How Businesses Use Information Technology: Insights for Measuring Technology and Productivity

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Abstract

Business use of computers in the United States dates back fifty years. Simply investing in information technology is unlikely to offer a competitive advantage today. Differences in how businesses use that technology should drive differences in economic performance. Our previous research found that one business use – computers linked into networks – is associated with significantly higher labor productivity. In this paper, we extend our analysis with new information about the ways that businesses use their networks. Those data show that businesses conduct a variety of general processes over computer networks, such as order taking, inventory monitoring, and logistics tracking, with considerable heterogeneity among businesses. We find corresponding empirical diversity in the relationship between these on-line processes and productivity, supporting the 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. The productivity impacts differ by plant age, with higher impacts in new plants. This new information about the ways businesses use information technology yields vital raw material for understanding how using information technology improves economic performance.

Keywords: Information Technology; E-business Processes; Productivity;

* ***Disclaimer:*** This paper reports the results of research and analysis undertaken by the authors. It has undergone a more limited review than official publications. We have benefitted from the comments of our discussant, Ian Meade, and other participants at the SSHRC International Conference on Index Number Theory and Measurement of Prices and Productivity. Opinions expressed are those of the authors and do not necessarily represent the official position of the U.S. Census Bureau. This report is distributed to inform interested parties of research and to encourage discussion.

I. Introduction

Businesses in the United States have used computers for fifty years. Links between labor productivity and the use of computers and other information technology (IT) have been established by empirical studies such as Jorgenson (2001) and Triplett and Bosworth (2002), in the aggregate, and by studies summarized in Stiroh (2003) and Pilat (2004) at the business unit level. The prevalence of IT means that just investing in IT no longer confers a competitive advantage. Differences in economic performance should depend instead on differences in the ways businesses use IT. Recent studies by Motohashi (2001) and (2003) support this hypothesis for Japan.

We test the hypothesis that different uses of IT have different economic impacts. New information on how U.S. manufacturing plants use computer networks 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 the CNUS can be linked to their responses to the ASM and the Census of Manufactures (CM), allowing us to examine the relationship between productivity and different uses of computer networks.

Our previous research using the CNUS data, reported in Atrostic and Nguyen (2005), found that productivity is about four percent higher in plants with networks, after accounting for multiple factors of production and plant characteristics. The effect on productivity is about twice as high when we account for the potential endogeneity of the computer network. A positive and significant relationship between computer networks and productivity continues to hold when we account for investment in computers in Atrostic and Nguyen (2006).

This paper makes several important contributions. First, ours is the first study linking productivity to specific ways that U.S. manufacturing plants use computer networks. Only one previous study, McGuckin *et al.* (1998), examined the link between productivity and how computers were used. However, that study was limited to five two-digit manufacturing industries examined in 1988 and 1993, and could not separate the use of computer networks from other uses of computers and advanced technologies. Second, because the rich CNUS data are new and little known, we present summary statistics that document the heterogeneity in the ways that plants use computer networks. Third, we extend our previous models of the productivity impact of computer networks to include the new CNUS information about the ways plants use those networks.

Our research yields strong empirical support for the hypothesis that the heterogeneity of IT – different ways of using computer networks – leads to corresponding heterogeneity in economic performance. First, labor productivity is significantly higher in plants running sophisticated software designed to integrate multiple business processes such as inventory and production than in plants that only have computer networks. Second, productivity is significantly higher in plants that conduct more processes over networks. Third, the productivity 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 broadly consistent across two sets of indicators of networked business processes, although empirical differences between them need further methodological research. These findings also are robust to alternative empirical specifications.

Our findings show that the CNUS data provide new insights into the sources of productivity. This finding is valuable to statistical agencies in the United States and in other countries, many of which recently collected or are planning to collect similar data. Periodically collecting information about the ways businesses use computer networks would yield vital raw material for understanding how using IT improves economic performance.

II. New Stylized Facts about IT Use

The new CNUS data show that plants use computer networks in myriad ways, including running complex software that links multiple processes, and conducting specific business processes over their networks. This section presents a few stylized facts about business use of computer networks. Detailed tabulations of CNUS responses are published at http://www.census.gov/estats.

FIERP Software. Fully integrated enterprise resource planning software (FIERP) is the kind of sophisticated software that links different kinds of business applications (such as inventory, tracking, and payroll) within and across plants. Figure 1 summarizes information from the CNUS that is presented in Table 1 about the presence of FIERP software in U.S. manufacturing in 2000.[1]

Stylized fact 1. FIERP software is found throughout manufacturing, although it remains relatively rare compared to computer networks. While about 88 percent of manufacturing plants in our sample have networks, only 26 percent have FIERP.

