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ASSESSING THE PRODUCTIVITY OF INFORMATION TECHNOLOGY EQUIPMENT IN U.S. MANUFACTURING INDUSTRIES

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ABSTRACT

In this paper we report results of an empirical assessment of the cost reducing impacts of recent dramatic increases in stocks of "high-tech" office and information technology equipment (O), using annual data from various two digit US manufacturing industries over the 1952-1986 time period.

While there are exceptions, on balance we find that in 1986, estimated marginal benefits of investments in this O equipment are less than marginal costs, implying over investment in O capital in 1986. The sign of the estimated elasticity of demand for labor with respect to changes in the stock of O capital is evenly divided in the fourteen industries, but whether positive or negative, in all industries this elasticity increases in absolute magnitude over time, indicating ever greater impacts of O capital on the demand for aggregate labor. Finally, our estimates of the elasticity of technical progress with respect to O-capital are very small in magnitude, implying that increases in O capital have only a small impact on technical progress.

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"We see computers everywhere except in the productivity statistics."

Attributed to Robert M. Solow

I. INTRODUCTION

The last two decades have witnessed an explosion in the amount of "high tech" computer power and information technology equipment purchased by American firms and businesses. Yet it has been difficult to establish that the extent of such investments can be rationalized in terms of realized cost savings. Indeed, a common perception is that this dramatic increase in office and information technology equipment has not had a commensurate impact on firms' cost and productivity performance. As Martin N. Baily and Robert J. Gordon have described this situation, "...official data show enormous productivity gains in the manufacture of computers, but apparently little productivity improvement in their use."[1]

In this paper we report results obtained in a study based on the economic theory of cost and production that attempts to assess the shadow value of office and information technology equipment in U.S. manufacturing industries, that quantifies the effects of this equipment on the demand for labor and other inputs, and that examines the relationship between changes in the stocks of this equipment and technical progress.

Precisely how one identifies and documents cost savings attained by investments in computer power is not clear. Within a given establishment, for example, cost savings achieved in one division or line of business might be offset by increased costs in another; further complexities can emerge for multi-establishment firms. Presumably, therefore, it makes more sense to look for cost reductions at the overall firm level, or perhaps even at an aggregate industry level. The lack of sufficiently reliable data at the firm level, however, suggests that analyses of the effects of investment in computer power might by necessity be confined to aggregate industry studies.

At the industry level, official productivity statistics indicate that over the last fifteen years the productivity growth record of US manufacturing industries has been much better than that for non-manufacturing industries,[2] due perhaps to difficult problems in measuring output in non-manufacturing industries, especially in the service sectors. If investments in office and information technology equipment have been productive, and given that the manufacturing industries have demonstrated more rapid productivity growth, one could argue that one would be most likely to identify and measure the effects of office and information technology investments by examining the productivity performance within and between various manufacturing industries.[3] That is what we attempt to accomplish in this paper.

The remainder of the paper is organized as follows. In Section II we provide some further background discussion, in Section III we outline the theoretical framework, in Section IV we present empirical findings, and in Section V we summarize and suggest avenues for further research.

II. BACKGROUND

A great deal of research and discussion has taken place on documenting and interpreting the effects of the explosion in computer power. For example, Timothy Bresnahan [1986] has measured spillovers from mainframe computers in financial services, Gary Loveman [1988] has examined interactions between information technology capital and labor productivity growth at the line-of-business level of aggregation, Erik Brynjolfsson and associates [1989] have examined the effects of information technology equipment on decentralization and firm size, H. Allan Hunt and Timothy L. Hunt [1986] and Paul Osterman [1986] have analyzed the impacts of computers on the employment of managers and clerical personnel, and Leonard Dudley and Pierre Lasserre [1989] have examined the effects of increased information on inventory costs and inventory holdings. Wide-ranging analyses on the effects of increased office and information technology equipment have also been undertaken by Martin N. Baily [1986], Baily and Alok K. Chakrabarti [1988], Michael L. Dertouzos, Richard K. Lester and Robert M. Solow [1990], Stephen S. Roach [1987], and by Lester C. Thurow [1987].

