Information Workers in the "New Economy": Has IT Investment Had a Favorable Effect on the Demand for Skilled Labor? [1]

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Abstract *From 1995 to 1999, U.S. average labor productivity (ALP) and total factor productivity (TFP) growth have apparently increased by a full percentage point, compared with the period from 1973 to 1995. During these four years, published statistics show a surge in computer and other IT (information technology) investment. Many economists believe that the U.S. is now a "new economy", driven by IT investment and the growth of the Internet. IT investment has become one of the largest components of overall equipment investment, and the fastest growing. Anecdotal evidence suggests that accompanying the growth in IT investment is a rise in demand for workers with the appropriate skills.*

In this paper, I use a production theory model with sectoral data for the period 1983 to 1996 to address the question of the effect of IT investment on average labor productivity, by estimating separately the effect on both skilled and unskilled workers. The paper also examines how the results would change by abandoning the use of the hedonic price index for computers and replacing it with a constant deflator. Measured effects on total factor productivity are also presented.

I find, contrary to expectation, that IT capital appears to reduce the demand for skilled workers more than unskilled workers. I also find no clear relationship between IT capital and TFP growth.

1. Introduction

More than 20 years after the productivity slowdown that began in 1973, U.S. average labor productivity (ALP) and multi-factor productivity (MFP) growth have finally shown signs of life. From 1995 to 1999, private ALP growth has increased to 2.15 percent from the sluggish 1.13 percent from 1973 to 1995, a sudden increase of more than a whole percentage point.[2] During the same period, investment in computers and other information technology equipment has surged in real terms, due partly to an increase in the growth rate of nominal equipment investment, but also due to an increase in the rate at which the computer deflator is falling. The simultaneous increase in computer investment and productivity growth has led many observers to conclude that the two are causally related, and that computers are finally fulfilling the promise of stimulating productivity growth. The received wisdom is now that the Solow Paradox is no more, and that the U.S. is embarking upon a new stage of economic growth.[3] The "new economy" of the late 1990s and 21st century will presumably no longer be constrained by the factors which led to the productivity slowdown of the 1970s.

At the aggregate level, the new economy hypothesis certainly appears to be gaining in credibility. Oliner and Sichel (2000), using a neoclassical growth accounting model for the aggregate private economy, find that fully

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[2] Private ALP measured as private chain-weighted GDP divided by total private hours worked.

[3] The "Solow Paradox" is Solow's quip that "We see computers everywhere except in the productivity statistics." from the April 1987 *New York Times Book Review.* This had become something of a mantra before the 1995 to 1999 productivity increase.

two thirds of the one percent increase in productivity can be attributed to the combination of the use of information technology and the production of computers. In an earlier paper (Oliner and Sichel, 1994), the same authors had used similar techniques and data to conclude that there was no Solow Paradox after all, since computers and information technology comprised such as small share of the total private capital stock. The new data point to a vastly increased role for IT equipment. Jorgenson and Stiroh (2000) also use a growth accounting framework, but analyze data for 34 private sector industries plus households and government. They find that the contribution of IT investment to MFP growth is quite significant, but highly concentrated in the computer and semiconductor industries. They do not find a large MFP growth increase in the major IT-using industries, such as Finance, insurance and real estate and Business services.

The new economy is not however without its skeptics. Gordon (1999) points out that the TFP increase is concentrated in the semiconductors and computers sectors, and that the upsurge in growth starting in 1995 has a lot to do with the rate of decrease of the computer deflator. Furthermore, he argues that a significant share of the productivity increase should be attributed to the procyclical productivity response normally observed in an upswing. Blinder (2000) also cautions that the measured growth is highly sensitive to the computer deflator, and we haven't yet seen if it will hold through the next recession.

One conclusion emerging from this debate is that it is helpful to understand the effects of IT investment in the IT-using sectors on ALP and MFP. In analyzing the ALP effect it would also be interesting to see how the net effect can be decomposed into employment of skilled and unskilled labor, as the effect of computers and other IT equipment on the wages and employment of unskilled workers has been a sensitive policy issue.[4] The current paper attempts to address these questions. The paper also addresses how sensitive the results are to the use of the hedonic computer deflator.

The empirical analysis in this paper follows that of Morrison (1997), by dividing capital into IT and non-IT capital, and using a cost-based production theory model to estimate the effects of these two types of capital on TFP and labor demand. However, I disaggregate labor hours into skilled and unskilled, based on occupational employment data, and investigate 9 major sectors comprising the private economy. Morrison's analysis, using data from 1952 to 1991 for 2-digit manufacturing industries, found that IT investment increases demand for labor, but saves on intermediate inputs. She also found that IT capital has a minor effect on MFP growth, concentrated mostly in the machinery sector.

Section 2 discusses the deflator issue, and provides some background on the trends of capital stock and hours worked during the 1983 to 1996 period. Section 3 describes the theoretical framework of the model. Section 4 presents the empirical results, and section 5 concludes.

2. Background

Although the fastest increase in productivity growth has been in the 1995 to 1999 period, the detailed data used as the basis for this paper is not as current. In particular, the time series of occupational matrices provided by the Bureau of Labor Statistics (BLS) are currently available only from 1983 to 1996, which is the period chosen for the empirical analysis. The hypothesis to be tested is that IT capital increases the demand for skilled labor, meaning those occupations which require more formal education. Certainly the relationships estimated in the earlier period should shed some light on the effects of IT investment on demand for skilled labor and TFP growth in the latter period. This presumption can be tested as more data become available.

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[4] Osterman (1986) investigated a related topic, analyzing the effect of computers on managers and clerical employment. Krueger (1993) estimated that computer use has raised the returns to education by 10 to 15 percent.

Before presenting the model, I will provide a brief description of the data, discuss some issues surrounding the computer deflator, and summarize some trends and patterns in capital stock and hours worked by sector.

The capital data used in this paper is derived from a time series of capital flow tables, based upon the published tables available from the Bureau of Economic Analysis (BEA), but interpolated using investment controls by asset and by purchasing industry. These tables show equipment investment, which is converted to capital stock using the perpetual inventory method. The employment data is total hours worked from BLS, divided into skilled and unskilled using the time series of occupational employment matrices, also from BLS. Two versions of investment and capital stock data for IT equipment have been calculated, one using the BEA equipment investment deflator for computers[5], and one using a constant deflator, treating constant price investment in computers as equivalent to current price investment.[6]

2.1. The Computer Deflator

Why experiment with a constant computer deflator? Can anyone fail to believe the impressive technological progress that has been occurring in the semiconductor and computer industries? I will try to make a case here for why the use of a constant computer deflator can at least be a useful thought experiment and may shed some light on the relationship between IT investment and productivity.

First, as the cost of computers goes down, the marginal use value goes down as well (Gordon, 2000). Figure 1 shows the path of the BEA computer deflator available from the U.S. National Income and Product Accounts (NIPA). According to this deflator, a dollar spent on computers in 1999 buys 436 times more power than the dollar spent on the Univac in 1965, 75 times the power of the dollar spent on the PDP-11 in 1975, and 20 times the power of the dollar spent on the PC in 1981. But the Pentium III we enjoy today may be utilized at a small fraction of the rate of the old PDP-11. In other words, the *capital services* from a dollar of computer investment is probably not increasing as much as the constant price measure would indicate, and in fact may not be increasing at all. Figure 2 shows the rate of decline in the deflator. While hovering between -10% and -20% from 1980 to 1995, from 1995 to 1999 the measured decline has been closer to -30%. I doubt that most business users of computer equipment would agree that capital services per dollar from computers have been increasing so quickly during this period.