Stylized fact 2. The 26 percent 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 at least 33 percent of

[1] 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.

plants in five others (Chemicals; Machinery; Computer and Electronic Products; Electrical equipment, Appliances, and Components; and Transportation Equipment).

Specific E-Business Processes. The CNUS asks two questions about two sets of such e-business processes. The first set contains information about the presence of seven networked processes: 1) Design Specifications; 2) Product Descriptions or Catalogs; 3) Demand Projections; 4) Order Status; 5) Production Schedules; 6) Inventory Data; and 7) Logistics or Transportation. Plants are asked whether they use these processes to share information with other production 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: 1) Purchasing; 2) Product Orders; 3) Production Management; 4) Logistics; and 5) Communication and Support. These five groupings are similar, but not identical, to the seven groupings in the first set.

Stylized fact 3. All processes are used in all industries. 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).

Stylized fact 4. Usage differs across processes. 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 are much more likely to be shared (e.g., Design Specifications (39 percent, on average) and Product Descriptions or Catalogs (45 percent)) than are Demand Projections (24 percent).

Sylized fact 5. Usage differs across industries. Data in Table 2 confirm the visual impression of Figure 2 that 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.

An alternative view of the same information is given in Figure 3, which groups the processes by industry. Manufacturing industries clearly differ in their use of on-line business processes. Some industries make scant use of them. For example, usage ranges from 14 percent to 29 percent in Wood products, from 18 to 36 percent in Apparel, and from 16 to 35 percent Nonmetallic Metals. Other industries use most of these processes. Usage ranges from 24 to 61 percent in Machinery, from 33 to 73 percent in Computer and Electronic Products, and from 35 to 65 percent in Electrical Equipment. A few processes are widely used within those industries. Design Specifications are shared by at least 56 percent of plants in these three industries, and Product Descriptions or Catalogs are shared by at least 61 percent.

III. Linking IT and Productivity

Although the empirical literature finds links between IT and productivity at both aggregate and business unit levels, there is little evidence on how that link works. One hypothesis is that IT may be a productivity-enhancing general-purpose technology found across economic sectors, as proposed, for example, by Breshnahan and Trajtenberg (1995) and Bresnahan and Greenstein (1997). A characteristic of general-purpose technologies is facilitating complementary investments, as discussed in Brynjolfsson and Hitt (2000). In the case of IT, these complementary investments may include reorganizing or streamlining existing business processes such as order taking, inventory control, accounting services, and tracking product delivery. The IT and complementary investments together yield computers linked into networks that further facilitate reorganizing and streamlining business processes. These networks may track shipments on-line, automatically monitor inventories, and notify suppliers when pre-determined inventory levels are reached. Routine business processes that are networked 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, Diewert and Smith (1994), 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. 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 by Brynjolfsson and Hitt (2000, 2003) argues that the productivity effects of parallel organizational changes rival the effects of changes in the production process. In another series of papers, Black and Lynch (2001, 2005) conclude that IT and organizational changes affect productivity. However, measures of organizational change are rarely found in data sets that also have good measures of standard production function variables.

Several recent studies suggest that IT itself is multi-faceted. Japanese businesses have used a range of e-business processes for some time. Initial research by Motohashi (2001) linked these processes with productivity. Recent research by Motohashi (2003) examines a longer time period. The new research finds that the impacts of e-business processes depend on the specific process used, and the effects vary over industry and time. The U.S. trucking industry uses several kinds of on-board computers that offer different functions. A series of papers by Baker and Hubbard (2003a and 2003b) and Hubbard (2003) analyze computer use in this industry. They 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.

Which plants are most likely to use these distinct 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. 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.

The slender empirical evidence is mixed. Baily, Hulten, and Campbell (1992) find little empirical evidence for the vintage capital model in examining transition matrices across years in U.S. manufacturing. 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 by Becker *et al.* (2004) 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. However, the database underlying this research is just being developed, and there have been no formal tests of the vintage model.

IV. Empirical Implementation

The main contribution of this paper is using the CNUS information to test the hypothesis that IT as a multi-faceted technology, where different uses of computer networks are different technologies that shift the production function. We base our empirical implementation on a standard Cobb-Douglas production function that we extend to take account of the features of our data. First, we 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 and then use measures of the presence of specific e-business processes. Finally, we test the robustness of the empirical results to an alternate measure of networked business processes by estimating separate regressions using two sets of e-business process measures.

A. Theoretical Model

Our core model is a three-factor Cobb-Douglas production function

(1) $Q = AK^{\alpha_1}L^{\alpha_2}M^{\alpha_3}$

where Q, K, L, and M denote output, capital, labor, and materials. The parameters α_1, α_2 and α_3 represent output elasticities of capital, labor, and materials. A is the usual "technological change" term, which is specified as a function of IT such that

(2) $A = \exp(\beta_0 + \beta_1 IT)$.

