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HOW BUSINESSES USE INFORMATION TECHNOLOGY: INSIGHTS FOR MEASURING CAPITAL AND PRODUCTIVITY

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ABSTRACT

HOW BUSINESSES USE INFORMATION TECHNOLOGY: INSIGHTS FOR MEASURING CAPITAL AND PRODUCTIVITY

Businesses in the United States have used computers for fifty years. Simply investing in information technology is unlikely to provide a competitive advantage. Differences in economic performance should depend instead on how businesses use that technology. Our previous research found that businesses using computers linked into networks have significantly higher labor productivity. In this paper, we extend our analysis with new information about the ways that businesses use their networks. Businesses conduct a variety of general processes over computer networks, such as order taking, inventory monitoring, and logistics tracking, suggesting heterogeneity among these kinds of information technology capital. The empirical diversity we find in the productivity impact of these processes supports this heterogeneity hypothesis. On-line supply chain activities such as order tracking and logistics have positive and statistically significant productivity impacts, but not processes associated with production, sales, or human resources. While productivity appears to be higher in newer plants, it seems unlikely that their productivity advantage comes from using e-business processes. The new information about the ways businesses use information technology yields vital raw material for understanding how using information technology improves economic performance.

I. Introduction

Businesses in the United States have used computers for fifty years. A large body of empirical research links the use of computer and information technology (IT) with labor productivity in the aggregate (e.g. Jorgenson 2001, Triplett and Bosworth 2002) and at the business unit level (e.g., studies summarized in Stiroh 2003 and Pilat 2004). IT's prevalence means that just investing in IT is no longer likely to confer a competitive advantage. Differences in economic performance should depend instead on differences in the ways businesses use IT. Recent studies support this hypothesis for Japan (Motohashi 2001 and 2003).

We test this hypothesis for the United States using new information about the ways businesses use IT. Data on the presence of computer networks in U.S. manufacturing plants, and how plants use them, were collected by the U.S. Census Bureau for the first time in the 1999 Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures (ASM). Respondents' answers to questions about computer networks can be linked to their answers to questions on the ASM, such as the value of shipments, employment, and materials, and to their responses to the Census of Manufactures.

Our previous research using the CNUS data found that productivity is about five percent higher in plants with networks, after accounting for multiple factors of production and plant characteristics (Atrostic and Nguyen 2002). A positive and significant relationship between computer networks and productivity continues to hold when we account for plant characteristics in prior periods, and investment in computers (Atrostic and Nguyen 2003). Our initial findings for the United States are consistent with recent findings for other countries (e.g., individual country studies in Pilat 2004).

This paper extends our previous analysis to include the new CNUS information about the ways that businesses use their networks. Because these data are new and little known, we first present summary statistics about some of the rich data in the CNUS and document the heterogeneity of IT capital in U.S. manufacturing.

Our regression analysis extends our previous models to explore whether the new information contributes to understanding how IT capital affects productivity. We find strong empirical support for the hypothesis that IT capital is heterogeneous, and that this heterogeneity leads to corresponding heterogeneity in economic performance. Labor productivity is significantly higher in plants running sophisticated software designed to integrate multiple business processes such as inventory and production. Productivity also is significantly higher in plants that conduct more processes over networks. The impact depends on the specific processes that are networked. Productivity is consistently higher in plants using computer networks to control supply chain activities such as inventory, transportation, and logistics. These findings are robust to alternative empirical specifications. They also are consistent across two sets of indicators of networked business processes.

Our findings demonstrate the viability of the CNUS information about how businesses use networked computers. This viability is valuable not just to statistical agencies in the United States, but also to statistical agencies in other countries, many of which recently collected or are planning to collect similar data. However, the empirical differences we find across the alternative sets of e-business process indicators suggest the need for further methodological research. Our results suggest that periodically collecting information about the ways businesses use computer networks would yield vital raw material for understanding how using IT improves economic performance.

II. How Information Technology Impacts Economic Performance

The literature offers several models of how IT might affect economic performance. IT might be a separate productive input, where capital services derived from IT differ from those derived from non-IT capital. Some recent research suggests that IT capital is heterogeneous, and that this heterogeneity affects economic performance. An IT variation to the long-standing vintage capital theory suggests that IT would have a greater impact on the performance of new businesses. Estimating a model with heterogeneous IT capital requires data about the kinds of IT capital that businesses have, and how they use it.

These models of IT capital assume that the data contain comparable measures of IT and non-IT capital. The CNUS data, however, contains only indicators of specific uses of IT. We describe several salient forms of heterogeneity in the CNUS data.

A. **Links between IT and Productivity Are Clear, but How Links Work Is Not**

IT may be a specific kind of capital input to a manufacturing production process. That is, within a general K, L, E, M production function specification,

(1) $K \equiv K_{IT} + K_{NIT}$, where

K is total capital input and K_{IT} and K_{NIT} are IT capital and non-IT capital inputs. This view is adopted in both the aggregate growth accounting literature (e.g., Jorgenson and Stiroh 2000, Oliner and Sichel 2001) and the micro-level productivity literature (e.g., Atrostic and Nguyen 2003, and Haltiwanger, Jarmin, and Schank 2003). IT capital is a homogeneous input, with all uses having similar effects on productivity.

Another view of IT is as a productivity-enhancing general-purpose technology found across economic sectors (e.g., Breshnahan and Trajtenberg, 1995, Bresnahan and Greenstein, 1997). A characteristic of general-purpose technologies is facilitating complementary investments (e.g., Brynjolfsson and Hitt, 2000). For IT, these complementary investments may include reorganizing or streamlining existing business processes such as order taking, inventory control, accounting services, and tracking product delivery. They may also include IT linking computers into networks that further facilitate reorganizing and streamlining business processes. Shipments may be tracked on-line, inventories may be automatically monitored, and suppliers notified when pre-determined levels are reached. Routine business processes become electronic, or on-line, business processes (e-business processes). Many core supply chain processes are widely cited as examples of successful e-business processes that, in turn, are expected to eliminate the process or shift its location among the participants in the supply chain.

An early case study for a distribution firm, for example, found that using computer technologies to track purchases and sales from inventory allowed it to increase productivity, and to economize on the ratio of inventory holdings to sales from inventory (Diewert and Smith 1994). Such efficiencies would allow a business to handle an increase in product or inventory variety without comparable increases in inventory costs.

