

12-31-1994

# The Three Faces of IT Value: Theory and Evidence

Lorin Hitt  
*Massachusetts Institute of Technology*

Erik Brynjolfsson  
*University of California, Los Angeles*

Geoff Walsham  
*University of Cambridge*

Follow this and additional works at: <http://aisel.aisnet.org/icis1994>

---

## Recommended Citation

Hitt, Lorin; Brynjolfsson, Erik; and Walsham, Geoff, "The Three Faces of IT Value: Theory and Evidence" (1994). *ICIS 1994 Proceedings*. 69.  
<http://aisel.aisnet.org/icis1994/69>

This material is brought to you by the International Conference on Information Systems (ICIS) at AIS Electronic Library (AISeL). It has been accepted for inclusion in ICIS 1994 Proceedings by an authorized administrator of AIS Electronic Library (AISeL). For more information, please contact [elibrary@aisnet.org](mailto:elibrary@aisnet.org).

# THE THREE FACES OF IT VALUE: THEORY AND EVIDENCE

Lorin Hitt

Erik Brynjolfsson

Sloan School of Management  
Massachusetts Institute of Technology

## ABSTRACT

The business value of information technology (IT) has been debated for a number of years. Some authors have found large productivity improvements attributable to computers, and casual observation suggests that IT has generated some benefits for consumers. However, others continue to question whether computers have had any bottom line impact on business performance. In this paper, we argue that productivity, consumer value and business performance are actually separate questions and that the empirical results on IT value depend heavily on which question is being addressed and what data are being used. Applying methods based on economic theory, we are able to test the relevant hypotheses for each of the three questions, using recent firm-level data on IT spending by 367 large firms. Our findings indicate that computers have led to higher productivity and created substantial value for consumers, but that these benefits have not resulted in measurable improvements in business performance. We conclude that while modeling techniques need to be improved, these results are consistent with economic theory, and thus there is no inherent contradiction between high productivity, high consumer value and low business performance.

## 1. INTRODUCTION

Doubts about the business value of computers have perplexed managers and researchers for a number of years. Businesses continue to invest enormous sums of money in computer technology, presumably expecting a substantial payoff, yet a variety of studies present contradictory evidence as to whether the expected benefits of computers have materialized (see Attewell 1993; Brynjolfsson 1993a; Wilson 1993, for reviews). The debate over information technology (IT) value is muddled by confusion as to what question is being asked and what the appropriate null hypothesis should be. In some cases, seemingly contradictory results are not contradictory at all because different questions were being addressed. Research has been further hampered by the lack of current and comprehensive firm-level data on IT spending.

In this paper, we attempt to clarify what the right questions are regarding IT value and explicitly define the appropriate theoretically-grounded hypotheses. Because detailed survey data on computer spending by several hundred large firms have recently been made available by the International Data Group (IDG), we can empirically examine each of these hypotheses using the same data set.

In interpreting the past findings regarding IT value, it is useful to understand that the issue of IT value is not a single question, but is composed of several related but quite distinct issues:

- 1) Have investments in computers increased productivity?
- 2) Have investments in computers improved business performance?
- 3) Have investments in computers created value for consumers?

The first issue concentrates on whether computers have enabled the production of more "output" while using fewer "inputs." The second is related to whether firms are able to use computers to gain competitive advantage and earn higher returns than they would have earned otherwise. The final issue is concerned with the magnitude of the benefits that have been passed on to consumers, or perhaps reclaimed from them.

We argue that these three questions are logically distinct and have different implications for how managers, researchers and policy makers should view computer invest-

ment. Because different researchers have used not only different methods, but also different data, it has been difficult to know the cause of the seemingly contradictory results.<sup>1</sup> In this paper, we demonstrate that for this same data on the same group of firms, computers appear to have 1) increased productivity and 2) provided substantial benefits to consumers, but that 3) there is no clear empirical connection between these benefits and higher business profits or stock prices. We show that there is no inherent contradiction in these results; they are all simultaneously consistent with economic theory. However, our findings do highlight that the answers one gets will depend on the questions one asks. Methods matter.

The remainder of this paper is organized as follows: in section 2 we review the existing literature and relevant theory, section 3 presents an empirical analysis of the three approaches, section 4 discusses the results, and section 5 concludes with a summary and implications.

## 2. THEORETICAL PERSPECTIVES AND PREVIOUS RESEARCH

Microeconomic theory and business strategy can provide useful foundations for assessing the benefits of IT. This section examines the relevant theory that was applied in many of the previous studies of the value of IT and provides a guide on how to interpret the various findings. In particular, three frameworks map consistently to three questions we raised in the introduction:

Issue	Framework
Productivity	Theory of Production
Business Performance	Theories of Competitive Strategy
Consumer Value	Theory of the Consumer

### 2.1 Theory of Production

The theory of production approach has been extensively applied to study the productivity of various firm inputs such as capital, labor and R&D expenditures for over sixty years (Berndt 1991) and more recently has been used to assess IT investments. The theory posits that firms possess a method for transforming various inputs into output that can be represented by a *production function*. Different combinations of inputs can be used to produce any specific level of

output, but the production function is assumed to adhere to certain mathematical assumptions.<sup>2</sup>

By assuming a particular form of the production function, it is possible to econometrically estimate the contribution of each input to total output in terms of the gross *marginal* benefit. This represents the rate of return on the last dollar invested and is distinct from the overall rate of return, which is the average return for all dollars invested.<sup>3</sup> Since firms will seek to invest in the highest value uses of an input first, theory predicts that rationally-managed firms will keep investing in an input until the last unit of that input creates no more value than it costs. Thus, in equilibrium, the net marginal returns (gross returns less costs) for any input will be zero. However, because costs are positive, the gross marginal returns must also be positive.

Thus, in equilibrium, the theory of production implies the following hypotheses:

H1a: IT spending has zero *net* marginal benefit, after all costs have been subtracted.

and

H1b: IT spending has a positive *gross* marginal benefit (i.e., it contributes a positive amount to output, at the margin).

These hypotheses are empirically-testable and deviations from them will require elaboration or modification of the basic theory and/or the underlying assumptions.