Although each of these studies has focused on important and interesting aspects of the explosion of computer power, to the best of our knowledge none has attempted to quantify the actual marginal benefits (in our framework, the shadow values) of investments in office and information technology equipment, and then compared them with the marginal costs of such investments. The approach we take in this paper is to do just that -- compute marginal benefits and marginal costs, compare them, and assess how benefits are revealed in terms of decreased demands for labor, energy and/or intermediate materials.

Before proceeding with a discussion of our theoretical framework, we believe it is useful to begin by documenting the dramatic changes in investment behavior that US manufacturing firms have displayed in the last decade. As a definitional matter, we define office and information technology equipment O as a composite of "high-tech" equipment, including office, computing and accounting machinery, communications equipment, scientific and engineering instruments, and photocopy and related equipment. We define equipment E as non-O producers' durable equipment, and structures S as non-residential structures.

In the first two columns of Table 1, aggregate capital-output ratios are presented, where both capital and output are in 1971$, and aggregate K is a simple sum of stocks of E, S and O. As is seen there, in all industries except lumber and wood, the aggregate capital-output ratio has increased in

Table 1

CAPITAL INTENSITY, INVESTMENT AND CAPITAL COMPOSITION
IN U.S. MANUFACTURING INDUSTRIES, 1976 AND 1986

	Aggregate Capital Intensity		Capital Stock Composition						Investment Shares in 1986		
			E Share		S Share		O Share				
Industry	1976	1986	1976	1986	1976	1986	1976	1986	E	S	O
Apparel	.80	.83	30.1%	22.0%	66.1%	68.2%	3.4%	9.8%	11%	72%	17%
Chemicals	1.86	1.99	66.7%	53.2%	12.1%	10.4%	21.2%	36.4%	45%	10%	45%
Clay	1.92	2.66	64.4%	41.3%	29.3%	19.9%	6.3%	38.7%	21%	12%	67%
Electric Machinery	.94	1.20	60.3%	42.1%	24.6%	16.5%	15.1%	41.4%	35%	12%	53%
Fabricated Metals	.91	1.16	70.1%	66.1%	26.3%	21.1%	3.5%	12.8%	57%	14%	29%
Food	.55	.60	72.3%	64.9%	16.7%	14.0%	11.0%	21.1%	60%	12%	28%
Furniture & Fixtures	1.45	1.46	23.2%	17.6%	76.1%	69.4%	1.7%	12.9%	15%	54%	31%
Instru-Ments	1.13	1.47	37.7%	31.8%	55.1%	37.2%	7.2%	31.0%	25%	22%	53%
Iron and Steel	.61	.96	69.2%	61.1%	19.8%	14.5%	11.0%	24.3%	71%	9%	20%
Lumber and Wood	.67	.56	44.1%	38.7%	54.3%	55.0%	1.6%	6.3%	42%	45%	13%
Machinery	.88	1.54	55.1%	28.0%	19.4%	8.8%	25.5%	63.3%	16%	4%	80%
Paper	1.90	2.05	72.3%	68.2%	24.5%	17.6%	3.2%	14.2%	58%	12%	30%
Printing & Publishing	.49	.69	41.3%	26.7%	49.7%	30.1%	9.1%	43.2%	28%	16%	56%
Transportation Eqpt.	.37	.48	55.8%	38.9%	37.0%	24.2%	7.2%	36.9%	28%	16%	56%

Notes: The aggregate capital intensity is computed as the simple sum of the three capital stock components (E, S and O) divided by gross output, all in 1971$.

the last decade, implying that manufacturing industries have undertaken substantial net investment and capital deepening from 1976 to 1986.

Not only has the aggregate capital-output ratio increased since 1976, but the composition of the aggregate capital stock has also changed substantially. In particular, in all manufacturing industries, the (non high-tech) equipment share of the aggregate capital stock has fallen, while the share of high-tech office and information technology equipment has increased, often dramatically, e.g., in clay the O share has increased from 6 to 39%, in furniture and fixtures from 2 to 13%, in printing and publishing from 9 to 43%, and in transportation equipment from 7 to 37%. The share of structures in total fixed capital stock decreased in 12 of the 14 industries, and increased slightly in the remaining two.

The increasing share of office and information technology equipment in manufacturing industries' total capital stock since 1976 reflects of course the correspondingly increasing share of O in total investment. This is demonstrated in the final three columns of Table 1, where it is seen that the 1986 share of O *investment* in total E + S + O investment is larger than the corresponding share of O in the total E + S + O *capital stock* for all industries except iron and steel. Moreover, in some industries the O share of total investment in 1986 is very large, e.g., 67% in clay and 80% in machinery.