A series of papers (e.g., Brynjolfsson and Hitt, 2000, and Brynjolfsson and Hitt, 2003) argues that the productivity effects of organizational changes rival the effects of changes in the production process. In another series of papers, Black and Lynch (2001, 2002) conclude that IT and organizational changes affect productivity. Motohashi (1999) reaches a similar conclusion for Japan. However, such measures are rarely found in large data sets that also have good measures of standard production function variables.

Several recent studies suggest that not only are IT and non-IT capital separate productive inputs, but that IT itself is multi-faceted. Japanese businesses have used a range of e-business processes for some time, and research has linked these processes with productivity (Motohashi 2001). New research finds that the impacts of e-business processes depend on the specific process used, and the effects vary over industry and time (Motohashi 2003). In the U.S. trucking industry, a series of papers show that it is important to know not just that IT is used, but also the details of the IT and how it is used (Baker and Hubbard 2003a and 2003b, and Hubbard 2003).

If different uses of IT have different impacts on economic performance, IT capital needs to be more precisely defined to encompass these distinct uses:

(2) $K_{IT} \equiv \Sigma_j K_{ITj}$ where

K_{IT} is total IT input and the K_{ITj} are distinct ways of using IT capital, indexed over j.

Which plants are most likely to use these e-business processes? The vintage capital model hypothesizes that new plants open with the newest, embodied technology, and that plants exit when their productivity becomes too low relative to the new entrants. However, Baily, Hulten, and Campbell (1992) find little evidence for the vintage capital model in examining transition matrices across years in U.S. manufacturing. A variant of the vintage hypothesis suggests that new plants may be more likely to use IT and other advanced technologies. The documented rapid pace of innovation in IT capital could confer an advantage to plants that start with homogeneous and state-of-the-art (or nearly so) IT. Such a homogeneous set-up may be easier to manage. Using up-to-date hardware and software together incorporates lessons learned from previous generations of users, increasing the probability that management and workers make effective use of the new IT capital. Dunne (1994) finds little support for a vintage effect in a study examining the use of a selected group of advanced technologies, while Luque (2002), using the same data, finds a complex relationship among age, plant size, and use of advanced technologies. Recent research finds that new firms invest in capital more intensively than do older firms, and they devote a larger share of their investment budget to IT (Becker *et al.* 2004). However, the database underlying this research is just being developed, and there have been no formal tests of the vintage model.

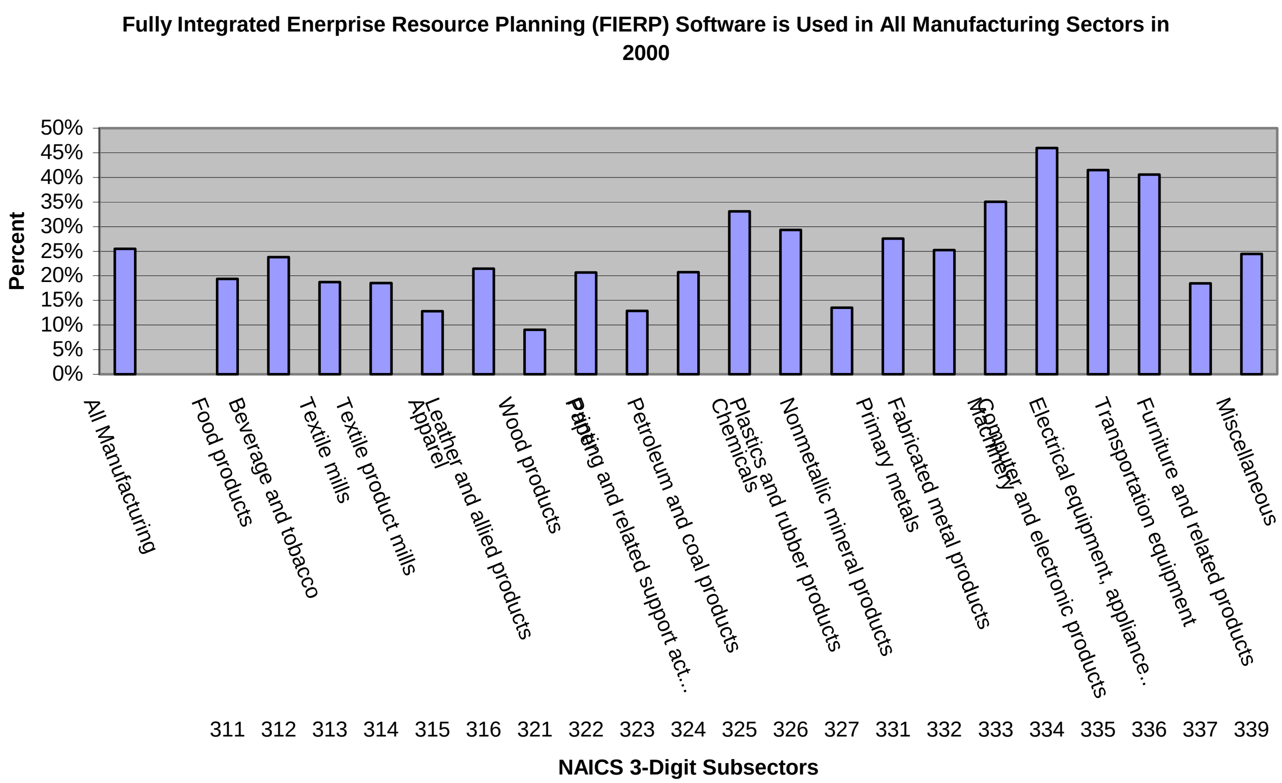
B. **New Stylized Facts on IT Use**

The CNUS data we use in this study are part of a Census Bureau measurement initiative to fill some data gaps on the growing use of electronic devices and networks in the economy (Mesenbourg 2001). Information on the presence of computer networks in U.S. manufacturing plants, and on how plants use those networks, was collected for the first time in the 1999 Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures (ASM). The CNUS data provide the first large-scale picture of the presence of computer networks, and how businesses use them, in U.S. manufacturing. Over 38,000 plants responded to the CNUS survey, with a response rate of 82 percent. Information about the survey, and the survey form, can be found at http://www.census.gov/estats.

Detailed tabulations of CNUS responses are published at http://www.census.gov/estats. Because these tabulations remain relatively unknown, we highlight summary information about two questions: the presence of complex software; and the kinds of business processes run over computer networks.