Consistent with the new stylized facts from the CNUS data, we extend this model to allow different uses of IT to have different impacts on economic performance. The distinct uses of IT in our data are the separate e-business processes (*EBProcess*). We incorporate them by rewriting the technological change term, A, as:

(3) $A = \exp(\beta_0 + \sum_k \beta_{kj} \mathit{EBProcess}_{kj})$

B. Estimating Equations

Our empirical specification accounts for important plant characteristics that may significantly affect a plant's labor productivity but are not in our theoretical model. That specification, given in Equation (4), also reflects the fact that the necessary variables are collected in various years:

$$
\begin{aligned}
(4) \qquad \mathrm{Log}(Q/L99) = {} & \beta_0 + \textstyle\sum_k \beta_{kj}\,\mathrm{EBProcess}_{kj} + \alpha_1 \log(K/L97) + \alpha_3 \log(M/L99) + \alpha_4 \log(L99) \\
& + \alpha_5 \log(MIX99) + \alpha_6 \mathrm{MULTI99} + \alpha_7 \log(RLP92(97)) + \textstyle\sum \gamma_i \mathrm{IND99}_i \\
& + \textstyle\sum_k \lambda_{kj}(\mathrm{NEW} \times \mathrm{EBProcess}_{kj}) + \lambda_1(\mathrm{NEW} \times \log(K/L97)) \\
& + \lambda_2(\mathrm{NEW} \times \log(M/L99)) + \lambda_3(\mathrm{NEW} \times \log(L99)) \\
& + \lambda_4(\mathrm{NEW} \times \log(MIX99)) + \lambda_5(\mathrm{NEW} \times \mathrm{MULTI99}) \\
& + \textstyle\sum \delta_i (\mathrm{NEW} \times \mathrm{IND99}_i) + \varepsilon
\end{aligned}
$$

E-business process variables. Equation (4) relates the use of various electronic business processes (EBProcess) to (log) labor productivity in 1999. The parameters of interest are the coefficients of the e-business processes, the β_{kj}, which we model as technological shifts in the production function. The β_{kj} are defined over three groups of business process measures k = 1, 2, 3, included in a particular estimate, and j = 1; 1, …, 5; or 1, …, 7; depending on the group. The groups are increasingly detailed indicators of IT capital, so we 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 process j in the k^{th} process group, controlling for the remaining independent variables.[2]

The first e-business process group is the complex software underlying integrated systems, FIERP. We create dummy variables for the presence of 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 dimension of IT capital that is separate from computer networks.

The second group of e-business process variables measure intensity, defined as the number of the seven e-businesses processes a plant uses. Intensity varies considerably among industries, as Figures 1 and 2 suggest. Intensity may proxy for the quality of a plant's capital, workforce, or management. Intensity may also proxy for the quality of the capital, workforce, or management of the plant's customers and suppliers. A plant may be more likely to use an e-business process such as communicating product designs over networks if the plant's customers, suppliers, or other plants within the firm also do so.

We measure intensity as dummy variables that correspond to the number of processes the plant uses. There are two sets of intensity dummy variables: a set of seven for the first set of e-business processes, and a set of five for the second set of processes. These intensity indexes

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[2] These β_{kj} may reflect differences in the underlying computer and organizational capital, because neither is measured separately.

allow us to examine whether the productivity relationship is monotonic or has a threshold or plateau.

The third group of basic e-business process measures is two sets of e-business process varibles. The first set of variables is based on responses to a question asking if the plant conducts each of the first set of seven processes on-line. The second set of dummy variables is based the second set of five on-line processes. The simple correlations between the two sets of variables 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 information technology.

Standard production function variables and plant characteristics. The dependent variable, Q/L99, is gross output labor productivity in 1999. 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/L97 is the book value of capital, measured relative to total employment (L), both collected in the 1997 CM[3]. Materials inputs, M/L99, are measured relative to total employment in 1999 (L99), and total employment in 1999 (L99) also enters separately. The second group of explanatory variables characterizes the plant. MIX99 is the ratio of non-production to production workers, to proxy for skill mix. MULTI99 indicates whether 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 variable, NEW, denotes plants that did not exist

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[3] Book value (K) is collected only in Economic Census years such as 1992 and 1997.

in 1992.[4] Details of the construction of these variables are given in Atrostic and Nguyen (2006) and (2005).[5]

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.