In brief, the investment and capital stock data indicate quite clearly than in almost all US manufacturing industries, not only has the aggregate capital-output ratio increased implying enhanced capital intensity, but the share of office and information technology equipment in the total capital stock has also increased dramatically since 1976.

With this overview of data trends in mind, we now present a model in which the impacts of these investments in O capital can be assessed quantitatively.

III. THEORETICAL FRAMEWORK

To assess the impacts on costs and productivity of investment in office and information technology capital (O), we employ the economic theory of cost and production. More specifically, we begin by specifying a variable cost function inclusive of adjustment costs, having the general form $G(Y,t,\mathbf{x},\Delta\mathbf{x},p)$, where $\mathbf{x}$ and $\Delta\mathbf{x}$ are 3x1 vectors denoting capital stock levels and absolute values of net investment in fixed inputs (E -- producers' durable equipment other than O, S -- non-residential structures, and O), p is a 3x1 vector of variable input prices (N -- energy, M -- non-energy intermediate materials and purchased services, and L -- labor), Y is gross output, and t is a time counter representing disembodied technical progress. The inclusion of $\Delta\mathbf{x}$ in G allows for internal costs of adjustment on the capital assets.

As a functional form for G, we employ the generalized Leontief variable cost function with non-constant returns to scale, developed and implemented empirically by Morrison [1988a,b,1989,1990],

$$G(Y,t,\mathbf{x},\Delta\mathbf{x},p) = Y\,[\sum_{i=1}^{3}\sum_{j=1}^{3}\alpha_{ij}\,p_i^{.5}p_j^{.5} + \sum_{i=1}^{3}\sum_{m=1}^{5}\delta_{im}\,p_i s_m^{.5} + \sum_{i=1}^{3}p_i\sum_{m=1}^{5}\sum_{n=1}^{5}\gamma_{mn}\,s_m^{.5}s_n^{.5}]$$

$$+\,Y^{.5}[\sum_{i=1}^{3}\sum_{k=1}^{3}\delta_{ik}\,p_i x_k^{.5} + \sum_{i=1}^{3}p_i\sum_{m=1}^{5}\sum_{k=1}^{3}\gamma_{mk}\,s_m^{.5}x_k^{.5}] + \sum_{i=1}^{3}\gamma_{lk}\,x_l^{.5}x_k^{.5}, \qquad (1)$$

where x_l, x_k denote the three fixed inputs (E, S and O), p_i and p_j index prices of the three variable inputs (L, N and M), and s_m and s_n depict the remaining five arguments $(Y,t,\Delta E,\Delta S$ and $\Delta O)$.

Six estimating equations are derived from this generalized Leontief variable cost function. Specifically, three variable input demand equations are obtained by employing Shephard's lemma, $v_i = \partial G/\partial p_i$, where v_i is the variable cost-minimizing demand for variable input i. In addition, three investment equations are derived by specifying Euler equations that capture the investment response to the difference between the <u>ex ante</u> market price P_k and the shadow value Z_k ($Z_k = -\partial G/\partial x_k$) for each of the fixed inputs; the implied rate of investment reflects of course the effects of internal adjustment costs. An additive disturbance term is appended to each of these six equations, and the resulting disturbance vector is assumed to be identically and independently normally distributed with mean vector zero and variance-covariance matrix Ω.

The estimation method used is three-stage least squares (3SLS), with the instrument (information) set consisting of T, beginning-of-year capital stocks for E, S and O, and once-lagged values of Y, E, O, S, L, N, M, P_E, P_S, P_O, ΔE, ΔS and ΔO; the endogenous variables in this equation system are the variable input quantities L, N and M, the investment quantities ΔE, ΔS and ΔO, and the level of output Y.[4] Finally, although the prices of variable inputs (P_L, P_N and P_M) are assumed to be exogenous, in the Euler equations it is expectations of future prices for P_L, P_N and P_M that are of relevance. For this reason, these variable input prices are instrumented, ensuring that expectational "surprises" are uncorrelated with the equation residuals, as is implied by the rational expectations hypothesis.[5]

