to 1965-1973 can be attributed to these factors. These findings contrast sharply with studies which ignore demand shifts by assuming a priori constant returns to scale (for example, Dale Jorgensen and Barbara Fraumeni).

I, The Model

Since we do not impose constant returns to scale, the proper index of conventional TFP growth is the "quasi-Divisia" index

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

where D denotes a rate of growth, Q is output, the X's represent traditional (non-R&D) inputs, F is total factor input, and $s_i=P_iX_i/PQ$ is the value share of the ith input.[3]

Let the production function be Q = G(X,R,T) were R and T denote the stock of R&D and the (disembodied) technology level. Differentiating with respect to time and assuming cost minimization over all inputs, we obtain

$$(2) \quad DQ = \Sigma[(P_iX_i/Q)/MC]DX_i+[(P_rR/Q)/MC]DR + DT$$

where MC is marginal cost and P_r is the service price, or opportunity cost, of R&D.[4]

The next step is to relate marginal cost to the price of output. We assume that price equals current average variable cost (AVC) plus the unit quasi-rents which accrue to past R&D (see K.J. Arrow; Ariel Pakes and Mark Schankerman). 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, $\eta = MC/AVC$, we obtain $MC = \eta P/(1+\theta)$.[5]

Substituting the expression for MC into (2) we obtain the output growth equation

$$(3) \quad DQ = \eta^{-1}(1+\theta)\Sigma s_i DX_i + \eta^{-1}(1+\theta)s_r DR + DT$$

Obtaining $DF = \Sigma s_i DX_i$ from (3) and using (1), the growth of TFP becomes

$$(4) \quad DTFP = \frac{(1+\theta-\eta)}{1+\theta} DQ + \frac{\eta}{1+\theta} DT + s_r DR$$

Next we obtain the equilibrium DQ. Assume a log linear per capita demand function. In growth rate form

$$(5)\quad DQ = \lambda + \alpha DP + \beta DY + (1-\beta)DN$$

where Y and N are income and population and λ reflects a demand time trend. The pricing rule implies

$$(6)\quad DP = DCV - DQ + D(1+\theta)$$

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. Factor prices are assumed to be determined outside the model. Differentiating with respect to time, using Shephard's Lemma and the relation $DT_c = -\eta DT$ (M. Ohta), we obtain

$$(7)\quad DCV = (1+\theta)\Sigma s_i DP_i + \eta DQ - \Pi DR - \eta DT$$

where $\Pi = P_r R/CV$. Substituting (5)-(7) into (4), we obtain the reduced-form expression for the growth rate of total factor productivity, DTFP:

$$\begin{aligned}(8)\quad DTFP = {} & A[\lambda+\alpha D(1+\theta)] + A\alpha(1+\theta)\Sigma s_i DP_i + A\beta DY + A(1-\beta)DN \\ & + s_r[1-A\alpha(1+\theta)]DR + A\eta(1-\alpha\theta)(1+\theta-\eta)^{-1}DT\end{aligned}$$

where $A = (1+\theta-\eta)[(1+\theta)(1+\alpha(1-\eta))]^{-1}$.

Equation (8) decomposes DTFP into four components: (1) factor price effect, $A\alpha(1+\theta)\Sigma s_i DP_i$; (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, $A\eta(1-\alpha\theta)(1+\theta-\eta)^{-1}DT$. 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 (private) rate of return in the form of quasi-rents, and the market clears. Because market-clearing is imposed, each component in the decomposition reflects both the direct impact on TFP of the factor in question and its indirect effect via induced changes in the output price. This formalizes Kendrick's suggestion (1973, p. 111) that the relationship between changes in productivity and output growth is "reciprocal" (i.e., DQ leads to DTFP which reduces DP and further raises DQ).