Potential endogeneity. Theory and the empirical literature suggest that computer networks, and specific uses of those networks, are likely to be endogenous. In Atrostic and Nguyen (2005), we addressed the potential endogeneity of the presence of computer networks in prior research using a two-step procedure that yields consistent estimates. A common empirical result with two-step procedures, as noted in Griliches and Mairesse (1995), is that the implied effect estimated falls, perhaps to the point of statistical insignificance, compared to the OLS estimate. However, in Atrostic and Nguyen (2005), we find that the implied effect from the two-step procedure in our data is about twice as great as from the OLS procedure (3.3 percent vs. 6.6 percent). This finding holds in Atrostic and Nguyen (2006) 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. The implied effect of computer networks

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[4] 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/L97) and materials intensity (M/L99), 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 2005.

[5] 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 2006), we incorporate this investment variable and 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 on electronic business processes, we use in this paper the entire sample of responding plants.

continues to be positive and significant, and is roughly twice as large (6.6 percent versus 12.4 percent).[6] To focus on e-business processes in this paper, we base estimates 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.

C. Data Sources

An important contribution of our work is that it is the first research to examine the new detailed information about the use of e-business processes in U.S. manufacturing plants. Another important contribution is that our findings are based on a large representative sample of U.S. manufacturing plants. Research using earlier data for the United States typically either had much smaller sample sizes or lacked data on the presence of computer networks, let alone data on how those networks are used.

The Computer Network Use Supplement (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 that is described in 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 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

[6] Brynjolfsson and Hitt 2003 and Black and Lynch 2001 report similar findings between OLS and IV estimates of coefficients of computer investment.

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.

Respondents' answers to CNUS questions about networks can be linked to the information the same respondents reported on regular 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.

V. 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 of those variables are very close to those estimated in our previous papers, and change very little across the specifications in this paper.

FIERP Software. 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 without networks and 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 is a distinct technology. Using FIERP may also signal different managerial decisions or capabilities. Using FIERP requires a large commitment by the plant to linking its business processes electronically. Wright *et al.* (1998) find that plants using FIERP software may adopt it 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.

The CNUS data do not ask which processes FIERP links in a specific plant. And FIERP is not the only way to link business processes. To examine these issues further, we turn to detailed information in the CNUS about the business processes that the plant conducts on-line, that is, over computer networks.

Intensity. Intensity, defined as the number of processes conducted on-line, is related to productivity. The relationship resembles a step function rather than a monotonic one. 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).

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 CNUS data do not report how much of the plant's operations depend on these processes.

Our findings are consistent with those of McGuckin *et al.* (1998) that plants using advanced technologies more extensively have higher productivity.[7] Our findings also are consistent with those of Forth and Mason (2003) for the United Kingdom.

As with FIERP, we test for vintage effects by interacting NEW with other standard explanatory variables and with the intensity measures. The coefficients of the intensity measures no longer are statistically significant and their absolute magnitudes are much smaller (column 4 of Table 4). The coefficients of most interaction terms between the intensity measures and NEW are not statistically significant. While productivity appears to be higher in newer plants in this specification, it seems unlikely that their advantage 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. Different e-business processes have different productivity impacts (column 1 of Table 5). Supply chain activities – on-line processes such as inventory, transportation, and logistics – are positively and significantly with productivity.

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, the coefficients are not statistically significant (for on-line catalogs and monitoring order status). This findings is consistent with

[7] 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.

new results for the United Kingdom where Clayton, Criscuolo, Goodrich, and Waldron (2004) find a negative productivity effect for selling on-line but a positive effect for buying on-line.[8]

Using e-business processes to communicate about production processes does not appear to affect productivity. The coefficient for the “production schedules” variable 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 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 (-0.0158, reported in

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[8] 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.

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 magnitude.

The estimated coefficients for the 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 intensity specification for the first group of seven processes in columns 1 and 2 of Table 6. Columns 3 and 4, Table 6 report the results using indexes of five processes. 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 6.0 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 (see column 3, Table 5). 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 (-0.0049), 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, Table 5. 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).

VI. Discussion

Our empirical findings with the new CNUS data support the hypothesis that electronic business processes are new technologies that shift the production function. We find statistically significant, positive, and economically meaningful links between productivity and several of these technologies, and we find these links across multiple specifications and measures. While the productivity impacts we observe could be due to the use of technologies, organizational structures, or management capabilities that are not measured in our data, such omissions, as Griliches and Mairesse (1995) note, would tend to bias the coefficients towards zero. We also find that different e-business processes have distinct impacts on productivity. In this section, we compare our findings with those of other researchers and then discuss what our findings imply for economic measurement.

Because collecting information about production processes and detailed forms of IT use is relatively rare for official statistical organizations, few studies' findings are directly comparable to ours. Our findings are, however, generally consistent with results based on other data sets and other countries.