Of particular interest to us in this paper is the shadow value of the office and information technology equipment (O), computed as

$$Z_O = -\partial G/\partial O, \quad (2)$$

revealing the marginal efficiency of the O capital, i.e., the extent to which an additional unit of O reduces variable costs G, <u>ceteris paribus</u>, where $G = P_L L + P_N N + P_M M$.[6] If firms were in long-run equilibrium, they would invest in O up to the point where the shadow value of office and information technology equipment (the marginal benefits) just equalled the <u>ex ante</u> rental price of this capital, P_O (the marginal cost); in long-run equilibrium, it would also be the case that $Z_E = P_E$ and $Z_S = P_S$. It is of course possible that the benefits from additional investment Z_O exceeded the marginal cost P_O, in which case there would be incentives for additional net investment. On the other hand, if firms have over-invested in office and information technology equipment, then the marginal benefits Z_O must be less than the marginal cost P_O. Presumably, those people who argue that industries have over-invested in office and information technology equipment implicitly are saying that $Z_O < P_O$.

Based on this line of reasoning, it is useful to construct a measure that compares benefits and costs, i.e., that takes the ratio of the shadow value to the ex ante rental price of O. It turns out that such a benefit-cost ratio measure is a capital service flow analog to the capital asset measure known as Tobin's q; this has been shown by, among others, Abel [1980] and Hayashi [1982]. In our context, therefore, we compute Tobin's q (benefit/cost) ratios as

$$q_k = Z_k/P_k, \quad k = E, S \text{ and } O. \tag{3}$$

When q_k is greater (less) than unity, there is under- (over-) investment in the k^{th} capital asset, and there are incentives for net investment (disinvestment); only when $q_k = 1$ -- when marginal benefits just equal marginal costs -- is the firm in long-run equilibrium (k = E, S and O). These ratios are therefore critically important for evaluating the economic rationale underlying investment behavior and thus the "productivity" of these investment decisions. In the empirical section of this paper, we will report on our estimates of q_k by industry for selected years.

A complementary measure of the impact of investment in office and information technology equipment is its effect on the productivity of other capital. In our context, we are interested in the effect of increases in O on the marginal product of all other equipment. Specifically, if $-\partial^2G/\partial E\partial O$ is positive (negative), then increases in O increase (decrease) the shadow value of E, making it more (less) productive in reducing variable costs, suggesting that E and O are substitutes (complements). To evaluate this derivative in elasticity form, we define ϵ_{EO} as the elasticity of the shadow value of capital equipment with respect to an increase in the stock of office and information technology equipment, and compute it as

$$\epsilon_{EO} = (-\partial^2G/\partial E\partial O)/TC, \tag{4}$$

where TC is total cost, computed as the sum of variable costs plus fixed costs, and where the fixed inputs are evaluated using shadow values.

Another measure of the impact of office and information technology equipment on costs and productivity deals with effects on demands for the variable inputs L, N and M. If increases in O have a "neutral" effect on cost-minimizing demands for L, N and M, then changes in O would affect demands for these inputs equiproportionally; on the other hand, if, for example, increases in O reduced human labor time substantially, slightly decreased energy usage and increased non-energy intermediate materials (say, through increased use of paper), then changes in O would have non-neutral impacts on demands for variable inputs. It is therefore of interest to construct an elasticity of the derived demand for variable input i with respect to O as

$$\epsilon_{iO} = (O/v_i)*(\partial v_i/\partial O) = (O/v_i)*(\partial^2G/\partial p_i\partial O), \quad i = L, N \text{ and } M, \tag{5}$$

where the second equality results from Shephard's lemma ($v_i = \partial G/\partial p_i$). Estimates of these elasticities will be presented in the following section of this paper.

