It and economic performance: evidence from micro studies

Law, Evidence

CHAPTER V: IT AND ECONOMIC PERFORMANCE: EVIDENCE FROM MICRO DATA STUDIES By B. K. Atrostic and Ron Jarmin* Micro data—that is, data on individual businesses that underlie key economic indicators—allow us to go behind published statistics and ask how IT affects businesses' economic performance. Years ago, analyses indicated a positive relationship between IT and productivity, even when official aggregate statistics still pointed towards a " productivity paradox. Now, such analyses shed light on how varied that relationship is across businesses, and how IT makes its impacts. This chapter focuses on research about businesses based on micro data collected by the U. S. Census Bureau. We highlight the kinds of questions about the use and impact of IT that only micro data allow us to address. Micro data studies in the United States and in other OECD countries show that IT affects the productivity and growth of individual economic units. Specific estimates of the size of the effect vary among studies.

Researchers comparing manufacturing plants in the United States and Germany, for example, find that in each country investing heavily in IT yields a productivity premium, but that the premium is higher in the United States than it is in Germany. They also find that the productivity premium varies much more for U. S. manufacturers. This greater variability is consistent with the view that the U. S. policy and institutional environments may be more conducive to experimentation by U. S. businesses. What kind of IT investments do U. S. businesses make? Census Bureau data on U.

S. manufacturing establishments show that they invest in both computer networks and the kind of complex software that coordinates multiple business processes within and among establishments. About 50 percent of these plants have networks, while fewer than 10 percent have invested in this complex software. Such a wide difference between the presence of networks and * Ms Atrostic (barbara. kathryn.gov) is Senior Economist, and Mr. Jarmin (ron. s.gov) is Acting Director, Center for Economic Studies, U. S. Census Bureau. 61

DIGITAL ECONOMY 2003 complex software in manufacturing, and equally wide-ranging differences in their presence among detailed manufacturing industries, highlight the diversity of IT use among businesses. Plants with networks have higher productivity, even after controlling for many of the plant's economic characteristics in the current and prior periods. Similar results are found in other OECD countries. Some studies suggest that businesses need to make parallel investments in worker training and revised workplace practices before IT investments yield productivity gains.

Careful micro data research shows that the relationship between IT and economic performance is complex. " IT" emerges as a suite of alternatives from which businesses make different choices. Estimates of the size of the effect, and how IT makes its impact, remain hard to pinpoint. Data gaps make it hard to conduct careful analyses on the effect of IT. Continuing efforts by researchers and statistical organizations are filling some of the data gaps, but the gaps remain largest for the sectors outside manufacturing —the sectors that are the most IT-intensive.

More definitive research requires that statistical agencies make producing micro data a priority. What Are Micro Data? Micro data generally contain information about many characteristics of the economic unit, such as plant employment, years in business, share of IT in costs, ways it uses IT, and its economic performance. Micro data exist for both businesses and individuals, and can be developed by private and public organizations. This chapter focuses on research using micro data about businesses that are collected by the U. S.

Bureau of the Census. BENEFITS OF MICRO DATA RESEARCH Standard analyses of productivity and similar economic phenomena frequently assume that businesses are identical, at least within an industry, and therefore also respond similarly to changes in economic circumstances. However, it is easy to challenge this assumption simply by observing the variety of businesses in any industry, no matter how narrowly the industry is defined, and how diverse their responses appear to be. Case studies in specific industries repeatedly bear out thisobservation.

Micro data allow us to assess the diversity of businesses and track behaviors such as their entry and exit into an industry. They also allow us to document changes in businesses' performance, such as employment, sales, and productivity, and see whether those changes are uniform among industries, within industries, or among businesses of given ages, sizes, and so forth. Two decades of research using micro data reveal tremendous variety in the economic characteristics and performance of businesses at any time, and over time. 1 An excellent summary is E. Barltesman and M.

