Energy Price Increases and the Productivity Slowdown in United States Manufacturing

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I. Introduction

Greater energy conservation, continued increases in productivity and real wages, and sustained economic growth are goals pursued today by almost all national governments. Since the 1973 OPEC energy price increases, however, disappointing economic trends in the United States, Canada and elsewhere have focused attention on the extent to which these goals are compatible. In particular, the post-1973 slowdown in the rate of growth of labor productivity is viewed by many as contributing considerably to recent acceleration of price inflation.[1] In this paper I examine the role of energy price increases in the productivity slowdown in U.S. manufacturing, 1973–77. The manufacturing sector is of particular interest since it is energy-intensive and important; in 1974 it accounted for 23.4 percent of U.S. gross domestic product, but consumed 36.2 percent of total U.S. energy.[2]

Although post-1973 energy market developments have heightened professional interest in energy-economy interactions, this issue is by no means new. More than a century ago in 1865 a melancholy William Stanley Jevons reckoned

> A rise in the price of coal, whether from taxation or scarcity, must levy open and insidious contributions upon us in a manner with which no other tax whatever can compare.[3]

Indeed, because he feared England would lose her superior command of coal, Jevons lamented "... we must not only cease to progress as before — we must begin a retrograde career."[4]

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[1] See, for example, U.S. Council on Wage and Price Stability [1979].

[2] John G. Myers and Leonard Nakamara [1978], p.4.

[3] William Stanley Jevons [1865], p. 444.

[4] Jevons [1865], p. 201.

A symmetric argument — that lower energy prices increase economic growth and productivity, albeit modestly — was made by Herbert A. Simon in 1950:

> . . . we have considered the effects of the introduction of cheap atomic power, available anywhere, upon the economy of a nation or a region. . . . The principal short-run effect upon an economy like that of the United States would be a modest increase in productivity, and a consequent increase in income; it does not seem likely it will be more than 1%. . . . Long-run effects of larger magnitude might be produced over a number of years if the increase in income resulted in a more rapid accumulation of capital, thus further increasing the productivity of the economy.[5]

Simon's conjecture was examined a decade later by Sam H. Schurr and Bruce Netschert, who speculated that

> . . . the marked acceleration in the increase in labor and capital productivity after World War I is attributable in some degree to the new methods of organizing production made possible through the growing electrification of industrial operations.[6]

Few would argue today that post-1973 energy price increases are likely to lead to a dramatic reversal of the historic electrification process in industry. Nonetheless, some distinguished economists believe these energy price increases will have an enormous negative effect on industrialized economies in the long run, though not necessarily a highly visible or dramatic one. Dale W. Jorgenson, for example, argues

> It will be difficult to come to terms with the impact of the OPEC cartel at an intellectual level until much time has passed. If the impact of the Great Depression of the 1930s was like a nuclear explosion in its devastating force, the impact of the OPEC cartel is like a mild but persistent form of radiation. Its effects are slow and insidious but ultimately equally devastating. The effects of higher energy prices are not easy to detect for quarter-to-quarter fluctuations in the national income and product accounts. In the short and intermediate term, we can expect the full gamut of "special factors" will be brought into play by economic commentators to explain the growing departure between current economic developments and past historical experience. . . . But in the long run, presumably when we are all dead, there is at least a modest probability that the most significant economic reversal since the Great Depression of the 1930s will be seen to be the slowdown in economic growth brought about by the establishment of the OPEC cartel.[7]

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[5] Herbert A. Simon [1950], pp. 246–247.

[6] Sam H. Schurr and Bruce Netschert [1960], p. 189. On this issue, also see Richard B. DuBoff [1966].

[7] Dale W. Jorgenson [1978], pp. 23–24.

In the Jorgenson framework, increased energy prices reduce capital formation in energy- and capital-intensive sectors, resulting in a smaller capital stock being passed on to future decades, thereby reducing future potential output. Moreover, and even more important empirically, since relative prices of the more energy-intensive goods rise by a greater proportion, energy price increases induce a shift in the composition of final demand to more labor-intensive sectors, thereby depressing in particular aggregate national labor productivity growth.[8] Total factor productivity growth at the national level is not affected as greatly, unless of course energy price-induced compositional shifts in final demand favor sectors with below average rates of growth in total factor productivity.[9]

While not necessarily denying that rising energy prices might eventually have a negative effect on measured productivity growth, Edward F. Denison believes that recent price increases have not had much of an impact yet, at least over the relatively short 1973–76 time period. Hence Denison concludes that "I do not believe that much of the productivity slowdown can be ascribed to energy prices."[10] However, after examining two more years' data (through 1978), J.R. Norsworthy, Michael J. Harper and Kent Kunze [1979] reckon that

> The 1973–78 slowdown is dominated by the effects of reduced capital formation. Some effect is also attributable to interindustry shifts in labor and capital. The sharp rise in energy prices may show up in a framework such as ours through its impact on capital formation and may help explain the relative weakness in capital formation in recent years.[11]

This brief survey of energy-economy interactions amply indicates a lack of consensus on the role of post-1973 energy price increases in the recent productivity slowdown. Hence in this paper I focus attention on how energy price increases might affect growth rates of measured labor and total factor productivity. The data I shall use, provided me by J.R. Norsworthy and Michael J. Harper, are for total U.S. manufacturing 1958–77. However, an essential part of the story I shall tell involves distinguishing production ("blue collar") from nonproduction ("white collar") labor; I gathered this disaggregated labor data for total manufacturing from published BLS sources.

In Section II, I provide a noneconometric analysis of these 1958–77 data, and point to evidence suggesting that a good portion of the productiv-

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[8] The indirect compositional effect is typically found to be considerably larger than the direct impact; see the simulations reported in Edward A. Hudson and Dale W. Jorgenson [1974, 1978a, b].

[9] Dale W. Jorgenson and Barbara M. Fraumeni [1979] also noted that if the fixed bias of technical change in a given sector is energy using, then increases in energy prices will reduce total factor productivity within that sector. Such an approach, however, does not permit the energy-using bias of technical change to vary in response to dramatic changes in energy prices.

[10] Edward F. Denison [1979], p. 138.

[11] J. R. Norsworthy, Michael J. Harper, and Kent Kunze [1979], p. 421.

ity slowdown in U.S. manufacturing might be attributed to a slowdown in the rate of growth of output without a corresponding reduction in capital formation and growth of white collar employment; these latter two inputs can of course be viewed as quasi-fixed factors. In Section III, I discuss a dynamic model of factor demands that allows for both variable and quasi-fixed inputs, and then in Section IV I report econometric results and implications for 1973–77 productivity trends. In particular, I address five empirical issues concerning possible means by which energy prices might affect productivity trends: (i) How has the economic capacity output Y* varied from the actual rate of output Y, i.e., what does an economic measure of capacity output, dependent on energy prices, look like over the 1958–77 time period? (ii) To what extent can the small total factor productivity growth rates 1973–77 be attributed to increased divergence of actual from economic capacity output? (iii) By how much do increased energy prices affect the optimal level of output? (iv) By what amount do higher energy prices affect Tobin's q? and (v) How do variations in output and capacity utilization affect the productivity of individual inputs? Finally, in Section V I provide some concluding remarks on the role of energy price increases on measured productivity trends.

II. Examination of Factors Coinciding with the Productivity Slowdown in U.S. Manufacturing

The economic theory of productivity measurement is closely related to the theory of cost and production. Denote the quantity of aggregate capital services as K, aggregate labor L, energy E, nonenergy intermediate materials M, gross output Y, and the state of technology A. Let there be a constant returns to scale production function with traditional neoclassical curvature properties,

$$Y = Af(K,L,E,M). \qquad \ldots .(2.1)$$

A logarithmic differential of (2.1) can be written as

$$\frac{d\mathit{ln}Y}{dt} = \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}K} \cdot \frac{d\mathit{ln}K}{dt} + \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}L} \cdot \frac{d\mathit{ln}L}{dt} + \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}E} \cdot \frac{d\mathit{ln}E}{dt}$$

$$+ \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}M} \cdot \frac{d\mathit{ln}M}{dt} + \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}A} \cdot \frac{d\mathit{ln}A}{dt} \,. \qquad \ldots .(2.2)$$

The partial derivatives

$$\frac{\partial \mathit{ln}Y}{\partial \mathit{ln}K}, \quad \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}L}, \quad \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}E} \text{ and } \frac{\partial \mathit{ln}Y}{\partial \mathit{ln}M}$$

are of course output elasticities; under competitive market conditions they equal input cost shares in the value of output. Denote these cost share as S_K, S_L, S_E and S_M. Since

$$\frac{\partial \ln Y}{\partial \ln A} = 1, \text{ writing } \frac{\partial \ln Y}{\partial t} = \frac{1}{Y}\frac{\partial Y}{\partial t} \equiv \frac{\dot{Y}}{Y},$$

and analogously for each of the inputs, we have from (2.2) that

$$\frac{\dot{Y}}{Y} = S_K\frac{\dot{K}}{K} + S_L\frac{\dot{L}}{L} + S_E\frac{\dot{E}}{E} + S_M\frac{\dot{M}}{M} + \frac{\dot{A}}{A}\,. \qquad \text{....(2.3)}$$

Total factor productivity $\frac{\dot{A}}{A}$ is obtained by rearranging (2.3),

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - S_K\frac{\dot{K}}{K} - S_L\frac{\dot{L}}{L} - S_E\frac{\dot{E}}{E} - S_M\frac{\dot{M}}{M}, \qquad \text{....(2.4)}$$

i.e., total factor productivity is growth in output minus growth in aggregate input, where aggregate input is the share-weighted growth of individual inputs. Since $S_K + S_L + S_E + S_M = 1$, we can rewrite (2.4) as

$$\frac{\dot{A}}{A} = S_K\left(\frac{\dot{Y}}{Y} - \frac{\dot{K}}{K}\right) + S_L\left(\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L}\right) + S_E\left(\frac{\dot{Y}}{Y} - \frac{\dot{E}}{E}\right)$$
$$+ S_M\left(\frac{\dot{Y}}{Y} - \frac{\dot{M}}{M}\right) \qquad \text{...(2.5)}$$

which states simply that total factor productivity is a share-weighted average of the single factor productivity measures.