These methods have been employed to study IT productivity for firm- and industry-level data. Loveman (1994) found that gross marginal benefits were not significantly different from zero for a sample of sixty manufacturing divisions (1978-1984 time period). Using more recent data firm-level data for Fortune 500 manufacturing and service firms (1988-1992 period), Brynjolfsson and Hitt (1993a, 1993b) and Lichtenberg (1993) found gross marginal benefits of over 60%. As a practical matter, the marginal costs of IT will depend on factors such as the depreciation rate, which can be difficult to determine. Brynjolfsson and Hitt (1993a, 1993b) and Lichtenberg (1993) calculated net benefits using various assumptions about depreciation rates and found that net returns to IT were likely to be positive. In contrast, Morrison and Berndt (1990) explicitly estimated a cost function for twenty manufacturing industries over the period 1968 to 1986 and found that net marginal benefits were -20%. Because these studies examined different time periods as well as slightly different specifications, it is not obvious how to reconcile the results.

## 2.2 Theories of Competitive Strategy

While the theory of production predicts that lower prices for IT will create benefits in the form of lower costs of production and greater output, it is silent on the question of whether firms will gain competitive advantage and therefore higher profits or stock values. For that, we must turn to the business strategy field and the literature on barriers to entry.

As Porter (1980) has pointed out, in a competitive market with free entry, firms cannot earn supranormal profits because that would encourage other firms to enter and drive down prices. Normal accounting profits will be just enough to pay for the cost of capital and compensate the owners for any unique inputs to production (e.g., management expertise) that they provide. Therefore, an input such as computers, which may be very productive, will not confer supranormal profits to any firm in an industry if it is freely available to all participants in that industry. In equilibrium, all firms will use such an input, but none will gain a competitive advantage from it. This is consistent with the argument of Clemons (1991) that IT has become a competitive necessity, but not a source of competitive advantage.

The only way IT (or any input) can lead to supranormal profits is if the industry has barriers to entry. Specifically, Bain (1956) has broadly defined a "barrier to entry" as anything that allows firms to earn supranormal profits, such as patents, economies of scale, search costs, product differentiation or preferential access to scarce resources.

The impact of IT on barriers to entry is ambiguous. On one hand, it may reduce economies of scale and search costs (Bakos 1993), thereby leading to lower industry profits. On the other hand, it may also enable increased product differentiation (Brooke 1992), supporting higher profits. Furthermore, IT may lead to increased profits if it increases the total value available to firms in the industry and barriers already exist. On balance, any or all of the above conditions may hold for a given industry, so competitive strategy theory does not clearly predict either a positive or negative relationship between IT and profits or market value (which, after all, represent the expected discounted value of future profits). This implies the following testable hypothesis:

H2: IT spending is uncorrelated with firm profits or stock market value.

Much of the previous research in this area has examined correlations between measures of IT spending and measures

of business performance (see Ahituv and Giladi 1993; Dos Santos, Peffer and Mauer 1993; Markus and Soh 1993; Strassmann 1990). Some studies have attempted to examine direct correlations between IT spending and performance ratios (e.g., Ahituv and Giladi 1993) while others examine how IT influences intermediate variables which in turn drive performance (Barua, Kriebel and Mukhopadhyay 1991; Ragowsky, Neumann and Ahituv 1994). In general, these studies find little overall correlation between IT spending and increased business performance, although the models are plagued with relatively low predictive power overall.

## 2.3 Theory of the Consumer

A third approach, also grounded in microeconomic theory, can be used to estimate the total benefit accruing to consumers from a given purchase. As shown in Figure 1, the demand curve for a good represents how much consumers would be willing to pay (i.e., the benefit they gain) for each successive unit of a good. However, they need only pay the market price, so consumers with valuations higher than the market price retain the surplus. By adding up the successive benefits of each additional unit of the good, the total benefit can be calculated as the area between the two curves. Schmalensee (1976) further showed that in a competitive industry, the surplus from an input to production will be passed along to consumers, so the area under the demand curve for an input such as computers will also be an accurate estimate of consumer surplus.<sup>4</sup>

The major difficulty with this approach is determining the locus of the demand curve.<sup>5</sup> Fortunately, in the case of IT, a natural experiment has occurred in which the cost of computer power has dropped by several orders of magnitude. By examining how the actual quantity of computers purchased has been affected over time, we can trace out the demand curve and calculate the total consumer surplus.

As shown in Figure 2, as the price of IT declines, benefits are created in two ways: 1) a lower price for investments that would have been made even at the old price and 2) new investments in IT that create additional surplus. In equilibrium, a decline in the price of an input will lead to an increase in spending on that input and an increase in consumer surplus. The fact that the price of IT has declined monotonically and spending has increased suggests the following simple hypothesis:

H3: IT spending is correlated with increased consumer surplus.

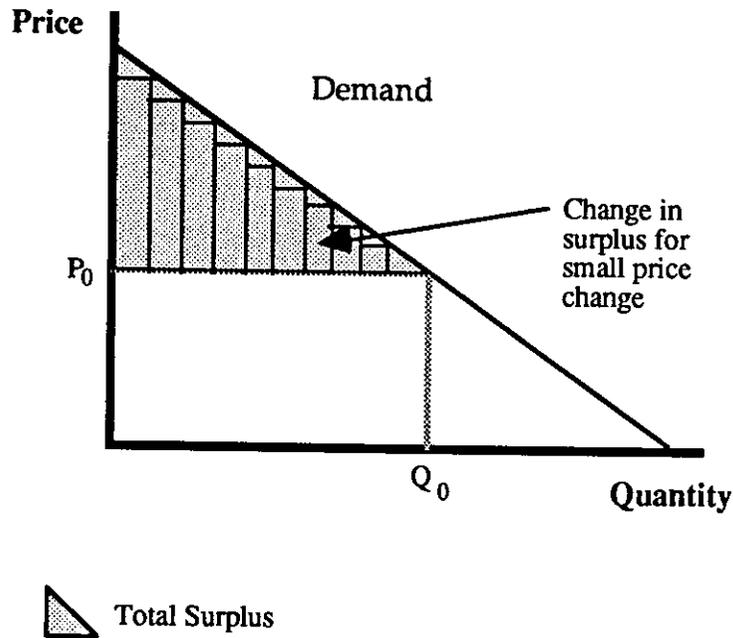


Figure 1. Illustration of Consumer Surplus as the Area between Price and Demand

The literature on the consumer surplus from IT is somewhat more sparse than the others. In addition to Bresnahan (1986), who studied the effects of IT spending on the financial services industry and found substantial benefits, this method has been applied to data on the entire U.S. economy by Brynjolfsson (1993b), who estimated that computers generated approximately \$50 billion in consumer surplus in 1987.