The important parameters in (8) are the price and income elasticities of demand and the cost elasticity of the variable cost function. Note two special cases. First, if demand is completely inelastic ($\alpha=0$), shifts in the cost function due to real factor price changes ($\Sigma s_i DP_i$) have no effect on output and hence on TFP. Second, if marginal cost pricing prevails ($\eta=1+\theta$; see note 5), then equation (8) collapses to DTFP = s_rDR+DT, which is the standard result whn TFP is defined only over conventional inputs.[6]

II. An Empirical Application

We now present an empirical illustration of the model. The decomposition requires three parameters, the variable cost elasticity, and the price and income elasticities of product demand. Given these parameters, the procedure is to compute the factor price, demand, and R&D effects and then to retrieve the technical change effect as a residual using equation (8).[7] Discrete (Tornquist) approximations to the Divisia indices in (8) are used. Annual data on gross value added (including energy), capital, labor and energy for the period 1958-78 were obtained from BEA, E. Grossman and Jack Faucett Associates. Published NSF data on R&D flows are used to construct a stock, using Kendrick's (1976) benchmark and a depreciation rate of 0.10. Price series on the inputs and outputs were obtained from the same sources and variables such as the rental prices for capital and R&D services were generated using familiar formulations. Real factor prices are measured as nominal factor prices deflated by the Consumer Price Index.

The log linear, per capita demand functions are estimated by ordinary least squares with a serial correlation adjustment, using real GNP as the income variable. The cost elasticities are obtained from a Cobb-Douglas variable cost function with non-neutral technical change (proxied by time trends). The envelope condition on R&D is imposed and estimated together with the variable cost function and the variable-input share equations. The system of equations is estimated by an iterative, seemingly unrelated equations procedure with an autocorretlation adjustment. The period covered is 1958-78.

Table 1 summarizes the results. The demand parameters are roughly similar to results reported by Hendrik Houthakker. We also obtained estimates from Data Resources, Inc. which broadly confirm the price elasticities but place the income elasticity closer to 1.5. A decomposition using this lower value is also performed and the differences will be noted below. The estimated cost elasticities are similar in the three industry groups, are statistically different from unity, and indicate some economies of scale at the industry level. The implied economies of scale may seem somewhat high but they are similar to recent estimates at the industry level by Ernst Berndt and Mohammed Khaled.[8]

We use these parameter values to decompose the TFP growth in total manufacturing, durables and nondurables for three periods, 1958-65, 1965-73 and 1973-78. In order to focus on the deceleration of TFP growth, we present in Table 2 the contributions of factor prices, demand, R&D, and residual technical change as a percentage of the change in TFP growth between the periods.

Table 1. Estimated Price, Income and Cost Elasticities *

	α	β	η
Manufacturing	-.33 (.21)	2.16 (.13)	.76 (.05)
Durables	-.20 (.21)	2.74 (.16)	.77 (.05)
Nondurables	-.56 (.18)	1.25 (.12)	.78 (.06)

*Estimated standard errors are in parentheses.

The growth in TFP declined sharply throughout the entire period. In percentage terms, DTFP declined by about 45% in manufacturing, 60% in durables, and 30% in nondurables between each pair of sub-periods. The relative contributions of the different factors vary among industry groups and between sub-periods. Real factor prices contribute only modestly to the deceleration in DTFP from 1958-65 to 1965-73, except in nondurables. Factor prices contribute more to the decline in DTFP from 1965-73 to 1973-78. These differences may be partly spurious, and simply reflect the inclusion of the petroleum industry in nondurables.[9] If durables are a good guide, the factor price effect has been modest.

The slowdown in demand growth is an important factor in the retardation of DTFP in all industry groups. About 10-20% of the decline in DTFP from 1958-65 to 1965-73 is accounted for by the demand effect, but this rises dramatically to more than 50% from 1965-73 to 1973-78. Factor prices and demand together (total scale effect) account for most, and in total manufacturing more than all, of the deceleration in DTFP. Despite the caveat regarding petroleum and the possibility we have overestimated returns to scale, the evidence points to the scale effect, and mainly demand deceleration, as a major factor behind the decline in DTFP from 1965-73 to 1973-78.

The decline in the growth of the R&D stock contributes modestly to the slowdown in DTFP from 1958-65 to 1965-73, less than 10%. The same is true for nondurables from 1965-73 to 1973-78, but in durables and total manufacturing R&D plays a very significant role, accounting for nearly a quarter of the retardation in DTFP.