Finally, in order to provide an interpretation of factors affecting aggregate labor productivity $\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L}$, we substract $\frac{\dot{L}}{L}$ from the left hand side of (2.3) and $(S_K + S_L + S_E + S_M)\frac{\dot{L}}{L}$ from the right hand side of (2.3), collect terms, and obtain

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + S_K\left(\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right) + S_E\left(\frac{\dot{E}}{E} - \frac{\dot{L}}{L}\right)$$
$$+ S_M\left(\frac{\dot{M}}{M} - \frac{\dot{L}}{L}\right) \qquad \text{.....(2.6)}$$

Equation (2.6) is very useful, for it states that growth in labor productivity is the sum of total factor productivity and the weighted growth rates of inputs relative to labor, where the weights again are cost shares.

In the context of the role of energy in labor productivity measurement, Equation (2.6) tells us that even if substantial energy conservation took place so that $\frac{\dot{E}}{E} - \frac{\dot{L}}{L}$ changed from its traditional positive value to negative, energy conservation is unlikely to have a substantial direct negative impact on measured labor productivity, since the cost share of energy is typically quite small, and thus $S_E\left(\frac{\dot{E}}{E} - \frac{\dot{L}}{L}\right)$ will tend to be negligible. Energy price increases could have indirect effects. If, for example, E and K were complementary inputs, increasing energy prices could result in reduced rates of capital formation, thereby decrease the $\left(\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right)$ term, alter the cost shares, and reduce labor productivity accordingly. Such an effect could be offset, however, if the $\left(\frac{\dot{M}}{M} - \frac{\dot{L}}{L}\right)$ and S_M terms increased due to E − M substitutability and energy price increases.

In the following pages I shall use relations (2.4), (2.5) and (2.6) to provide a framework for analyzing productivity movements in U.S. manufacturing. Since these equations are essentially continuous rather than discrete, I employ the Törnqvist discrete approximation[12] to the continuous Divisia index of (2.4),

$$\ln(A_t/A_{t-1}) = \ln(Y_t/T_{t-1}) - \overline{S}_{K,t}\ln(K_t/K_{t-1}) - \overline{S}_{L,t}\ln(L_t/L_{t-1}) - \overline{S}_{E,t}\ln(E_t/E_{t-1}) - \overline{S}_{M,t}\ln(M_t/M_{t-1}) \quad \ldots . (2.7)$$

where $\overline{S}_{i,t}$ is the arithmetic mean of the ith cost share in periods t and t−1, i.e.,

$$\overline{S}_{i,t} = \tfrac{1}{2}(S_{i,t} + S_{i,t-1}), \quad i = K, L, E, M. \quad \ldots . (2.8)$$

Data for total U.S. manufacturing, 1958–77, were generously provided me by J. Randolph Norsworthy and Michael J. Harper at the U.S. Department of Labor, Bureau of Labor Statistics, Office of Productivity and Technology. Since an important portion of the analysis in this paper deals with labor disaggregated into production (hereafter, B) and nonproduction (W) labor, it was necessary to obtain additional data for these two labor types from published BLS sources.[13] Aggregate labor L was then constructed as a Divisia index of B and W.

Following other researchers, I have taken the "peak capacity" years of 1965 and 1973 as years separating subperiods, and therefore have broken the 1958–77 time span into three distinct intervals — 1958–65, 1965–73, and

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[12] For a further discussion of properties of this index number, see W. Erwin Diewert [1976].

[13] These data were constructed using procedures and sources discussed in the Data Appendix of E. R. Berndt and C. J. Morrison [1980], except that no adjustment was made for changes over time in educational attainment.

1973–77.[14] Mean cost shares of the K, L, B, W, E, and M inputs for these subperiods are presented in Table 1 below.

A few comments should be made regarding the entries in Table 1. First, the cost share of energy is very small — around 1½ percent until 1973 and less than 2½ percent in 1977.[15] One important implication of this small energy cost share is that variations in energy prices or quantities will not weigh heavily in productivity calculations in U.S. manufacturing, at least not directly. Secondly, the share of capital costs in total value of output is approximately 10 percent, and has declined slightly in the 1973–77 time period. In the Norsworthy-Harper data capital income is calculated essentially as the nonlabor portion of manufacturing value-added. Thus this capital share includes not only the returns to producers' durable equipment and nonresidential structures, but also those accruing to land, inventories and other working capital.[16] Third, the share of aggregate labor is approximately 25 percent; production labor constitutes about 15 percent, and nonproduction labor 10 percent. Since 1973, the production labor share has fallen more than that of nonproduction workers.[17] Finally, the predominant factor share is that of nonenergy intermediate materials — roughly 60 percent until 1973 and slightly more after 1973. The M data are based on establishment surveys and censuses, and include sales between establishments within the manufacturing sector, as well as those between manufacturing and nonmanufacturing firms.

Before proceeding with a discussion of alternative measures of productivity trends, I list in Table 2 the average annual growth rates of quantities of gross output and inputs. The most striking feature is the dramatic slowdown in the average annual growth rate of gross output Y — from 5.411 and 3.827 percent in 1958–65 and 1965–73 to just 1.030 percent in 1973–77. Although aggregate labor input L actually fell 0.702 percent per annum in the 1973–77 time period, this reduction is due entirely to a decrease in production hours at work (B), which fell at an annual average rate of 1.451 percent; nonproduc-

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[14] In section IV below I examine the empirical validity of this particular sub-period classification.

[15] This cost share for energy is considerably less than the 4–5 percent figures for U.S. manufacturing in 1947–71 published by Jack Faucett Associates [1973] and used in the studies of Ernst R. Berndt and Dale W. Jorgenson [1973], Edward A. Hudson and Dale W. Jorgenson [1974, 1978a, b], and Ernst R. Berndt and David O. Wood [1975, 1979].

The Faucett energy data include estimates of self-generated electricity and also include crude petroleum inputs into the petroleum refining sector. In the Norsworthy-Harper U.S. census data, crude petroleum is treated as M rather than E, and energy is confined to purchased energy used for heating, lighting, and motive power. See John G. Myers and Leonard Nakamura [1978] for further discussion.

[16] Using U.S. Department of Commerce, Bureau of Economic Analysis data on stocks of producers' durable equipment and nonresidential structures, and Jorgensonian rental prices for these two capital asset types, I compute that the value of capital plant and equipment services as a fraction of the total value of capital services in U.S. manufacturing varies from about one-half to two-thirds.

[17] These data include pay for time at work and supplementary benefits.

Table 1
Mean Cost Shares of K, L, B, W, E, and M Inputs in U.S. Manufacturing Based on Norsworthy-Harper and BLS Data, 1958–1977

Year	S_K	S_L	S_B	S_W	S_E	S_M
1958–65	.1195	.2724	.1688	.1036	.0153	.5929
1965–73	.1161	.2764	.1710	.1054	.0145	.5930
1973–77	.0928	.2504	.1536	.0967	.0210	.6358

Notation: K — aggregate capital
L — aggregate labor
B — production labor
W — nonproduction labor
E — aggregate energy
M — aggregate nonenergy intermediate materials

Table 2
Average Annual Growth Rates of Quantities of Gross Output and Inputs U.S. Manufacturing — Percentage Points

Time Periods	Y	K	L	B	W	E	M
1958–65	5.411	2.400	2.190	2.532	1.630	4.893	4.900
1965–73	3.827	3.905	1.022	0.763	1.440	3.815	3.893
1973–77	1.030	1.818	-0.702	-1.451	0.541	1.841	1.080

tion hours at work (W) actually increased slightly (0.541 percent per year).[18] The smaller reduction in growth of W than B may reflect a certain amount of labor hoarding of relatively skilled "overhead" labor over the business cycle; this and other possible hypotheses will be discussed later.

Using Equation (2.5), extended to allow for L being disaggregated into B and W, I then calculate total factor productivity as a share-weighted average of individual factor productivities. These results are presented in Table 3.

A substantial recent slowdown in total factor productivity for manufacturing is indicated by the entries in the final column of Table 3. However, this slowdown is not really new or dramatic. More specifically, total factor productivity fell by more than half from an annual average growth rate of 1.495 percent (1958–65) to 0.707 percent (1965–73), and then fell again by more than half to 0.340 percent (1973–77). Evidently the slowdown of total factor productivity has been going on for some time. Total factor productivity deceleration in manufacturing is not a dramatic new development coinciding with the OPEC-induced energy price increases of 1973–74.

