Information Technology and its impact on Productivity

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Information technology applications are profoundly altering the way in which production operations are carried out in a variety of industries. But only some of these changes can be expected to enhance productivity, notably those applications that automate a process (substituting faster machine control for human actions) or that improve on the capabilities of existing machinery (functioning at faster speeds or with fewer necessary operations to achieve the same outcome) (Kelley, 1994).

Much of the early research on the relationship between technology and productivity use economy-level or sector level data and found little evidence of a relationship (Brynjolfsson and Hitt, 2000b). In several papers, Morrison and Berndt examined Bureau of Economic Analysis data for manufacturing industries at the two-digit SIC level (1952-1991) and found that the gross marginal product of “high tech capital” (including computers) was less than its costs and that in many industries these supposedly labor-saving investments were associated with an increase in labor demand (Berndt and Morrison, 1995; Morrison, 1996).

Morrison and Berndt also found evidence of overinvestment in high tech capital in the mid to late 1980s, following a period of strong investment incentives in the late 1970s. By the end of 1980s, however, the returns to investment and falling prices for high tech capital more than justified the high investment levels in non-durable goods industries, and the benefit-cost ratio was also increasing for durable-goods industries. Additionally, they found that the underlying substitution patterns suggest that high-tech capital expansion increases demand for most capital and noncapital inputs overall, but saves on materials inputs. In durable industries, however, they found that both energy and “other” capital appear somewhat substitutable with high tech capital, and in nondurable industries increasing high-tech intensity may be a factor underlying stagnating labor demand (Morrison, 1996)

It is important to emphasize that in the data analyzed by Berndt and Morrison, “high tech” equipment refers to high-tech office and information technology equipment, including office, computing and accounting machinery, communications equipment and scientific and engineering instruments. Have the analysis included automation equipment directly used in any step of the manufacturing process and for which its valued added could be directly associated with a product, the relevance of these findings would be of direct applicability to this study. However, Berndt and Morrison's studies are a good example of how measurement of productivity and its determinants is more accurate for manufacturing than for non-manufacturing industries, since inputs and outputs are more easily defined and measured.

However, by the early 1990s, analyses at the firm-level were beginning to find evidence that computers had a substantial effect on firms' productivity levels. Using data from over 300 large firms (Fortune 500 manufacturing firms and Fortune 500 service firms) over the period 1988-1992, Brynjolfsson and Hitt (1995, 1996) and Lichtenberg (1995) estimated production functions that use firm's output (or value-added) as the dependent variable and use ordinary capital, IT capital, ordinary labor, IT labor, and a variety of dummy variables for time, industry, and firm. From their findings they were able to realize that there is a clear positive relationship, but also a great deal of individual variation in firms' success with IT.

Brynjolfsson and Hitt (1996) found that IS spending has made a substantial and statistically significant contribution to the output of firms. Their point estimates indicate that, dollar for dollar, spending on computer capital created more value than spending on other types of capital. They found that he contribution of IS to output does not vary much across years, although there is a weak evidence of decrease over time. They also found some evidence of differences across various sectors of the economy. Although the returns to computers in durable and nondurable manufacturing are as high or higher than the returns in any other sector, they were unable to reject the hypothesis that these rates of return are the same across most sectors due to the imprecision of estimates. Furthermore, several of their regressions suggest that the marginal product of computers is significantly higher than the return on investment for other types of capital, although this comparison is dependent on the assumed cost of computer capital.

Overall, their findings suggest that for their large sample of firms, the productivity paradox—despite enormous improvements in the underlying technology, the benefits of

IS spending have not been found in aggregate output statistics—disappeared in the 1987-1991 period. These findings are perfectly applicable to large firms like the ones in this study (average sales nearly $7.4 billion). It is the intention of this study to determine whether the productivity paradox, when considering a specific IT like CAD/CAM, has also disappeared for small to medium sized manufacturing firms.

There are a number of directions in which their work could be extended. Although their approach allowed them to infer the value created by intangibles like product variety by looking at changes in the revenues at the firm level, more direct approaches might also be promising such as directly accounting for intangible outputs such as product quality or variety. In this study we intend to answer this question by attempting to find alternative ways to directly measure the effect that CAD/CAM technology might have on intangible outputs such as product quality or variety, two of the most relevant stated benefits for this technology.

Moreover, as stated by Brynjolfsson and Hitt (1996), the type of extension, which is likely to have the greatest impact on practice, is further analysis of the factors, which differentiate firms with high returns to IT from low performers. Since their study has presented evidence that the computer "productivity paradox" is a thing of the past, it seems appropriate that the next round of work should focus on identifying the strategies which have led to large IT productivity (Brynjolfsson and Hitt, 1996). In addition to determine whether the productivity paradox have disappeared for small to medium sized manufacturing firms, through this study we expect to determine whether there are specific strategies, in addition to the adoption and implementation of CAD/CAM, that have led some firms to obtain high returns.