Our empirical results suggest a strong link between the use of IT and productivity, and that the links differ for different forms of IT. Studies by Black and Lynch (2001) find strong complementarities among work practices, workforce skill, and the share of workers that use computers, suggesting that the relationships we observe could occur for such reasons.[9] However, our data lack information about complementary investments, work practices, or workforce skill, and with only one year of data, we are not able to estimate models that control for some of these factors.

The new e-business process measures collected in the CNUS capture important dimensions of modern computer technologies. Because detailed measures of computer technologies 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. We find that correlations between the two sets of measures are not strong, despite similar-sounding categories in both. The two sets of measures generally yield somewhat different results, although one result emerges clearly: Plants using e-business processes to conduct supply-chain functions have higher labor productivity.

[9] Their data, however, lack information on whether the computers are networked.

Our analyses of the CNUS data suggest that its measures capture important aspects of computer network technologies but that there is more to be learned. Repeating a CNUS-type supplement would provide the information needed to examine such methodological issues. It would also provide and the two periods of data required for more rigorous econometric testing of the productivity impact of different forms of IT capital.

VII. Conclusions

Despite well-established links between IT and productivity, little is known about the heterogeneity of the technology, and whether that heterogeneity is associated with differences in economic performance. This paper uses new data from a large sample of U.S. manufacturing plants to explore these issues. The data show clear differences among industries in the use of specific kinds of information technology. We find empirical support for the hypothesis that this heterogeneity is associated with differences in 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. 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 seem to come by using 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. Nor does the single year of data available allow us to explore dynamic behaviors. Future research will link responses in the CNUS with responses for the same plants to questions about supply-chain activities performed in the plant that were asked in the 2002 Census of Manufactures. The linked data will allow us to refine our understanding of why the CNUS data show a positive and significant link between productivity and conducting supply-chain processes over computer networks.

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Table 1
The Share of Plants Using Fully Integrated Enterprise Resource Planning (FIERP) Software in 2000 Varies Across Manufacturing Sectors

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%

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 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 Intensity of E-Business Process Use

Dependent Variable: Gross Output Labor Productivity
(t-statistics in parentheses)

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.1444	(175.63)**	2.9689	(111.63)**	3.1897	(180.65)**	3.0059	(116.62)**
Log (K/L97)	0.0642	(30.49)**	0.0739	(21.92)**	0.0632	(30.04)**	0.0726	(21.56)**
Log (M/L99)	0.4310	(173.93)**	0.4556	(120.00)**	0.4306	(174.11)**	0.4550	(119.75)**
Log (L99)	-0.0058	(2.79)**	-0.0057	(1.76)&	-0.0089	(4.21)**	-0.0101	(3.09)**
Log (Mix99)	0.0349	(10.80)**	0.0371	(7.23)**	0.0351	(10.88)**	0.0369	(7.22)**
MULTI99	0.0733	(13.74)**	0.0908	(9.94)**	0.0704	(13.20)**	0.0861	(9.42)**
New	-0.0498	(9.15)**	0.1986	(6.74)**	-0.0495	(9.11)**	0.1798	(6.32)**
New x (Standard Inputs Above)	No		Yes				Yes	
Log (RLP92)	0.2127	(73.02)**	.02123	(73.00)**	0.2121	(72.86)**	0.2119	(72.85)**
Network only	0.0389	(5.27)**	0.0467	(3.54)**	(--)	(--)	(--)	(--)
FIERP & Network	0.0445	(5.33)**	0.0435	(3.03)**	(--)	(--)	(--)	(--)
New x (Network Only)	No		-0.0098	(0.62)	(--)	(--)	(--)	(--)
New x (FIERP & Network)	No		0.0054	(0.31)	(--)	(--)	(--)	(--)
Intensity Index1: Uses 7 processes								
Index1=1	(--)	(--)	(--)	(--)	0.0077	(4.93)**	0.0074	(4.62)**
Index1=2	(--)	(--)	(--)	(--)	-0.0073	(1.07)	-0.0070	(0.62)
Index1=3	(--)	(--)	(--)	(--)	0.0056	(0.70)	0.0125	(0.99)
Index1=4	(--)	(--)	(--)	(--)	0.0173	(2.00)*	0.0281	(2.07)*
Index1=5	(--)	(--)	(--)	(--)	0.0377	(4.22)**	0.0472	(3.43)**
Index1=6	(--)	(--)	(--)	(--)	0.0357	(3.86)**	0.0405	(2.88)**
Index1=7	(--)	(--)	(--)	(--)	0.0340	(4.33)**	0.0385	(3.29)**
New x Intensity Index	(--)	(--)	(--)	(--)	No		Yes	
R^2	0.8133		0.8144		0.8138		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 Groups of E-Business Process Measures

Dependent Variable: Gross Output Labor Productivity
(t-statistics in parentheses)