It was noted in Equation (2.5) that total factor productivity is a share-weighted average of the individual factor productivities. The first six columns

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[18] Note that the B and W series measure hours at work, which have grown at a slower rate than hours paid for, due to the increasing relative importance of supplementary benefits to B and W workers.

Table 3
Alternative Measures of Productivity Growth in U.S. Manufacturing
Average Annual Growth Rates (in Percentage Points)

Time Periods	$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L}$	$\frac{\dot{Y}}{Y} - \frac{\dot{B}}{B}$	$\frac{\dot{Y}}{Y} - \frac{\dot{W}}{W}$	$\frac{\dot{Y}}{Y} - \frac{\dot{K}}{K}$	$\frac{\dot{Y}}{Y} - \frac{\dot{E}}{E}$	$\frac{\dot{Y}}{Y} - \frac{\dot{M}}{M}$	$\dot{A}/A$
1958-65	3.152	2.807	3.720	2.940	0.494	0.487	1.495
1965-73	2.777	3.040	2.353	-0.075	0.011	-0.064	0.707
1973-77	1.745	2.518	0.487	-0.773	-0.796	-0.049	0.340

of Table 3 provide some interesting information on differing trends in these single-factor productivities. The Y/L series indicates that a rather sharp decline occurred after 1973 in output per unit of aggregate labor input — from 3.152 percent (1958–65) and 2.777 percent (1965–73) to a considerably smaller 1.745 percent (1973–77). Hence growth in aggregate labor productivity fell more during 1973–77 than growth in total factor productivity. Columns 2 and 3 show, however, that this trend in aggregate labor productivity masks very distinct patterns in output per unit of production labor at work ($\dot{Y}/Y - \dot{B}/B$) and output per unit of nonproduction labor at work ($\dot{Y}/Y - \dot{W}/W$). Production labor productivity has varied only slightly — 2.807 percent (1958–65), 3.040 percent (1965–73) to 2.518 percent (1973–77), while nonproduction labor productivity has fallen much more steeply to 0.487 percent (1973–77). Hence the slowdown in aggregate labor productivity is primarily reduced productivity growth of nonproduction workers.

The other input whose average productivity has recently fallen considerably is capital; growth in $\dot{Y}/Y - \dot{K}/K$ fell from 2.940 percent per year (1958–65) to -0.075 percent (1965–73), and then to -0.773 percent (1973–77). Stated in a slightly different way, capital-output ratios in U.S. manufacturing have increased slightly since 1965, contrary to the earlier 1958–65 pattern. The reader should note that the capital quantity data are not adjusted for cyclical utilization, i.e., they are not multiplied by an index of capacity utilization such as that of the Federal Reserve Board. Nor was the data on white collar or overhead labor multiplied by such an index. Reasons for not adjusting the capital data by capacity utilization are well known.[19] It might also be noted that the Norsworthy-Harper data include capital expenditures on pollution abatement. Based on unpublished BEA data, Norsworthy, Harper and Kunze [1979, p. 405] calculate that if these pollution abatement capital expenditure data were removed from the capital stock series in U.S. manufacturing, the rate of growth of the net capital stock would be reduced negligibly prior to 1965, would decrease by 0.29 percent per year from 1965 to 1973, and by 0.69 percent per year from 1973 to 1978. Hence, even if the capital data were fully adjusted in this way for pollution

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[19] For a review of this issue, see the Jorgenson-Griliches and Denison exchange in the U.S. Department of Commerce, *Survey of Current Business* [1972].

abatement, the rate of growth of $\dot{Y}/Y - \dot{K}/K$ would still be much smaller in 1965–77 than in 1958–65. I should add that if one were to adjust the data consistently for "nonproductive" or "noncapacity increasing" pollution abatement activities, one would also want to modify the L, E and M series. For example, Myers and Nakamura [1978, p. 11] state that in certain manufacturing industries, 2 to 3 percent of total energy consumption is due to pollution control, much of it being installed between 1973 and 1976.

Table 3 shows that the behavior of average energy productivity since 1973 has been especially disappointing. Given substantial energy price increases from 1973 to 1977,[20] one would have hoped that average energy productivity would have improved since 1973. Indeed, elsewhere I have shown that, other things equal, the percent increase in average energy productivity divided by the percent increase in energy prices is the negative of the traditional own price elasticity of demand for energy.[21] Thus data in Table 3 could be interpreted to reflect an extremely low price elasticity of demand for energy — perhaps even of the wrong sign, if all other things were equal. However, in addition to the fact that a substantial increase in energy consumption during 1973 to 1976 may be due to installation of regulation-induced pollution abatement capital, a good portion of energy use, especially that for space heating and lighting and to some extent that for process heating — is of an overhead character not closely related to short-run variations in output. This implies that there are short-run increasing returns to energy, much like the well-documented short-run increasing returns to labor,[22] and that the disappointing growth in energy productivity since 1973 may reflect regulatory effects and unusually small growth in output occurring during the same time period rather than miniscule price responsiveness.

Earlier in this section I noted that it was possible to rearrange the basic total factor productivity Equation (2.4) to highlight factors related to movements in labor productivity. In (2.6), for example, growth in labor productivity was shown to be the sum of total factor productivity and the weighted growth rates of inputs relative to labor, where the weights are cost shares, i.e.,

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + S_K\left(\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right) + S_E\left(\frac{\dot{E}}{E} - \frac{\dot{L}}{L}\right) + S_M\left(\frac{\dot{M}}{M} - \frac{\dot{L}}{L}\right) \quad \ldots . (2.6)$$

When labor is disaggregated into hours at work of production (B) and non-

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[20] The Norsworthy-Harper data indicate that over the 1973–77 time period, the real price of energy rose at an average annual rate of 12.4 percent (a 22.3 percent increase in nominal energy prices minus the 9.9 percent increase in the price of gross output).

[21] See E. R. Berndt [1978].

[22] For further discussion and quantitative estimates, see C. J. Morrison and E. R. Berndt [1979].

production (W) workers, the following analogous expressions can be obtained:

$$\frac{\dot{Y}}{Y} - \frac{\dot{B}}{B} = \frac{\dot{A}}{A} + S_K\left(\frac{\dot{K}}{K} - \frac{\dot{B}}{B}\right) + S_W\left(\frac{\dot{W}}{W} - \frac{\dot{B}}{B}\right) + S_E\left(\frac{\dot{E}}{E} - \frac{\dot{B}}{B}\right) + S_M\left(\frac{\dot{M}}{M} - \frac{\dot{B}}{B}\right) \quad \ldots . (2.9)$$

and

$$\frac{\dot{Y}}{Y} - \frac{\dot{W}}{W} = \frac{\dot{A}}{A} + S_K\left(\frac{\dot{K}}{K} - \frac{\dot{W}}{W}\right) + S_B\left(\frac{\dot{B}}{B} - \frac{\dot{W}}{W}\right) + S_E\left(\frac{\dot{E}}{E} - \frac{\dot{W}}{W}\right) + S_M\left(\frac{\dot{M}}{M} - \frac{\dot{W}}{W}\right) \quad \ldots . (2.10)$$

In a sense, these relations "explain" movements in the productivity growth of labor. However, one must be careful in interpreting the right-hand side variables as "causes" and the left-hand side variable as "effect," since (2.6), (2.9) and (2.10) are all basic rearrangements of the same total factor productivity identity.

With these caveats in mind, in Table 4 I report quantitative magnitudes of the labor productivity Equation (2.6). Recall that Y/L growth fell slightly from 3.152 percent per year (1958–65) to 2.777 percent (1965–73), and then fell by more than 1 percentage point to 1.745 percent per year (1973–77). The initial drop in Y/L growth between the 1958–65 and 1965–73 time periods coincides with a substantial drop in total factor productivity (1.495 percent in 1958–65 versus 0.707 percent in 1965–73); the slowdown in growth of labor productivity would have been larger had not the capital-labor ratio increased at a rapid rate of 2.883 percent per year.[23]

What is more surprising, however, is that growth in the capital-labor ratio has continued at a rapid rate — 2.520 percent per year, 1973–77 — even while labor productivity growth dropped substantially. Hence the argument that the recent slowdown in labor productivity growth has coincided with reduced rates of capital formation[24] does not appear to be borne out by the data, at least for the U.S. manufacturing sector 1973–77.[25]

However, some authors, Peter K. Clark [1978] and John A. Tatom [1979a,b] among others, have concluded that reduced rates of capital formation have recently occurred. Part of the divergence of views, I submit, is due

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[23] This point has been made earlier by J. Randolph Norsworthy and Michael J. Harper [1979a] and J. Randolph Norsworthy, Michael J. Harper and Kent Kunze [1979], and conflicts with earlier findings by Peter K. Clark [1978]. See the first paper for further discussion.

[24] This argument has been made by, among others, Burton G. Malkiel [1979].

[25] See, however, the earlier discussion on pollution abatement capital, which if excluded could indicate a greater slowdown in rates of capital formation per hour at work.