The CNUS asks plants if they use fully integrated enterprise resource planning software (FIERP), that is, the kind of sophisticated software that links different kinds of business applications (such as inventory, tracking, and payroll) within and across businesses. Figure 1 summarizes information in Table 1 about the use of FIERP software in U.S. manufacturing in 2000. (The CNUS was conducted as a supplement to the 1999 ASM, but the data were collected during 2000, and are thought to reflect usage in 2000). This complex software is found throughout manufacturing. However, FIERP software remains relatively rare compared to computer networks. While about 88 percent of manufacturing plants in our sample have networks, only 26 percent have FIERP software. This average masks variations in use among industries. FIERP was used by fewer than 15 percent of plants in four industries (Apparel; Wood Products; Printing and Related Support Activities; and Nonmetallic Mineral Products), but by least 33 percent of plants in five others (Chemicals; Machinery; Computer and Electronic Products; Electrical equipment, Appliances, and Components; and Transportation Equipment).

Figure 1



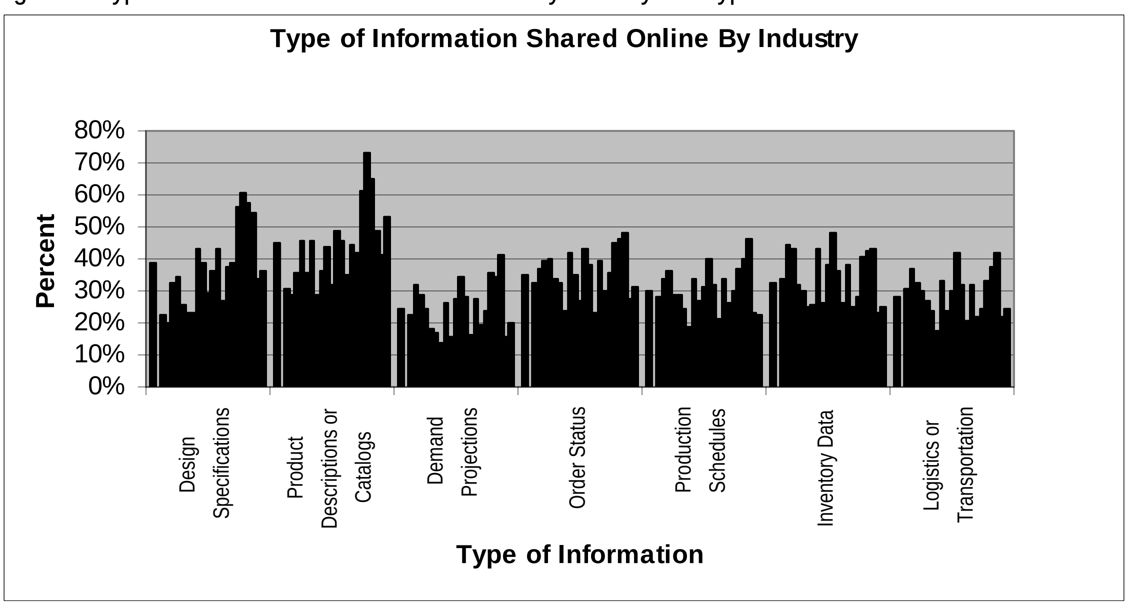
Source: Authors' calculations based on U.S. Census Bureau 2002

The CNUS asks two sets of questions about the range of business processes that plants conduct over their computer networks. The first set contains information about the presence of seven networked processes: Design Specifications; Product Descriptions or Catalogs; Demand

Projections; Order Status; Production Schedules; Inventory Data; and Logistics or Transportation. Plants are asked whether they use these processes to share information with other business units (many U.S. manufacturing plants are part of multi-unit businesses), customers, or suppliers. The second set asks about 28 detailed business processes in five broad groupings. The five groupings in the second set are similar, but not identical, to the seven groupings in the first set.

Each of the seven processes in the first set is used, on average, by at least 24 percent of manufacturing plants, and plants in all 21 manufacturing industries share each kind of process information online (Table 2). Although all processes are used in all industries, usage differs across processes and among industries. One summary of this usage and its heterogeneity is shown in Figure 2. For each process, the first bar is the average for all manufacturing sectors, followed by a space, then bars for each manufacturing industry. Some processes, such as Design Specifications, and Product Descriptions or Catalogs, are much more likely to be shared than are Demand Projections.

Figure 2: Type of Information Shared Online Varies by Industry and Type of Information



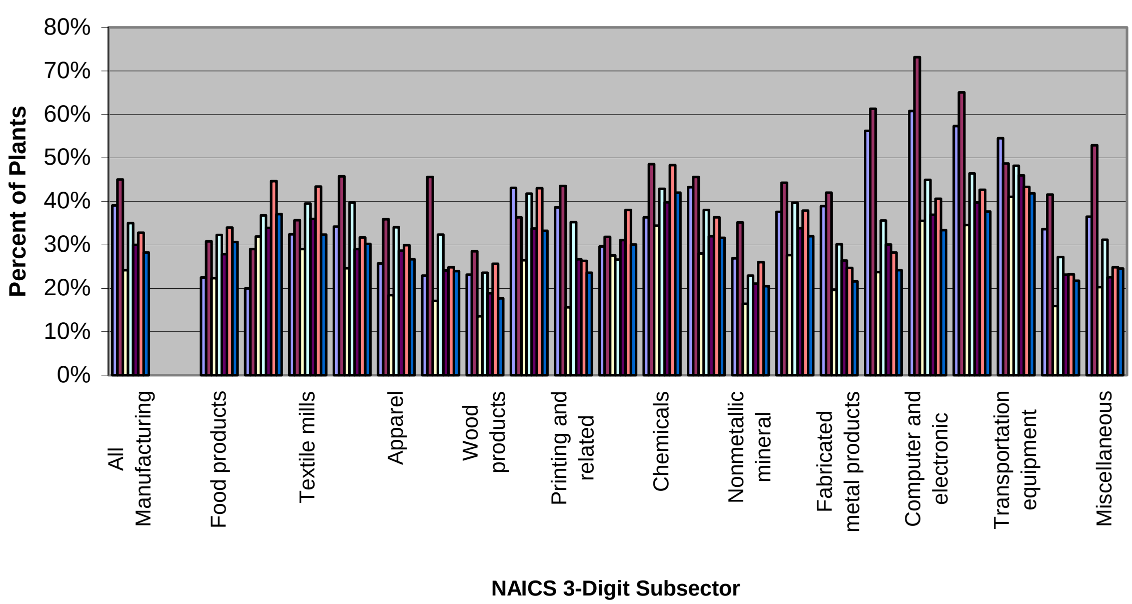
Source: Authors' calculations based on U.S. Census Bureau 2002

The use of each process differs among manufacturing industries. For example, data in Table 2 confirm the visual impression of Figure 2 that a high proportion of manufacturing plants in nearly all industries share information online for some processes, such as Product Descriptions or Catalogs. Sharing is particularly high in Computer and Electronic products (73 percent); Electrical Equipment, Appliances, and Components (65 percent); and Machinery (61 percent). These same industries are among the highest online sharers of several other kinds of e-business process information, such as Design Specifications; Demand Projections; and Order Status.