Doms, “ Understanding Productivity: Lessons from Longitudinal Microdata,” Journal of Economic Literature, Vol. 38 (September 2000). It reviews research conducted at the U. S. Census Bureau and gives references for reviews of micro data research conducted elsewhere. A detailed report on initial micro data research on productivity is provided in M. Baily, C. Hulten, and D. Campbell, “ Productivity Dynamics in Manufacturing Plants,” Brookings Papers on Economic Activity: Microeconomics 1992. 1 62 DIGITAL ECONOMY 2003 Micro data can paint a clearer picture of how aggregate economic statistics change.

They also allow researchers to apply econometric techniques that take account of the kinds of complex relationships that simply cannot be presented in tables or other aggregated formats. Comparing findings from research studies using different data sets allows us to see which estimates appear to be robust, and which ones seem to depend on the specific data we use, and on the specific equations we estimate. RESEARCH REQUIRES GOOD MICRO DATA Micro data research takes advantage of the high-quality information about individual businesses that underlies major economic indicators.

The micro data sets typically are large and nationally representative, making it more likely that they capture the tremendous diversity among businesses. 2 Researchers often are able to link data at the micro level across surveys and over time. For example, consider the new information on whether businesses have computer networks, and how they use those networks that was collected in the Computer Network Use Supplement (CNUS) to the 1999

Annual Survey of Manufactures (ASM). The plant-level micro data about computer networks collected in the CNUS can be linked to information about employment, shipments, use of other inputs, etc. , collected about the same plants in the 1999 ASM and to ASMs for other years, and to data that was collected about the same plants in the 1997 Economic Census. Such exact linkages yield much richer information bases than any single supplement, survey, or census alone. When micro data can be linked, researchers also can use econometric techniques to control for unobserved characteristics that are specific to an individual plant or business.

These techniques allow researchers to have more confidence that findings, such as the effect of IT actually are due to IT and not to related but unmeasured characteristics, such as good management or a skilled work force. The Role of Information Technologies in Business Performance Recent research using micro data generally concludes that IT and productivity are related. Indeed, micro data analyses indicated a positive relationship between IT and productivity when official aggregate statistics still pointed towards a “ productivity paradox. Two recent reviews of plant- or firm-level empirical studies of informationtechnology(including but not limited to computers) and economic performance conclude that the literature shows positive relationships between information technology and productivity. However, specific estimates of the size of the effect vary widely among studies. How IT makes its impact also remains hard to pinpoint. While micro data provide raw material for important analyses, they are not a panacea.

Researchers must address significant challenges when using existing micro data to analyze questions about the economic performance of businesses.

See Z. Griliches, “ Productivity, R&D, and the Data Constraint,” American Economic Review, Vol. 84 No. 1 (March 1994); and Z. Griliches, and J. Mairesse, “ Production functions: The Search for Identification,” NBER Working Paper 5067 (March 1995). 3 2 More information on these surveys is available at http://www. census. gov/eos/www/ebusiness614. htm. 63 DIGITAL ECONOMY 2003 THE ROLE OF IT IN PRODUCTIVITY—A BRIEF SURVEY OF THE LITERATURE Many recent studies use micro data to document and describe the productivity of different kinds of businesses, and to examine its sources.

The simple model that suggests productivity growth occurs among all existing plants simply does not fit with what the micro data show. Instead, the micro data show that much of aggregate productivity growth comes about through a much more diversified and dynamic process. Less productive plants go out of business, relatively productive plants continue, and the new entrants that survive are more productive than either. Micro data research on the effect of IT explores how IT fits into this complex picture of business behavior.

Dozens of research papers over the last decade examine various facets of the relationship between IT and productivity. Two recent reviews summarizing the current literature on IT and productivity conclude that there is an impact, although there is much variation among studies in the estimated magnitudes of that effect (Dedrick, J. , Gurbaxani, V. , and K. Kraemer, 2003, “ Information Technology and Economic Performance: A Critical Review of the Empirical Evidence,” ACM Computing Surveys, Vol. 35, No. 1, March and Stiroh, K. J. 2002, “ Reassessing the Impact of IT in the Production Function: A Meta-Analysis,” Federal Reserve Band of New York, November). 4 Dedrick et al. (2003) review over 50 articles published between 1985 and 2002, many of which are firm-level studies with productivity as the performance measure. They conclude that firmlevel studies show positive relationships, and that gross returns to information technology investments exceed returns to other investments. They warn against concluding that higher gross returns mean that plants are under-investing in information technology.