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.1804	(180.07)**	3.0169	(117.44)**	3.1579	(178.82)**	2.9945	(115.16)**
Log (K/L97)	0.0634	(30.15)**	0.0732	(21.76)**	0.0630	(29.86)**	0.0723	(21.34)**
Log (M/L99)	0.4312	(173.86)**	0.4542	(119.71)**	0.4308	(174.09)**	0.4555	(120.04)**
Log (L99)	-0.0069	(3.34)**	-0.0078	(2.47)**	-0.0086	(4.09)**	-0.0094	(2.84)**
Log (Mix99)	0.0367	(11.28)**	0.0385	(7.53)**	0.0349	(10.82)**	0.0364	(7.11)**
MULTI99	0.0685	(12.79)**	0.0849	(9.30)**	0.0718	(13.47)**	0.0884	(9.67)**
New	-0.0496	(9.12)**	0.1797	(6.41)**	-0.0497	(9.14)**	0.1813	(6.32)**
New x (Standard Inputs Above)	No		Yes		No		Yes	
Log (RLP92)	0.2122	(72.95)**	0.2119	(72.96)**	0.2120	(72.79)**	0.2115	(72.72)**
E-Business Process Group 1								
Design	-0.0164	(3.04)**	-0.0158	(2.93)**	(--)	(--)	(--)	(--)
Catalog	0.0072	(1.47)	0.0082	(1.66)&	(--)	(--)	(--)	(--)
Demand projections	0.0113	(1.67)&	0.0110	(1.63)&	(--)	(--)	(--)	(--)
Order status	-0.0097	(0.97)	-0.0096	(1.48)	(--)	(--)	(--)	(--)
Production schedules	0.0113	(1.54)	0.0108	(1.49)	(--)	(--)	(--)	(--)
Inventory data	0.0277	(3.89)**	0.0269	(3.79)**	(--)	(--)	(--)	(--)
Logistics or transportation	0.0259	(4.03)**	0.0251	(3.93)**	(--)	(--)	(--)	(--)
E-Business Process Group I1								
Purchasing	(--)	(--)	(--)	(--)	0.0171	(3.67)**	0.0259	(3.40)**
Product Orders	(--)	(--)	(--)	(--)	-0.0098	(2.07)*	-0.0048	(0.63)
Production management	(--)	(--)	(--)	(--)	-0.0049	(0.92)	-0.0058	(0.66)
Logistics	(--)	(--)	(--)	(--)	0.0191	(3.75)**	0.0276	(3.31)**
Communication and Support	(--)	(--)	(--)	(--)	0.0313	(4.60)**	0.0236	(2.02)*
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

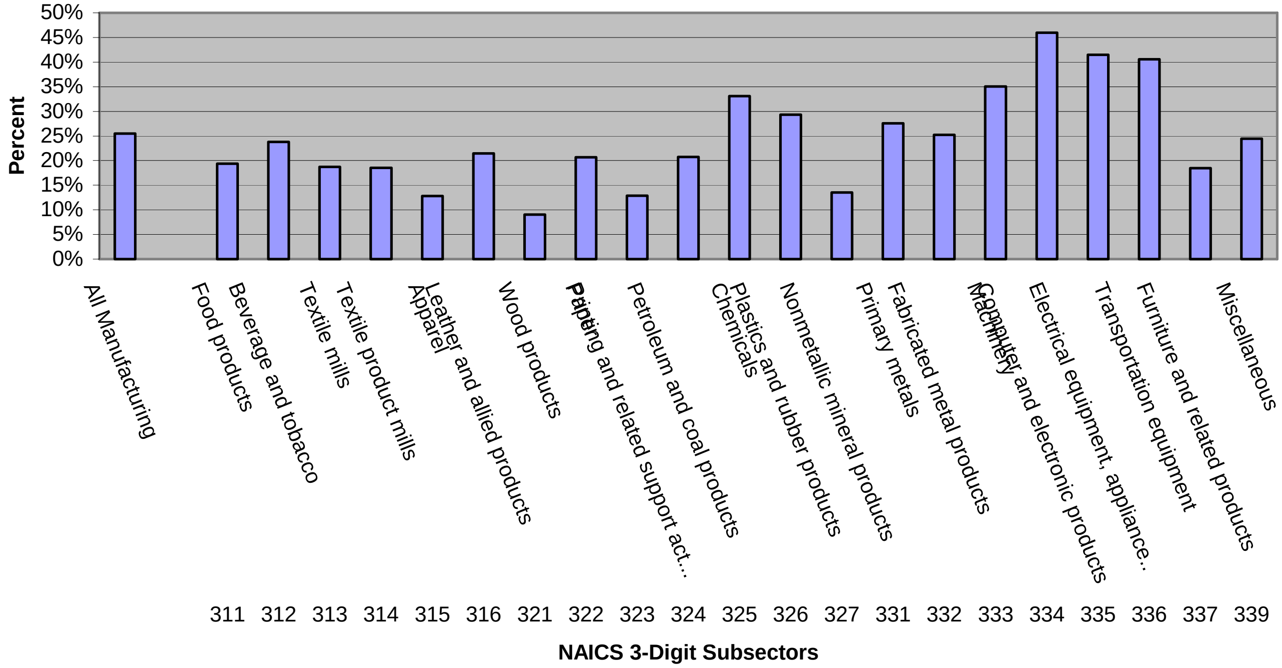
Table 6. Labor Productivity Regressions: Two Measures of Intensity of E-Business Process Use
Dependent Variable: Gross Output Labor Productivity
(t-statistics in parentheses)