#### 2.4 Comparing and Integrating the Alternative Approaches

As noted in the discussion above, the three methods measure several different things. The production theory approach measures the marginal benefit of IT investment. The performance ratio approach shows whether the benefits created by IT can be appropriated by firms to create competitive advantage. The consumer surplus approach focuses on whether the benefits are passed on to consumers.

For a given level of productivity, lower entry barriers will lead to lower prices and therefore reduce business profits while increasing consumer value. If productivity increases, it is possible, but not inevitable, that both profits and consumer value will increase. The exact division will depend both on the total size of the pie and on how the pie is divided.

### 3. EMPIRICAL ANALYSIS

In order to investigate the effects of computer investment, we apply each of the approaches described in section 2 to the same data set. Therefore, it is possible to examine how the three approaches are interrelated without the potential confusion created by the comparison of different studies with different data. By the same token, for each approach, we attempt to apply the same model used in the previous literature for that approach. Therefore, our results can be more easily compared with prior work. This strategy should help highlight which differences are due to data and which are due to models.

#### 3.1 Data

The data used for this analysis comprise an unbalanced panel of 367 firms over the period 1988-1992 with 1,248 data points overall, out of a possible 1,835 data points (5x367) if the panel were complete. We obtained computer spending from an annual survey conducted by International Data Group (IDG) of computer spending by large firms (top half of the Fortune 500 manufacturing and service listings) over the period 1988-1992. These data were matched to Standard and Poor's Compustat II database to obtain values for the output, capital, labor, industry classification, and other financial data. We augmented these data

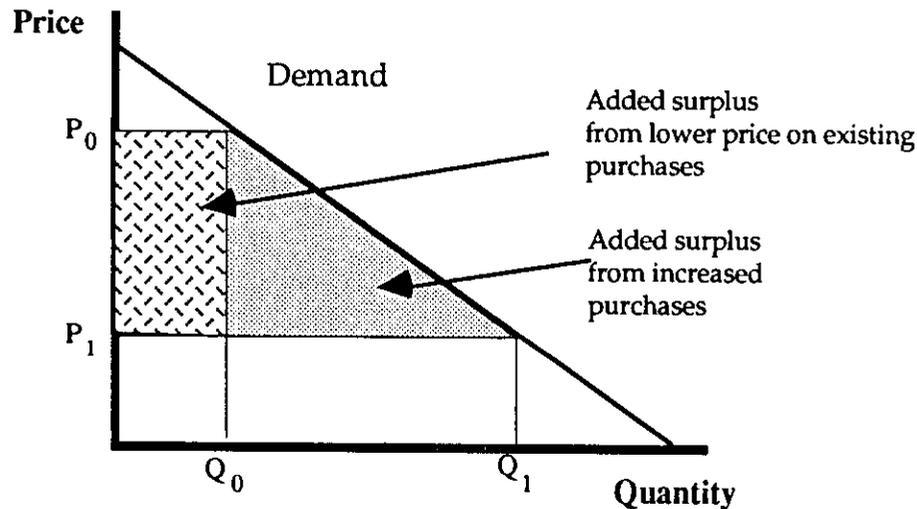


Figure 2. Components of Added Surplus: Additional Value on Existing Units and Added Value from Increased Purchases.

with price indices from a variety of sources to remove the effects of inflation and allow inter-year comparisons on the same basis. The precise variable definitions and sources are shown in Table 1 and sample statistics for the key variables are given in Table 2.

There are a number of limitations of this data set. First, the IDG data are self-reported, which could lead to error in reporting and sample selection bias. However, the large size of our sample should help mitigate the impact of data errors. The high response rate (75%) suggests that the sample is likely to be reasonably representative of the target population. In addition, Lichtenberg (1993) compared this data with an alternative source (*Infoweek*) and found high correlations for specific firms; the total annual values are generally consistent with a survey done by CSC/Index (Quinn et al. 1993) and aggregate computer investment data by the Bureau of Economic Analysis. Second, the survey records a relatively narrow definition of IT, namely Computer Capital, including only PCs, terminals, minicomputers, mainframes and supercomputers, but not the related peripherals, and thus the results need to be interpreted accordingly. Finally, we use estimation procedures for some items, particularly the value of PCs and terminals and labor expenses. However, we tested a range of alternative

estimates for these values and find that the overall results are essentially unchanged.

### 3.2 Production Function Approach

We apply the production function approach to this data set using the same methods employed by previous researchers (Brynjolfsson and Hitt 1993a, Lichtenberg 1993; Loveman 1994). We relate three inputs, measured in constant 1990 dollars, Total Computer Capital (C), Non-computer Capital (K) and Labor (L) to firm Value Added (V) by a Cobb-Douglas production function.<sup>6</sup> We also use dummy variables to control for the year the observation was made ( $D_t$ ), and the sector of the economy in which a firm operates ( $D_j$ ):

$$V = \exp\left(\sum_t D_t + \sum_{j=1} D_j\right) C^{\beta_1} K^{\beta_2} L^{\beta_3}$$

After taking logarithms and adding an error term, we have the following estimating equation:

