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PRODUCTIVITY GROWTH AND MATERIALS USE IN U. S. MANUFACTURING*

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INTRODUCTION

This paper uses data for U. S. manufacturing to examine the importance for the measurement of productivity growth of alternative assumptions about the production function. In particular, does the use of a value-added production function introduce a major bias? This is an important issue, since Bruno [1984] has argued that such a bias can account for an important fraction of the observed slowdown in productivity growth that has occurred since 1973.

The paper first reviews the algebraic relationships among three alternative measures of productivity growth. Then it examines how output and materials are measured for U. S. manufacturing in practice. Then these data are adjusted for the effect of intramanufacturing shipments, and the results of the comparison among measures are presented. The paper concludes that U. S. manufacturers have economized on purchased intermediate goods, and that there may be a small bias in value-added based productivity measures as a result of this shift.

ALTERNATIVE PRODUCTION SPECIFICATIONS

A common starting ground for many analyses of productivity is a production function of the following form:

$$Q = Q(L,K,N,t). \tag{1}$$

In this specification, Q is final output, L is labor input, K is capital input, N is materials input, and t is a measure of technology. In applications to actual data three alternative special cases of the production function are often assumed. They are as follows:

$$Q = A(t)F(L,K,N) \tag{2a}$$

$$Q - N = V_d = B(t)G(L,K) \tag{2b}$$

$$Q = H[V\{C(t)L,K\};N]. \tag{2c}$$

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Assumption (2a) simply assumes that there is output-augmenting technical change. This form of the production function was used, for example, by Griliches and Mairesse [1983]. Assumption (2b) assumes that V_d (double-deflated value-added) is a function of capital and labor inputs with value-added-augmenting technical change. Assumption (2b) is often made in the literature, for example, in Solow's [1957] work on the neoclassical growth model, or more recently in my own work [Baily, 1981, 1982].

Assumption (2c) imposes separability on the production function. Capital and labor together produce an alternative concept of value-added, labeled V, which then combines with materials to produce final output. The specification in (2c) is the one used by Bruno [1984], who also assumed that there is labor-augmenting technical change occurring within the value-added function.

The three alternatives (2a), (2b), and (2c) by no means exhaust all the possibilities, but do they represent a sample from the literature. Except for special functional forms, the three specifications are inconsistent with each other and will yield three different measures of the rate of productivity growth. The three measures are the logarithmic rates of change of $A(t)$, $B(t)$, and $C(t)$, respectively; and with constant returns to scale and competitive returns to factors, these three rates of growth are given as follows:

$$g_A = g_Q - \alpha_L g_L - \alpha_K g_K - \alpha_N g_N \tag{3a}$$

$$g_B = g_{V_d} - \tilde{\alpha}_L g_L - \tilde{\alpha}_K g_K \tag{3b}$$

$$g_C = (1/\alpha_L)[g_Q - \alpha_L g_L - \alpha_K g_K - \alpha_N g_N]. \tag{3c}$$

The α's are the shares of factor payments in final output, the $\tilde{\alpha}$'s are the factor shares in value-added, and the g's are growth rates. Equations (3a) and (3c) show that g_A and g_C are proportional to each other, with the share of labor income in final output (which may vary over time) being the factor of proportionality. The separability assumption was used by Bruno to discuss alternative concepts of value-added. For our purposes, it turns out that the only difference between (2a) and (2c) is that the latter assumes labor-augmenting change.

Define n as the ratio of materials use to final output N/Q. It can then be shown that the relationship between g_B and g_A is as follows:

$$g_B = [1/(1 - \alpha_N)][g_A + g_n((\alpha_N - n)/(1 - n))]. \tag{4}$$

Consider first the case when the ratio of materials use to output is not changing (so that $g_n = 0$). Then g_B and g_A are also proportional to each other, with the factor of proportionality equal to unity minus the materials cost share. This means that if g_A were constant over some period, but the materials share were rising, the g_B would be increasing over time.

When materials use does change relative to output, then g_n is nonzero. In the base year the relative price of materials is unity, and the current dollar share α_N is the same as the constant dollar share n. If the relative price of materials is increasing over time and materials use is declining (the empirically relevant case for the United States), then the second term in brackets in equation (4) is negative for years beyond the base year. Bruno [1984] identifies this term as the downward bias in value-added productivity measurement. Of course, for years prior to the base year, the same argument implies that the term is positive. Its effect, therefore, is to accentuate a slowdown in the value-added measure of productivity growth if it takes place in or near the base year, as Bruno pointed out.[1]

Two differences between equation (4) and Bruno's similar expression are, first, that no specific functional form has been imposed here; the production functions could be Cobb-Douglas, CES, or translog. And, second, the extent of the biases or differences in alternative productivity measures can be linked directly to observed variables, without the intermediate estimation of production function parameters.