However, there is less variation among industries for other e-business processes. For example, Inventory Data are shared on-line by 48 percent of plants in Chemicals, 45 percent of plants in Beverage and Tobacco, and 43 percent each in Textile Mills; Paper; Electrical Equipment, Appliances, and Components; and Transportation Equipment.

We present an alternative view of the same information in Figure 3, grouped this time by industry. Manufacturing industries clearly differ in their use of on-line business processes. Some industries make scant use of them (such as Wood, Apparel, and Nonmetallic Metals), while others (such as Machinery, Computer and Electronic Products, and Electrical Equipment) use most of them, and the use of a few processes is widespread within those industries.

Figure 3: Use of On-Line Processes Varies Among Industries



Source: Authors' calculations based on U.S. Census Bureau 2002.

III. Empirical Implementation

We choose the standard Cobb-Douglas production function as the basis of our empirical implementation, extending the specification in our previous empirical models (e.g., Atrostic and Nguyen 2002 and 2003) to include the new measures of IT we develop from the CNUS data. Using this extended specification, we first assess the empirical importance for labor productivity of using integrated enterprise planning software. Next, we estimate the relationship between labor productivity and conducting business processes over computer networks. We begin with an intensity measure to get a broad picture of whether a relationship exists between productivity and e-business processes. Using measures of the presence of specific e-business processes, we check how different processes are associated with productivity. To test the robustness of the empirical results to an alternate measure of networked business processes, we estimate separate regressions using the two sets of e-business process measures. The first part of this section discusses our estimating equations and details of how we specify variables empirically. Our data sources are discussed in the final part of this section.

A. Estimating Equations

We account empirically for important plant characteristics that may significantly affect a plant's labor productivity but are not in our theoretical model. Our specification also reflects the fact that data on critical theoretical variables are not all available for the same year. Our final specification is given in Equation (3):

$$(3) \quad Log(Q/L99) = \beta_0 + \sum_k \beta_{kj}\, EBProcess_{kj} + \alpha_1 log(K/L97) + \alpha_3 log(M/L99) + \alpha_4 log(L99)$$

$$+ \alpha_5 log(MIX99) + \alpha_6 MULTI99 + \alpha_7 log(RLP92(97)) + \sum \gamma_i IND99_i$$

$$+ \sum_k \lambda_{kj}(NEW \times EBProcess_{kj}) + \lambda_1(NEW \times K/L97)$$

$$+ \lambda_2(NEW \times log\,(M/L99)) + \lambda_3(NEW \times log\,(L99))$$

$$+ \lambda_4(NEW \times log(MIX99)) + \lambda_5(NEW \times MULTI99)$$

$+ \sum \delta_i$ (NEW x $IND99_i$) + ε

Equation (3) relates the use of various electronic business processes (EBProcess) to (log) labor productivity. We model these processes as technological shifts in the production function, although they may result from differences in the underlying computer and organizational capital, because neither is measured separately.[1] The β_{kj} are the parameters of interest, where k = 1, 2, 3, defined over three groups of e-business process measures, and j = 1; 1, …, 5; or 1, …, 7; depending on the group, and k indicates the group included in a particular estimate. We view the groups as being increasingly detailed indicators of IT capital, and so include only one group at a time in the estimations. The three groups are described below. Each β_{kj} can be interpreted as measuring the effect on labor productivity of electronic business processes j in the k^{th} group, controlling for the remaining independent variables.

The dependent variable, Q/L99, is gross output labor productivity. It is measured as the value of shipments (Q) divided by total employment (L). Both values come from the 1999 ASM. The first group of explanatory variables is the standard production function variables. K is the book value of capital, measured relative to total employment (L) in 1997. These two variables are taken from the 1997 CM. Intermediate inputs, M, are included, along with total employment (L). MIX is the ratio of non-production to production workers, to proxy for skill mix. MULTI denotes that the plant belongs to a multi-unit firm, RLP is the plant's labor productivity in a prior period relative to its detailed industry, and IND represents the plant's industry. Suffixes of 92, 97, and 99 denote whether data on the variable are available in 1992, 1997, or 1999. A dummy

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[1] Computer investment, a proxy for the flow computer services that is an input to the production function, is available only for a small subset of plants. In previous research (Atrostic and Nguyen 2003), we incorporate this investment variable. We find that computer networks and computer investment have distinct relationships to productivity. We also find that estimates of most inputs and plant characteristics are stable across specifications with and without computer investment. The main exception is the coefficient on MIX, the ratio of non-production to production workers, which is higher in the restricted sample. To allow a large enough sample for meaningful empirical work with the information on electronic business processes, we use in this paper the entire sample of responding plants.

variable, NEW, denotes plants that did not exist in 1992.[2] Details of the construction of these variables are given in Atrostic and Nguyen 2003 and 2004.

We first create dummy variables for the presence of the complex software underlying integrated systems, FIERP, and for the presence of a computer network. Logical cross-classifications of FIERP and the presence of computer networks assure that the FIERP variable picks up a separate dimension of IT capital.

The second group of variables allows us to examine the relationship between productivity and breadth – the number of e-businesses processes a plant uses. That number is likely to considerably among industries, as Figures 1 and 2 suggest. Breadth may proxy for the plant's general sophistication, or the quality of its capital, workforce, or management. We create a set of seven variables, corresponding to the number of processes the plant uses. These variables allow us to examine whether the productivity relationship is monotonic or has a threshold or plateau. We do not have information about how much the plant's operations depend on these processes. Two pieces of evidence suggest that our measure of the number of processes will provide useful information. First, simple correlations among most of the e-business process variables in the CNUS data are 0.4 or less, suggesting that something is different about production in plants that use more or fewer processes. Second, previous research with the SMT shows a correlation of about 0.85 between a count of processes used and the share of a plant's operations that depended on them (Doms *et al.* 1997).