**Table 1. Variable Definitions**

Variable	Computation	Source
Output	Gross Sales deflated by Output Price (see below).	Compustat
Value Added	Output minus Labor (see below).	Compustat
Computer Capital	Market value of central processors plus value of PCs and terminals. Deflated by Computer price (see below).	IDG Survey
Non-Computer Capital	Deflated Book Value of Capital less Computer Capital as calculated above (for deflator see below).	Compustat
Labor	Labor expense (when available) or estimate based on sector average labor costs times number of employees. Deflated by Labor Price (see below).	Compustat
Sector	Grouped in eight economic sectors based on primary SIC code (mining, durable manufacturing, non-durable manufacturing, transport and utilities, trade, finance, other service).	Compustat
Total Shareholder Return	Price change plus accumulated dividends divided by initial price.	Compustat
Return on Equity	Pretax income divided by total shareholders equity.	Compustat
Return on Assets	Pretax income divided by total assets.	Compustat
Return on Sales	Pretax income divided by total sales.	Compustat
Computer Price	Gordon's deflator for computer systems - extrapolated to current period at same rate of price decline (-19.7%/yr.).	(Gordon 1993)
Output Price	Output deflator based on 2-digit industry from BEA estimates of industry price deflators. If not available, sector level deflator for intermediate materials, supplies and components.	(Bureau of Economic Analysis 1993)
Labor Price	Price index for total compensation.	(Council of Economic Advisors 1992)
Capital Price	GDP deflator for fixed investment. Applied at a calculated average age based on total depreciation divided by current depreciation.	(Council of Economic Advisors 1992)
Book Value (of Assets)	Assets (except Property, Plant and Equipment) deflated by BEA deflator for fixed investment plus Computer Capital + Non-Computer Capital (as above).	Compustat
Market Value	Total Liabilities plus Market Value of Common Equity (year-end) plus Carrying Value of Preferred Equity.	Compustat
R&D Capital	Capital stock of R&D computed by accumulating 20 year annual R&D expenditure and adjusting for inflation following Hall (1990).	Compustat, Deflators from (Hall 1990)
Advertising	Advertising Expense reported on Compustat deflated by Consumer Price Index.	Compustat

**Table 2. Sample Statistics**  
Average over all five years in constant 1990 dollars

	Average Firm	All Firms
Output	\$8.42 Bn	\$2,104 Bn
Value Added	\$3.10 Bn	\$774 Bn
Computer Capital	\$110 mm	\$27.5 Bn
Non-Computer Capital	\$8.24 Bn	\$2,057 Bn
Labor Expense	\$1.76 Bn	\$439.3 Bn

$$\log V = \sum_i D_i + \sum_{j=1} D_j + \beta_1 \log C + \beta_2 \log K + \beta_3 \log L + \epsilon$$

In this specification,  $\beta_1$  represents the output elasticity of Computer Capital, which is the percentage increase in output provided by a small increase in Computer Capital. Dividing the elasticity by the share of Computer Capital in total output provides an estimate of the (gross) marginal return on computer investment.

Unbiased estimates of the parameters can be obtained by Ordinary Least Squares (OLS) provided the error term is uncorrelated with the regressors. However, following Brynjolfsson and Hitt (1993a) we also employ Iterated Seemingly Unrelated Regression (ISUR) to potentially enhance estimation efficiency.<sup>7</sup> Furthermore, we test the assumption that the error term is uncorrelated with the regressors by computing Two Stage Least Squares estimates (2SLS) with lagged values of the independent variables as instruments.<sup>8</sup>

The results of this analysis are presented in Table 3. When all industries and years are estimated simultaneously, we find that the output elasticity of computer capital is .0307, implying a gross marginal return of approximately 86.5%.<sup>9</sup> The gross marginal return for other capital and labor is 8.5% and 1.21 respectively, which is approximately what would be expected for inflation-adjusted estimates of these figures and is consistent with estimates of production functions performed by other researchers (e.g., 1993a). Considering the standard error for our estimate of the gross rate of return to computer capital, we find strong support for the hypothesis that computers have contributed positively to total output ( $p < .001$ ).<sup>10</sup> This is consistent with

hypothesis H1b. To calculate the net returns, it is necessary to subtract an estimate of the annual cost of capital. Strikingly, even if we assume that capital costs are as high as 34% per year,<sup>11</sup> we can reject the hypothesis that the net return to computer investment is zero, contradicting hypothesis H1a. Our 2SLS estimates are close to the OLS estimates, suggesting that the equation is properly specified, and this result is confirmed by a Hausman specification test (Hausman 1978). All of these results are consistent with the more detailed analyses of the same data by Brynjolfsson and Hitt (1993b) and by Lichtenberg (1993). In section 4, we discuss the implications of these findings.

### 3.4 Business Performance Analysis

Our business performance model follows in the tradition of the existing IT literature on business value (Ahituv and Giladi 1993; Alpar and Kim 1990; Harris and Katz 1989; Strassmann 1990; Weill 1992). While there is not a single standard form for the estimating relationship, we posit a simple but flexible form which accommodates the features of previous research and uses dependent variables employed by other authors. Firm performance is assumed to be a function of the Computer Capital (C), the sector in which a firm operates (j), the time period considered (t), and the size (S) of the firm as measured by total capital. The sector variable will help control for different barriers to entry and differences in performance among sectors. We include size to avoid confounding any performance benefits that are received by large firms with computer spending.<sup>12</sup> We take logarithms of Computer Capital and Size to create a normal distribution for the regressors. Thus we can write:

**Table 3. Production Function Analysis**

	ISUR Estimates	OLS Estimates	2SLS Estimates
Computer Capital	.0307*** (.00688)	.0427*** (.00740)	.0530*** (.0151)
Non-Computer Capital	.228*** (.00792)	.221*** (.00837)	.197*** (.00999)
Labor	.686*** (.0107)	.698*** (.0131)	.724*** (.0173)
Dummy Variables	Sector and Year	Sector and Year	Sector and Year
N	1248	1248	763
R <sup>2</sup>	95.1%	95.3%	94.9%
<u>Marginal Returns</u>			
Computer Capital	86.5%	120%	131%
Non-Computer Capital	8.6%	8.3%	7.2%

\*\*\* = p < .001, \*\* = p < .01, \* = p < .05

Heteroskedasticity-consistent standard errors used for OLS.

$$\text{Performance Ratio} = A(j,t) + \alpha_1 \log C + \alpha_2 \log S + \epsilon$$

Three measures of performance (see Table 1 for precise definitions) are considered here that have been employed in past research: 1) Total shareholder return (Dos Santos, Peffer and Mauer 1993; Strassmann 1990) is used to measure how much value a firm has created for shareholders; 2) Profitability as measured by Return on Assets (ROA) (Barua, Kriebel and Mukhopadhyay 1991; Cron and Sobol 1983; Strassmann 1990; Weill 1992) measures how effectively a firm has utilized its existing physical capital to earn income; and 3) Profitability as measured by Return on Equity (Alpar and Kim 1990) provides an alternative measure of how effectively a firm has utilized its financial capital and is algebraically related to "Economic Value Added," a measure attracting increasing interest in the managerial community (Tully 1993).