Alternative Measures of Output

The U. S. Bureau of the Census uses the Annual Surveys of Manufacturers and the Quinquennial Censuses to construct a data series of production by manufacturing establishments. The nominal values of shipments are deflated by four-digit industry price indexes or, in many cases, by five-digit product class prices and adjusted for changes in inventory. The output measure obtained from shipments adjusted for inventory change we shall call gross production. The growth rates of gross production over the

1. Materials are valued using 1972 prices, so that a given decline in materials use contributes too much to the value-added measure of productivity growth if it takes place when the relative materials price is less than unity, and contributes too little if the price is greater than unity.

TABLE I

RATES OF GROWTH OF ALTERNATIVE MANUFACTURING OUTPUT MEASURES (PERCENT PER YEAR)

Years (1)	Gross production (2)	Intermediate goods (3)	Value-added (census) (4)	Value-added (BEA) (5)	F. R. Board Index (6)
1967–1973	3.59	2.83	4.44	4.14	4.35
1973–1980	1.22	0.65	1.80	1.09	1.75
Difference	−2.37	−2.18	−2.65	−3.06	−2.61

Source. Unpublished data provided by the Bureau of Economic Analysis; printout dated 11/30/83. FRB index is from the *Economic Report of the President*, February 1984.

periods 1967–1973 and 1973–1980 are shown in column 2 of Table I.

The Census Bureau also measures intermediate goods purchased by manufacturing establishments from the same surveys and censuses. Computing the deflator for these purchases is difficult because the composition of the intermediate goods is not known directly. The Bureau is still using the 1972 input-output table as the basis for weighting the individual price indexes. An exception to this is energy, however, since the Annual Survey does include fairly detailed information on energy use. The rates of growth of real intermediate goods are shown in column 3 of Table I.

By subtracting real goods purchased from gross production, the Census Bureau also estimates double-deflated value-added, and the growth rates for this concept of output are shown in column 4 of Table I. Columns (2), (3), and (4) do show evidence of declining intermediate goods use over the whole period, so that the Census Bureau's value-added grows faster than gross production in both subperiods.

The Bureau of Economic Analysis estimates nominal value-added in manufacturing using total compensation paid to labor and capital. That is difficult because some firms have both manufacturing and nonmanufacturing establishments, so that their income flows must be separated by industry. The BEA deflates its estimate of nominal value-added using a price series based heavily on the implicit value-added deflator from the Census Bureau. This carries over the double-deflation technique. However, BEA also tries to take account of excise taxes and purchases of business services by manufacturers. Both of these are ignored in the Census Bureau's estimate of value-added. The BEA value-added series is also known as the GDP originating in manufacturing, and it forms the basis for the productivity series published by the Bureau of Labor Statistics. Column (5) of Table I shows the growth rates for BEA value-added, and it can be seen that they are slower than those for Census value-added, particularly after 1973. The BEA series indicates that purchases of services by manufacturing establishments have grown since 1967.

Unfortunately, there is no independent measure of purchased services, so that any measurement error is included in their estimated value. And since the error may be quite large, many people prefer to count intermediate goods only and ignore services. This assumes that BEA is simply failing to count some labor and capital income. In what follows, I shall show results for both cases—intermediate goods alone, and intermediate goods and services.[2] The results differ quite a bit for the two cases.

The Federal Reserve Board also publishes an index of manufacturing output. It is published monthly and in the short run is based on a mixture of gross production data and input data and is intended as a short-run cyclical indicator. It uses value-added weights to aggregate industries and is intended to be a value-added index. The FRB revises the trends to keep them roughly in line with the Census value-added series. The growth rates for this index are shown in column (6) of Table I.