The third group of basic e-business process measures is two sets of dummy variables. The first set is based on responses to the first question about e-business processes in the CNUS. This question asks whether the plant conducts each of seven processes on-line (Design Specifications; Product Descriptions or Catalogs; Demand Projections; Order Status; Production Schedules; Inventory Data; and Logistics or Transportation). The second set of dummy variables

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[2] In the estimating equation (1), labor (L99) enters the denominator of the dependent variable. It also enters the denominator of two of the independent variables, capital intensity (K/L) and materials intensity (M/L), and it enters by itself as an independent variable. If L is measured with error, the coefficient estimates of the equation will be biased. We addressed this issue in Atrostic and Nguyen 2004.

is based on responses to the second question about e-business processes. This question asks about 27 detailed e-business processes, in five groups. We create the second set of five e-business process variables by aggregating responses within the five groups (Purchasing; Product Orders; Production Management; Logistics; and Communication and Support). The simple correlations between the two sets of variable are less than 0.4. Using both sets of dummy variables provides a sensitivity test on the robustness of our empirical findings, and on the number of empirically important dimensions to IT capital.

Interaction terms form the fourth group of variables. We include interactions between NEW and the standard production function terms, such as capital, labor, and multi-unit status because they were empirically important in our previous empirical work. Interacting NEW with the e-business process measures tests the hypothesis that there is a technology vintage effect.

Theory and the empirical literature suggest that computer networks, and specific uses of those networks, are likely to be endogenous. We addressed the potential endogeneity of the presence of computer networks in prior research using a two-step procedure that yields consistent estimates (Atrostic and Nguyen 2004a). A common empirical result is that the implied effect estimated with a two-step procedure falls, perhaps to the point of statistical insignificance, compared to the OLS estimate (e.g., Griliches and Mairesse 1995). However, in our data, the implied effect from the two-step procedure is about twice as great as from the OLS procedure (3.3 percent vs. 6.6 percent) (Atrostic and Nguyen 2004a). This finding holds when we include computer investment as a proxy for the services of computer capital, in the best sample with computer capital information that the data allow us to make (Atrostic and Nguyen 2003). The implied effect of computer networks continues to be positive and significant, and is roughly twice as large (6.6 percent versus 12.4 percent).[3] To focus on e-business processes, we base estimates in this paper on the most complex OLS specification in our previous work. The robustness of our previous OLS estimates suggests that these OLS estimates are unlikely to overstate the relationship between e–business processes and labor productivity.

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[3] Brynjolfsson and Hitt 2003 report similar findings between OLS and IV estimates of coefficients of computer investment.

B. Data Used in Estimations

Respondents' answers to CNUS questions about networks can be linked to the information the same respondents reported on regular Annual Survey of Manufactures (ASM) survey forms, such as the value of shipments, employment, and materials, and to their responses to the Census of Manufactures (CM). The appendix contains more information on the 1999 CNUS, 2000 ASM, and the 1992 and 1997 CM. Our empirical work is based on about 27,000 manufacturing plants for which we have information on their use of computer networks and other key variables.

IV. Empirical Findings

How businesses use IT matters: Different e-business processes have distinct effects on productivity. This result holds under the several measures of e-business processes in our data, and under alternative empirical specifications. We present our findings in Tables 4, 5, and 6. We report in the tables, but do not discuss in the text, the coefficients of most standard explanatory variables. The coefficient estimates are very close to those estimated in our previous papers, and change very little across the specifications in this paper.

FIERP. Plants running software systems that connect multiple kinds of business processes (FIERP) have labor productivity that is roughly 4.5 percent higher than in plants with networks but without FIERP. (The coefficient of FIERP in column 1 of Table 4 is 0.0445). We control for the presence of computer networks, prior conditions, and many characteristics of the plants. A significant relationship continues to hold between FIERP and productivity when we interact the vintage variable “NEW” with FIERP, the computer network variable, and the standard production function input variables. The interaction terms with FIERP and the network variable are not statistically significant. The effect of FIERP remains about 4.5 percent in this specification, and significant (the coefficient of FIERP is 0.0435, reported in column 2).

These findings suggest that FIERP software may be a distinct form of IT capital. The use of FIERP may also signal that plants modified or re-engineered their processes, perhaps to take advantage of the software’s capabilities. Plants using such software may adopt the software to carry out newly re-engineered processes, or as a way of carrying out the re-engineering, as their business processes adapt to the software (Wright *et al.* 1998). Using FIERP requires a large commitment by the plant to linking its business processes electronically, but we do not know which of those processes are linked by FIERP in a specific plant. Nor is FIERP required to link processes that may have a large impact on productivity. To examine these issues further, we turn to information in the CNUS about the number of specific business processes that the plant conducts on-line, that is, over computer networks.

Breadth. We find that breadth – the number of processes conducted on-line – is related to productivity, but not monotonically. Using one process has a statistically significant but small productivity impact; the coefficient of 0.0077 is shown in column 3 of Table 4. Using more processes has little impact until four processes are used, at which point the productivity impact appears to plateau. Productivity is about four percent higher in plants with four or more on-line processes (the coefficients range from 0.0340 to 0.0377). Our findings are consistent with those of McGuckin et al. (1998) that plants using advanced technologies more extensively have higher productivity.[4] As with FIERP, we test for vintage effects by interacting NEW with other standard explanatory variables, and with the breadth measures. The coefficient of NEW again changes sign, becoming positive, significant, and large (0.1798). The coefficients of the breadth measures no longer are statistically significant, and their absolute magnitudes are much smaller. Also, the coefficients of most interaction terms between the breadth measures and NEW are not statistically significant. While productivity appears to be higher in newer plants in this specification, it seems unlikely that the productivity advantage of new plants comes from e-business processes.

Specific e-business processes. Does it matter which processes the plant conducts on-line? To examine the separate impact of conducting different processes on-line, we enter each of the seven e-business processes in our empirical specification as independent variables. We find

[4] They also find that intensity of advanced technology use is associated with higher productivity, and that both intensity and extensiveness appear to be independent factors. McGuckin *et al.* use a measure of intensity reflecting the share of the plant's operations to which the technologies are applied, while we use a count measure, but Doms *et al.*1997 find the two measures closely correlated in the data used by those two studies.

that different e-business processes have different productivity impacts (column 1 of Table 5). Productivity is higher in plants using computer networks to control supply chain activities such as inventory, transportation, and logistics.