The analysis of each of the measures was performed using OLS, as well as ISUR. The OLS results are in Table 4a. The measures of ROE and ROA are consistent with competitive strategy theory and previous research: we cannot reject hypothesis H2, that Computer Capital has no effect on ROE or ROA. However, we do find that Computer Capital has a small *negative* correlation with total share-

holder return. The regression for total return indicates that firms with 1% higher Computer Capital spending are associated with a reduction of about 0.01% in shareholder return. However, when the analysis is repeated on a year by year basis (Table 4b), we find that the effect is only present in one of the years in the sample. Therefore, while there is little evidence that IT is correlated with changes in firm performance as predicted by H2, the evidence we do find suggests that, if anything, there is a negative effect. This possibility is further explored in section 4.

### 3.4 Consumer Surplus

In order to estimate consumer surplus for our sample, we use the index number method proposed by Bresnahan (1986). He showed that for a general utility function (the translog), the increase in consumer surplus between two periods (t, t+1) is a function factor Share of Computer Capital (s), the Price of Computer Capital (p) and Value Added (V), as follows:

$$\text{Surplus}_{t+1} = \frac{1}{2}(s_{t+1} + s_t) * \log \left( \frac{p_t}{p_{t+1}} \right) * V$$

**Table 4a. Business Performance Analysis**

	<b>Total Return (1 Year)</b>	<b>Return on Equity (1 Year)</b>	<b>Return on Assets (1 Year)</b>
Computer Capital	-.0165* (.00786)	.00621 (.00758)	-.000336 (.00220)
Size	.0148* (.00733)	-.00310 (.00698)	-.00277 (.00200)
Dummy Variables	Sector and Year	Sector and Year	Sector and Year
N	1233	1259	1304
R <sup>2</sup>	21.6%	6.1%	10.0%
<u>Perf. Measure</u>			
Mean	11.8%	17.9%	7.2%
Std. Deviation	27.1%	22.7%	7.3%

\* -  $p < .05$ , Heteroskedasticity-consistent standard errors in parenthesis

**Table 4b. Sign and Significance Levels of Computer Capital Coefficient in Single Year Performance Regressions**

	<b>Total Return (1 Year)</b>	<b>Return on Equity (1 Year)</b>	<b>Return on Assets (1 Year)</b>
1988	n.s.	n.s.	n.s.
1989	n.s.	n.s.	n.s.
1990	negative *	n.s.	n.s.
1991	n.s.	n.s.	n.s.
1992	n.s.	n.s.	n.s.

n.s. = not significantly different from zero; \* =  $p < .05$

The intuition behind this equation is that it represents the area under the demand curve between two price points, similar to the consumer surplus shown in Figures 1 and 2. To apply this equation, we further assume that the quantity of computer capital can be adjusted between years by purchasing more or less depending on prices. We compute annual surplus for the firms in our sample as shown in Table 5.

Overall, we find that Computer Capital has created significant value for consumers. In 1990, the price change in computers created \$4.1 billion in value for the firms in our sample. This is consistent with hypothesis H3 and is proportional to the consumer surplus calculation for the economy as a whole performed by Brynjolfsson (1993b).<sup>13</sup>

**Table 5: Consumer Surplus Analysis**  
 (Assuming Net Return to Computer spending is  
 zero on the margin, Constant 1990 dollars)

Year	Computer Capital Stock	Value Added	Computers as a share of Value Added	Price of Computers (1990=1)	Surplus using 1992 Output
1988	\$13.1 Bn	\$677.0 Bn	1.94%	1.43	na
1989	\$15.8 Bn	\$639.0 Bn	2.47%	1.19	\$3.36 Bn
1990	\$25.1 Bn	\$861.9 Bn	2.91%	1.00	\$4.11 Bn
1991	\$34.8 Bn	\$844.2 Bn	4.12%	.83	\$5.37 Bn
1992	\$48.6 Bn	\$848.5 Bn	5.73%	.70	\$7.52 Bn

#### 4. DISCUSSION: RECONCILING THE RESULTS

To summarize the empirical results, we find that computer investment has had a significant impact on firm output. Our production function estimates of the productivity of Computer Capital suggest a gross rate of return of nearly 87%, which imply positive net returns for most plausible estimates of the cost of capital. These results are consistent with recent studies on IT and productivity by Brynjolfsson and Hitt (1993b) and Lichtenberg (1993) but inconsistent with earlier findings employing a similar approach (Love-man 1994; Morrison and Berndt 1990). When examining business performance as the dependent variable, we find no evidence of a positive impact and even some evidence of a small negative impact on performance. This is similar to previous research which typically found no relationship between IT and business performance (Strassmann 1990; Barua, Kriebel and Mukhopadhyay, 1991; Ahituv and Giladi 1993). Finally, using the consumer surplus approach, we estimate the total benefit to computers to be substantial. The increase in surplus (above costs) is at least \$4.1 billion per year. This is consistent with previous approaches to this issue that used different data (Bresnahan 1986; Brynjolfsson 1993b).

The most striking aspect of the empirical results is that Computer Capital appears to be correlated with substantial increases in net output and consumer surplus, but to have little or no relationship with business performance. These findings are based on data from the same firms, over the same time period, using the same measures of computers, so the conventional explanation of incomparable data sets does not apply. How, then, does one reconcile the results? Below, we put forth two possible explanations for this

finding, one based on elaboration of the theory and one which stresses the need for new econometric models.

##### 4.1 Creating Value and Destroying Profits

The theoretical discussion in section 2 highlights that profits, productivity, and consumer value are not equivalent. Information technology is commonly characterized as reducing the coordination costs involved in finding appropriate suppliers and switching production to new suppliers (Malone 1987). Such an increase in efficiency (and therefore productivity) can be shown to intensify competition by lowering barriers to entry and eliminating the inefficiencies in the market which enable firms to maintain a degree of monopoly over their customers (Bakos 1991). The result would be higher productivity and consumer value, but lower profits.