Most studies do not adjust for the high obsolescence rate of information technology capital, which lowers net returns. Also, total investment in information technology may be understated because most studies measure only computer hardware, but not related labor or software, or costs of coinvention, such as re-engineering business processes to take advantage of the new information technology. Stiroh (2002) reviews twenty recent empirical studies of the relationship between information technology and output and productivity. The studies generally find a positive effect of information technology on output.

However, the estimates differ across studies, and the studies differ in many dimensions, including time periods covered and specific estimation techniques used. Stiroh looks for predictable effects of differences in characteristics of the studies, such as time periods, level of aggregation (e. g. , industry, sector, or entire economy), and estimation techniques. He finds that much of the variation across studies in the estimates of the effect of information technology probably reflects differences in characteristics of the studies. 4

Many of those studies, including many studies discussed in this chapter, were conducted at the Center for Economic Studies (CES) at the U. S. Census Bureau. Appendix 5. A describes both CES, a research unit that conducts research and supports the needs of researchers and decision makers throughout government, academia, and business, and some of the major data sources available there for micro data research on the impact of IT. 64 DIGITAL ECONOMY 2003 Stiroh also reports the findings of additional research he conducts using a single industry-level database to estimate many of the different equations used in the studies he reviewed.

His research finds that information technology matters, but that even within a single database, estimates of the magnitude of that effect depend on the particular equation that is estimated. Finally, Stiroh notes a potential for publication bias. Because theory predicts a positive relationship between IT and productivity, researchers may tend to report, and editors may tend to accept for publication, only those papers with the “ right” results on the impact of IT. However, as his research demonstrates, estimates are sensitive to both the data used and the particular equation that is estimated.

He concludes that information technology matters, but the wide variation in empirical estimates means that much “ depends on the details of the estimation” and “ one must be careful about putting too much weight on any given estimates. ” The conclusion that recent studies show a positive effect of information technology stands in contrast to earlier studies, many of which found no relationship. Both Dedrick (2003) and Stiroh (2002) note that the best data available to early researchers suffered from small sample sizes, few or no small firms or plants, and lack of data on information technology investment.

These data gaps may be why early micro data studies failed to find a relationship between IT and performance. CAUSE AND EFFECT: DOES USING IT MAKE BUSINESSES MORE PRODUCTIVE? The literature so far yields mixed findings on cause and effect between IT and plant-level economic performance. Early research is limited to manufacturing. The first findings in this area were that more productive plants may be more likely to adopt best practices, including new technologies, and that they are able to afford to do so. However, later research suggests that less productive plants may invest in those technologies, perhaps trying to boost their productivity. 6 Recent research expands the scope of analysis of the effect of IT in the retail sector. It examines the relationship between investments in information technology and two performance measures for retail firms, productivity and growth in the number of establishments. The research finds that, in retail, IT is closely related to productivity growth, but not to growth in the number of establishments that retail firms operate. 5 R. H. McGuckin, M. L. Streitwieser, and M. E. Doms, “ The Effect of Technology Use on Productivity Growth,” Economic Innovation and New Technology Journal, 7 (October 1998). 6 Stolarick Kevin M. , “ Are Some Firms Better at IT? Differing Relationships between Productivity and IT Spending,” Center for Economic Studies Working Paper CES-WP-99-13, U. S. Census Bureau, Washington, DC (1999); and B. K. Atrostic, and S. Nguyen, “ IT and Productivity in U. S. Manufacturing: Do Computer Networks Matter,” Center for Economic Studies Working Paper CES-02-01, U. S.