Our findings for the remaining processes are somewhat surprising. The extensive comment and focus on "e-commerce" – selling on-line – might lead one to expect that processes associated with it would be related to productivity. However, we find that the coefficients either are not statistically significant (for on-line catalogs and monitoring order status), or are small (for design projections, whose coefficient of 0.0113 is significant at the 10 percent level). These findings are consistent with new results for the United Kingdom (Clayton, Criscuolo, Goodrich, and Waldron 2003), where selling on-line has a negative productivity effect while buying on-line has a positive effect.[5]

Using e-business processes to communicate about production processes does not appear to affect productivity. The coefficient is not significant, and is small (0.0113). This finding is not consistent with, for example, findings by Motohashi (2001) for Japan and Greenan and Mairesse (1996) for France, which suggest a strong productivity effect from using computers or e-business processes for core production processes, and not for other processes. The initial research for Japan, however, was based on a single year of data. New results, based on a 10-year panel, suggest more complex relationships between e-business processes and productivity, and that these relationships vary over time and among industries (Motohashi 2003). The empirical results for the final process, sharing design specifications online, are somewhat surprising. Plants sharing these processes online have significantly lower productivity, although the coefficient of –0.0164 means that the magnitude is small.

Our main findings about the differential impact of e-business processes largely hold when we interact the vintage variable, NEW, with other explanatory variables and with the e-business

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[5] The U.K. results are not fully comparable, however, because their data only contain information about buying and selling on-line, and not about any of the other e-business processes for which we have information in the CNUS data.

process variables. Many e-business processes, and the coefficients of most interaction terms with e-business processes, do not have significant or substantial links to productivity. Sharing designs on-line continues to have a negative and significant coefficient (-0.0245, reported in column 2 of Table 5). On-line logistics and transportation processes continue to have a positive impact of roughly three percent.

Robustness. The rich information in the CNUS allows us to test the robustness of these findings with an alternate set of five e-business processes (Purchasing; Product Orders; Production Management; Logistics; and Communication and Support). The results, reported in Tables 5 and 6, yield the same broad patterns of significance, and the coefficients are broadly similar in size.

Coefficients from the specifications with the breadth measure based on these five e-business process variables are reported in columns 3 and 4 of Table 5. To make it easier to compare empirical results across the two groups of variables, we repeat the results from the breadth specification for the first group of seven processes in columns 1 and 2 of Table 5. Productivity is higher in plants using more e-business processes; the coefficients all are positive and significant. Productivity is about two percent higher in plants using any one of these five e-business processes. The productivity impact increases with the number of processes used, reaching roughly 6.4 percent for plants using all five e-business processes. This pattern holds when we interact the standard and e-business variables with NEW. Most of the e-business process variables in this group remain significant in the specification that includes interactions with NEW (column 4), but none of the (unreported) interaction terms between the e-business process variables and NEW are significant.

Like the seven e-business processes in the first group, the five processes in this group have distinct productivity impacts. We find that those impacts are similar between the two groups. Supply chain processes – on-line purchasing, logistics, and communication and support – again are positively and significantly associated with labor productivity, with coefficients of 0.0171, 0.0191, and 0.0313. Using e-business processes to manage production has no significant impact, and the coefficient is small (-.0049), while processes associated with taking product orders on-line are negatively and significantly related to productivity, although the effect is small (-0.0098).

The effects of adding interaction terms with vintage are reported in column 4. The coefficient on product order processes remains negative but loses statistical significance, and coefficients on the production management remains insignificant. Supply chain processes -- Purchasing; Logistics; and Communication and Support – remain positive and statistically significant. As before, we find evidence that productivity is higher in new plants (the coefficient of NEW is positive and significant), but little to suggest that the difference is due to IT (none of the (unreported) coefficients of interaction terms significant).

V. Discussion

Our empirical findings suggest that electronic business processes may be viewed as new technologies that shift the production function. The productivity impacts we observe could be due to the use of technologies, organizational structures, or management capabilities that are not measured. Such omissions would tend to bias the coefficients towards zero (Griliches and Mairesse 1995). We find instead that several of these technologies, across several specifications and measures, have statistically significant, positive, and economically meaningful impacts. We also find that different e-business processes have distinct impacts on productivity. To assess these findings, we compare them with those of other researchers. We then discuss what our findings imply for measuring IT capital.

Because collecting information about production processes and detailed forms of IT capital (and IT spending) is relatively rare for official statistical organizations, there are few studies whose findings are directly comparable to ours. While McGuckin *et al.* (1998) touches on the link between productivity and how computers are used in selected U.S. manufacturing industries, the SMT data do not allow them to separate the use of computer networks from other uses of computers and advanced technologies. Moreover, Doms, Dunne, and Troske (1997) stress that the advanced technologies measured in the SMT data should not be interpreted as computer technologies.

Our findings are consistent with results with other data sets and other countries. Research for France (Greenan and Mairesse 1996) finds that the specific business processes in which businesses use computers matter. Applying networks to core production processes appears to be linked to productivity for French firms, while networking "back office" operations such as personnel or bookkeeping are not. Motohashi (2001 and 2003) is one of the few other studies with a large and nationally representative sample of firm-level data on how businesses use computer networks. Initial research for Japan (Motohashi 2001) found results similar to those of Greenan and Mairesse 1996, but more recent research yields a picture that is more mixed, with productivity effects varying across industries, over time, and among processes (Motohashi 2003).

Our empirical results suggest a strong link between the use of IT and productivity, and that the links differ for different forms of IT. There may be other reasons for the relationships we observe. For example, these plants may be making other complementary investments in re-engineering their business processes or increasing the skill level of their workforce. Our data do not allow us to test these alternative hypotheses.

The new data on how businesses use computer networks narrow important gaps in the data we need to understand how information technology affects plant-level productivity. But measuring business processes, standard technologies, and detailed forms of IT capital are relatively new activities for statistical organizations. Previous experience collecting any such information was a decade ago, when the U.S. Census Bureau sampled roughly 38,000 plants in the 1988 and 1993 Surveys of Manufacturing Technology (SMT), and was limited to five two-digit SIC industries.

The new e-business process measures collected in the CNUS generally capture important dimensions of modern computer capital inputs to the production process. Because detailed measures of computer and other high-tech capital are just beginning to become available in the micro data underlying official statistics, it is important to test the robustness of specific definitions and measures. The two sets of e-business processes measures in the CNUS data provide the raw material for one robustness test. Although the two sets of measures have similar-sounding categories, correlations between the two sets of categories are not strong. Not surprisingly, we find that the two sets of measures yield somewhat different results. One result emerges clearly from both sets of measures: Plants using e-business processes to conduct supply-chain functions have higher labor productivity.