Estimates of the average annual contribution of computer capital to total output generally exceed $0.60 per dollar of capital stock, depending on the analysis and specification (Brynjolfsson and Hitt; 1995,1996; Lichtenberg, 1995; Dewan and Min, 1997). These estimates are statistically different from zero, and in most cases significantly exceed the expected rate of return of about $0.42 (the Jorgensonian rental price of computers- see Brynjolfsson and Hitt, 2000a). This suggests either abnormally high returns to investors or the existence of unmeasured costs or barriers to investment. Similarly, most estimates of the contribution of information systems labor to output exceed $1 (and are as high as $6) for every $1 of labor costs.

Several researchers have also examined the returns to IT using data on the use of various technologies rather than the size of the investment. Greenan and Mairesse (1996) matched data on French firms and workers to measure the relationship between a firm's productivity and the fraction of its employees who report using personal computer at work. Their estimates of computers' contribution to output are consistent with earlier estimates of the computer's output elasticity.

Other micro-level studies have focused on the use of computerized manufacturing technologies. Kelley (1994) found that the most productive metal-working plants use computer-controlled machinery. In her study, she analyzed the effect of information technology on the efficiency of production operations—measured as production hours per unit of output-- in a specific manufacturing process. She used survey data from 854 establishments engaged in the machining process in 21 different industries to construct and test an empirical model that takes into account product characteristics, the type of technology (computer-programmable automation or conventional controlled) machines, the extent of technological change at the plant, process-specific characteristics such as the scale of operations and the degree of customization, labor policies, and structural features of the organization of work. The results indicate that there is a significant efficiency advantage from using programmable automation technology, and that technological advantages accumulate with experience and with the repeated opportunities for learning associated with large volume and frequent product changes. She found that the must efficient use of this technology occurs in plants with work practices that involve a higher ratio of machines to workers (as in a cellular approach to manufacturing) and allow production workers to perform programming tasks to a greater degree. She also found that unionized plants are also significantly more efficient than non-union plants.

Computerization has also been found to increase productivity in government activities both at the process level, such as package sorting at the post office or toll collection (Muhkopadhyay, Rajiv and Srivinivasan, 1997) and at higher levels of aggregation (Lehr and Lichtenberg, 1998). The work from Mukhopadhyay, Rajiv and Srinivasan (1997), represents one of the first attempts to assess the impact of IT on both process output and quality. They examined the optical character recognition and barcode sorting technologies in the mail sorting process at the United States Postal Service. Their analysis was at the application level, and thus does not involve the aggregation of IT impact over multiple processes. They used data from 46 mail processing centers over 3 years to study this IT impact. Their results show that mail sorting output significantly increases with higher use of IT. In addition, they found that IT improves quality, which in turn enhances output. They also found that input characteristics exert considerable influence in determining the output and quality of the mail sorting operation.

Taken collectively, these studies suggest that IT is associated with substantial increases in output. Questions remain about the mechanisms and direction of causality in these studies. Perhaps instead of IT causing greater output, “good firms” or average firms with unexpectedly high sales disproportionately spend their windfall on computers. For example, while Doms, Duke and Troske (1997) found in their time-series analysis that plants using more advanced manufacturing technologies had higher productivity and wages, they also found that this was commonly the case even before the technologies were introduced. These results suggest that the commonly observed cross-sectional correlation between technology use and workers wages and productivity may be due to time-invariant unobserved worker quality differences. Alternatively, these results are consistent with worker skill and technology adoption being related to some omitted factor such as managerial ability.

In their study, Doms, Duke and Troske (1997) used both a cross-sectional data set as well as a plant-level panel data. The data they utilized was from three main sources: (1) the 1988 and 1993 Survey of Manufacturing Technology (SMT) for data on manufacturing plants’ use and adoption of new factory automation equipment; (2) a matched employer-employee data set for information on worker characteristics; (3) the Census Bureau’s Longitudinal Research Database—a panel data set of manufacturing plants. Their study serves to document how plant-level wages, occupational mix, workforce education, and productivity vary with the adoption and use of new factory automation technologies such as computer-automated design, numerically controlled machines, local area networks, and programmable controllers.

It is relevant to mention that the sample of plants used in their analysis is relatively small, only 358 plants, and is predominantly composed of large producers. Also, the sample of plants used in the time-series analysis is plants that survived between 1977 and 1992. Both samples are composed of plants exclusively in SIC 34-38. Therefore, their results need to be interpreted as being descriptive of the technology-employment patterns in large, surviving, manufacturing plants in a few selected industries. In this study, we will explore whether the same results found by Doms, Duke and Troske (1997) are applicable when considering small to medium sized manufacturing companies, i.e. plants using CAD/CAM technology had higher productivity, paid higher wages to their workers, employed high skilled workers and were open to adopt new technologies even before they adopted CAD/CAM. It will be interesting for this study to model, and examine empirically, a firm's initial decision on the type of workers and capital used to produce output, taking into account the impact this investment has on firm's ability to adopt new technologies. This is a question not answered by Doms, Duke and Troske (1997).