Independent Variables	(1)		(2)		(3)		(4)	
Intercept	3.1897	(180.65)**	3.0059	(116.62)**	3.1512	(177.95)**	2.988	(114.19)**
Log (K/L97)	0.0632	(30.04)**	0.0726	(21.56)**	0.0635	(30.17)**	0.0730	(21.63)**
Log (M/L99)	0.4306	(174.11)**	0.4550	(119.75)**	0.4310	(174.11)**	0.4557	(120.10)**
Log (L99)	-0.0089	(4.21)**	-0.0101	(3.09)**	-0.0083	(3.93)**	-0.0091	(2.73)**
Log (Mix99)	0.0351	(10.88)**	0.0369	(7.22)**	0.0344	(10.66)**	0.0358	(7.00)**
MULTI99	0.0704	(13.20)**	0.0861	(9.42)**	0.0727	(13.66)**	0.0898	(9.84)**
New	-0.0495	(9.11)**	0.1798	(6.32)**	-0.0496	(10.66)**	0.1804	(6.25)**
New x (Standard Inputs Above)	No		Yes		No		Yes	
Log (RLP92)	0.2121	(72.86)**	0.2117	(72.85)**	0.2123	(72.88)**	0.2119	(72.85)**
Intensity Index 1: Uses of 7 processes from Group 1								
Index1=1	0.0077	(4.93)**	0.0074	(4.62)**	(--)	(--)	(--)	(--)
Index1=2	-0.0073	(1.07)	-0.0070	(0.62)	(--)	(--)	(--)	(--)
Index1=3	0.0056	(0.70)	0.0125	(0.99)	(--)	(--)	(--)	(--)
Index1=4	0.0173	(2.00)*	0.0281	(2.07)*	(--)	(--)	(--)	(--)
Index1=5	0.0377	(4.22)**	0.0472	(3.43)**	(--)	(--)	(--)	(--)
Index1=6	0.0357	(3.86)**	0.0405	(2.88)**	(--)	(--)	(--)	(--)
Index1=7	0.0340	(4.33)**	0.0385	(3.29)**	(--)	(--)	(--)	(--)
New x Intensity Index 1	No		Yes					
Intensity Index 2: Uses of 5 processes from Group 2								
Index2=1	(--)	(--)	(--)	(--)	0.0233	(2.74)**	0.0091	(0.60)
Index2=2	(--)	(--)	(--)	(--)	0.0452	(5.68)**	0.0347	(2.53)**
Index2=3	(--)	(--)	(--)	(--)	0.0444	(5.80)**	0.0407	(3.06)**
Index2=4	(--)	(--)	(--)	(--)	0.0553	(7.17)**	0.0546	(4.13)**
Index2=5	(--)	(--)	(--)	(--)	0.0623	(7.69)**	0.0607	(4.43)**
New x Intensity Index 2					No		Yes	
R^2	0.8138		0.8149		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