Our analyses of the multiple measures in the CNUS data also show that there is more to be learned about measuring e-business processes and other dimensions of computer capital. Repeating a CNUS-type supplement would provide an opportunity to examine such methodological issues. Equally importantly, collecting a second supplement would provide the two periods of data required for more rigorous econometric testing of the productivity impact of different forms of IT capital.

VI. Conclusions

Different uses of IT have different impacts on productivity. Using computer networks to run the kind of business-wide software that allows multiple business processes to be coordinated within a business unit and across related businesses is associated with higher labor productivity. This positive software effect is in addition to the productivity gain associated with having a computer network.

Using the network to conduct business processes on-line (that is, to run e-business processes) is associated with higher labor productivity, and productivity increases with the number of on-line processes. The productivity effect of individual on-line processes varies. Supply-chain processes such as inventory control and logistics monitoring have strong positive links to productivity. These links are stable across econometric specifications. They also are economically consequential, with each process associated with a separate two to three percent increase in productivity. However, using the network to conduct other processes, such as using on-line processes to monitor production, shows no empirical relationship to productivity, and sharing design specifications on-line has a surprising negative relationship that is consistent across specifications.

We find evidence that, controlling for IT and other variables, younger plants have higher productivity. However, that higher productivity does not appear to come through the use of IT and e-business processes. The CNUS data do not allow us to determine the factors, such as better management, higher degrees of complementary investments, or better-skilled workers, contributing to the higher productivity for these plants. A second CNUS supplement would allow us to apply econometric techniques that control for endogeneity in multi-period data. These techniques would allow us to address more precisely questions such as whether better plants use e-business processes, or whether using these processes makes plants more productive.

Future research will link the plants in the CNUS with their responses to questions about supply-chain activities performed in the plant that were asked in the 2002 Census of Manufactures, when those data become available. The linked data will allow us to assess the quality of responses about supply-chain processes in the CNUS data and refine the inferences we draw from the CNUS data that conducting supply-chain processes over computer networks is positively and significantly linked to productivity.

VII. References

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VIII. Tables

Table 1
Share of Plants Using Fully Integrated Enterprise Resource Planning (FIERP) Software in 2000 by Manufacturing Subsector

NAICS Code	Description	Use FIERP
	All Manufacturing	26%
311	Food products	19%
312	Beverage and tobacco	24%
313	Textile mills	19%
314	Textile product mills	19%
315	Apparel	13%
316	Leather and allied products	21%
321	Wood products	9%
322	Paper	21%
323	Printing and related support activities	13%
324	Petroleum and coal products	21%
325	Chemicals	33%
326	Plastics and rubber products	29%
327	Nonmetallic mineral products	13%
331	Primary metals	28%
332	Fabricated metal products	25%
333	Machinery	35%
334	Computer and electronic products	46%
335	Electrical equipment, appliances, and components	41%
336	Transportation equipment	41%
337	Furniture and related products	18%
339	Miscellaneous	24%

Source: Authors' tabulations, based on U.S. Census Bureau, *1999 E-business Process Use by Manufacturers Final Report on Selected Processes* (March 1, 2002), www.census.gov/estats.

Data are based on the North American Industry Classification System (NAICS)

Table 2

Percentage of Manufacturing Plants that Share Information Online with Customers or Suppliers, By Type of Information

NAICS Code	Description	6a Design Specifications	7a Product Descriptions or Catalogs	8a Demand Projections	9a Order Status	10a Production Schedules	11a Inventory Data	12a Logistics or Transportation
	All Manufacturing	39%	45%	24%	35%	30%	33%	28%
311	Food products	22%	31%	22%	32%	28%	34%	31%
312	Beverage and tobacco	20%	29%	32%	37%	34%	45%	37%
313	Textile mills	32%	36%	29%	39%	36%	43%	32%
314	Textile product mills	34%	46%	25%	40%	29%	32%	30%
315	Apparel	26%	36%	18%	34%	29%	30%	27%
316	Leather and allied products	23%	46%	17%	32%	24%	25%	24%
321	Wood products	23%	29%	14%	24%	19%	26%	18%
322	Paper	43%	36%	26%	42%	34%	43%	33%
323	Printing and related support activities	39%	44%	16%	35%	27%	26%	24%
324	Petroleum and coal products	30%	32%	28%	27%	31%	38%	30%
325	Chemicals	36%	49%	34%	43%	40%	48%	42%
326	Plastics and rubber products	43%	46%	28%	38%	32%	36%	32%
327	Nonmetallic mineral products	27%	35%	16%	23%	21%	26%	20%
331	Primary metals	38%	44%	28%	40%	34%	38%	32%
332	Fabricated metal products	39%	42%	20%	30%	26%	25%	22%
333	Machinery	56%	61%	24%	36%	30%	28%	24%
334	Computer and electronic products	61%	73%	35%	45%	37%	41%	33%
335	Electrical equipment, appliances, and components	57%	65%	35%	46%	40%	43%	38%
336	Transportation equipment	55%	49%	41%	48%	46%	43%	42%
337	Furniture and related products	34%	42%	16%	27%	23%	23%	22%
339	Miscellaneous	36%	53%	20%	31%	23%	25%	25%

Table 3. Summary Statistics on Software and On-Line Business Processes In U.S. Manufacturing Plants 2000

Variable	Mean*	Employment Share of Plants*
Fully Integrated Resource Planning Software (FIERP)	**26%**	**39%**
On-Line Business Processes		
Design Specifications	**39%**	**53%**
Product Descriptions or Catalog	**45%**	**55%**
Demand Projections	**24%**	**54%**
Order Status	**35%**	**51%**
Production Schedules	**30%**	**46%**
Inventory Data	**33%**	**49%**
Logistics or Transportation	**28%**	**45%**

Source: Authors' tabulations, based on U.S. Census Bureau, *1999 E-business Process Use by Manufacturers Final Report on Selected Processes* (March 1, 2002), www.census.gov/estats.