Is this theoretical story consistent with business practice? Possibly, it is. In an in-depth study of the banking industry, Steiner and Teixeira (1991) found that while IT seemed to be creating enormous value, it was simultaneously intensifying competition and destroying profitable businesses by enabling entry and radically lower prices. Clemons and Weber (1990) discovered a similar outcome in their analysis of the "big bang," which introduces a computerized system for matching buyers and sellers in London's stock market. It is important to note that the fundamental technologies involved (e.g., ATMs and automated stock trading) were ultimately available to all competitors in an industry, so investing firms were unable to appropriate the full value they were creating. However, in each of these cases, large benefits have been created for con-

sumers. Thus, there is some theoretical and anecdotal support for our econometric finding that computers can create value and yet destroy profits.<sup>14</sup>

#### 4.2 Measurement and Modeling Problems

The issues of measurement and modeling shortcomings are probably the most cited problems with empirical research. By considering over 1,200 observations and triangulating on IT value using three modeling approaches, we may be able to mitigate the measurement problem somewhat. However, we still believe modeling weaknesses cannot be ruled out as explanations for the results of each of our models.

First, a key assumption of the production function approach is that inputs “cause” output. Yet, it may also be true that output “causes” increased investment in inputs, since capital budgets are often based on expectations of what output can be sold. While we did not find direct evidence of such simultaneity in our Hausman tests, this may simply reflect the inadequacy of our instrument list. Second, while the gross returns to computers appear to be very high, the net returns are much more difficult to calculate, especially in light of the fact that significant maintenance “liabilities” may be created whenever computer projects are undertaken (Kemerer and Sosa 1991).

Third, an implicit assumption of the consumer surplus approach is that the demand curve is stable over time, so that increases in the quantity purchased can be directly attributed to declines in price. In reality, it is likely that diffusion of the computer “innovation” would have led to some increase in quantity even if prices had not declined. Gurbaxani and Mendelson (1990) found that, by the 1980s, the vast majority of the increase in the quantity of computers purchased could be attributed to price declines, not diffusion. In any event, as shown by Brynjolfsson (1993b), our consumer surplus estimates are likely to be underestimates to the extent they do not account for diffusion, and therefore our finding of significant value would only be strengthened if diffusion were explicitly modeled.

We are most concerned by the fourth modelling weakness: the possibility that the insignificant results in the performance ratio regressions may simply be due to the fact that these models are comparatively blunt instruments. Past models on smaller data sets have usually been unable to explain more than about 10% to 20% of the variance in performance measures, as measured by  $R^2$ , and this also holds true for our analysis.<sup>15</sup> As noted by Ahituv and Giladi (1993), IT is just one item in a multitude of factors that affect firm returns and most of these other factors are

not controlled for in the model. A simple calculation highlights the importance of statistical power in finding the relationship between IT and business value. If our production function regression is correct, then computers should be increasing firm return on assets by approximately 0.7% each year. While this is a significant contribution in dollar terms, it would be less than one standard error in the performance regression, evaluated at the sample mean (0.95%), and would therefore be undetectable by such models.<sup>16</sup>

To explore the possibility that alternative models have higher “resolution,” we examine one promising approach, based on the concept of Tobin’s Q. This theory derives a specific relationship between the market value of the firm and the types of assets owned by the firm. This approach has a strong theoretical grounding in economics, has been applied by Griliches (1994) and Hall (1993b) to assessing the value of R&D investment, and explicitly acknowledges the central issue of barriers to entry.

To explore the potential of this approach, we follow Hall (1993b) and represent the Market Value of a firm (MV) to be a function of the Book Value of assets (BV) and the use of specialized assets such as Advertising (A), R&D capital (R), and Computer Capital (C), which affect barriers to entry (see Table 1 for precise variable definitions). We also introduce control variables for sector and year ( $D_j$  and  $D_i$ ). This yields the following equation which can be estimated by ISUR:

$$\log MV = \sum_i D_i + \sum_{j=i} D_j \delta \log BV + \gamma_1 \frac{C}{BV} + \gamma_2 \frac{R}{BV} + \gamma_3 \frac{A}{BV} + \epsilon$$

Since, R&D and Advertising data are only available for some subset of the firms, the analysis is repeated using different combinations of the Computer Capital, R&D and advertising variables. The overall results of this analysis (Table 6) show that while Advertising is consistently positive and significant, and R&D is positive when it is significant, the results for Computer Capital are less clear. While the coefficient is always positive, it is significant in the advertising-only regression ( $p < .01$ ), but not in the others.

Although the analysis based on Tobin’s Q theory leaves much less of the variance unexplained (only about 20%), it is difficult to draw any inferences from this exploratory analysis, except perhaps that it appears promising.

**Table 6. Market Value Analysis  
(ISUR Estimates, Dependent Variable is Market Value)**

Coefficient	Computer Only	Computer and Advertising	Computers and R&D	Computers, Advertising and R&D
$\delta$ (Book Value)	.913*** (.0113)	.976*** (.0182)	.0900*** (.0172)	.987*** (.0270)
$\gamma_1$ (IT/BV)	.0220 (.358)	2.62*** (.944)	.300 (.434)	2.70 (2.00)
$\gamma_2$ (R&D/BV)			.570*** (.170)	-.093 (.200)
$\gamma^3$ (Advertising/BV)		.659*** (.170)		.887*** (.200)
Dummy Variables	Year and Sector	Year and Sector	Year and Mfr. Sector	Year and Mfr. Sector
R <sup>2</sup> (1992)	87.8%	88.9%	86.5%	87.6%
N (total)	1255	509	520	232

\*\*\* -  $p < .001$ , \*\* -  $p < .01$ , \* -  $p < .05$

## 5. CONCLUSION

The question of IT value is far from settled. Indeed, one advantage to the comparative approach we have taken is that the existing gaps in knowledge become more apparent. For instance, our analysis underscored the relatively low power of the commonly used models of IT's effect on business performance and we presented some possible steps that can be taken to improve this situation.

Equally importantly, we clarified the point that there are three related, but distinct dimensions to the question: the effect of computers on productivity, the effect of computers on business performance, and the effect of computers on consumer surplus. Our empirical examination confirmed that, like any multidimensional object, IT's value can look different depending on the vantage point chosen. While we found evidence that IT may be increasing productivity and consumer surplus, but not necessarily business profits, we also showed that there is no inherent contradiction if computers create value but destroy profits.