The final measure we compute to evaluate the impact of office and information technology equipment on costs and productivity refers to its interaction with technical progress. Specifically, short-run techncial progress can be evaluated by computing the partial derivative $-\partial G/\partial t$, and then the effects of changes in the stock of office and information technology equipment on technical progress can be calculated as $-\partial^2G/\partial t\partial O$; in elasticity form, we compute this impact of increases in O on technical progress growth as

$$\epsilon_{tO} = (-\partial^2G/\partial t\partial O)/TC. \tag{6}$$

When ϵ_{tO} is positive (negative), increases in the stock of O accelerate (decelerate) the rate of technical progress, ceteris paribus. Note also that an alternative interpretation of this elasticity can be obtained by reversing the order of the derivatives, in which case one assesses how the shadow value of capital $(-\partial G/\partial O)$ is affected by technical progress $(\partial G/\partial t)$.[7]

IV. DATA AND EMPIRICAL RESULTS

Annual two-digit manufacturing data, 1952-1986, have been provided us by Michael Harper of the U.S. Bureau of Labor Statistics. The data series on Y, L, N and M were constructed by BLS personnel using data from the Census of Manufactures and the Annual Surveys of Manufactures, and data series on capital stocks and investment for E, S and O are based on detailed industry measures constructed by John A. Gorman, John C. Musgrave and associates at the Bureau of Economic Analysis.[8] In particular, the category of capital we call office and information technology capital (O) consists of a Divisia index of four asset codes in the Gorman et al. data set: 14 -- office, computing and accounting machinery; 16 -- communications equipment; 25 -- scientific and engineering instruments; and 26 -- photocopy and related equipment.

Using tax and depreciation data series, BLS officials have also constructed annual rental price measures for the various types of capital equipment and structures.[9] We have modified their ex post rental price computation to obtain an ex ante measure by incorporating Moody's Baa corporate bond yield as the ex ante interest rate, and have set the capital gains term in the traditional Hall-Jorgenson rental price formulae to zero for each component of capital.[10] A Divisia index was then constructed separately for P_E, P_S and P_O, and implicit Divisia indexes for E, S and O were also computed.

We have estimated parameters in the six-equation system for a number of two-digit manufacturing industries using the 3SLS estimation procedure, as outlined above. Since the number of parameters estimated for each industry is substantial, in this paper we do not report detailed parameter estimates by industry.[11] Rather, we focus attention on the indicators of productivity performance outlined in the previous section -- estimated Tobin's q (benefit/cost) ratios for office and information technology equipment, the elasticity of the shadow value of E with respect to O, elasticities of demands for variable inputs with respect to increases in O, and the interaction between technical progress and changes in the stock of O. We begin with the estimated Tobin's q values, reported in Table 2 below.

In the first four columns of Table 2, we report estimated Tobin's q ratios at five-year intervals from 1971 to 1986, by industry. A number of results are worth noting. First, in 1971 q was less than one in all but two industries (where it was barely above unity); the sample mean of the q's over all fourteen industries in 1971 was 0.65.

Second, after 1971 there appears to be considerably greater variability in the q ratios for O capital. Values of q in 1976 range from 0.68 to 1.91, in 1981 from 0.24 to 2.56, and in 1986 from -1.80 to 4.96. The two industries with very large q's in 1986 are fabricated metals (q = 3.90) and machinery (4.96), both of which were already investing heavily in O equipment, as was shown in Table 1. The negative q values for O capital in 1986 in food (-0.71), furniture and fixtures (-1.80) and instruments (-0.82) imply that

Table 2

ESTIMATES OF TOBIN'S Q VALUES FOR INFORMATION TECHNOLOGY CAPITAL, AND EFFECTS ON THE SHADOW VALUE OF CAPITAL EQUIPMENT, SELECTED YEARS BY INDUSTRY

Industry	Tobin's q Estimated Value 1971	1976	1981	1986	Elasticity of Shadow Value of Capital Equipment w.r.t. O-Capital 1971	1976	1981	1986
Apparel	0.72	0.68	0.24	0.26	-.0030	-.0020	-.0020	-.0015
Chemicals	0.61	0.88	0.80	1.03	-.0007	-.0004	-.0004	-.0003
Clay	0.76	0.88	0.91	1.51	.0060	.0030	.0020	.0010
Electric Machinery	0.73	0.79	0.33	0.05	-.0001	-.0000	-.0000	-.0000
Fabricated Metals	1.01	1.52	2.56	3.90	.0020	.0020	.0020	.0009
Food	0.91	1.91	0.58	-0.71	.0003	.0003	.0003	.0002
Furniture & Fixtures	0.92	1.07	0.52	-1.80	-.0100	-.0080	-.0040	-.0020
Instruments	0.57	1.03	0.88	-0.82	-.0009	-.0006	-.0003	-.0001
Iron and Steel	0.62	0.74	0.48	1.30	.0006	.0000	.0000	.0000
Lumber and Wood	0.42	1.20	0.24	0.03	-.0130	-.0120	-.0100	-.0070
Machinery	1.06	1.82	1.83	4.96	.0002	.0001	.0001	.0000
Paper	0.74	1.39	1.48	0.89	.0010	.0007	.0005	.0002
Printing & Publishing	0.55	1.07	0.94	0.71	-.0001	-.0001	-.0000	-.0000
Transportation Eqpt.	0.59	1.21	0.94	1.34	.0002	.0002	.0001	.0000
Sample Mean								
All Industries	0.65	1.16	0.91	0.90				
Only 9 Industries*	0.64	0.98	0.71	0.79				