Alternative Measures of Materials Prices

Table II shows some alternative measures of the relative price of purchased materials. Column 2 shows the PPI for crude materials relative to the PPI for finished goods, the price series used by Bruno [1984].[3] These published producer price indexes are rather odd measures. The weights used for the different components are not based on relative quantities produced or used by manufacturers, and energy counts heavily in the crude materials price index.[4]

Columns 3 and 4 show the prices of intermediate goods and intermediate goods and services relative to the price of gross production for the manufacturing sector. These indexes show rather a different pattern from the crude materials prices. The index for goods increases only about 10 percent between 1972 and 1974 and then remains flat through 1978, before increasing another 7.3 percent between 1978 and 1980. The index for goods and services shows a rather similar pattern, but the extent of the relative price increase is smaller. According to BEA, the price of purchased services rose less than the price of purchased goods.

2. When intermediate services are ignored, the estimate of value-added rises—the Census estimate is larger than the BEA estimate. The additional income is assumed to be divided between capital and labor in the same ratio that is found by BEA.

3. The series shown in Table II is a little different from that used by Bruno because of revisions in the data.

4. It is easy to misinterpret the importance of energy to the crude materials index. The "fuel" component of the index does not have a large relative importance and removing it from the overall materials index has only a modest effect. However, crude petroleum and natural gas used as a feedstock are not considered fuels. When these components are added, to form all "energy" uses, the weight of energy in the index is high. The relative price of non-energy crude materials fell from 1974 to 1980.

TABLE II

ALTERNATIVE MEASURES OF THE RELATIVE PRICE OF MATERIALS
(INDEX 1972 = 100)

Years (1)	PPI crude materials[a] (revised) (2)	Intermediate goods[b] (3)	Intermediate goods and services[c] (4)
1955	104.3	—	—
1967	91.8	97.5	98.3
1972	100.0	100.0	100.0
1973	124.9	105.2	103.9
1978	109.9	110.8	107.9
1980	113.2	119.2	112.3

a. The producer price index for crude materials divided by the producer price index for finished goods, from the *Economic Report of the President*, February 1984.
b. Deflator for intermediate goods divided by the deflator for gross production, for the manufacturing sector. From unpublished data, Bureau of Economic Analysis.
c. Deflator for intermediate goods and services divided by the deflator for gross production. Source as for b.

THE PROBLEM OF INTRAMANUFACTURING SHIPMENTS

The manufacturing industry is its own best customer. The Census Bureau collects its data on an establishment basis, and many of these establishments produce items such as brakes for automobiles or compressors for refrigerators. These are then the intermediate goods purchased by other manufacturing establishments for assembly into final goods. If the quantity of intramanufacturing shipments is I, then gross production equals $Q + I$, and intermediate goods purchased equal $N + I$. The deflators also refer to these concepts.

The great advantage of using value-added as an output measure, given the way the data is collected in practice, is that intramanufacturing sales are netted out. Gross production, by contrast, is an output measure that includes not only automobiles and refrigerators, but then double-counts the brakes and compressors that go into them. This means that while, in theory, letting materials be an explicit factor of production makes sense, in practice, using value-added does have an advantage. The choice basically, depends on the level of aggregation. For productivity analysis conducted at the establishment level there are no intra-industry sales to worry about. Gross production equals the theoretical concept Q, and purchased intermediate goods can be taken as a legitimate factor input. At the level of GDP for the whole

TABLE III

MATERIALS SHARES AND PRICES, ADJUSTED FOR INTRA-INDUSTRY SHIPMENTS, PERCENT AND INDEX NUMBERS, 1972 = 100.

	Intermediate goods only			Intermediate goods and services		
Years (1)	Constant dollar share n (2)	Current dollar share α_n (3)	Relative price P_N (4)	Constant dollar share n (5)	Current dollar share α_n (6)	Relative price P_N (7)
1967	26.7	24.6	92.2	40.5	38.9	95.9
1972	25.8	25.8	100.0	40.2	40.2	100.0
1973	22.9	27.1	118.2	38.6	42.3	109.7
1978	22.3	32.0	137.4	39.5	47.1	119.3
1980	19.9	34.7	174.5	39.1	51.0	130.5

economy, raw material imports, apart from energy, are pretty small; and gross production would contain so much double and triple counting it would be almost meaningless. For the analysis of productivity within manufacturing, there is a reasonable case for using either gross production or value-added.