The business decision to invest in computer equipment is based on the nominal cost of that equipment. This is because businessmen implicitly make the decision to equate the shadow value of the new equipment to the user cost of capital. The shadow value of a quasi-fixed factor is the marginal cost savings of variable factors such as labor and intermediate inputs. The user cost is directly proportional to the price. As the price (and user cost) falls, the measured increment to stock of a given nominal amount of investment rises by the same proportion, so the shadow value of a certain nominal cost of computers should remain unchanged in equilibrium.

A third point to consider is that with a deflator falling so quickly, much of the measured real growth in demand

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[5] The BEA deflator is a hedonic deflator, which treats a computer as a good comprised of various characteristics, such as CPU speed and type, amount of memory, video quality, amount of hard disk storage, CD ROM drive, etc. The CPU itself, for example, is priced in terms of some yardstick measure, such as a software benchmark. The hedonic deflator attempts to measure how much the price of a unit of "computing power" has fallen over time.

[6] See the data appendix for a more detailed description of the capital flow and other data used in this study. Note that the interval of estimation was limited by the range of the occupational employment time series.

may actually be attributable to the deflator. Jorgenson and Stiroh (1999, 2000) repeatedly make the point that falling computer prices are the main cause of increasing investment in computers.[7] Figure 3 shows that, measured in nominal terms, the share of computers to total equipment investment rose from a level of an average 3.5% from 1965 to 1980, to about 10% by 1985. The share of computer investment has remained at about the same from 1980 to 1999. In real terms, the ratio of computer investment to the total has increased from near zero in 1965, to about .2 in 1999. In the period from 1995 to 1999 alone, the ratio increased from .05 to .2[8] During the past 9 years, the unit cost of a typical desktop PC has been in the $1500 to $2000 range, although there has been some decline in the last two years. The rough constancy of the nominal investment share of computers since 1985 suggests that the number of units shipped has grown apace with total equipment investment. This appears to be more a story of slow but steady growth in units of computers, not a drastic increase in investment in response to a fall in price.

Finally, for the purpose of gauging the productivity of the computer sector itself, one needs to consider the deflator issue. The BEA computer deflator accounts for much of the measured productivity growth in the computer producing sector. Figure 5 compares average labor productivity of the computer sector using a constant deflator for output versus using the BEA deflator. Figure 6 compares the corresponding growth rates of ALP. The average rate of growth of nominal output over hours for 1990 to 1997 was 10%; the average rate of growth of real output over hours was a staggering 28.2%.

I am not arguing here that the hedonic method of deflating computers is wrong.[9] For many reasons, it is worthwhile to know how much the power of computers has increased over time. However, for the study of productivity and investment, it would also be helpful to know the sensitivity of the empirical estimates with respect to the use of this deflator. Note that by using a constant deflator, we still have a deflator that falls relative to the GDP deflator by over 30% for the period 1983 to 1996.

2.2. Trends in Capital and Hours

The database used for this paper is for 9 aggregate sectors comprising the total private economy. Those sectors are listed in table 1, which also summarizes the distribution of skilled and unskilled labor by major sector, as well as IT and non-IT capital. IT capital consists of computers, communications equipment and software. The definition of skilled and unskilled labor from the occupational matrix is described in more detail in the data appendix, but generally the skilled occupations are aggregates of managers, professionals and technicians. The distinction between "skilled" and "unskilled" workers is attempted to measure the level of formal education. Many categories of production workers included in the unskilled category may actually require considerable on-the-job training, but probably have little post-secondary education. Many of the workers categorized as unskilled may also use a computer in their work. For example, secretaries and clerks are included in the

[7] Jorgenson and Stiroh (1999, p. 109) reason that "The rapid diffusion of information technology is a direct consequence of the swift decline in the price of computer-related equipment, which has led to a vast and continuing substitution of IT equipment for other forms of capital and labor."

[8] Since the BEA data is in chain-weighted dollars, the ratio cannot be called a share, since the components of investment do not add up to the total. However, a look at the change in this ratio is nevertheless instructive, since it shows how much the chain weighted index of IT investment has grown relative to the chain weighted index of equipment investment in total.

[9] Denison goes so far as to argue that the use of hedonic deflators to construction national accounts is inappropriate. Not surprisingly, Triplett (1999) considers Denison's arguments incorrect.

unskilled category. The working hypothesis in the empirical analysis is that IT capital substitutes for unskilled labor, but is complementary to skilled labor.

IT capital is presented both using the BEA computer deflator, and with a constant deflator. Note that the bulk of IT investment is found in the Utilities, Trade and Services sectors. Services and Construction have the highest shares of skilled labor.

The percent of skilled labor in the total private economy increased slightly from 1983 to 1996, from 29.5% to 32.9%. IT capital increased from 16% to 56.6% if measured with the BEA deflator, or from 20.1% to 39% if using the constant deflator. The share of skilled labor went up in every major sector except for Wholesale and retail trade, where it fell from 18.7% to 17.7%. The share of IT capital increased significantly in every sector, whichever deflator is used.

Table 2 presents levels and growth rates of capital-output ratios for IT equipment capital constructed using the BEA deflator, IT equipment capital constructed using a constant deflator, and non-IT capital.[10] The overall period from 1983 to 1996 was divided at 1992, to highlight features of the current upswing.

Even using the constant computer deflator, IT capital-output ratios rose at an average of 6% over the entire interval. The fastest growing sectors were Construction and Nondurable manufacturing. Using the BEA deflator, the average growth rate is more than double, at 14.2%. The highest IT capital-output ratios are in Utilities and communication and Services. An interesting fact in this table is that non-IT investment has actually been declining at an average annual rate of -0.5% over the entire period. It has been declining even faster from 1992 to 1996, just when IT investment began to grow faster. Whether we use the constant deflator or the BEA deflator, overall capital intensity has been rising in all sectors.

Table 3 contains the ratios of hours to constant price output, and the growth rates. This ratio is the inverse of ALP, so negative growth rates in this table indicate rising ALP. For the aggregate economy, the hours to output ratios of both categories have been decreasing. Skilled labor ratios decline at an average of 0.5% for the entire period, and at 2.6% from 1992 to 1996. Unskilled ratios decline at 1.7% over the entire period, and at 3.0% since 1992. Construction and Transportation have increased the intensity of skilled labor. In Services, the skilled labor intensity increased from 1983 to 1992, but this was reversed from 1992 to 1996, leaving no net change over the period. All major sectors except Construction show a decline in intensity of the unskilled labor categories. But for the period 1992 to 1996, all sectors show a decline in unskilled labor intensity.

These tables seem to be consistent with a hypothesis of substitution of IT capital for unskilled labor. The next section presents the analytical framework that will be used to estimate the impact of IT capital on the two types of labor.

[10] IT capital consists of computers and peripherals, communications equipment and software. The full database is for 54 industries comprising the private U.S. economy, which were aggregated to 9 major sectors for this paper. See the data appendix for a more detailed description of this data.