Bureau of the Census, Washington, DC (2002). M. Doms, R. Jarmin, and S. Klimek, “ IT Investment and Firm Performance in U. S. Retail Trade,” Center for Economic Studies Working Paper CES-WP-02-14, U. S. Bureau of the Census, Washington, DC (2002). 7 65 DIGITAL ECONOMY 2003 Does the BusinessEnvironmentMatter? —International Comparisons Although researchers have found evidence of the effect of IT on productivity at the micro level across many countries, the effect on aggregate productivity and economic growth has varied across countries. This is true even though IT is universally available.

While the United States and a few other economies enjoyed the boom of the late 90s, many European economies experienced sluggish growth. Several explanations have been put forward including differences in the policy and institutional settings across countries, measurement issues, and time lags (micro data research showed positive effects of IT in the United States before aggregate statistics). Some have hypothesized that the U. S. economy was able to make more effective use of the new general-purpose technology of IT because its regulatory and institutional environment permits firms to experiment more. An important component of the U. S. bility in this regard is the efficient reallocation of resources away from firms whose experiments in the marketplace fail, to those whose experiments succeed. The OECD's Growth Project (Box 5. 1) study found evidence that the Schumpeterian processes of churning and creative destruction (or market selection) yield greater economic effects in the United States than in other OECD countries. These processes affect aggregate productivity growth as lower productivity firms shrink and exit and higher productivity firms enter and grow. Is it the case that IT has had a greater impact on business performance in the United States because the U.

S. policy and institutional environment is more conducive to market selection and learning? Box 5. 1. OECD International Micro Data Initiative No single country has the resources and technical expertise to independently resolve all the measurement issues and fill all the information gaps associated with measuring the impact of IT. The OECD Growth Project provided a comprehensive analysis of the impact of information andcommunicationtechnology (ICT) on productivity and economic growth in several OECD countries, using aggregate, industry-level, and plant-level data. Based on that project's success, U. S.

Commerce Secretary Evans requested additional micro data research, and provided the OECD with seedmoney. This new project seeks to build on efforts already under way in several OECD member countries. One facet of the OECD micro data project on ICT is a series of multi-national collaborations, with a small number of countries involved in each collaboration. Each group is developing its own way of reconciling the differences in each country's existing micro data that are important to comparative studies, such as the sectors covered, the scope of businesses included in each sector, and the specific questions asked.

The OECD project also seeks explicitly to foster coordination and collaboration on e-business issues between data producers and data users in each country. Project members are from both the OECD's Statistical Working Party of the Committee on Industry and Business Environment (largely data users focused on productivity and growth statistics) and the new Working Party on Indicators on the Information Society (largely producers of statistical indicators). 66 DIGITAL ECONOMY 2003

Recent research using micro data from the United States and Germany attempts to address this question. 8 The analysis first compares the differences between various groups (e. g. , young vs. old, or those that invest heavily in IT vs. those that do not) of manufacturing establishments within each country. These differences are then compared across the two countries. This allows the researchers to contrast the impact of IT on economic performance between the two countries. The results suggest that U. S. anufacturing establishments benefit more from investing in IT and are more likely to experiment with different ways of conducting business than their German counterparts even after controlling for several plant specific factors such as industry, age, size, and so on. Figure 5. 1 summarizes results from an analysis of the impact of changing technologies on productivity outcomes.

For the analysis, businesses undergoing an episode of high investment are assumed to be actively changing their technology. Manufacturers in both countries were grouped according to investment intensity as defined by investment per worker.

The researchers examined investment in both general and IT-specific equipment. The core comparison group had no investment. The other two groups—with investment in any equipment, and investment in IT equipment —were split into " high" and " low" investment groups at the 75th percentile of the investment intensity distributions. Plants with " high" investment intensities were those with intensities exceeding at least 75 percent of all other investing plants. These computations were done for both overall investment in equipment (excluding structures) and for IT equipment, giving a combined seven investment intensity categories.

Businesses undergoing an episode of high investment intensity can be thought of as actively changing their technologies. The market will reward some of these and punish others. The crux of the analysis summarized in Figure 5. 1 is to first compare the performance of plants across the various investment intensity groups to a baseline of firms with no investment within each country (i. e. , the bars for the listed investment intensity categories in the figure represent the percent difference from the omitted zero investment category for each country).