Table 4
Factors Coinciding with Growth in Labor Productivity, U.S. Manufacturing
Average Annual Growth Rates (in Percentage Points)

Time Periods	$\frac{\dot{K}}{K}-\frac{\dot{L}}{L}$	$\frac{\dot{E}}{E}-\frac{\dot{L}}{L}$	$\frac{\dot{M}}{M}-\frac{\dot{L}}{L}$	$\dot{A}/A$	$\frac{\dot{Y}}{Y}-\frac{\dot{L}}{L}$
1958–65	0.210	2.703	2.710	1.495	3.152
1965–73	2.883	2.793	2.871	0.707	2.777
1973–77	2.520	2.543	1.782	0.340	1.745

to measurement and classification issues. Data trends for the private business sector analyzed by Clark may differ from those of the manufacturing sector examined in this paper. Potentially even more important however, is the fact that Clark and Tatom multiply their capital input series by the Federal Reserve Board measure of capacity utilization in the manufacturing sector in order to obtain cyclically adjusted measures of capital services. When this adjustment is made to the Norsworthy-Harper data, a rather different picture emerges. During the 1958–65, 1965–73 and 1973–77 intervals, the Federal Reserve Board measure of capacity utilization in U.S. manufacturing grew by 2.534 percent, –0.282 percent and –1.668 percent per year, respectively.[26] If these figures are added to the K/L entries of Table 4, the revised K/L growth rate figures are 2.744 percent, 2.601 percent, and 0.852 percent for 1958–65, 1965–73 and 1973–77. These revised series accord better with the view that growth in capital per hour at work has fallen considerably since 1973, and that as a consequence, labor productivity growth has decelerated. Which view is "correct" depends partly on where one wishes to place the slowdown of output growth in the productivity accounting scheme. Edward Denison[27] has argued persuasively that utilization ought to be treated separately from input measurement. In any case, it is clear that if one uses cyclically adjusted capital data, then one must be very cautious indeed in arguing that investment incentives are needed in order to stimulate capital formation and growth in labor productivity; in U.S. manufacturing 1973–77, a growing capital stock was put in place and the problem for productivity evidently was one of lack of growth in demand for manufacturing output, not deficiency in supply of available capital plant and equipment.

In Table 5 I report growth rates of input quantities relative to production hours at work (the top half of Table 5) and relative to nonproduction hours at work (bottom half). Capital per production hour at work grew at virtually the same rate during 1965–73 and 1973–77 — around 3.2 percent per year. Although Y/B growth did not fall substantially in 1973–77 relative to earlier periods, as noted earlier Y/W growth dropped sharply and significantly. The

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[26] The FRB capacity utilization data are taken from the Economic Report of the President [1980], Table B-42, p. 251.

[27] See Denison's paper and comments in U.S. Department of Commerce, *Survey of Current Business* [1972].

Table 5
Factors Coinciding with Growth in Productivity of Production (B) and Nonproduction (W) Hours at Work in U.S. Manufacturing
Average Annual Growth Rates (in Percentage Points)

Time Periods	$\frac{\dot K}{K}-\frac{\dot B}{B}$	$\frac{\dot W}{W}-\frac{\dot B}{B}$	$\frac{\dot E}{E}-\frac{\dot B}{B}$	$\frac{\dot M}{M}-\frac{\dot B}{B}$	$\frac{\dot A}{A}$	$\frac{\dot Y}{Y}-\frac{\dot B}{B}$
1958-65	-0.132	-0.902	2.361	2.368	1.495	2.807
1965-73	3.142	0.677	3.052	3.130	0.707	3.040
1973-77	3.269	1.992	3.292	2.531	0.340	2.518

Time Periods	$\frac{\dot K}{K}-\frac{\dot W}{W}$	$\frac{\dot B}{B}-\frac{\dot W}{W}$	$\frac{\dot E}{E}-\frac{\dot W}{W}$	$\frac{\dot M}{M}-\frac{\dot W}{W}$	$\frac{\dot A}{A}$	$\frac{\dot Y}{Y}-\frac{\dot W}{W}$
1958-65	0.770	0.902	3.263	3.270	1.495	3.720
1965-73	2.465	-0.677	2.375	2.453	0.707	2.353
1973-77	1.277	-1.992	1.300	0.539	0.340	0.487

bottom row of Table 5 shows that all inputs grew at a smaller rate relative to W in 1973–77 than in earlier periods; alternatively, W grew relatively more rapidly. Why this occurred is not clear. Nonproduction workers may be relatively fixed inputs in the short run, and thus their impact on aggregate productivity trends could be particularly negative when output grows at a rate smaller than expected. This hypothesis will be examined further in Section III of this paper. An alternative hypothesis, which will not be examined, is that the very slow growth in Y/W since 1973 reflects increased costs of regulation — paperwork, monitoring, etc. whose incidence falls in particular on the services of nonproduction laborers. *A priori,* it seems that such an effect would be of relatively small magnitude. Yet another possible hypothesis is that growth of W employment reflects the changing composition of output in manufacturing, which requires high-skill workers. Why this output change would become so pronounced during 1973–77 is unclear, however.

In summary, then, energy price or quantity variations since 1973 do not appear to have played a significant direct or indirect role in the slowdown of labor productivity in U.S. manufacturing, 1973–77. There are two principal reasons for the small direct effect: (i) energy costs are a very small portion of total cost, and thus energy variations do not weigh heavily in productivity calculations; and (ii) energy variations have been small, i.e., energy-output ratios have not changed much since 1973, in spite of substantial energy price increases. Nor have indirect effects of energy price increases appeared in the data, such as sharply reduced K/L ratios. Analysis of the data indicates instead that (i) total factor productivity growth has been decreasing for some time — at least since 1965 — and deceleration in its growth does not appear to be greater since the 1973 OPEC energy market developments; (ii) aggregate labor productivity growth has fallen more sharply since 1973 than has total factor productivity; however, disaggregation of aggregate labor into production hours at work (B) and nonproduction hours at work (W) reveals that growth of Y/B has been remarkably stable over the entire 1958–77 time period, while Y/W growth has fallen considerably, especially since 1973; (iii) if one assesses capital formation effects on productivity by examining changes in K/L or K/B ratios, one finds that there has been no great slowdown in capital formation since 1965; however, if one adjusts the capital data by the Federal Reserve Board capacity utilization index, K/L and K/B ratios fall significantly after 1973; (iv) the above data analysis suggests to me that the slowdown in productivity growth in U.S. manufacturing 1973–77 may be due in large part to the coincident reduction in the growth rate of output. Since inputs such as W and K tend to be fixed in the short run, and since a substantial portion of energy input may also be of an overhead nature, productivity trends since 1973 may have been much less gloomy had output grown at its 1958–73 rate of around 4½ percent per year, rather than at its much lower 1 percent rate from 1973–77.

III. A Dynamic Model of Factor Demands: Implications for Productivity Trends

In the previous section I speculated that U.S. manufacturing data point to the possibility of certain inputs being quasi-fixed in the short run, and that this relative fixity might have adversely affected productivity growth during the 1973–77 time period when output grew at an unusually low rate. This hypothesis — that productivity growth is procyclical due to quasi-fixity of certain inputs — is of course a much studied issue, particularly in the context of short-run increasing returns to labor.[28] The new wrinkles to be examined here involve a more complete theoretical specification of the dynamic cost-minimization process when nonproduction labor (W) and total capital (K) are fixed in the short run, the explicit incorporation of energy (E) into the production framework, and a closer examination of implications for total factor and labor productivity. I now proceed with a brief theoretical discussion of a dynamic model of factor demands incorporating internal costs of adjustment; for a more complete treatment, see E. R. Berndt, M. A. Fuss, and L. Waverman [1979], C. J. Morrison and E. R. Berndt [1979], and E. R. Berndt, C. J. Morrison and G. C. Watkins [1980].

Define the production function of a firm as

$$Y = F(v,x,\dot{x},t) \qquad \ldots . (3.1)$$

which represents various efficient combinations of variable inputs v and quasi-fixed inputs x that can be used to produce output Y at time t. If levels of the quasi-fixed inputs vary ($\dot{x} \neq 0$), output falls for any given amount of x and v, because of the necessity to devote resources to changing the stock rather

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[28] For a recent review of this literature, see C. J. Morrison and E. R. Berndt [1979].

than producing output. This diminution in output brought about by $\dot{x} \neq 0$ constitutes "internal costs of adjustment."[29]

In the short run, firms can be viewed as maximizing restricted variable profits (revenue minus variable costs) conditional on variable input prices $\hat{w}_j$ ($j=1, \ldots, J$), output price P, levels of the quasi-fixed inputs x_i and changes in these quasi-fixed input levels $\dot{x}_i$. Alternatively, one can view firms as minimizing normalized variable costs

$$G = \sum_{j=1}^{J} w_j v_j, \quad w_j = \hat{w}_j / \hat{w}_1,$$

conditional on

$$w_j, Y, x_i, \dot{x}_i .$$

The normalized restricted cost function

$$G = G(w, x, \dot{x}, Y, t), \qquad \ldots . (3.2)$$

where t is intended to represent the state of technology, can be shown under reasonable regularity conditions on F, to be increasing and concave in w, increasing and convex in $\dot{x}$, and decreasing and convex in x.