Since the purpose here is to make comparisons among the three production specifications, I have adjusted the gross production and intermediate goods data to make them correspond more closely to the theoretical concepts Q and N. This can be done with two simplifying assumptions. Define i as the ratio of intramanufacturing shipments to gross output I/Q, and assume that i is a constant. This says, essentially, that the industrial structure does not change. Second, assume that the price of I is the same as the price of Q. This assumption was also used by Bruno [1984]. With these assumptions the values for n, α_N, and P_N can be inferred from the data on gross production (GP), intermediate purchases (IN), and their deflators:

$$\alpha_N = \alpha_{IN} - i(1 - \alpha_{IN}) \tag{5a}$$

$$n = IN/GP - i(1 - IN/GP) \tag{5b}$$

$$P_N = \alpha_N/n. \tag{5c}$$

From the 1967 input-output table we have that I/GP is 36.5 percent. This gives a value for i of 57.5 percent, assumed to remain constant. Table III shows values of the three series given in (5) for selected years. The constant dollar adjusted shares shown in Table III reveal a very substantial reduction in the use of intermediate goods in manufacturing, and the adjusted price index shows a very large increase in the relative price of these materials. These data give clear support to the hypothesis that over the period 1967–1980 there was a decline in the terms of trade of the manufacturing sector and a consequent shift to economize on external purchases of goods. The assumptions made to adjust for intra-industry shipments have probably accentuated the decline in n and the rise in P_N somewhat. But the basic result does make sense. Quite apart from the increase in energy prices, the manufacturing sector experienced a decline in its terms of trade because its own productivity growth has been much more rapid since 1967 than that occurring outside manufacturing.

If purchased services are included, the picture changes. There is a smaller price increase and a much smaller reduction in intermediate purchases. These data suggest that manufacturing establishments shifted from goods purchases to services purchases, but achieved little change in the overall volume of their intermediate purchases.

RESULTS AND CONCLUSIONS

The Bureau of Labor Statistics publishes an estimate of multifactor productivity growth, and this corresponds to what has been called g_B for goods and services here. From this basis, comparable estimates of the alternative growth measures were computed using the results we have just derived. The upper part of Table IV shows the average productivity growth rates for the periods 1967–1973 and 1973–1980 for the three measures. The magnitudes of the three alternative estimates of productivity growth are very different. The assumption of labor-augmenting technical change is very different from the assumptions of output-augmenting or value-added-augmenting change. However, the alternative measures are not in fact telling fundamentally different stories about recent economic growth. To show this, the values are all rescaled. The growth rate g_A is left alone. g_B is multiplied by the constant $(1 - \overline{\alpha}_N)$, where $\overline{\alpha}_N$ is the materials cost share in 1972, and g_C is multiplied by the constant $\overline{\alpha}_L$, the labor cost share in 1972.

The lower half of Table IV shows the effect of this rescaling and allows more meaningful comparisons. It shows a remarkable similarity among the alternatives, particularly up to 1973. One

TABLE IV

ALTERNATIVE MEASURES OF PRODUCTIVITY GROWTH IN U. S. MANUFACTURING, PERCENT PER YEAR

	Intermediate goods only			Intermediate goods and services		
Years (1)	g_A (2)	g_B (3)	g_C (4)	g_A (5)	g_B (6)	g_C (7)
1967–1973	2.36	3.11	4.51	1.71	2.81	4.04
1973–1980	0.97	0.95	1.96	0.20	0.28	0.48
			Values rescaled to match g_A			
1967–1973	2.36	2.30	2.35	1.71	1.68	1.70
1973–1980	0.97	0.70	1.02	0.20	0.16	0.20
Difference	−1.39	−1.60	−1.33	−1.50	−1.51	−1.50

Source. Calculated by the author as described in the text.

major divergence comes in the goods-only case after 1973. The value-added measure g_B does indeed accentuate the slowdown. Roughly 15 percent of the slowdown in g_B after 1973 is eliminated by using a three-factor production function. The specific term in equation (4) that Bruno identifies as the bias in value-added accounts for -0.27 of the slowdown of -1.60 in g_B. For the goods and services case, all three measures give virtually identical estimates of the productivity growth slowdown. If BEA is accurately measuring intermediate purchases, then the bias is negligible.

The conclusion of this comparison of alternative specifications is that they all tell a similar story about recent economic growth. The slowdown in productivity growth is not created by a particular production function assumption. The bias described by Bruno is at most small, and may be negligible, depending upon which measure of value-added is being used. Of course, Bruno himself has not claimed that the whole slowdown is attributable to value-added bias. He has emphasized cyclical and other causes of the slowdown [Bruno, 1982, 1984], and the need for such alternative explanations is reinforced by the findings of this paper.

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