The technical change effect is computed residually and therefore captures all contributory factors not accounted for by the model (including measurement error). This residual accounts for the bulk of the decline in DTFP from 1958-65

Table 2. Decomposition of the Deceleration in Total Factor Productivity Growth in Manufacturing Industries*

Industry	Average ΔDTFP	Factor Prices %	Demand %	Total Scale %	R&D %	Residual Technical Change %
Manufacturing						
1958-65 to 1965-73	-.0157	9.4	13.7	23.1	4.3	72.6
1965-73 to 1973-78	-.0072	33.4	68.3	101.7	17.4	-19.1
Durables						
1958-65 to 1965-73	-.0198	4.4	11.9	16.3	7.2	76.5
1965-73 to 1973-78	-.0095	5.3	63.7	69.0	23.8	7.2
Nondurables						
1958-65 to 1965-73	-.0074	32.5	22.0	54.5	0.9	44.6
1965-73 to 1973-78	-.0063	55.0	44.0	99.0	2.3	-1.3

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*The parameter estimates for α, β and η used in the decomposition are taken from Table 1.

to 1965-73 (about 75% in manufacturing and durables and 45% in nondurables), but very little from 1965-73 to 1973-78. In fact, the negative contribution in manufacturing and nondurables suggests that residual technical change accelerated at the same time that DTFP declined.[10] The main conclusion is that the deceleration of demand, and to a lesser extent the factor price and R&D effects, dominate the recent slowdown in productivity growth.

III. Concluding Remarks

We propose and illustrate empirically a framework for decomposing changes in TFP in the presence of economies of scale. The traditional growth accounting framework with constant returns is a special case of our model. The empirical results suggest that the deceleration of demand is a leading factor in the recent decline of TFP growth in American manufacturing. Our analysis underscores the importance of understanding the forces behind the slowdown in demand, but we do not address this question here.

There are several ways to extend the analysis: 1) explore more fully the link between the quasi-rents and the service price of R&D; 2) endogenize the determination of factor prices; and 3) relax the assumption that R&D earns the normal private return, estimate the realized rate of return in the model and use it to evaluate the impact of R&D on TFP growth.

FOOTNOTES

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1. For example, see M. Ishaq Nadiri, William D. Nordhaus, and J. Norsworthy and L. Fulco.
2. For more discussion of this issue, see T. Cripps and R. Tarling, A. Parikh, and W. E. G. Salter.
3. Charles Hulten shows that if the production function is not linearly homogeneous, the "quasi-Divisia" index (with value rather than cost shares as weights) must be used in order to preserve path independence of the index. Also see Nadiri and Schankerman.
4. An 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_r, would then represent the associated gross rate of return (multiplied by an investment goods deflator).
5. Note that P=MC provided $\eta=1+\Theta>1$, that is, 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, which implies (local) decreasing returns to conventional inputs.

6. In other words, TFP growth is equivalent to shifts in the production function provided marginal cost pricing (and cost minimization) prevails. These shifts represent movements in a technological relationship, but our ability to identify them from market data (DTFP) requires behavioral assumptions. Note that long run constant returns is neither a necessary nor sufficient condition. Of course, the behavioral assumption of marginal cost pricing may only be plausible under non-increasing returns to scale. See Nadiri and Schankerman, and M. Denny, M. Fuss and L. Waverman.

7. In the calculations we assume $\Pi=\Theta$, or equivalently that the service price of R&D equals the current unit quasi-rents to R&D. This equality reflects the fact that the quasi-rents represent the opportunity cost of not "selling" the (rights to the) R&D. The assumption $\Pi=\Theta$ does not require a normal net rate of return to R&D, but our cost minimization assumption does (see note 4).

8. Note two points. First,the null hypothesis $\eta=1$ is uniformly rejected. The computed X^2 values are 8.1, 4.0 and 10.0 in manufacturing, durables and non-durables, respectively, compared to the .05 critical value of 3.84. Constant returns was also rejected in various forms of the translog cost function we estimated. See Berndt and Khaled for the rationale of increasing returns at the industry level. Second, since $\eta<1$, it follows that the condition for marginal cost pricing ($\eta=1+\Theta$; note 5) is also rejected.

9. It would be useful to check this by omitting the petroleum industry and re-doing the empirical estimation and the decomposition. We plan to do so in future work.

10. These qualitative conclusions are unaffected if we substitute the smaller income elasticities of demand for durables and manufacturing (≈ 1.5) provided by DRI. There is a neglibible change in the residual technical change effect from

1958-65 to 1965-73; it becomes zero in manufacturing and 15% in durables from 1965-73 to 1973-78. The sharp reversal of the importance of the residual still holds.

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