Two properties of G are especially important for empirical implementation. First, the partial derivative of G with respect to the normalized price of any variable input w_j equals the short-run cost-minimizing demand for v_j, i.e.,

$$\frac{\partial G}{\partial w_j} = v_j, \quad j = 2, \ldots, J. \qquad \ldots . (3.3)$$

Second, the partial derivative of G with respect to the quantity of any quasi-fixed input equals the negative of the normalized shadow cost or normalized rental price of the quasi-fixed input, i.e.,

$$\frac{\partial G}{\partial x} = -u_i, \quad i = 1, \ldots, N. \qquad \ldots . (3.4)$$

where $u_i = a_i(r+\delta_i)$, and where a_i is the normalized asset or acquisition price of the i^{th} quasi-fixed input, r is the rate of return, and δ_i is the rate of depreciation.

The long-run or dynamic economic problem facing the firm is to minimize the present value of the future stream of costs,

$$L(0) = \int_0^{\infty} e^{-rt} \left(\sum_{j=1}^{J} \hat{w}_j v_j + \sum_{i=1}^{N} \hat{a}_i z_i \right) dt \qquad \ldots . (3.5)$$

where $z_i = \dot{x}_i + \delta_i x_i$

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[29] For an intuitive discussion of internal adjustment costs, see Robert E. Lucas [1967], F. P. R. Brechling and Dale T. Mortenson [1971], Michael Rothschild [1971], and S. J. Nickel [1978, Chapter 3].

is the gross addition to the stock of the i^{th} quasi-fixed factor. This minimization problem is solved by choosing the time paths of the control variables v(t), $\dot{x}(t)$ and the state variable x(t) that minimize L(0), given initial conditions x(0) and v(t), x(t) > 0.

Since the normalized restricted variable cost function G incorporates the solution to the short-run cost minimization problem, i.e., it yields the optimal demand for the variable factors conditional on the values of the quasi-fixed factors, we can substitute (3.2) into (3.5). When the resulting function is integrated by parts, we obtain

$$L(0) + \sum_{i=1}^{N} a_i x_i(0) = \int_0^\infty e^{-rt} \left\{ G(w, x, \dot{x}, Y, t) + \sum_{i=1}^{N} u_i x_i \right\} dt. \qquad \ldots. (3.6)$$

This can be interpreted as follows: since G assumes short-run optimization behavior conditional on Y(t), w(t), x(t) and $\dot{x}(t)$, the optimization problem (3.5) facing the firm is to find among all the possible $G(w(t), x(t), \dot{x}(t), Y(t))$ combinations that time path of x(t), $\dot{x}(t)$ which minimizes the present value of costs.

A solution to (3.5) can be obtained using either the Euler first order conditions or Pontryagin's maximum principle. Assuming static expectations with respect to normalized factor prices and output, we can write the Hamiltonian as:

$$H(x, \dot{x}, \mu, t) = e^{-rt} \left(G(w, x, \dot{x}, Y, t) + \sum_{i=1}^{N} u_i x_i \right) + \mu \dot{x} \qquad \ldots. (3.7)$$

When μ is eliminated from the necessary conditions, we obtain

$$-G_x - rG_{\dot{x}} - u + G_{\dot{x}}\ddot{x} + G_{x\dot{x}}\dot{x} = 0 \qquad \ldots. (3.8)$$

where the x, $\dot{x}$ subscripts denote derivatives and $\ddot{x}$ is the second partial derivative with respect to time. The steady-state (long-run) solution satisfies

$$-G_x(w, x^*) - rG_{\dot{x}}(w, x^*) - u = 0, \qquad \ldots. (3.9)$$

x^* being unique as long as

$$|-G^*_{xx} - rG^*_{x\dot{x}}| = 0,$$

where * indicates evaluation at $x = x^*$ and $\dot{x} = 0$. Equation (3.9) can be rewritten as

$$-G_x(w, x^*) = u + rG_{\dot{x}}(w, x^*), \qquad \ldots. (3.9a)$$

and interpreted as follows: the left-hand side is the marginal benefit to the firm of changing quasi-fixed inputs (e.g., the reduction in variable costs brought about by purchasing capital equipment or hiring additional non-production workers), while the right hand side is the marginal cost (user cost plus the marginal adjustment cost) of a change in the amount of capital or skilled labor services at $\dot{x} = 0$. In long-run equilibrium, marginal benefits must equal marginal costs.

The internal cost of adjustment model outlined above is attractive in that it yields clearly defined short-run variable input demand Equations (3.3), and is based on explicit dynamic optimization. Arthur B. Treadway [1969] has linked this type of model to the "flexible accelerator" or "partial adjustment" literature by showing that $\dot{x}$ can be generated from (3.8) and (3.9) as an approximate solution (in the neighborhood of $x^*(t)$) to the multivariate linear differential equation system

$$\dot{x} = M^*(x^* - x), \qquad \ldots . (3.10)$$

where M^* is determined from the solution to the quadratic form

$$-G^*_{x\dot{x}}M^{*2} - rG^*_{x\dot{x}}M^* + G^*_{xx} + rG^*_{x\dot{x}} = 0. \qquad \ldots . (3.11)$$

In the special case of only one quasi-fixed input, Treadway has shown that

$$\dot{x}_1 = M^*_1(x^*_1 - x_1), \qquad \ldots . (3.12)$$

where at the stationary point when $G^*_{x\dot{x}} = 0$,

$$M^*_1 = -\frac{1}{2}\left(r - (r^2 + 4G_{x_1x_1} / G_{\dot{x}_1\dot{x}_1})^{1/2}\right). \qquad \ldots . (3.13)$$

It should be noted that M^*_1 varies inversely with r, and is not constrained to be constant, as is the case with typical partial adjustment models. However, if G were quadratic so that $G_{x_1x_1}$ and $G_{\dot{x}_1\dot{x}_1}$ were constant parameters, and if the discount rate r were relatively stable, M^*_1 would also tend to be quite stable.

Once one specifies a functional form for G and alters the continuous time model into a discrete time specification, one can obtain short-run demand equations for variable inputs ("utilization" equations) using (3.3) and net accumulation equations for the quasi-fixed inputs using (3.9) and (3.10). From these demand equations, expressions for short, intermediate and long-run price and output elasticities can be derived which completely summarize the dynamic time paths of factor demands. In particular, following the Marshallian tradition, short-run elasticities can be defined as those obtained when x is fixed, intermediate run as the impact when x has adjusted partially as determined by M^*, and long-run as the response when x has adjusted fully to x^* and $\dot{x} = 0$. Short, intermediate and long-run average total cost curves can be defined in a perfectly analogous manner.

The above discussion, though largely theoretical, has several important implications for productivity measurement. First, the measure of total factor productivity will depend on the extent of short-run disequilibrium. To see this, recall that according to the classic Wong-Viner envelope theorem, average total cost (ATC) follows the inequality

$$ATC_{SR} \geq ATC_{IR} \geq ATC_{LR} \quad \ldots .(3.14)$$

with the equality holding only when the firm initially is in long-run equilibrium. This occurs because with output fixed, the firm is constrained in the short run by its fixed inputs, but in the long run it can adjust all inputs to long-run equilibrium levels. Total factor productivity $\dot{A}/A$ will as a consequence generally be smaller in the short than long run, i.e.,

$$\left(\frac{\dot{A}}{A}\right)_{SR} \leq \left(\frac{\dot{A}}{A}\right)_{IR} \leq \left(\frac{\dot{A}}{A}\right)_{LR} ; \quad \ldots . (3.15)$$

the equality again holds only when initially the firm is in long-run equilibrium. If, for example, the year 1973 was one with firms very close to long-run equilibrium, but if in 1977 the combination of dramatic energy price increases and reduced growth rates of output left firms considerably further away from their long-run equilibrium factor demands, then the 1973–77 estimate of total factor productivity growth would be altered, and comparison between 1965–73 "peak" years with 1973–77 could be misleading.

This problem — that total factor productivity growth measures may be procyclical — has occupied the attention of productivity accountants for some time, and has been the source of considerable controversy. One possible approach is to make some allowance for disequilibrium by using, say, the Wharton or the Federal Reserve Board measure of capacity utilization, adjusting some or all of the inputs (or perhaps output) by this index, and then calculating a "cyclically adjusted" $\dot{A}/A$. A basic problem with such a procedure is that the Wharton and FRB capacity output measures are essentially unrelated to an economic notion of capacity output, defined as that level of output Y* which minimizes short-run average total costs.[30] In particular, if energy price increases shift economic capacity Y*, then economic capacity utilization ratios Y/Y* would be affected, which in turn would influence $\dot{A}/A$ measures. Such input price effects on capacity output cannot be captured by the mechanical formulas typically used to compute the Wharton and FRB capacity utilization rates.

One attractive feature of the theoretical framework outlined above is that it permits calculation of an economic measure of capacity output Y*, and also allows one to determine how Y* would be affected by changes in input prices. In the case of a single quasi-fixed input, say capital K, an increase in the price of a variable input will increase (decrease) Y* if the

[30] This capacity output notion is consistent with long-run constant returns to scale. If the long-run ATC curve is U-shaped, however, then capacity output is that level of output on the short-run ATC curve tangent to the long-run ATC curve. See L. R. Klein [1960] for further discussion.

variable input and K are complements (substitutes).[31] Hence if energy and K are complements, recent energy price increases may have increased Y*, thereby reducing capacity utilization ratios Y/Y*; such a phenomenon is unlikely to be captured by the Wharton or FRB capacity utilization indices, which could therefore be biased upward in recent years.