3. The Model

The objective of the empirical analysis will be to determine the impact of IT and non-IT capital on the demand for skilled and unskilled labor, based on estimated parameters from a model derived from cost minimization with quasi-fixed factors. For this purpose, the framework developed primarily by Morrison (1990, 1997) is suitable. This framework uses a Generalized Leontief (GL) restricted variable cost function $G(Y, t, \mathbf{x}, \mathbf{p})$ where Y is real output, t is a measure of technical change or TFP growth, $\mathbf{x}$ is a vector of quasi-fixed inputs, and $\mathbf{p}$ is a vector of prices of the variable factors. Note that this form includes the levels of the quasi-fixed factors as arguments. The shadow value of the quasi-fixed factors is their marginal reduction in the variable cost G.

For this study I specify a form of GL restricted cost function with long-run constant returns to scale imposed:

$$G = Y^{1/2}\left[\left(\sum_i \sum_j \beta_{ij} p_i^{1/2} p_j^{1/2} + \sum_i \alpha_{it} p_i t^{1/2}\right) Y^{1/2} + \sum_i \sum_k \delta_{ik} p_i x_k^{1/2} + 2\sum_k \alpha_{kt} x_k^{1/2} t^{1/2}\right] + \sum_i p_i \sum_k \sum_l \gamma_{kl} x_k^{1/2} x_l^{1/2} \qquad \textbf{(1)}$$

where p_i, p_j = prices of variable inputs i and j
x_K, x_L = quantities of quasi-fixed factors k and l
Y = output
t = technical change

In this model, intermediate purchases (m), skilled labor (s) and unskilled labor (u) are the variable factors. IT capital (o) and non-IT capital (e) are the quasi-fixed factors and t is the rate of disembodied technical change, or MFP growth. The variable factor demand equations can be derived from the restricted variable cost function using Shephard's Lemma:

$$\frac{\delta G}{\delta p_i}\frac{1}{Y} = \frac{v_i}{Y} = \sum_j \beta_{ij}(p_j/p_i)^{1/2} + \alpha_{it} t^{1/2} + Y^{-1/2}\left(\sum_k \delta_{ik} x_k^{1/2} + 2\sum_k \alpha_{kt} x_K^{1/2} t^{1/2}\right) + \sum_k \sum_l \gamma_{kl} x_k^{1/2} x_l^{1/2}/Y \qquad \textbf{(2)}$$

Assuming competitive equilibrium, the output price equation can be added to the system, by setting $P = MC$, where MC is marginal cost:

$$P_Y = \frac{\delta G}{\delta Y} = \sum_i \sum_j \beta_{ij} p_i^{1/2} p_j^{1/2} + \sum_i \alpha_{it} p_i t^{1/2} + .5\, Y^{-1/2}\left(\sum_i \sum_k \delta_{ik} p_i x_k^{1/2} + 2\sum_i p_i \sum_k \alpha_{kt} x_k^{1/2} t^{1/2}\right) \qquad \textbf{(3)}$$

For each of the 9 major sectors and for the total private economy, a five equation system was estimated, including the cost function *G*, three variable input demand functions for *m*, *s* and *u*, and the output price equation.

The elasticity of demand for a variable factor v_i with respect to the quantity of a quasi-fixed factor x_k can be calculated as:

$$\frac{\delta^2 G}{\delta p_i \delta x_k} \frac{x_k}{v_i} \tag{4}$$

Similarly, the elasticity of technical progress with respect to the quantity of a quasi-fixed factor can be calculated as:

$$\frac{\frac{\delta^2 G}{\delta t \delta x_k}}{TC} \tag{5}$$

where TC is the sum of total variable and fixed costs.

$$TC = G + \sum_k P_k x_k \tag{6}$$

Although the model is rich in the information it provides on variable factor substitution, capacity utilization and investment determinants, we will focus in this paper only on the two elasticities defined above.

4. Empirical Results

The 20 parameters in the model described above were estimated for each of the 9 major sectors, and for the total private economy. Two sets of regressions were performed, one using the BEA computer deflator, and the other with the constant deflator. The parameter estimates for the two models are presented in the appendix.

I will begin by presenting the effects of IT and non-IT capital on demand for skilled and unskilled labor. The results using the BEA computer deflator are shown in table 4, and table 5 shows the results using a constant computer deflator. Note that the elasticities are reported as averages over certain time periods, since the measures vary by year. I present results for two subintervals, 1983 to 1991 and 1992 to 1996 as well as for the whole time period.

The results indicate that, in general, IT investment is reducing the demand for both skilled and unskilled labor over the total economy. Using the BEA deflator, the average elasticity over the entire period is -.11 for skilled labor, and -.07 for unskilled labor. Using the constant computer deflator, the elasticities are much larger, -.50 for skilled labor, and -.26 for unskilled labor. It seems counterintuitive that the elasticity is larger for skilled labor, after seeing the data from tables 2 and 3.

Between the 9 major sectors, the results vary substantially. In table 4 (BEA deflator) Agriculture, forestry and fisheries and Construction show large elasticities for both types of labor. Durable and Nondurable manufacturing have different signs. In Nondurable manufacturing, IT investment appears to be associated with increasing intensity of both skilled and unskilled labor, but skilled labor is affected much more strongly. In Durable manufacturing on the other hand, there is a stronger negative impact on skilled labor as opposed to unskilled. In the Service sector, which is by far the largest user of IT equipment, the elasticities are -.15 and -.17 for skilled and unskilled labor. Wholesale and retail trade show positive elasticities, but the elasticity for skilled labor (.73) is much larger than that for unskilled (.10).

In table 5 (constant deflator), the overall negative elasticity is much larger, and this pattern is also evident in the Service sector, which makes up about a quarter of total employment. Agriculture, forestry and fisheries and Construction still have large negative elasticities. The elasticity for Mining, petroleum and gas extraction has changed from being close to zero with the BEA deflator to a large positive number using the constant deflator. It is not clear what is happening in this sector. It has experienced large cyclical swings in employment which are more highly correlated with output price than anything else, so it may be a difficult sector for this model to explain. The table 5 results for Durable and Nondurable manufacturing have negative elasticities for both skilled and unskilled labor in each sector, so that the sign changes from positive to negative for Nondurables, when changing from the BEA to the constant deflator. On the contrary, the signs change from negative to positive in the Transportation sector.

On average the net effect is that IT capital is estimated to be labor saving in the economy as a whole, but with a stronger effect on skilled labor. The sectoral pattern is mixed, although negative signs predominate. The use of the BEA deflator appears to reduce the measured labor saving effect compared with the constant deflator.

Tables 6 and 7 show the estimated elasticities of technical change (TFP) to investments in IT and non-IT capital. Using the BEA computer deflator (table 6), the effects on TFP are small, but positive, for both IT and non-IT investment. IT capital is found to reduce TFP in the Mining, Construction and Utilities sectors. Non-IT capital reduces TFP in the Mining, Nondurables and Trade sectors. Using the constant deflator (table 7), the effect of IT capital on TFP for the total private economy is negative, whereas the effect of non-IT capital is positive. At the sectoral level, the effects of IT capital in table 6 are negative for Durable and Nondurable manufacturing, Utilities and Services, which include all of the large employment industries except for trade. Non-IT capital has a negative effect on the Mining, Transportation and Trade sectors, as in table 6.

The results are ambiguous. Unfortunately, no strong conclusions can be drawn as to the effect of IT capital on TFP. The choice of deflator makes a big difference in the parameter estimates, and there is a significant link between TFP and non-IT capital when using the constant deflator.