*Excludes fabricated metals, food, furniture and fixtures, instruments and machinery industries, whose q values in 1986 were "outliers".

increases in O capital resulted in an *increase* in variable costs -- a rather surprising finding.

Third, sample means of q for 1971, 1976, 1981 and 1986 over all fourteen industries are 0.65, 1.16, 0.91 and 0.90, respectively, while sample means of q when the the five "outlier" industries are deleted are 0.64, 0.98, 0.71 and 0.79. These results imply, therefore, that were say, $1 invested in each of these fourteen (or nine) industries in 1986, on average the returns to such investments would not be sufficiently large to justify the investment, for the average reduction in costs would be $0.90 (for all industries), or $0.79 (excluding the five "outlier" industries). Hence, while there are exceptions, on balance there appears to be an overinvestment in O capital in 1986 in the sense that marginal benefits are less than marginal costs.

In the final four columns of Table 2, we present estimates of the elasticity of the shadow value of (non high-tech) E capital with respect to changes in the quantity of O capital. The signs of these elasticities show no clear pattern across industries, and elasticity estimates are evenly divided between positive and negative values. Moreover, in all industries except lumber and wood, the value of this elasticity is no greater than 1% in absolute value. We conclude, therefore, that there is little interaction between the shadow value of E capital and the quantity of O capital. In this sense, the E and O capital inputs appear to be reasonably independent.

We now move on to a discussion of the impacts of changes in O capital on the demands for labor, energy and non-energy intermediate materials. As in shown in Table 3, the sign of the estimated elasticity of the derived demand for labor with respect to O capital varies by industry, with seven industries having negative estimates (indicating a type of substitutability between labor and O), and the other seven being positive (suggesting complementarity). A

Table 3

ESTIMATED ELASTICITY OF DERIVED DEMAND FOR VARIABLE INPUTS WITH RESPECT TO INFORMATION TECHNLOGY CAPITAL, SELECTED YEARS BY INDUSTRY

	Demand for Labor				Demand for Energy				Demand for Materials			
Industry	1971	1976	1981	1986	1971	1976	1981	1986	1971	1976	1981	1986
Apparel	-.016	-.021	-.029	-.040	.163	.211	.360	.466	.008	.011	.014	.018
Chemicals	-.044	-.079	-.098	-.118	.321	.277	.265	.474	-.031	-.048	-.052	-.062
Clay	-.006	-.011	-.026	-.035	-.036	-.053	-.156	-.202	.001	.005	.005	.012
Electric Machinery	-.012	-.015	-.018	-.025	-.010	.006	.229	.812	-.008	-.009	-.009	-.008
Fabricated Metals	-.004	-.003	-.006	-.009	.135	.151	.135	.285	-.008	-.008	-.012	-.019
Food	.056	.072	.097	.145	.184	.117	.262	.511	-.026	-.032	-.036	-.046
Furniture & Fixtures	-.019	-.027	-.047	-.073	-.081	-.092	-.087	.211	.011	.015	.025	.047
Instruments	.034	.044	.057	.132	-.008	-.018	-.020	.335	-.053	-.054	-.062	-.121
Iron and Steel	.034	.047	.064	.074	.011	-.003	-.021	-.177	-.038	-.044	-.055	-.093
Lumber and Wood	-.003	-.004	-.005	-.008	.153	.123	.229	.319	-.006	-.007	-.009	-.242
Machinery	.009	.011	.016	.027	.006	-.069	-.136	-.684	-.061	-.072	-.103	-.231
Paper	.010	.015	.022	.047	.005	.003	-.007	.030	-.016	-.024	-.029	-.048
Printing & Publishing	.011	.016	.024	.047	-.000	-.015	-.072	.210	-.022	-.028	-.039	-.059
Transportation Eqpt.	.009	.011	.016	.029	-.026	-.048	-.105	-.128	-.011	-.013	-.019	-.028

somewhat surprising finding here is that whether positive or negative, in all industries this elasticity increases in absolute magnitude over time, indicating ever-greater impacts of O capital on the demand for labor. These results deserve further analysis, perhaps along the lines of disaggregating labor into groups with varying degrees of education.