Short- and long-run productivity growth rates for individual inputs are also affected by the extent of disequilibrium. Unlike the case for total factor productivity, however, single factor productivity measures do not follow any general inequality but instead depend on substitutability-complementarity relations among fixed and variable inputs. Suppose again there is only one quasi-fixed input, K. In response to an exogenous increase in Y, short-run "overshooting" (defined as short-run demand for a variable input being larger than long-run demand) or short-run "undershooting" occurs for an input if that variable input and K are substitutes or complements, respectively.[32] It follows, then, that if nonproduction labor W is complementary with the fixed input K, then if output falls, demand for W will not fall by as much, and average productivity of W will fall more in the short run than in the long run. Since the econometric literature contains numerous discussions of capital-skill complementarity,[33] a plausible hypothesis helping to explain the sharp drop in Y/W productivity growth rates 1973–77 is that W and K are complementary, and since output grew at an unexpectedly small rate in this period, growth in demand for W did not fall proportionally.

To illustrate the above remarks, let us now specify a functional form for the variable restricted cost function G with short-run nonhomothetic properties but with long-run constant returns to scale imposed. For a single quasi-fixed input K,[34] an attractive functional form is

$$\begin{aligned}G &= B + P_W W + P_E E + P_M M\\ &= Y(\alpha_0 + \alpha_{0t}t + \alpha_W P_W + \alpha_E P_W + \alpha_M P_M + \tfrac{1}{2}(\gamma_{WW}P_W^2\\ &\quad + \gamma_{EE}P_E^2 + \gamma_{MM}P^2{}_M) + \gamma_{WE}P_W P_E + \gamma_{WM}P_W P_M + \gamma_{EM}P_E P_M\\ &\quad + \alpha_{Wt}P_W t + \alpha_{Et}P_E t + \alpha_{Mt}P_M t) + \alpha_K K_{-1} + \gamma_{EK}P_E K_{-1} + \gamma_{WK}P_W K_{-1}\\ &\quad + \gamma_{MK}P_M K_{-1} + \alpha_{Kt}K_{-1}t + \tfrac{1}{2}(\gamma_{KK}K_{-1}^2) + \tfrac{1}{2}(\gamma_{\dot{K}\dot{K}}\dot{K}^2/Y) \qquad \ldots .(3.16)\end{aligned}$$

where all prices are normalized by P_B, the price of production labor.

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[31] Surprisingly, not much has been written on this issue. The only paper of which I am aware is an unpublished one by Robert H. Rasche and John Tatom [1977c], which restricts attention to the case of a single quasi-fixed input.

[32] For further discussion, see C. J. Morrison and E. R. Berndt [1979].

[33] See, for example, Zvi Griliches [1969].

[34] Generalization to two quasi-fixed inputs is straightforward, although constraining M* to be diagonal appears necessary. C. J. Morrison and E. R. Berndt [1979].

Using (3.3), one can obtain short-run demand equations for variable inputs. For nonproduction labor, the short-run demand equation is

$$W/Y = \alpha_W + \alpha_{Wt}t + \gamma_{EW}P_E + \gamma_{WW}P_W + \gamma_{MW}P_M + \gamma_{WK}K_{-1}/Y \quad \ldots . (3.17)$$

When W and K are complements, γ_{WK} is positive and W/Y varies directly (average W productivity varies inversely) with the capital-output ratio K_{-1}/Y. Similar short-run demand equations occur for other variable inputs. The net accumulation or net investment equation turns out to be of the flexible accelerator form. Using (3.14) we have

$$\dot{K}_t \equiv K_{t+1} - K_t = M^*_{KK,t}(K^*_t - K_t) \quad \ldots . (3.18)$$

where

$$K^* = (Y/\gamma_{KK})(\alpha_K + \gamma_{WK}P_W + \gamma_{EK}P_E + \gamma_{MK}P_M + \alpha_{Kt}t + u_K),$$

where u_K is the rental price of capital P_K normalized by P_B and where

$$M^*_{KK} = -\tfrac{1}{2}[r_t - (r_t^2 + 4\gamma_{KK}/\gamma_{\dot{K}\dot{K}})^{1/2}]. \quad \ldots . (3.19)$$

By appropriately differentiating G/Y from (3.16), we can solve for that level of output Y* which minimizes short-run average total costs of production. This yields the economic capacity output Y*,

$$Y^* = -(\gamma_{KK}K^2_{-1} + \gamma_{\dot{K}\dot{K}}\dot{K}^2_{-1})/(\alpha_K K_{-1} + \alpha_{Kt}K_{-1}t + \gamma_{WK}P_W K_{-1} + \gamma_{EK}P_E K_{-1} + \gamma_{MK}P_M K_{-1} + u_K K_{-1}) \quad \ldots . (3.20)$$

which indicates very clearly what are the factors affecting an economic notion of short-run capacity output.

In the next section of this paper I present some estimates of how post-1973 energy price increases might have affected Y*, and how reductions in growth of Y might have affected total and individual factor productivity measures during the turbulent 1973–77 time period.

Before doing that, I want to digress briefly and comment on one other aspect of the dynamic factor demand model sketched above. Earlier I noted that Burton G. Malkiel [1979], among others, has argued that a slowdown in capital formation has recently taken place, that this adversely affects labor productivity, and that one element negatively influencing investment activity has been the low value of Tobin's q, defined as the market value of a firm divided by the replacement cost of its physical capital stock. Recall also that in Section II I noted that the U.S. manufacturing data 1973–77 did not indicate a significant slowdown in the growth of the capital-labor ratio, unless one adjusted the capital data by the FRB index of capacity utilization. Nonetheless, it is of some interest to examine whether energy price increases could have negatively affected Tobin's q, and if so, by how much.

Tobin's q was originally presented in the context of a financial portfolio model.[35] A slight variant of q with more "real" than "financial" structure has been developed by Andrew Abel [1978, Essay IV] and John Ciccolo and Gary Fromm [1979]. In its amended form, q is the shadow price of installed capital goods divided by the tax-adjusted price of uninstalled capital goods. Abel used a dynamic optimization framework similar to that above and showed that investment was an increasing function of the shadow price of this amended q. In the present context for the i^th^ quasi-fixed input, q_i can be defined as

$$q_i = \frac{-\partial G/\partial x_i}{u_i}, \qquad \ldots . (3.21)$$

i.e., the ratio of the shadow price of installed capital (the reduction in variable costs due to increasing the stock of the quasi-fixed input) divided by the normalized rental price of that input. In long-run equilibrium, $q_i = 1$. Net accumulation of the ith input will be positive (negative) when q_i is greater (less) than unity. Using (3.16) in the model with K as the only quasi-fixed input, we obtain

$$q_k = -\frac{(\alpha_K + \gamma_{WK}P_W + \gamma_{EK}P_E + \gamma_{MK}P_M + \alpha_{Kt}t + \gamma_{KK}K_{-1}/Y)}{u_K} \qquad \ldots . (3.22)$$

Note that if E and K are complementary inputs ($\gamma_{EK}>0$), then increases in energy prices will reduce q_K. Whether E–K complementarity is sufficient to explain the sharp reduction in Tobin's q since 1973 is an empirical issue.

IV. Econometric Results for Dynamic Models

In this section I present preliminary econometric results for U.S. manufacturing 1958–77 based on the model with a single quasi-fixed input K discussed in the previous section, as well as preliminary results based on an analogous model with two quasi-fixed inputs (W and K). The results are preliminary in that the energy and capital data in particular need to be reconciled with those of other studies.[36] Estimation was carried out using the nonlinear maximum likelihood algorithm in TSP at the University of British Columbia.

The empirical issues I address in this section include the following: (i) How has the economic optimal capacity output Y* varied with the actual rate

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[35] See James Tobin [1969], and earlier works, including James Tobin [1961] and William C. Brainard and James Tobin [1968].

[36] See the discussion in Section II above.

of output Y, i.e., what does an economic measure of capacity utilization look like over the 1958–77 time period? (ii) To what extent can the small total factor productivity growth rates 1973–77 be attributed to increased divergence of actual from economic capacity output? (iii) By how much do increased energy prices affect the optimal level of output? (iv) By what amount do increased energy prices affect Tobin's q_K? and (v) How do variations in output and capacity utilization affect the productivity of individual inputs? In order to keep the text of this conference paper reasonably concise, I omit the standard complete presentation of parameter estimates, t-statistics, etc. and instead move directly to a discussion of issues.

Economic measures of capacity utilization for the one and two quasi-fixed input models are presented in the second and third columns of Table 6, respectively; for purposes of comparison, in the next two columns I reproduce the Wharton and FRB measures. A number of comments are in order. First, the economic measures are always greater than unity, whereas the Wharton and FRB figures are always less than unity. To some extent, this can be interpreted simply as a scaling convention, particularly since Wharton and FRB measures approaching 90 percent are often viewed as being very near "full capacity." On the other hand, that the economic measures are greater than unity is informative, for it indicates that production is to the right of the minimum point of the short-run average total cost curve, thereby inducing cost-reducing positive net investment. In the last two columns of Table 6 I present estimated ratios of short-run marginal cost to long-run average total cost evaluated at the actual level of output.[37]

The one quasi-fixed input model predicts positive net investment in all years, although the predicted positive amount is very small in 1958, 1959 and 1974. The two quasi-fixed input model performs about the same as the single fixed factor model in predicting $\dot{K}$, but somewhat surprisingly, the estimated single fixed factor model with W–K complementarity predicts correctly all negative accumulations in W; the two quasi-fixed input model correctly predicts negative $\dot{W}$ in 1969 and 1970, but misses the net reductions in 1960 and 1974.