Then the researchers compared the within country differences across the United States and Germany to see in which country the reward for experimentation (as measured by high investment episodes) is highest. Panel A shows that U. S. businesses that invest heavily, both overall and in IT, are much more productive than those that invest little or none at all. The same holds true for Germany, but the productivity premium is much higher in the United States. Panel B shows that U. S. businesses that invest heavily (i. e. are experimenting with new technologies) have more varied productivity outcomes as measured by the standard deviation than do firms that invest little or not at all. This is not the case in Germany. In fact, the German data show that firms that invest intensively have less varied productivity outcomes. This is consistent with the notion that the U. S. policy and institutional environment is more conducive to market experimentation. These results should be viewed with caution as they relate to only two countries and there are many factors the researchers do not control for. 8 J.

Haltiwanger, R. Jarmin, and T. Schank, " Productivity, Investment in ICT and Market Experimentation: Micro Evidence from Germany and the U. S. ," Center for Economic Studies Working Paper CES-03-06, U. S. Bureau of the Census, Washington, DC (2003). 67 DIGITAL ECONOMY 2003 Figure 5. 1. Differences in Productivity Outcomes between Germany and the United States Panel A: U. S. Firms Investing Heavily in IT and Other Capital Have Higher Productivity Premiums 100% % Difference in Mean Productivity Relative to Group with No Investment U. S. 90% 80% 70% 60% 50% 40% 30% 20% 10% 0% Low / 0

Germany High / 0 Low / Low Low / High High / Low High / High Investment Intensity (Equipment / IT) Panel B: U. S. Firms Investing Heavily in IT and

Other Capital Experience More Varied Productivity Outcomes 50% U. S. % Difference in Standard Deviation of Productivity Relative to Group with No Investment Germany 40% 30% 20% 10% 0% -10% -20% -30% -40% Low / 0 High / 0 Low / Low Low / High High / Low High / High Investment Intensity (Equipment / IT) Note: Differences are in logs and are shown relative to a reference group of firm with zero total investment.

Source: Haltiwanger, Jarmin and Schank 2003. DOES IT MATTER HOW IT IS USED? Businesses in the United States have used IT for fifty years. Originally, firms that used IT may have had advantage over competitors who did not. But today, simply investing in IT may no longer be enough. The question for economic performance is no longer whether IT is used, but how it is used. 68 DIGITAL ECONOMY 2003 Figure 5. 2. Computer Networks Were Common in U. S. Manufacturing Industries in 1999, But Sophisticated Network Software Was Not 100 90 80 70 60

Plants with Networks Employment at Plants with Networks Plants with Fully Integrated Enterprise Resource Planning Software Percent 50 40 30 20 10 0 G ts ts s s s s s o t es ry ts s al em ic d ru bb er pr od l ts ill re ts uc rie ou en al ill ts ts rie uc te pe uc cc ts N ne uc uc RI iti pm od ne ba tm od st pa uc uc et TU od od Pa la st od tiv hi od od du du pr re lla ac til uc pr to Ap pr ui – ac pr pr od m e FA C od in ce an Te x ar eq al od M W oo 32 al d an d im is al c d s 5 Ch pr in pr d – d d 2 pr y uc m uc ts d s r pr lie ni Fo er te od 31 U et te – n od M co an d – t, tio tro e Pr AN in la m al la 3 e go en go 33 til m re ra rta 31 – ec ed M m Te x le 31 ve nd 1 9 1 1 d lic el 33 e d re 32 Pl as tic s – – 3 – 32 po ra 33 ab an an bl AL nd qu ns ra ur he et br re g du ra le Tr a itu 31 m tin at D on Le ca te on rn 31 – in pu tri N 6 Fu 2 Pr N – Pe – tro Fa 2 le – 4 um Be al ic – ec 33 m 33 6 – – – 31 – Co El 7 3 4 32 4 33 33 5 33 – NAICS 3-Digit Industry Source: Atrostic, B. K. and J. Gates, 2001, “ U. S. Productivity and Electronic Business Processes in Manufacturing,” CES-WP-01-11, Center for Economic Studies, U. S. Bureau of the Census, Washington, DC.