## 6. ACKNOWLEDGMENTS

This research has been generously supported by the MIT Center for Coordination Science, the MIT Industrial Performance Center, and the MIT International Financial Services Research Center. We would like to thank Chris Kemerer

and the conference referees for helpful comments on earlier drafts of this paper. We are also grateful to International Data Group for providing essential data.

## 7. REFERENCES

- Ahituv, N., and Giladi, R. "Business Success and Information Technology: Are They Really Related." *Proceedings of the Seventh Annual Conference of Management IS*, Tel Aviv University, 1993.
- Alpar, P., and M. Kim. "A Comparison of Approaches to the Measurement of IT Value." *Proceedings of the Twenty-Second Hawaii International Conference on System Science*, Honolulu, 1990.
- Attewell, P. "Information Technology and the Productivity Paradox." Mimeograph, City University of New York, 1993.
- Bain, J. *Barriers to New Competition*. Cambridge, Massachusetts: Harvard University Press, 1956.
- Bakos, Y. "Reducing Market Search Costs: Implications for Electronic Marketplaces." University of California, Irvine Working Papers in Information Systems (Revised), January 1993.

- Bakos, Y. "A Strategic Analysis of Electronic Marketplaces." *MIS Quarterly*, Volume 15, Number 3, 1991.
- Barua, A.; Kriebel, C.; and Mukhopadhyay, T. "Information Technology and Business Value: An Analytic and Empirical Investigation." University of Texas at Austin Working Paper, May 1991.
- Berndt, E. *The Practice of Econometrics: Classic and Contemporary*. Reading, Massachusetts: Addison-Wesley, 1991.
- Bresnahan, T. F. "Measuring the Spillovers from Technical Advance: Mainframe Computers in Financial Services." *The American Economic Review*, Volume 76, Number 4, 1986, pp. 742-755.
- Brooke, G. M. "The Economics of Information Technology: Explaining the Productivity Paradox." MIT Sloan School of Management CISR Working Paper 238, April 1992.
- Brynjolfsson, E. "The Productivity Paradox of Information Technology." *Communications of the ACM*, Volume 35, December 1993a, pp. 66-77.
- Brynjolfsson, E. "Some Estimates of the Contribution of Information Technology to Consumer Welfare." MIT Sloan School of Management Working paper September 1993b.
- Brynjolfsson, E., and Hitt, L. "Is Information Systems Spending Productive? New Evidence and New Results." In J. I. DeGross, R. P. Bostrom, and D. Robey (Editors), *Proceedings of the Fourteenth International Conference on Information Systems*, Orlando, Florida, 1993a.
- Brynjolfsson, E., and Hitt, L. "New Evidence on the Returns to Information Systems." MIT Sloan School of Management Sloan WP 3571-93, October 1993b.
- Bureau of Economic Analysis, U. S. Department of Commerce. *Fixed Reproducible Tangible Wealth in the United States, 1925-85*. Washington, DC: U.S. Government Printing Office, 1993.
- Christensen, L. R., and Jorgenson, D. W. "The Measurement of U.S. Real Capital Input, 1929-1967." *Review of Income and Wealth*, Volume 15, Number 4, 1969, pp. 293-320.
- Clemons, E. K. "Evaluation of Strategic Investments in Information Technology." *Communications of the ACM*, Volume 34, Number 1, 1991, pp. 22-36.
- Clemons, E., and Weber, B. "London's Big Bang: A Case Study of Information Technology, Competitive Impact and Organizational Change." *Journal of Management Information Systems*, Volume 6, Number 4, 1990, pp. 41-60.
- Council of Economic Advisors (Editors). *Economic Report of the President*. Washington, DC: United States Government Printing Office, 1992.
- Cron, W. L., and Sobol, M. G. "The Relationship Between Computerization and Performance: A Strategy for Maximizing the Economic Benefits of Computerization." *Journal of Information and Management*, Volume 6, 1983, pp. 171-181.
- Dos Santos, B. L.; Peffers, G. K.; and Mauer, D. C. "The Impact of Information Technology Investment Announcements on the Market Value of the Firm", *Information Systems Research*, Volume 4, Number 1, 1993, pp. 1-23.
- Gordon, R. J. *The Measurement of Durable Goods Prices*. Chicago: University of Chicago Press (for NBER), 1993.
- Griliches, Z. "Market Value, R&D and Patents." *Economic Letters*, Volume 7, 1994, pp. 183-187.
- Gurbaxani, V., and Mendelson, H. "An Integrative Model of Information Systems Spending Growth." *Information Systems Research*, Volume 1, Number 1, 1990, pp. 23-46.
- Gurbaxani, V., and Mendelson, H. "The Use of Secondary Analysis in MIS Research." In *The Information Systems Research Challenge: Survey Research Methods*. Boston: Harvard Business School Press, 1991.
- Hall, B. H. "The Manufacturing Sector Master File: 1959-1987, Documentation." NBER Working Paper 3366, April 1990.
- Hall, B. H. "New Evidence on the Impacts of Research and Development." *Micro-BPEA Conference*, Washington, DC, 1993a.
- Hall, B. H. "The Stock Market's Valuation of R & D Investment During the 1980's." *American Economic Review*, Volume 83, Number 2, May 1993b, pp. 259-264.
- Harris, S. E., and Katz, J. L. "Predicting Organizational Performance Using Information Technology Managerial Control Ratios." In *Proceedings of the Twenty-Second Hawaii International Conference on System Science*, Honolulu, 1989.
- Hausman, J. A. "Specification Tests in Econometrics." *Econometrica*, Volume 45, November 1978, pp. 1251-1271.

Jensen, M. C. "The Modern Industrial Revolution, Exit, and the Failure of Internal Control Systems." *Journal of Finance*, Volume XLVIII, Number 3, 1993, pp. 831-881.

Kemerer, C. F., and Sosa, G. L. "Systems Development Risks in Strategic Information Systems." *Information and Software Technology*, Volume 33, Number 3, 1991, pp. 212-223.

Lichtenberg, F. "The Output Contributions of Computer Equipment and Personnel: A Firm Level Analysis." Columbia Business School Working Paper, October 1993.