The economic measures of capacity utilization compare reasonably well with the FRB index, but considerably less so with the Wharton measure.[38] Both economic measures of capacity utilization indicate relative peak years in 1965, 1973 and 1977, while peak years for the FRB index are 1966, 1973 and 1977. The Wharton relative peaks are in 1966, 1969, 1973 and 1977. Economic capacity utilization measures are lowest in 1958–59, 1970–71, and

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[37] The calculation assumes that inputs are elastically supplied; when input supply curves are upward sloping, these figures likely understate the ratio of SRMC to LRAC. For a discussion of the effects of upward sloping supply curves of labor on a calculation of potential output, see Jeffrey M. Perloff and Michael L. Wachter [1979].

[38] For the single (two) fixed factor model, simple correlations between the economic measure and the FRB index are .419 (.523), while those between the economic measure and the Wharton index are only .244 (.140); the simple correlation between the Wharton and FRB index is .605.

Table 6
Alternative Measures of Capacity Utilization, and Ratio of Estimated Short-Run Marginal Cost to Long-Run Average Total Cost
U.S. Manufacturing, 1958-77

Year	Capacity Utilization Model with K Fixed	Capacity Utilization Model with W,K Fixed	FRB Measure	Wharton Measure	SRMC/LRAC Model with K Fixed	SRMC/LRAC Model with W,K, Fixed
1958	1.106	1.091	0.752	0.742	1.015	1.026
1959	1.110	1.118	0.819	0.789	1.013	1.030
1960	1.171	1.131	0.802	0.769	1.024	1.035
1961	1.177	1.130	0.774	0.737	1.026	1.036
1962	1.197	1.145	0.816	0.765	1.027	1.038
1963	1.224	1.167	0.835	0.777	1.031	1.044
1964	1.226	1.164	0.856	0.795	1.031	1.042
1965	1.232	1.190	0.896	0.842	1.030	1.045
1966	1.214	1.170	0.911	0.882	1.027	1.040
1967	1.184	1.129	0.869	0.869	1.026	1.033
1968	1.178	1.119	0.871	0.892	1.024	1.030
1969	1.169	1.108	0.862	0.902	1.025	1.029
1970	1.111	1.036	0.793	0.841	1.018	1.012
1971	1.110	1.052	0.784	0.827	1.017	1.015
1972	1.204	1.139	0.835	0.879	1.033	1.037
1973	1.240	1.185	0.876	0.932	1.040	1.049
1974	1.092	1.079	0.838	0.905	1.012	1.018
1975	1.160	1.096	0.729	0.798	1.030	1.026
1976	1.259	1.170	0.795	0.860	1.051	1.048
1977	1.267	1.183	0.819	0.887	1.055	1.052
Mean	1.182	1.130	0.827	0.834	1.028	1.034

1974–75, essentially coinciding with low points of the Wharton and FRB measures, although the latter both indicate slight downturns in 1961.

The economic capacity utilization measures differ from the Wharton and FRB values in one very important respect, however. According to the FRB measure, the relative peak years of 1973 (.876) and 1977 (.819) were considerably smaller than the 1966 all-time peak (.911), whereas for the economic measures the peaks are essentially equal. In particular, the economic measures for 1973 and 1977 are virtually identical. The Wharton index differs slightly; its all time peak is 1973 (.932), and the 1966 (.882) and 1977 (.887) peaks are about equal but smaller than that in 1973.

One implication of this for total factor productivity measurement is that if one believes the economic measures, then comparisons between 1965–73 and 1973–77 are quite legitimate, since the peak years 1965, 1973, and 1977 represent basically equal levels of capacity utilization. In particular, on the basis of these data it appears that the 1973–77 slowdown in total factor productivity relative to 1965–73 cannot be attributed to the end year 1977 being one of unequal capacity utilization.

A third empirical issue to be considered concerns the effects of increased energy prices on the economically optimal level of output Y*. Recall that in the earlier discussion I noted that if E and K were complementary inputs, then increases in P_E would increase Y*. Although E–K complementarity occurs in both the single and two quasi-fixed input models (the 1977 long-run cross price elasticities for ϵ_{EK} are -0.086 and -0.065, respectively, while those for ϵ_{KE} are -0.029 and -0.022), the effect of increased energy prices on Y* is estimated to be quite small. For example, the estimated 1977 elasticity of Y* with respect to an increase in P_E is 0.021 for the single quasi-fixed factor model, and 0.047 for the model with two quasi-fixed inputs. These small positive estimates contrast sharply with those of Robert H. Rasche and John A. Tatom [1977a, b] and John A. Tatom [1979a, b] who use a Cobb-Douglas model and estimate that the elasticity of Y* with respect to P_E is negative and about -.10. On the basis of these data, however, I conclude that energy price increases since 1973 are unlikely to have affected capacity output significantly.

The fourth empirical issue to be examined is the effect of increased energy prices on Tobin's amended q_K, defined in Equation (3.22). In Table 7 I compare "actual" values of Tobin's q for the U.S. manufacturing sector[39] with those estimated by the dynamic models; all three measures are indexed to unity in 1973. Both dynamic models predict sharp drops for q_K in 1974, but the actual drop is much larger than that predicted; moreover the q_K in 1977 are predicted to be larger than in 1973, though such a recovery did not in fact take place. Rising energy prices during the 1974–77 time period are not predicted to have had a substantial effect on q_K; indeed, in 1977 the estimated elasticity of Tobin's q_K with respect to an increase in P_E is -0.030 in the single-fixed factor model, and -0.031 in the two quasi-fixed factor specification. The principal reason underlying the predicted increase in q_K since 1974 is that q_K is very responsive to output increases and therefore is predicted to recover along with output. The estimated elasticities of q_K with respect to output in 1974 are 1.031 (K fixed) and 1.379 (W, K fixed). Hence, whatever it was that contributed to the sharp fall in q_K since 1973, the analysis undertaken here suggests that rising energy prices cannot be named as the principal villain.

The fifth and final empirical issue considered in this section is the effect of variations in output and capacity utilization on the average productivity of individual factors. In both the single and two quasi-fixed factor models, long-run constant returns to scale imply that the elasticity of demand for each input with respect to output is unity. In the short run when certain inputs are fixed, however, these output elasticities may be greater or less than unity, depending on the substitutability-complementarity relationships among variable and fixed inputs.

Short-run elasticities of demand for production labor with respect to output are estimated as slightly greater than unity (around 1.2) in both the K fixed and W, K fixed models; in the K fixed model, the corresponding elasti-

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[39] Taken from Daniel M. Holland and Stewart C. Myers [1980], Table 2.

Table 7
Tobin's Amended q_K in Selected Years
U.S. Manufacturing

Year	Model with K Fixed	Model with K,W Fixed	Actual Value[1]
1973	1.000	1.000	1.000
1974	0.738	0.703	0.491
1975	0.880	0.798	0.591
1976	1.085	1.019	0.618
1977	1.111	1.043	0.618

[1] Taken from Daniel M. Holland and Stewart C. Myers [1980]. Entries from all columns are normalized to unity in 1973.

city for nonproduction labor is only about 0.6, while the W, K fixed model assumes that this short-run elasticity is zero. These results imply that as output fell from 1973 into 1974–75, the average productivity of production labor should have increased slightly, but that the average productivity of nonproduction labor should have decreased more sharply. Then as output increased considerably again in 1976–77, average productivity of B should have fallen or at least risen less rapidly, while that of W should have risen more sharply.

This predicted pattern of year-to-year variations within the 1973–77 time frame is consistent with the observed data. Although the K fixed model performs quite well in predicting differences in growth rates of B and W productivity during the 1973–77 time period, it substantially overestimates the absolute growth rate levels; predicted annual average growth rates are 3.972 percent and 1.889 percent, while actual rates were 2.518 percent and 0.487 percent, respectively. The model with W and K both fixed in the short run substantially overpredicts growth in B productivity (4.186 percent), but slightly underestimates growth in W productivity (0.238 percent). Incidentally, both models are unable to predict the slowdown in 1973–77 total factor productivity; estimated growth rates for 1965–73 and 1973–77 are equal at 0.87 percent per year for the K fixed model, and are 0.86 and 0.90 percent respectively in the W, K specification. In summary, then, for labor productivity the dynamic models are reasonably successful in predicting differences in growth rates of B and W productivity, but are unable to account for the sharp drop in absolute growth rate levels during 1973–77.

With respect to energy, both the K fixed and W, K fixed models find that short-run elasticities of demand for E with respect to output are less than unity (about 0.5 in the former and 0.8 in the latter); this helps explain the disappointing energy productivity trends over the 1973–77 time period. However, even with these small output elasticities and relatively low short-run energy price elasticities (about -0.20 in the K fixed and -0.15 in the W, K fixed model), both models predict modest growth in average energy productivity during 1973–77 of around 1 percent per year; actual energy productivity fell

0.8 percent per year, although in the latter portion (during 1975–77) it rose at an annual rate of around 2.6 percent, somewhat greater than the predicted growth rates of about 2.0 percent.