The firm-level productivity studies can shed some light on the relationship between IT and organizational restructuring. For example, productivity studies consistently find that the output elasticities of computers exceed their (measured) input shares. One explanation for this finding is that the output elasticities for IT are about right, but the productivity studies are underestimating the input quantities because they neglect the role of unmeasured complementary investments. Dividing the output of the whole set of complements by only the factor share of IT will imply disproportionately high rates of return for IT (Brynjolfsson and Hitt, 2000b).

A variety of other evidence suggests that hidden assets play an important role in the relationship between IT and productivity. Brynjolfsson and Hitt (1995) estimated a firm fixed effects productivity model. This method can be interpreted as dividing firm-level IT benefits into two parts; one part is due to variation in firms' IT investments over time, the other to firm characteristics. Brynjolfsson and Hitt found that in the firm fixed effects model, the coefficient on IT was about 50 percent lower, compared to the results of an ordinary least square regression, while the coefficients on the other factors, capital an labor, changed only slightly. This change suggests that unmeasured and slowly changing organizational practices (the "fixed effect") significantly affect the returns to IT investment. The weight of the firm-level evidence shows that a combination of investment in technology and changes in organizations and work practices facilitated by these technologies contribute to firm's productivity growth and market value (Brynjolfsson and Hitt ,2000b). In this study we will attempt to answer one of the questions that remained open in the study performed by Brynjolfsson and Hitt (2000b), i.e. categorize and measure the relevant changes in organizations and work practices, and relate them to CAD/CAM and productivity.

Further analysis, based on earlier results by Schankerman (1981) in the R&D context, suggested that these omitted factors were not simply IT investments that were erroneously misclassified as capital or labor. Instead, to be consistent with econometric results, the omitted factors had to have been accumulated in ways that would appear on the current balance sheet. Firm-specific human capital and organizational capital are two examples of omitted inputs that would fit this description (Brynjolfsson and Hitt, 2000b).

Another indirect implication from the productivity studies comes from evidence that effects of IT are substantially larger when measured over longer time periods. Brynjolfsson and Hitt (2000a) examined the effects of IT on productivity growth rather than productivity levels, which had been the emphasis in most previous work, using data that included more than 600 firms over the period 1987 to 1994. When one-year differences in IT are compared to one-year differences in firm productivity, the measured benefits of computers are approximately equal to their measured costs. However, the measured benefits rise by a factor of two to eight as longer time periods are considered, depending on the econometric specification used. One interpretation of these results is that short-term returns represent the direct effects of IT investment, while the longer-term returns represent the effect of IT when combined with related investments in organizational change. In this study, the time period from the adoption of CAD/CAM will be considered as a variable to validate whether these results apply to small to medium/sized manufacturing companies.

A final perspective on the value of these organizational complements to IT can be found using financial market data, drawing on the literature on Tobin's q. This approach measures the rate of return of an asset indirectly, based on comparing the stock market value of the firm to the replacement value of the various capital assets it owns.

Typically, Tobin's q has been employed to measure the relative value of observable assets such as R&D or physical plant. However, as suggested by Hall (1999a, 199b), Tobin's q can also be viewed as providing a measure of the total quality capital, including the value of "technology, organization, business practices, and other produced elements of successful modern corporation." Using an approach along these lines, Brynjolfsson and Yan (1997) found that while one dollar of ordinary capital is valued at approximately one dollar by the financial markets, one dollar of IT capital appears to be correlated with between $5 and $20 of additional stock market value for Fortune 1000 firms using data spanning 1987 to 1994. Since these results largely apply to large, established firms rather than new high-tech startups, and since they predate most of the massive increase in market valuations for technology stocks in the late 1990s, these results are not likely to be sensitive to the possibility of a recent "high-tech stock bubble."

A more likely explanation for these results is that IT capital is disproportionately associated with other intangible assets like the costs of developing new software, populating a database, implementing a new business process, acquiring a more highly skilled staff, or undergoing a major organizational transformation, all of which go uncounted on a firm's balance sheet.

In this interpretation, for every dollar of IT capital, the typical firm has also accumulated between $4 and $19 in additional intangible assets. A related explanation is that firms must occur substantial "adjustment costs" before IT is effective. These adjustment costs drive a wedge between the value of a computer resting on the loading dock and one that is fully integrated into the organization (Brynjolfsson and Hitt, 2000b).

The evidence from the productivity and the Tobin's q analyses provides some insights into the properties of IT-related intangible assets, even if we cannot measure these assets directly. Such assets are large, potentially several multiples of the measured IT investment. They are unmeasured in the sense that they do not appear as a capital asset or as other components of firm input, although they do appear to be unique characteristics of particular firms as opposed to industry effects. Finally, they have more effect in the long term than the short term, suggesting that multiple years of adaptation and investment are required before their influence is maximized (Brynjolfsson and Hitt, 2000b).

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