In the middle four columns of Table 3, we examine interactions between O capital and the derived demand for energy. As is seen there, in eleven of the fourteen industries, the estimated elasticity of demand for energy with respect to O capital is positive, suggesting a type of energy-O capital complementarity. By contrast, in eleven of the fourteen industries, the corresponding elasticity for non-energy intermediate materials is negative, suggesting substituability between O-capital and these materials.

Our final calculations examine interactions between O capital and technical progress. We begin in Table 4 by computing estimated rates of technical progress by industry for 1976 and 1986, calculated by simply evaluating the derivative $\epsilon_{Ct} = -(\partial G/\partial t)/TC$. Results are presented in the first two columns of Table 4. Note that in all industries except iron and steel, technical progress was positive, and in the electric machinery and printing and publishing industries it was particularly strong.

In the final four columns of Table 4, we present estimates of the elasticity of technical progress with respect to O-capital, using Eq. (6) and our 3SLS parameter estimates. In ten of the fourteen industries, this estimated elasticity is positive, implying that increases in O-capital accelerate the rate of technical progress; in four industries, the reverse result is obtained. It is worth noting that whether negative or positive, these elasticities are all very small -- the largest is about two-tenths of one percent.

We conclude, therefore, that there is little evidence to suggest that increases in office and information technology equipment have a substantial acceleration impact on technical progress in US manufacturing industries; what impact there is appears to be rather small.

Table 4

3SLS ESTIMATES OF ϵ_{Gt} and ϵ_{tO} -- TECHNICAL PROGRESS AND THE ELASTICITY OF TECHNICAL PROGRESS WITH RESPECT TO CHANGES IN OFFICE AND INFORMATION TECHNOLOGY EQUIPMENT

	Annual Growth Rate Technical Progress		Elasticity of Technical Progress with respect to O-Capital			
Industry	1976	1986	1971	1976	1981	1986
Apparel	.007	.006	-.0005	-.0004	-.0004	-.0003
Chemicals	.007	.004	-.0003	-.0002	-.0001	-.0001
Clay	.001	.002	.0007	.0004	.0002	.0001
Electric Machinery	.016	.019	.0001	.0001	.0000	.0000
Fabricated Metals	.004	.004	.002	.0002	.0001	.0001
Food	.008	.006	-.001	-.001	-.0009	-.0007
Furniture & Fixtures	.001	.001	.0001	.0001	.0000	.0000
Instruments	.009	.009	.001	.001	.0006	.0003
Iron and Steel	-.005	-.003	.0006	.0004	.0003	.0003
Lumber and Wood	.010	.008	-.0009	-.0010	-.0007	-.0005
Machinery	.006	.011	.0003	.0002	.0001	.0009
Paper	.000	.001	.0010	.0007	.0005	.0003
Printing & Publishing	.013	.012	.0004	.0003	.0002	.0001
Transportation Eqpt.	.001	.001	.0001	.0001	.0000	.0000

V. CONCLUDING REMARKS

Our purpose in this paper has been to examine empirically the cost-reducing impacts of recent dramatic increases in stocks of "high-tech" office and information technology equipment, using annual data from various two-digit U.S. manufacturing industries over the 1952-1986 time period. Our theoretical framework is based on the theory of cost and production. The empirical specification we employ is that of a dynamic factor demand model, with labor, energy and non-energy intermediate materials as variable inputs, and office and information technology equipment (O), non-O producers' durable equipment (E) and non-residential structures (S) as quasi-fixed inputs. For each industry, we computed the ratio of marginal benefits of O investment to marginal costs, and also calculated a number of related elasticities.