5. Concluding Comments

The purpose of this paper has been to investigate the relationship between the increased adoption of IT capital equipment and ALP and TFP growth, as well as to discern differences in the effect on the ALP of skilled versus unskilled labor. The question has been examined empirically using a medium level of aggregation, that of 9 major sectors comprising the private economy. The results are mostly negative, and somewhat counterintuitive. Although IT equipment is found to contribute to ALP, the effect is to reduce employment of skilled workers more than unskilled workers. No consistent relationship is found between IT capital investment and TFP growth.

The patterns of behavior vary widely at the level of the 9 major sectors. This suggests it should be worthwhile to pursue the same line of analysis at a finer level of sectoral detail. The 9 sector aggregation may be masking important differences in behavior at the 2-digit or 3-digit SIC level.

It is also striking how much difference the computer deflator makes. While it is certainly tempting to stand by the use of the BEA hedonic deflator, there are reasons to suspect that it might be exaggerating the true contribution of the IT capital stock and we therefore must use caution in the choice of deflator. It is instructive to note that statisticians in other OECD countries have not, for the most part, adopted the approach followed by BEA in the deflation of computers. Perhaps the choice of a constant deflator is too severe, but it at least provides information as to the margin of difference in the estimates associated with the choice of deflator.

The issue of the effect of computer and other IT equipment investment on ALP and TFP growth is certainly begging for more in depth analysis. But at first glance, the claim that the new economy is due to IT investment has not been confirmed.

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APPENDIX A: DATA SOURCES

This appendix describes the data used for this paper. Unless otherwise noted, all series are annual and cover the period from 1983 to 1996.

A. Nominal Sectoral Output

Nominal sectoral output is derived at the level of 320 commodities. The output series are derived from the BEA Benchmark input-output table for 1982, 1987, 1992 and 1996. To estimated the data between benchmark years, various sources are used. The *Annual Survey of Manufactures* 5-digit product shipments data are adjusted for inventory change to estimate output for the manufacturing sectors. Detailed data from the Department of Agriculture and the Department of Interior are used for the agriculture, mining and extraction sectors. For much of the service sector, either the Gross Output from BEA or the Jobs, Hours and Output (JHO) from the Office of Economic Projections at BLS is used.

B. Output Price

Output is converted to constant prices using sectoral deflators maintained by Inforum, also at the level of 320 commodities. For manufacturing, BLS producer price indexes are used. Deflators from the BEA Gross Output data as well as the JHO from BLS are used for many service sectors. Detailed prices for agriculture and mineral sectors are derived by compiling quantity and value data from the same sources as used for output.

C. Equipment Investment

Inforum has constructed a time series of capital flow tables, of dimension 320 by 56. For 1977, 1982 and 1987, we have used information from the capital flow tables available from BEA. For other years, data from the BEA *Fixed Reproducible Tangible Wealth* investment by asset by industry have been used to help determine the trends in industry shares of important asset classes. The tables are controlled each year to row (detailed producers' durable equipment by commodity) and column (equipment investment by purchaser) controls, derived by Inforum.

D. Capital Stock

Capital stock estimates for this study were constructed using a simple perpetual inventory method, at the level of 56 industries. Capital investment in IT equipment is assumed to consist of Computers (SIC 357, except 3578-9), Communication equipment (SIC 366) and Computer and data processing (SIC 737). Non-IT investment and capital stock is comprised of all other commodities. Depreciation rates were taken from Fraumeni (1997). The measure used in this study is a net capital stock, with no adjustments for obsolescence or discards.

E. Cost of Capital

The cost of capital is an *ex ante* user cost of capital, $uc = p_{eq}(r+d)\frac{1-TZ-c}{1-T}$, where p_{eq} is a price deflator for equipment investment, r is the Moody's AAA bond rate, d is an average rate of depreciation for the asset types in the stock, T is the effective corporate tax rate by industry, c is the investment tax credit, and Z the present value of a dollar of depreciation.

F. Hours Worked

Total hours worked by industry is taken from the BLS JHO database.

G. Skilled and Unskilled Workers

The division between skilled and unskilled workers was made on the basis of the time series of occupational employment matrices, available from BLS for the period 1983 to 1996. “Skilled” workers were assumed to be comprised of the following major categories: Executive, administrative and managerial; Professional specialty; Technicians and related support. “Unskilled” workers were assumed to be comprised of: Marketing and sales; Administrative support; Service occupations; Agriculture, forestry and fishing occupations; Precision production, craft and repair; and Operators, fabricators and laborers. Total hours in each industry were divided on the basis of the share in jobs in the occupational matrix.

H. Wage Rates

Wage rates are for total labor compensation, including benefits. Total labor compensation by industry was taken from the Gross Product Originating (GPO) data from the NIPA. Average compensation per hour for high skilled labor was derived from the Occupational Compensation Survey and the Employment Cost Index. Average compensation for the unskilled labor was derived as a residual.

I. Intermediate Purchases

Intermediate purchases are derived from published data for benchmark years, and interpolated using interpolated coefficients multiplied by output.