* Based on plants responding to specific questions, so underlying counts differ

Table 4. Labor Productivity Regressions: FIERP Software and Breadth of Process Use
Dependent Variable: Gross Output Labor Productivity

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.14445	**	2.969	**	3.1670	**	3.0059	**
Log (K/L97)	0.0642	**	0.0739	**	0.0632	**	0.0726	**
Log (M/L)	0.4310	**	0.4556	**	0.4307	**	0.4550	**
Log (L)	-0.0058	**	-0.0057	&	-0.0089	**	-0.0100	**
Log (Mix)	0.0349	**	0.0371	**	0.0351	**	0.0369	**
MULTI	0.0733	**	0.0908	**	0.0704	**	0.0861	**
New	-0.0498	**	0.1986	**	-0.0495	**	0.1798	**
New x (Standard Inputs Above)	No		Yes		No		Yes	
Log (RLP92)	0.2127	**	.02123	**	0.2121	**	+0.2117	**
Network only	0.0389	**	0.0467	**	(--)	(--)	(--)	(--)
FIERP & Network	0.0445	**	0.0435	**	(--)	(--)	(--)	(--)
New x (Network Only)	No		-0.0098		(--)	(--)	(--)	(--)
New x (FIERP & Network)	No		0.0054		(--)	(--)	(--)	(--)
Breadth Index: Uses N processes								
1	(--)	(--)	(--)	(--)	0.0077	**	0.0052	
2	(--)	(--)	(--)	(--)	-0.0073		0.0030	
3	(--)	(--)	(--)	(--)	0.0056		-0.0087	
4	(--)	(--)	(--)	(--)	0.0174	*	-0.0146	
5	(--)	(--)	(--)	(--)	0.0377	**	-0.0123	
6	(--)	(--)	(--)	(--)	0.0357	**	-0.0057	
7	(--)	(--)	(--)	(--)	0.0340	**	-0.0074	
New x Breadth Index	(--)	(--)	(--)	(--)	No		Yes	
R^2	0.8133		0.8144		0.8134		0.8149	
Industry (3-Digit NAICS)	Yes		Yes		Yes		Yes	
Number of Plants	26799		26799		26799		26799	

** significant at the 1% level
* significant at the 5% level
& significant at the 10% level

Table 5. Labor Productivity Regressions: Two Sets of E-Business Processes
Dependent Variable: Gross Output Labor Productivity

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.1804	**	3.024	**	3.1579	**	2.9945	**
Log (K/L97)	0.0634	**	0.0729	**	0.0630	**	0.0723	**
Log (M/L)	0.4312	**	0.4537	**	0.4308	**	0.4555	**
Log (L)	-0.0069	**	-0.0083	**	-0.0086	**	-0.0094	**
Log (Mix)	0.0367	**	0.0393	**	0.0349	**	0.0364	**
MULTI	0.0685	**	0.0848	**	0.0718	**	0.0884	**
New	-0.0496	**	0.1700	**	-0.0497	**	0.1813	**
New x (Standard Inputs Above)	No		Yes		No		Yes	
Log (RLP92)	0.2122	**	0.2118	**	0.2120	**	0.2115	**
E-Business Process Group 1								
Design	--0.0164	**	-0.0245	**	(--)	(--)	(--)	(--)
Catalog	0.0072		0.0061		(--)	(--)	(--)	(--)
Demand projections	0.0113	&	0.0206	&	(--)	(--)	(--)	(--)
Order status	-0.0097		-0.0004		(--)	(--)	(--)	(--)
Production schedules	0.0113		0.0130		(--)	(--)	(--)	(--)
Inventory data	0.0277	**	0.0153		(--)	(--)	(--)	(--)
Logistics or transportation	0.0259	**	0.0310	**	(--)	(--)	(--)	(--)
E-Business Process Group I1								
Purchasing	(--)	(--)	(--)	(--)	0.0171	**	0.0259	**
Product Orders	(--)	(--)	(--)	(--)	-0.0098	**	-0.0048	**
Production management	(--)	(--)	(--)	(--)	0.0049		-0.0058	
Logistics	(--)	(--)	(--)	(--)	0.0191	**	0.0276	**
Communication and Support	(--)	(--)	(--)	(--)	0.0313	**	0.0236	**
Industry (3-Digit NAICS)	Yes		Yes		Yes		Yes	
R^2	0.8139		0.8150		0.8137		0.8148	
Number of Plants	26799		26799		26799		26799	

** significant at the 1% level
* significant at the 5% level
& significant at the 10% level
.

Table 6. Labor Productivity Regressions: Two Measures of Breadth of Process Use
Dependent Variable: Gross Output Labor Productivity

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.14445	**	2.969	**	3.151	**	2.988	**
Log (K/L97)	0.0642	**	0.0739	**	0.0635	**	0.0730	**
Log (M/L)	0.4310	**	0.4556	**	0.4310	**	0.4557	**
Log (L)	-0.0058	**	-0.0057	&	-0.0083	**	-0.0091	**
Log (Mix)	0.0349	**	0.0371	**	0.0344	**	0.0358	**
MULTI	0.0733	**	0.0908	**	0.0727	**	0.0898	**
New	-0.0498	**	0.1986	**	-0.0496	**	0.1804	**
New x (Standard Inputs Above)	No		Yes		No		Yes	
Log (RLP92)	0.2127	**	.02123	**	0.2123	**	0.2119	**
Breadth Index 1: Uses N of 7 processes from Group 1								
1	0.0077	**	0.0052		(--)	(--)	(--)	(--)
2	-0.0073		0.0030		(--)	(--)	(--)	(--)
3	0.0056		-0.0087		(--)	(--)	(--)	(--)
4	0.0174	*	-0.0146		(--)	(--)	(--)	(--)
5	0.0377	**	-0.0123		(--)	(--)	(--)	(--)
6	0.0357	**	-0.0057		(--)	(--)	(--)	(--)
7	0.0340	**	-0.0074		(--)	(--)	(--)	(--)
New x Breadth Index 1	No		Yes					
Breadth Index 2: Uses N of 5 processes from Group 2								
1	(--)	(--)	(--)	(--)	0.0233	**	0.0091	
2	(--)	(--)	(--)	(--)	0.0452	**	0.0347	*
3	(--)	(--)	(--)	(--)	0.0446	**	0.0407	**
4	(--)	(--)	(--)	(--)	0.0553	**	0.0546	**
5	(--)	(--)	(--)	(--)	0.0623	**	0.0607	**
New x Breadth Index 2					No		Yes	
R^2	0.8133		0.8144		0.8136		0.8147	
Industry (3-Digit NAICS)	Yes		Yes		Yes		Yes	
Number of Plants	26799		26799		26799		26799	

** significant at the 1% level
* significant at the 5% level
& significant at the 10% level