New data from the 1999 Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures (ASM) are beginning to be used to model how manufacturing plants use computer networks in the United States. Respondents’ answers to questions about processes can be linked to the information the same respondents reported on regular ASM survey forms, such as the value of shipments, employment, and product class shipments. Figure 5. 2 presents researchers’ estimates of the diffusion of computer networks. The research finds that computer networks are widely diffused within manufacturing, with networks at about half of all plants.

The share of employment at plants with networks is almost identical in durable and non-durable manufacturing. Use of networks varies a great deal within those sub-sectors; the share of plants with networks ranges from lows of about 30 percent to highs of about 70 percent. The CNUS also provides new information about some aspects of how plants use computer networks. Figure 5. 2 reports estimates of the diffusion of fully integrated enterprise resource planning software (FIERP); that is, the kind of software that links different kinds of applications (such as inventory, tracking, and payroll) within and across businesses.

Plants in all manufacturing industries use this complex software. However, FEIRP software remains relatively rare compared to computer networks. While about half of all manufacturing plants have networks, fewer than 10 percent have this kind of software. 69 32 32 – 32 7 6 – an at ip L 5 – s DIGITAL ECONOMY 2003 Initial research finds that computer networks have a positive and significant effect on plant's labor productivity. After accounting for multiple factors of production and plant characteristics, productivity is about five percent higher in plants with networks. When economic characteristics in prior periods and investment in computers are also accounted for, there continues to be a positive and statistically significant relationship between computer networks and U. S. manufacturing plant productivity. 10 These initial findings for the United States are consistent with findings for other countries. Recent research for Canada, the Netherlands, and the United Kingdom, for example, all find positive relationships between using computer networks and productivity. 11 Research for Japan finds that computer expenditures and computer networks both affected productivity between 1990 and 2001.

In more recent years, the effects are larger, but they also vary much more among industries. 12 Some micro data research for the United States during the 1990s suggests that IT needs to be used together with worker training and revised workplace practices to yield productivity gains. These findings are based on data containing detailed information about the use of computers in the workplace. They also contain information rarely available in other sources on the employers' management and worker training policies. 3

Research for Australia and Canada, previously cited, also finds that returns to IT are intertwined with the use of R&D, innovation, and changes in workplace practices and organization. This line of research suggests that IT is important, but that it makes its impact when accompanied by changes in other factors and practices. IS THE IMPACT OF IT THE SAME FOR ALL KINDS OF IT, EVERYWHERE? —EVIDENCE FROM STUDIES OF MARKET STRUCTURE IT was widely expected to alter the structure of markets. The direction, however, was unclear.

Lower information costs might make it easier for smaller businesses to collect, analyze, and use information and so allow them to enter distant markets or compete more effectively with larger firms. At the same time, the lower information costs might make it easier for larger businesses 9 Atrostic and Nguyen (2002). 10 Atrostic and Nguyen, " The Impact Of Computer Investment And Computer Network Use On Productivity," paper presented NBER-CRIW Conference on " Hard-to-Measure Goods and Services: Essays in Memory of Zvi Griliches," Washington, DC (September 2003). J. Baldwin, and D.

Sabourin, " Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector," Research Paper Series, 174, Analytical Studies Branch, Statistics Canada (October 2001) present findings for Canada. E. Bartlesman, G. van Leeuwen, and H. R. Nieuwenhuijsen, " Advanced Manufacturing Technology and Firm Performance in the Netherlands," Netherlands Official Statistics, Vol. 11 (Autumn 1996) present findings for the

Netherlands. C. Criscuolo and K. Waldron, “ e-Commerce use and firm productivity,” Economic Trends (November 2003) present findings for the United Kingdom.