Figures and Tables

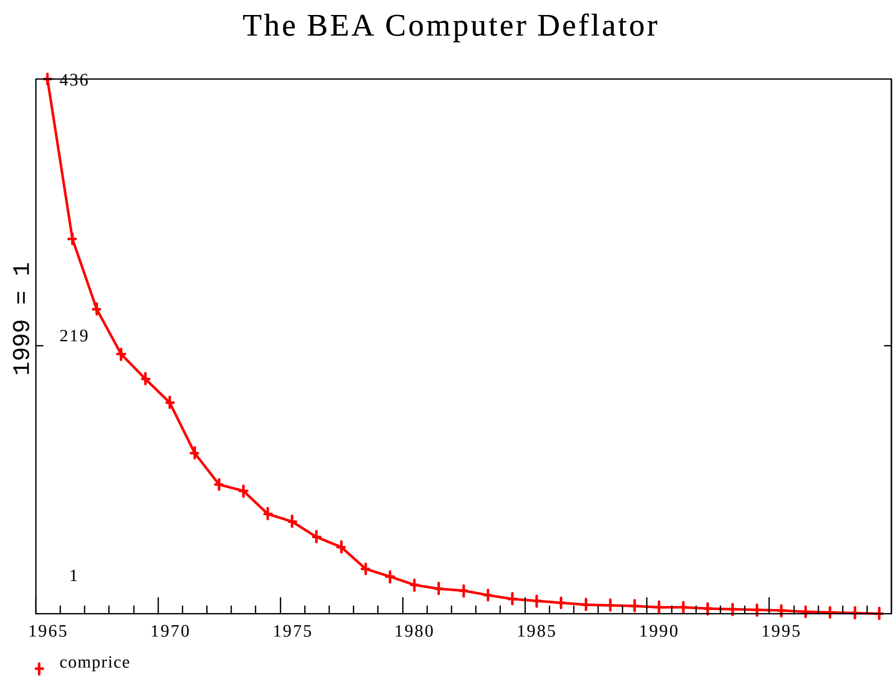

Figure 1

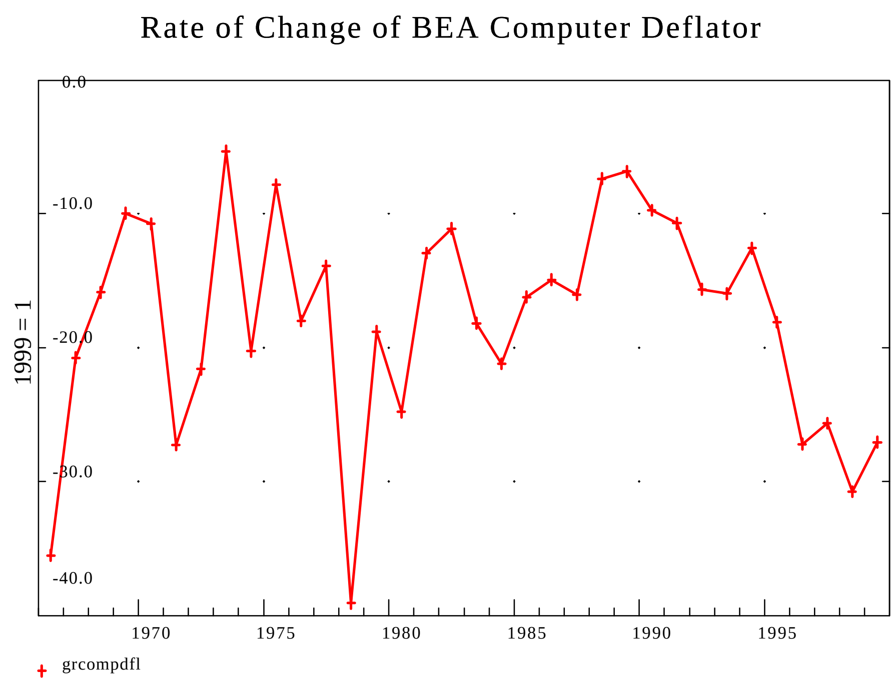

Figure 2

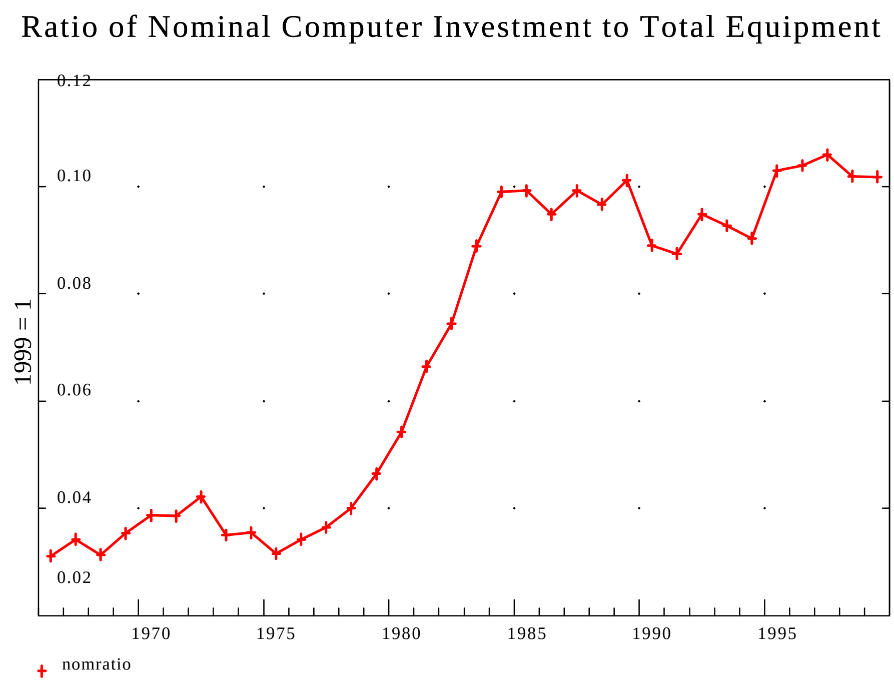

Figure 3

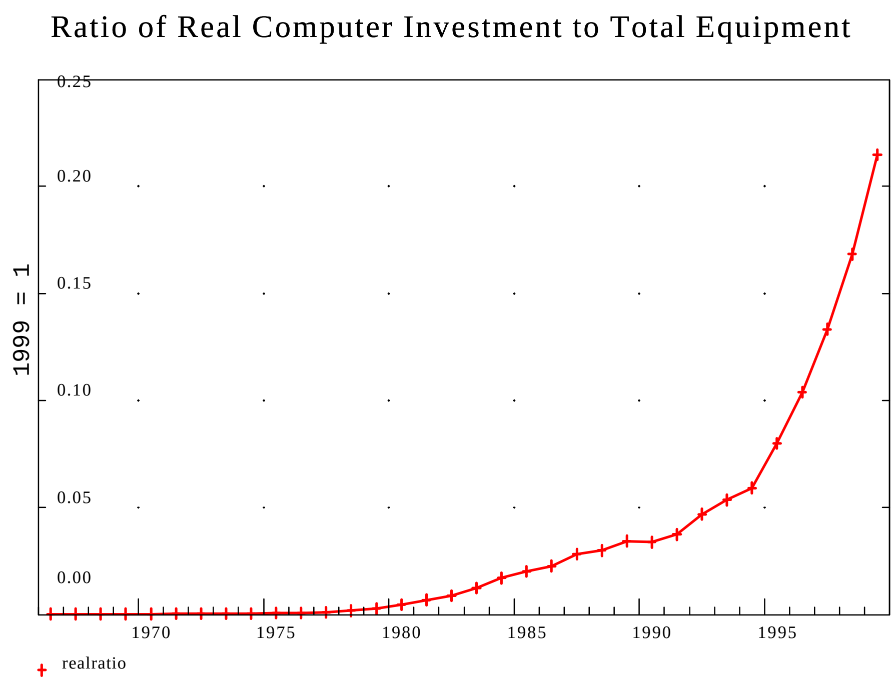

Figure 4

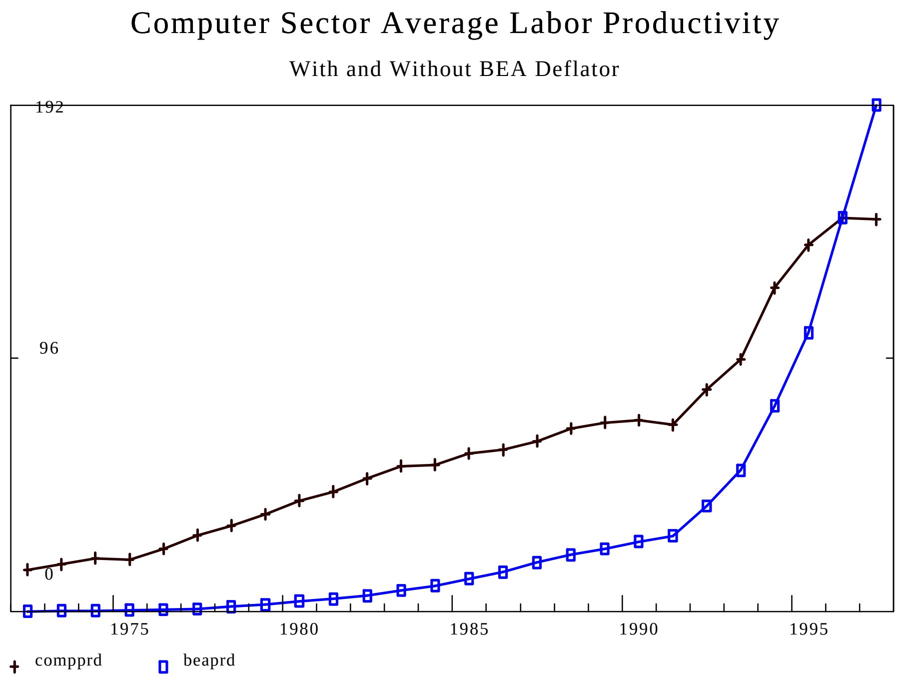

Figure 5

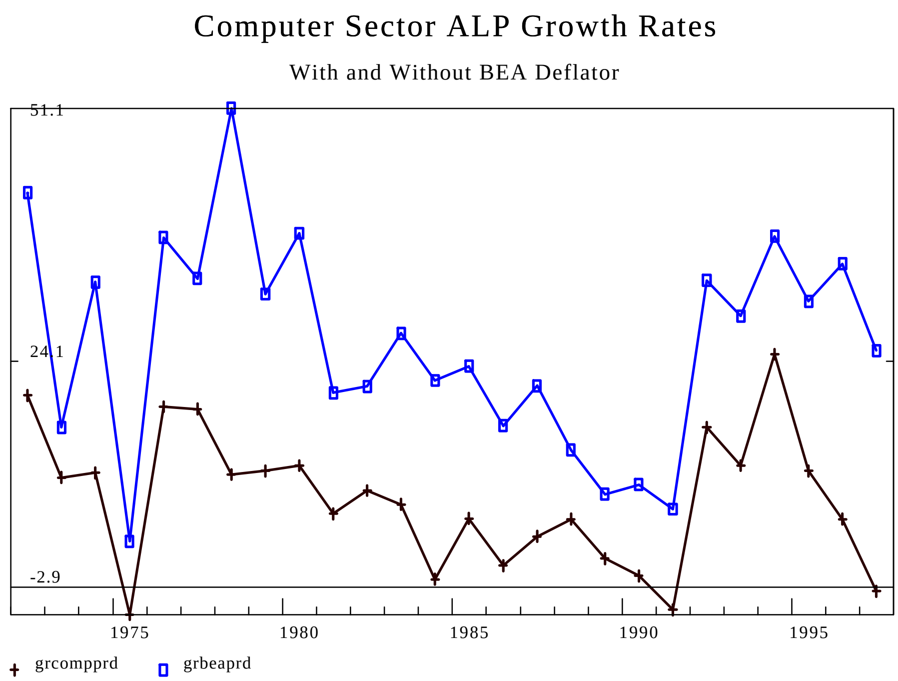

Figure 6

Table 1. Summary of Skilled and Unskilled Labor, IT and non-IT Capital by Major Sector
Hours are in Millions, Capital is in Millions of 1987 Constant Dollars

Skilled and Unskilled Labor by Sector

	1983			1996		
	Skilled	Unskilled	Percent Skilled	Skilled	Unskilled	Percent Skilled
Total Private Economy	541,541	1,294,037	29.5	788,876	1,606,217	32.9
Agriculture, Forestry & Fisheries	5,923	13,205	31.0	7,750	12,383	38.5
Mining, Petroleum & Gas Extraction	8,027	16,413	32.8	5,034	10,509	32.4
Construction	19,692	21,374	48.0	31,332	28,989	51.9
Durable Manufacturing	76,099	271,559	21.9	82,123	278,411	22.8
Nondurable Manufacturing	34,599	193,493	15.2	41,762	192,111	17.9
Transportation	11,234	79,468	12.4	22,463	111,191	16.8
Utilities and Communication	20,845	69,199	23.1	22,782	70,950	24.3
Wholesale and Retail Trade	74,240	323,417	18.7	87,550	407,948	17.7
Services	290,882	319,950	47.6	488,079	481,321	50.3

IT and Non-IT Capital by Sector, Constant Deflator

	IT	Non-IT	Percent IT	IT	Non-IT	Percent IT
Total Private Economy	326,913	1,297,534	20.1	1,204,583	1,880,306	39.0
Agriculture, Forestry & Fisheries	651	72,989	0.9	2,168	75,179	2.8
Mining, Petroleum & Gas Extraction	3,108	48,948	6.0	7,764	41,547	15.7
Construction	8,035	103,513	7.2	43,892	194,401	18.4
Durable Manufacturing	33,138	197,783	14.4	121,680	252,911	32.5
Nondurable Manufacturing	18,681	174,867	9.7	73,138	232,594	23.9
Transportation	8,467	142,592	5.6	39,323	155,147	20.2
Utilities and Communication	101,921	155,673	39.6	220,625	241,500	47.7
Wholesale and Retail Trade	50,729	155,388	24.6	159,523	181,877	46.7
Services	102,183	245,783	29.4	536,470	505,150	51.5

IT and Non-IT Capital by Sector, BEA Deflator

	IT	Non-IT	Percent IT	IT	Non-IT	Percent IT
Total Private Economy	247,635	1,297,534	16.0	2,449,357	1,880,306	56.6
Agriculture, Forestry & Fisheries	423	72,989	0.6	4,943	75,179	6.2
Mining, Petroleum & Gas Extraction	1,948	48,948	3.8	17,735	41,547	29.9
Construction	5,381	103,513	4.9	105,697	194,401	35.2