V. Concluding Remarks on the Role of Energy Price Increases on Measured Productivity Trends

In this paper I have examined the role of energy price increases in the productivity slowdown in U.S. manufacturing, 1973–77. Energy price or quantity variations since 1973 do not appear to have had a significant direct role in the slowdown of aggregate labor productivity in U.S. manufacturing, 1973–77. Two principal reasons were cited for this small direct effect. First, energy costs are a very small portion of total cost, and thus energy variations do not weigh heavily in productivity calculations. Second, observed energy quantity variations have been very small since 1973; for example, energy-output ratios have remained basically unchanged in 1977 from their 1973 levels, in spite of substantial energy price increases.

However, one way in which energy price increases could have affected labor productivity more significantly is through indirect effects, such as price induced reductions in capital-labor and energy-labor ratios. Such reductions would be consistent with E–K complementarity and E–L substitutability. As indicated in Table 4, however, there has been only a very slight slowdown in the rate of growth of the K/L ratio from 1965–73 (2.883 percent per year) to 1973–77 (2.520 percent), and in the rate of growth of the E/L ratio — 2.793 percent in 1965–73 versus 2.543 percent during 1973–77. Moreover, *a priori* it would seem that if rising energy prices were to reduce capital formation and induce substitution of workers for machines, this effect would be greater for production laborers (B) than for nonproduction workers (W). However, examination of U.S. manufacturing data disaggregated into B and W indicates that the growth rate of capital per production hour at work *increased* slightly from 3.142 percent (1965–73) to 3.269 percent (1973–77) per year, while that of capital per nonproduction hour at work *decreased* from 2.465 percent per year (1965–73) to 1.277 percent (1973–77). Even more surprising, although aggregate labor productivity fell significantly during the 1973–77 time period, growth in output per production hour at work was remarkably stable over the entire 1958–77 time period at 2½ to 3 percent per year; in contrast, growth in output per nonproduction hour at work fell from 3.720 percent per year (1958–63) to 2.353 percent (1965–73), and then fell much more sharply to only 0.487 percent per year (1973–77). In summary, then, empirical evidence in support of the hypothesis that energy price increases reduce capital formation within the manufacturing sector and induce substitution of machines for workers, thereby significantly reducing labor productivity growth, is not very convincing — at least based on these data for U.S. manufacturing through 1977. While the evidence could be viewed as being consistent with energy price increases very modestly reducing rates of capital formation in manufacturing, it does not appear to be as supportive of the energy-labor substitutability hypothesis, the latter hypothesis advanced ironically both by E–K complementarity and E–K substitutability advocates.[40] Moreover, as seen in Section IV energy price increases are unlikely to have negatively affected Tobin's q significantly.

That the evidence on the E–K and E–L relationships remains unsettled is regrettable. It should be noted that the Jorgenson interpretation of effects of rising energy prices on aggregate national rates of capital formation, labor productivity growth, and economic growth relies only partially on E–K complementarity and E–L substitutability within manufacturing, and depends considerably more on price-induced compositional changes among sectors in final demand. Evidence on such a general equilibrium hypothesis has not been examined in this paper.[41]

But if energy price increases were not responsible for the 1973–77 productivity slowdown, what were the principal causes? Based on the evidence in Section II, since inputs such as W and K tend to be fixed in the short run, and since E might also be somewhat insensitive to output variations in the short run, I conjectured that the slowdown in productivity growth in U.S. manufacturing 1973–77 may have been due in large part to the coincident reduction in the growth rate of output. This hypothesis was formulated more rigorously within the context of dynamic models of factor demands that included not only K and W but also B, E and M inputs. Econometric results, presented in Section IV, disclosed that economic measures of capacity utilization were about equal in 1965, 1973, and 1977, implying that the 1973–77 total factor productivity slowdown could not be attributed to the choice of these particular years for the 1965–73 and 1973–77 comparisons. Although the dynamic models fared quite well in predicting *differences* among B, W and E productivity growth rates during 1973–77, the models consistently overpredicted *absolute* productivity growth rates of the inputs. In brief, the dynamic models were unable to explain the 1973–77 slowdown in total factor productivity.[42]

In summary, energy price increases are unlikely to have played a major direct or indirect role in the 1973–77 productivity slowdown in U.S. manufacturing. However, to the extent that energy price increases reduce future rates of capital formation, their effect on labor productivity in the 1980s may be more substantial than in the brief 1973–77 time period. What caused the 1973–77 productivity slowdown regrettably remains a question for which we do not yet have a satisfactory set of answers.

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[40] See, for example, James M. Griffin and Paul R. Gregory [1976] and Ernst R. Berndt and David O. Wood [1975, 1979].

[41] For alternative partial and general equilibrium specifications, see William Hogan and Alan Manne [1977] and John Solow [1979].

[42] The model would of course have fared better if time had been entered in squared form (t^2) rather than simply as a linear term. Such an exercise, however, would be less than satisfying and convincing intellectually.

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Discussion

Paul R. Gregory*

I suspect I was invited to comment on Mr. Berndt's paper because of work co-authored with Jim Griffin arguing that energy and capital are substitutes. Perhaps it was anticipated that Berndt would argue that K-E complementarity was a contributory factor to the post 1973 productivity slowdown — a position I would then dispute. In Berndt's paper, K-E complementarity is not at all crucial; thus, this conference is deprived of one source on controversy.

I find myself in agreement with Berndt's major conclusions — an uncomfortable position for a discussant. The major issue addressed by Berndt is: Did the acceleration in the relative price of energy since 1973 play a significant role in the slowdown of labor productivity and total factor productivity in U.S. manufacturing? As Berndt demonstrates, if one attacks this question with the conventional tools of growth accounting and production functions, it is difficult to place much blame on a single factor (energy) that accounts for 1 to 2 percent of gross input costs. One must therefore search for indirect effects that are less obvious and more difficult to quantify.

Mr. Berndt is to be congratulated on his thoughtful exploration of the direct and indirect avenues through which energy affects productivity. The most innovative feature of his work is the estimation of a capacity utilization index (CU) that captures the impact of factor price changes on productivity. At the end of this discussion, I shall suggest additional approaches that Berndt may wish to consider, but I doubt that their pursuit would alter his basic findings.

Mr. Berndt's conclusions are: 1) Energy productivity has declined, but the energy share is too small to be an important explanation of the productivity decline. 2) The rise in the relative price of energy has not led to significant changes in factor proportions. There is little evidence of K-E complementarity (unless K is adjusted by a mechanical capacity utilization index). The rise in K/L has, in fact, prevented the labor productivity decline from being greater. 3) Changes in capacity utilization in a regime where K and white collar workers are quasi-fixed do not account for the productivity decline. 4) Indirect energy price effects working via Tobin's amended q_k are small and do not explain the marked decline in q_k noted by other researchers.

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5) The major factors in the productivity decline are the declines in K productivity and the productivity of white collar workers. Berndt argues that both of these factors are quasi-fixed.

To the student of growth accounting, the first conclusion is entirely expected. The second conclusion rules out the extreme effects on K/L ratios predicted by other researchers. Given conclusion 5, declines in capacity utilization appear to suggest a convenient scapegoat for the productivity decline, but Berndt's CU index shows no real change in CU in the base and terminal years of his sub-periods. Berndt's CU index does explicitly incorporate the short-run disequilibria effects of changing relative prices when K and white collar workers are quasi-fixed, thus ruling out an indirect energy effect on CU. In view of the innovative nature of Berndt's CU measure and the importance of CU, I suggest that Berndt elaborate his results beyond the limited discussion in his text.

A brief technical comment before proceeding to more substantive issues: Apparently Berndt has estimated K by deflating the K cost share by the rental cost. Yet during periods of low capacity utilization, the short-run shadow price of K falls below the rental cost, and variations in the ratio of the shadow price to the rental price of K will be attributed to K. It would appear appropriate to test the model using direct measures of capital stock as Berndt has done in previous work.

The most substantive question is whether Berndt's model could be modified using realistic assumptions to reverse his conclusion that energy was not a significant factor in the post 1973 productivity decline. One way to alter Berndt's conclusion is to abandon his approach entirely and to model energy's impact on inflation (an exogenous supply shock) and then inflation's impact on productivity. This matter has been brought to the attention of this conference already, and I leave it to wiser heads than mine for elaboration. Also one could turn to other sectors (utilities, for example) where energy is a more important input. If one remains within the confines of manufacturing and of Berndt's own cost function model, several experiments suggest themselves.

The first experiment would be to fit the model over a shorter period (concentrating, say, on the 1970s) to test for changes in economic structure. A Chow test on a split sample of 1958–73 and 1974–77 would be appropriate.

A second experiment would be to drop the assumption of a homogeneous capital stock. This may allow one to account for the failure of energy demand to decline as rapidly as predicted. Insofar as energy usage is tied to the engineering characteristics of the capital stock, substantial declines in energy demand may require substantive changes in the capital stock, and such changes occur slowly over time. Moreover, a heterogeneous capital stock allows one to link rising energy prices and Tobin's q_k. The rising price of energy may reduce the shadow price of existing capital, which now earns less quasi rent because it is an unwanted vintage. The decline in q_k means less new investment and thus less technological progress embodied in the production process.

I would be surprised if any of these modifications (short of going to a macro inflation model) would alter Berndt's basic point that energy has not played an important role in the productivity decline experienced by U.S. manufacturing, but Mr. Berndt may wish to deal with them in his further work on this subject.