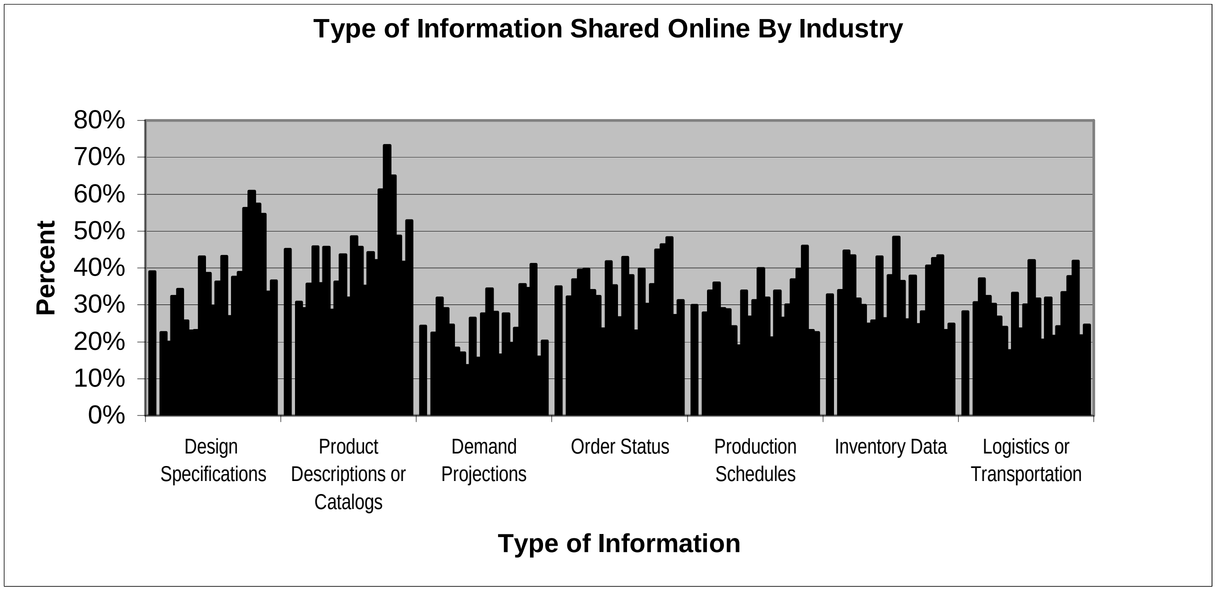
Figure 1

Fully Integrated Enerprise Resource Planning (FIERP) Software is Used in All Manufacturing Sectors in 2000

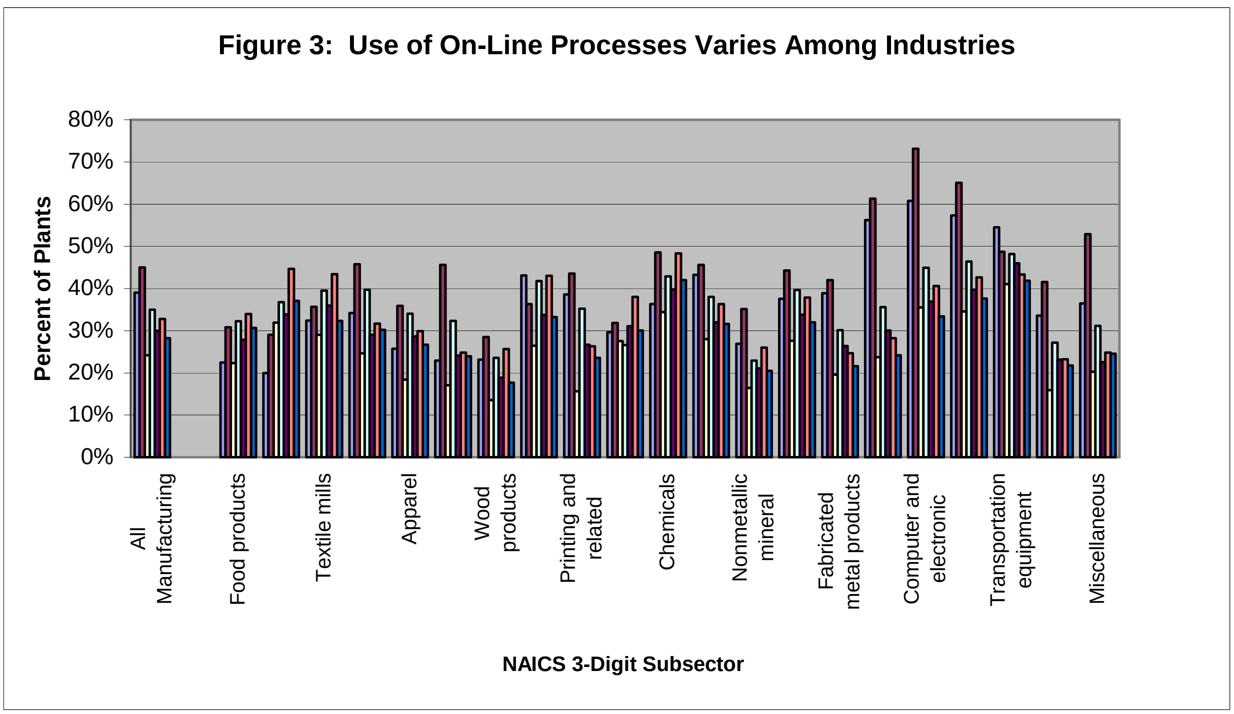


Source: Authors' calculations based on U.S. Census Bureau 2002

Figure 2: Some Kinds of Information Are More Likely to Be Shared On-line



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



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