Durable Manufacturing	20,749	197,783	9.5	287,005	252,911	53.2
Nondurable Manufacturing	11,140	174,867	6.0	172,244	232,594	42.5
Transportation	6,961	142,592	4.7	66,398	155,147	30.0
Utilities and Communication	97,196	155,673	38.4	307,550	241,500	56.0
Wholesale and Retail Trade	31,359	155,388	16.8	366,959	181,877	66.9
Services	72,479	245,783	22.8	1,120,827	505,150	68.9

Table 2. Capital-Output Ratios by Major Sector: 1983-1996

	K/Q Ratios			Annual Growth		
	1983	1992	1996	83-90	92-96	83-96
IT Equipment Capital/Output: BEA Deflator						
Total Private Economy	0.040	0.110	0.254	11.2	21.0	14.2
Agriculture, Forestry & Fisheries	0.002	0.008	0.019	12.8	22.9	15.9
Mining, Petroleum & Gas Extraction	0.016	0.043	0.115	11.0	24.8	15.3
Construction	0.018	0.078	0.269	16.0	30.9	20.6
Durable Manufacturing	0.019	0.069	0.166	14.1	21.9	16.5
Nondurable Manufacturing	0.010	0.048	0.114	17.5	21.4	18.7
Transportation	0.029	0.057	0.168	7.4	26.9	13.4
Utilities and Communication	0.240	0.346	0.509	4.1	9.6	5.8
Wholesale and Retail Trade	0.035	0.093	0.257	10.9	25.4	15.4
Services	0.038	0.147	0.355	14.9	22.0	17.1
IT Equipment Capital/Output: Constant Deflator						
Total Private Economy	0.053	0.093	0.125	6.2	7.5	6.6
Agriculture, Forestry & Fisheries	0.004	0.006	0.008	5.1	8.8	6.3
Mining, Petroleum & Gas Extraction	0.025	0.034	0.050	3.4	9.7	5.3
Construction	0.028	0.062	0.112	9.0	14.6	10.8
Durable Manufacturing	0.031	0.054	0.070	6.2	6.4	6.3
Nondurable Manufacturing	0.017	0.037	0.048	8.8	6.6	8.1
Transportation	0.036	0.052	0.099	4.1	16.4	7.9
Utilities and Communication	0.251	0.326	0.365	2.9	2.8	2.9
Wholesale and Retail Trade	0.056	0.075	0.112	3.2	10.0	5.3
Services	0.054	0.123	0.170	9.1	8.1	8.8
Non-IT Equipment Capital/Output						
Total Private Economy	0.210	0.205	0.195	-0.3	-1.2	-0.5
Agriculture, Forestry & Fisheries	0.420	0.281	0.293	-4.5	1.1	-2.8
Mining, Petroleum & Gas Extraction	0.397	0.289	0.269	-3.5	-1.8	-3.0
Construction	0.355	0.425	0.494	2.0	3.8	2.5
Durable Manufacturing	0.186	0.163	0.146	-1.5	-2.7	-1.8
Nondurable Manufacturing	0.157	0.165	0.154	0.5	-1.7	-0.2
Transportation	0.601	0.398	0.393	-4.6	-0.4	-3.3
Utilities and Communication	0.384	0.423	0.399	1.1	-1.4	0.3
Wholesale and Retail Trade	0.173	0.138	0.127	-2.5	-2.0	-2.3
Services	0.130	0.168	0.160	2.8	-1.1	1.6