Loveman, G. W. "An Assessment of the Productivity Impact on Information Technologies." In T. J. Allen and M. S. Scott Morton (Editors), *Information Technology and the Corporation of the 1990s: Research Studies*. Cambridge, Massachusetts: MIT Press, 1994, pp. 84-110.

Malone, T. W. "Modelling Coordination in Organizations and Markets," *Management Science*, Volume 33, 1987, pp. 1317-1332.

Markus, L., and Soh, C. "Banking on Information Technology: Converting IT Spending into Firm Performance." In R. Banker, R. Kauffman, and M. Mahmood (Editors), *Strategic Information Technology Management: Perspectives on Organizational Growth and Competitive Advantage*. Harrisburg, Pennsylvania: Idea Group Publishing, 1993, pp. 375-404

Morrison, C. J., and Berndt, E. R. "Assessing the Productivity of Information Technology Equipment in the U.S. Manufacturing Industries." National Bureau of Economic Research Working Paper 3582, January 1990.

Porter, M. *Competitive Strategy*. New York: Free Press, 1980.

Quinn, M. A.; Craumer, M. A.; Weaver, A.; Buday, R. S.; and Waite, T. J. "Critical Issues of Information Systems Management for 1993." *The Sixth Annual Survey of Information Systems Management Issues*. Cambridge, Massachusetts: CSC Index, 1993.

Ragowsky, A., Neumann, S., and Ahituv, N. "Documenting the Benefit an Organization May Gain by Using Information Systems." Mimeograph, Tel Aviv University, February 1994.

Schmalensee, R. "Another Look at Social Valuation of Input Price Changes." *American Economic Review*, Volume 66, Number 1, 1976, pp. 239-243.

Steiner, T. D., and Teixeira, D. B. *Technology and Business: Creating Value and Destroying Profits*. Homewood, Illinois: Dow Jones Irwin, 1991.

Strassmann, P. A. *The Business Value of Computers*. New Canaan, Connecticut: Information Economics Press, 1990.

Tully, S. "The Real Key to Creating Wealth." *Fortune*, September 20, 1993, pp. 30-50.

Varian, H. *Microeconomic Analysis*, Third Edition. New York: W. W. Norton & Company, Inc., 1992.

Weill, P. "The Relationship Between Investment in Information Technology and Firm Performance: A Study of the Valve Manufacturing Sector." *Information Systems Research*, Volume 3, Number 4, December 1992.

White, H. "A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity." *Econometrica*, Volume 48, May 1980, pp. 817-838.

Wilson, D. "Assessing the Impact of Information Technology on Organizational Performance." In R. Banker, R. Kauffman, and M. A. Mahmood (Editors), *Strategic Information Technology Management*. Harrisburg, Pennsylvania: Idea Group, 1993.

## 8. ENDNOTES

1. This problem is by no means unique to the IT value debate. Gurbaxani and Mendelson (1991) ascribe it to the entire IS field.
2. Specifically, the production function is assumed to be quasi-concave and monotonic (Varian 1992).
3. It bears pointing out that *total* benefits of IT spending can still be large even if *marginal* benefits are zero or negative. In fact, a high marginal rate of return may be a sign of underinvestment.
4. When an industry is not perfectly competitive, the area under the derived demand curve will generally underestimate welfare.
5. In particular, see Berndt (1991) for an excellent discussion of simultaneity in supply-demand systems and Gurbaxani and Mendelson (1990) on the role of technology diffusion.
6. The Cobb-Douglas form is by far the most commonly assumed type of production function. It has the virtues of simplicity and empirical validity and can be con-

- sidered a first-order approximation to any other type of production function.
7. Since this data set is a panel of repeated observations on the same set of firms, it is likely that the error terms for a single firm will be correlated over time. One way to accommodate this feature is to employ ISUR to estimate separate equations for each year and allow the error terms for the same firm in different years to be correlated. Our use of ISUR is confirmed by the estimated correlation structure from the ISUR procedure: adjacent year correlations range from .46 to .76, suggesting a substantial amount of within-firm autocorrelation.
  8. For example, the instruments for the 1992 data points would be the 1991 values of IT Capital, Non-IT Capital and Labor Expenses, along with the sector and time dummy variables.
  9. The rate of return is equal to the elasticity divided by the percentage of IT in Value-Added, which is .0355. Therefore, the gross marginal benefit is:  $.0307/.0355 = 86.5\%$ .
  10. We report White (1980) standard errors to avoid possible biases in our hypothesis tests from heteroskedasticity. However, a comparison for OLS standard errors to White standard errors shows little change supporting homoskedasticity.
  11. This estimate is derived from the Jorgensonian cost of capital (Christensen and Jorgenson 1969). The cost is a function of the risk free rate, a risk premium, and depreciation charges. Following Hall (1993b), we use 6% as the risk free rate and assign a risk premium of 3%. The Bureau of Economic Analysis (1993) assumes computers depreciate over a period of seven years, or 14% per year. While computers rarely "wear out," we believe rapid price declines justify a more conservative assumption of 25% per year "depreciation," which yields a total cost of capital of 34% per year.
  12. Also, by including size, this specification can replicate IT investment ratios. If the coefficient on the size variable is negative one, this is essentially a correlation between the logarithm IT investment/ size and performance.
  13. The above surplus calculation follows the convention of assuming that the net marginal benefit of the input (IT) is zero. However, if we use our production function estimate that IT created an excess return of 52.5% on each additional unit purchased, this amount has to be added in to get total consumer surplus. For 1990, this amounts to an additional \$2.0 billion of consumer benefit, bringing the total surplus to \$6.1 billion in 1990.
  14. Jensen (1993) makes a related argument about how technology-based productivity improvements in the tire industry created massive overcapacity, consolidation and exit from the industry for a number of firms.
  15. By contrast, an  $R^2$  of 95% or more has been achieved for production function analyses and consumer surplus analyses (e.g., Brynjolfsson 1993b; Brynjolfsson and Hitt 1993a).
  16. The hypothetical increase in firm return is based on the following rough calculation: increase in value added each year by IT as a fraction of total assets = {IT capital stock (\$110 million) \* net marginal benefit of IT (54%) }/ total capital (\$8,420 million) = .7%. The standard error calculation is as follows: standard error on IT coefficient (.00202)\* log of average computer capital measured in millions of dollars ( $\log(110) = 0.95\%$ ).