Our principal empirical findings can be summarized as follows. First, our estimates of the benefit-cost (Tobin's q) ratios varied considerably among industries (with increasing variability over time), but in 1986 the average benefit-cost ratio across all industries was 0.90, and if five "outlier" industries were excluded, this ratio fell to 0.79. It is worth noting here that the denominator of the benefit-cost ratio is a rental price of capital, which in our empirical formulation had the expected capital gains term set to zero. Since the price of O equipment fell steadily and considerably over the 1952-86 time period, one might argue that an expectation of declining prices should be incorporated into the benefit-cost calculation. Had we incorporated the capital gains (in this case, capital losses) term into the rental price formula, the denominator of the benefit-cost ratio would have been larger, and thus the ratio would have been even smaller. We conclude, therefore, that while there are exceptions, on balance there appears to have been an overinvestment in O capital in 1986 in the sense that marginal benefits are less than marginal costs.

Second, our estimates of the elasticity of the shadow value of non high-tech capital with respect to changes in the quantity of O capital vary in sign across industries, but are always very small in absolute magnitude. This suggests that these two inputs are reasonably independent.

Third, the sign of the estimated elasticity of demand for labor with respect to changes in the stock of O capital is evenly divided in the fourteen industries, but whether positive or negative, in all industries this elasticity increases in absolute magnitude over time, indicating ever greater impacts of O capital on the demand for labor. We believe that further analysis, perhaps involving the disaggregation of labor by education and occupation, may provide further important information on the impact of O capital on employment patterns.

Fourth, in eleven of the fourteen industries, the estimated elasticity of demand for energy with respect to changes in the stock of O capital is positive (suggesting a type of energy-O capital complementarity), while the corresponding elasticity for intermediate materials is negative (indicating a type of materials-O capital substitutability).

Finally, we have computed the estimated rate of technical progress, and the elasticity of technical progress with respect to O-capital. There is little evidence to suggest that increases in O capital have a substantial impact on technical progress in US manufacturing industries; what impact there is appears to be rather small.

FOOTNOTES

[1]Baily-Gordon [1988], pp. 350-351.

[2]See, for example, the quarterly reports "Productivity and Costs" issued by the U.S. Department of Labor, Bureau of Labor Statistics.

[3]It is worth noting here, however, that when the U.S. Bureau of the Census obtains data from manufacturing establishments, the only data it collects is on its production activities; in particular, the Census data does not include data from central office operations, marketing activities, etc. This implies that when one employs Census data, as we do in this study, we confine ourselves to examining the effects of office and information technology equuipment on production activities.

[4]Note that although Y is permitted to be an endogenous explanatory variable, there is no equation explicitly determining Y. For an alternative formulation in which Y is also explicitly modeled, see Morrison [1989,1990].

[5]For further discussion, see Hansen and Singleton [1982], and for an empirical implementation, Pindyck and Rotemberg [1983].

[6]Curvature restrictions on the technology require that the variable cost function be decreasing and concave in x, implying that, among other restrictions, it must be the case that $\partial^2 G/\partial O^2 > 0$.

[7]For further discussion of these two interpretations, see Morrison [1988b]. It should also be noted that this elasticity takes into account the effects of scale economies and the presence of quasi-fixed inputs. For further discussion, see Morrison [1989].

[8]For discussion of data construction procedures, see Gorman et al. [1985] and Musgrave [1986].

[9]Discussion of rental price construction methods and references to appropriate BLS publications are found in Harper et al. [1989].

[10]In the BLS data base, the depreciation rates for each asset follow a hyperbolic pattern and are not necessarily constant over time; depreciation rates for the E, S and O composites also vary across industries and time due to changes in the composition of the stocks. In fact, however, the depreciation rates tend to be very stable over time for each asset. For 1986, the capital stock-weighted average depreciation rates for E in the machinery, chemicals and iron and steel industries are approximately 6, 8 and 6%, respectively, for S they are all about 4%, and for O the weighted-average depreciation rates for these three industries are 17, 15 and 14%, respectively.

[11]In each sector, the γ_{YY}, γ_{TY} and γ_{TT} terms were set to zero. In several sectors, additional constraints were imposed, and in some cases the sample period was adjusted slightly. It is worth noting, however, that in virtually all cases the concavity condition for O capital was satisfied at each observation -- a surprising and fortunate result.

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