Table 3. Skilled and Unskilled Labor Hours by Major Sector: 1983-1996
Hours Worked/Output
Hours are in Millions, Output is in Millions of Constant 1987 Dollars

	L/Q Ratios			**Annual Growth**		
	1983	1992	1996	83-92	92-96	83-96
Hours/Output: "Skilled" Categories						
Total Private Economy	0.087	0.091	0.082	0.4	-2.6	-0.5
Agriculture, Forestry & Fisheries	0.034	0.036	0.030	0.6	-4.3	-0.9
Mining, Petroleum & Gas Extraction	0.065	0.044	0.033	-4.3	-7.6	-5.3
Construction	0.068	0.082	0.080	2.2	-0.7	1.3
Durable Manufacturing	0.071	0.062	0.047	-1.7	-6.5	-3.1
Nondurable Manufacturing	0.031	0.032	0.028	0.2	-3.3	-0.9
Transportation	0.047	0.054	0.057	1.4	1.5	1.4
Utilities and Communication	0.051	0.042	0.038	-2.2	-2.9	-2.4
Wholesale and Retail Trade	0.083	0.071	0.061	-1.7	-3.7	-2.3
Services	0.154	0.170	0.155	1.1	-2.4	0.0
Hours/Output: "Unskilled" Categories						
Total Private Economy	0.209	0.188	0.167	-1.2	-3.0	-1.7
Agriculture, Forestry & Fisheries	0.076	0.055	0.048	-3.6	-3.3	-3.5
Mining, Petroleum & Gas Extraction	0.133	0.087	0.068	-4.7	-6.2	-5.2
Construction	0.073	0.075	0.074	0.2	-0.4	0.0
Durable Manufacturing	0.255	0.191	0.161	-3.2	-4.2	-3.5
Nondurable Manufacturing	0.174	0.148	0.127	-1.8	-3.9	-2.4
Transportation	0.335	0.293	0.281	-1.5	-1.0	-1.3
Utilities and Communication	0.171	0.136	0.117	-2.5	-3.7	-2.9
Wholesale and Retail Trade	0.360	0.330	0.286	-1.0	-3.6	-1.8
Services	0.170	0.171	0.152	0.1	-2.9	-0.8

Table 4. Elasticity of Labor Demand with respect to IT-Capital
BEA Computer Deflator

	IT Equipment Skilled Labor			IT Equipment Unskilled Labor		
	83-91	92-96	83-96	83-91	92-96	83-96
Total Private Economy	-0.08	-0.17	-0.11	-0.05	-0.11	-0.07
Agriculture, Forestry & Fisheries	-0.63	-1.55	-0.96	-0.38	-1.11	-0.64
Mining, Petroleum & Gas Extraction	0.09	-0.01	0.05	0.03	-0.03	0.01
Construction	-1.24	-1.18	-1.21	-1.20	-1.25	-1.22
Durable Manufacturing	-0.10	-0.23	-0.15	-0.04	-0.10	-0.06
Nondurable Manufacturing	0.46	0.36	0.42	0.06	0.01	0.04
Transportation	-0.31	0.21	-0.12	-0.05	0.03	-0.02
Utilities and Communication	-0.20	-0.46	-0.30	-0.24	-0.41	-0.30
Wholesale and Retail Trade	0.71	0.78	0.73	0.12	0.08	0.10
Services	-0.02	-0.38	-0.15	-0.04	-0.42	-0.17

Table 5. Elasticity of Labor Demand with respect to IT-Capital
Constant Computer Deflator

	IT Equipment Skilled Labor			IT Equipment Unskilled Labor		
	83-91	92-96	83-96	83-91	92-96	83-96
Total Private Economy	-0.35	-0.79	-0.50	-0.18	-0.41	-0.26
Agriculture, Forestry & Fisheries	-1.34	0.25	-0.77	-0.77	0.02	-0.49
Mining, Petroleum & Gas Extraction	1.68	4.99	2.86	0.68	2.19	1.22
Construction	-1.44	-1.12	-1.33	-1.35	-1.13	-1.27
Durable Manufacturing	-0.40	-1.10	-0.65	-0.27	-0.58	-0.38
Nondurable Manufacturing	-0.30	-0.93	-0.53	-0.20	-0.43	-0.28
Transportation	0.27	0.66	0.41	0.05	0.13	0.08
Utilities and Communication	-0.19	-0.89	-0.44	-0.02	-0.23	-0.09
Wholesale and Retail Trade	0.66	0.65	0.66	-0.01	-0.07	-0.03
Services	-0.51	-1.18	-0.75	-0.52	-1.24	-0.77

Table 6. Elasticity of Technical Progress with respect to IT and Non-IT Capital - BEA Computer Deflator

	IT Equipment			Non-IT Equipment		
	83-91	92-96	83-96	83-91	92-96	83-96
Total Private Economy	0.002	0.005	0.003	0.001	0.001	0.001
Agriculture, Forestry & Fisheries	0.000	0.000	0.000	1.642	0.756	1.325
Mining, Petroleum & Gas Extraction	-0.001	-0.002	-0.001	-0.052	-0.025	-0.043
Construction	-0.003	-0.009	-0.006	0.510	0.227	0.409
Durable Manufacturing	0.001	0.003	0.002	0.005	0.002	0.004
Nondurable Manufacturing	0.000	-0.001	0.000	-0.031	-0.015	-0.025
Transportation	0.001	0.002	0.001	0.018	0.008	0.014
Utilities and Communication	-0.003	-0.005	-0.004	0.008	0.007	0.008
Wholesale and Retail Trade	0.009	0.028	0.016	-0.088	-0.039	-0.071
Services	0.005	0.012	0.007	0.021	0.011	0.017

Table 7. Elasticity of Technical Progress with respect to IT and Non-IT Capital - Constant Computer Deflator

	IT Equipment			Non-IT Equipment		
	83-91	92-96	83-96	83-91	92-96	83-96
Total Private Economy	-0.005	-0.008	-0.006	0.030	0.021	0.027
Agriculture, Forestry & Fisheries	0.000	0.001	0.001	0.371	0.235	0.322
Mining, Petroleum & Gas Extraction	0.011	0.019	0.014	-1.634	-1.111	-1.447
Construction	-0.005	-0.008	-0.006	0.401	0.267	0.353
Durable Manufacturing	-0.001	-0.002	-0.001	0.033	0.022	0.029
Nondurable Manufacturing	-0.001	-0.002	-0.001	0.037	0.026	0.033
Transportation	0.002	0.003	0.002	-0.048	-0.024	-0.040
Utilities and Communication	-0.008	-0.009	-0.009	0.024	0.020	0.022
Wholesale and Retail Trade	0.020	0.028	0.023	-0.087	-0.053	-0.075
Services	-0.017	-0.024	-0.019	0.070	0.049	0.062

Table A-1. Estimated Parameters of the GL Model with BEA Computer Deflator

	b_{uu}	b_{ss}	b_{mm}	b_{us}	b_{um}	b_{sm}	a_{ut}	a_{st}	a_{mt}	d_{uo}
Total Private Economy	0.3184	0.2875	1.1238	0.0173	0.0376	-0.0154	-0.0432	-0.0283	-0.0163	-0.0489
Agriculture, Forestry & Fisheries	0.4859	0.5370	1.9192	-0.0279	0.0680	0.0317	-0.1016	-0.1017	-0.1505	-6.8482
Mining, Petroleum & Gas Extraction	0.0109	0.0104	0.3504	-0.0058	-0.0335	-0.0253	0.0217	0.0276	0.0309	0.3115
Construction	0.4325	0.4664	0.3156	-0.0332	0.0263	-0.0384	0.1106	0.1043	0.0894	-4.1905
Durable Manufacturing	0.0995	0.1437	0.7809	-0.1509	0.2627	0.0503	-0.0395	-0.0251	-0.0052	-0.1062
Nondurable Manufacturing	0.4176	0.2690	1.0149	0.0025	0.0217	0.0226	-0.0087	0.0082	0.0189	0.6004
Transportation	0.8858	0.5101	0.7743	0.0014	0.0557	0.0008	-0.1227	-0.0804	-0.0737	-0.0177
Utilities and Communication	0.1434	-0.1083	0.5246	-0.0154	0.0365	0.0177	-0.0056	-0.0019	-0.0150	-0.6144
Wholesale and Retail Trade	0.8608	0.5996	0.8767	0.0651	0.0652	-0.0424	-0.0735	-0.0662	-0.0629	2.8015
Services	0.3325	0.2996	0.3436	-0.0432	0.0456	-0.0523	-0.0523	-0.0526	-0.0754	-0.9281

	d_{ue}	d_{so}	d_{se}	d_{mo}	d_{me}	g_{to}	g_{te}	g_{oo}	g_{ee}	g_{oe}
Total Private Economy	-0.4449	-0.0253	-0.6488	-0.1324	-1.7221	0.0037	0.0377	-0.0743	0.3862	-0.0213
Agriculture, Forestry & Fisheries	-0.5371	-6.7474	-0.6239	-6.9841	-1.7845	0.7064	0.0459	-11.415	0.1516	1.4784
Mining, Petroleum & Gas Extraction	0.0898	0.3255	-0.0531	0.1468	0.0299	-0.0439	-0.0238	0.0312	0.2470	0.0704
Construction	-0.6107	-4.2012	-0.5183	-4.1948	-0.1013	0.3665	-0.0819	-0.3198	0.4653	0.3153
Durable Manufacturing	0.2505	-0.0754	0.1217	-0.4200	-1.2510	0.0124	0.0290	-0.0826	-0.0626	-0.0822
Nondurable Manufacturing	-1.1582	0.6731	-1.3142	0.4244	-1.7166	-0.0655	-0.0064	-0.0955	1.3688	0.1135
Transportation	-0.5807	-0.0014	-0.5926	0.1947	-0.5256	0.0208	0.0455	0.5172	0.1437	-0.3727
Utilities and Communication	0.8841	-0.5097	1.0363	-0.2476	0.4758	0.0261	-0.0188	-0.2862	-1.1507	0.4447
Wholesale and Retail Trade	-2.7973	2.9349	-2.6949	2.9961	-2.8050	-0.2893	0.1601	0.5924	1.3202	-0.5113
Services	0.7612	-0.9065	1.0563	-0.8946	1.6666	0.0861	0.0558	-0.9747	-3.2806	0.9649

Table A-2. Estimated Parameters of the GL Model with Constant Computer Deflator

	b_{uu}	b_{ss}	b_{mm}	b_{us}	b_{um}	b_{sm}	a_{ut}	a_{st}	a_{mt}	d_{uo}
Total Private Economy	0.3564	0.3408	1.0462	-0.0304	0.0916	-0.0025	0.0314	0.0439	0.0609	-1.8547
Agriculture, Forestry & Fisheries	0.2563	0.2545	1.1216	-0.0194	0.0709	0.0648	-0.1171	-0.1142	-0.1415	0.0428
Mining, Petroleum & Gas Extraction	0.2284	0.2391	0.4708	-0.0024	0.0029	0.0306	-0.0913	-0.0908	-0.0787	9.8390
Construction	0.4654	0.4922	0.3791	-0.0233	0.0036	-0.0609	0.1154	0.1100	0.0906	-3.0232
Durable Manufacturing	0.0489	0.0267	0.4815	-0.1034	0.2528	0.0801	-0.0015	0.0016	0.0414	-1.8533
Nondurable Manufacturing	0.4402	0.2030	0.9901	-0.0153	0.0091	0.0157	0.0113	0.0187	0.0440	-1.5318
Transportation	1.0229	0.6081	0.7926	-0.0358	0.0717	0.0309	-0.1434	-0.1001	-0.0912	1.1299
Utilities and Communication	-0.3649	-0.3538	0.5097	-0.0175	0.1101	0.0312	-0.0324	-0.0154	-0.0141	-0.6105
Wholesale and Retail Trade	0.8868	0.6565	1.0138	0.1082	0.0460	-0.0252	-0.1054	-0.1063	-0.0994	2.7964
Services	0.1755	0.1140	0.2445	-0.0580	0.0680	-0.0217	0.0342	0.0317	0.0122	-3.6209

	d_{ue}	d_{so}	d_{se}	d_{mo}	d_{me}	g_{to}	g_{te}	g_{oo}	g_{ee}	g_{oe}
Total Private Economy	-0.3213	-1.8240	-0.4501	-2.1144	-1.4010	0.0781	-0.0722	-2.1116	-0.0696	2.2954
Agriculture, Forestry & Fisheries	0.0395	0.2133	-0.0381	-0.0011	-0.4432	0.1394	0.0990	24.6824	-0.1317	-5.1930
Mining, Petroleum & Gas Extraction	-1.3178	10.0241	-1.5345	9.5845	-1.3769	-1.1017	0.3110	21.2734	0.0468	-6.2479
Construction	-0.7391	-3.0669	-0.6303	-2.9956	-0.2152	0.1927	-0.0673	0.6808	0.5542	0.1310
Durable Manufacturing	0.7885	-1.5079	0.6882	-2.5600	0.0510	0.0873	-0.0238	-2.7341	-1.2094	1.9902
Nondurable Manufacturing	-0.7555	-1.2212	-0.6981	-1.9282	-1.1941	0.0789	-0.0429	-2.6109	0.7921	1.5880
Transportation	-0.9766	1.1209	-0.9513	1.4234	-0.8890	-0.0440	0.0628	0.7995	0.3416	-0.6889
Utilities and Communication	2.0519	-0.6329	1.9075	-0.3800	0.7821	0.0551	-0.0330	-1.7011	-2.6125	1.5387
Wholesale and Retail Trade	-3.3272	3.2190	-3.5013	3.2722	-3.6892	-0.2707	0.2494	1.6163	2.3000	-1.8209
Services	2.2638	-3.5779	2.6194	-3.4875	2.8094	0.2731	-0.1560	-6.2799	-6.1535	5.8777