K. Motohashi, “ Firm level analysis of information network use and productivity in Japan,” presented at the conference on Comparative Analysis of Enterprise (micro) Data, London (September 2003). S. Black, and L. Lynch, “ How to Compete: The Impact of Workplace Practices and Information Technology on Productivity,” Review of Economics and Statistics, Vol. 83 No. 3 (August 2001); and D. Neumark and P. Cappelli, “ Do ‘ High Performance’ Work Practices Improve Establishment-Level Outcomes? ” Industrial and Labor Relations Review (July 2001). 13 12 11 70 DIGITAL ECONOMY 2003 to retain a competitive advantage.

Similarly, use of the Internet might make it easier for consumers to compare prices, and so lead to a reduction in prices for products sold on-line or in “ bricks and mortar” establishments. At the same time, a firm building an on-line sales-based business may incur costs that brick and mortar businesses might not, such as cost associated with having inventories available for immediate delivery anywhere in the United States (or the world). The issues are scarcely settled. In this section, selected examples from micro data research illustrate IT’s multifaceted nature and complex economic effects.

Trucking A series of studies make use of public-use truck-level data from the Census’ Vehicle Inventory and Use Surveys to examine how IT has affected the trucking industry. Each of these studies indicates the importance of knowing not just that IT is used, but also the details of the IT and how it is used. These studies examine the impact of two classes of on-board computers (OBCs). Standard OBCs function as trucks' " black boxes," recording how drivers operate the trucks. These enable dispatchers to verify how truck drivers drive.

Advanced OBCs also contain capabilities that, among other things, allow dispatchers to determine where trucks are in real time and communicate schedule changes to drivers while drivers are out on the road. These advanced capabilities help dispatchers make and implement better scheduling decisions, and help them avoid situations where trucks and drivers are idle, awaiting their next haul. One of these studies assesses OBCs' impact on productivity by estimating how much they have increased individual trucks' utilization rate, as measured by their loaded miles during the time they are in service. 4 It finds that advanced OBCs have increased truck utilization by 13 percent among trucks that adopt them; overall, this effect implies a three percent increase in capacity utilization industry-wide, which translates to about $16 billion in annual benefits. The vast majority of this increase comes from trucks in the for-hire, long-haul segment of the industry, and most of these returns only began to accrue years after trucking firms first began to adopt OBCs. In contrast, the study finds no evidence that standard OBCs have led to increased truck utilization.

Combined, these results indicate not just the magnitude of IT's impact on productivity in the industry but also its nature and timing. IT adoption has led to large productivity gains due to advanced OBCs' real-time communication capabilities, which enable trucking firms to ensure that trucks operating far from their base are on the road and loaded. These gains, however, appear to have lagged adoption by several years. The other two studies examine how OBCs have affected how the industry is organized. One study investigates how OBCs affect whether shippers use internal fleets or for-hire carriers to ship goods. 5 This study finds that the different classes of OBCs have different effects on this T. Hubbard, 2003, " Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking," American Economic Review, September. G. Baker and T. Hubbard, " Make Versus Buy in Trucking: Asset Ownership, Job Design, and Information," American Economic Review, Vol. 93 No. 3 (June 2003). 15 14 71 DIGITAL ECONOMY 2003 decision. The diffusion of standard OBCs has tended to increase shippers' use of internal fleets, but the diffusion of advanced OBCs has tended to increase their use of for-hire fleets.

This implies that IT-enabled improvements in monitoring drivers have led shippers to integrate more into trucking, but IT-enabled improvements in scheduling capabilities have led to more contracting-out of trucking. This systematic difference indicates that whether IT tends to lead to larger, more integrated firms or to smaller, more focused firms depends critically on the new capabilities the IT provides. The second of the two organizational studies is similar: it investigates how OBCs have affected whether drivers own the trucks they operate. 6 Traditionally, " owner-operators" have been an important part of the industry. An advantage associated with owner-operators is that they have strong incentives to drive in ways that preserve their trucks' value; these incentives have traditionally been far weaker for " company drivers," who do not own their trucks. This study shows that OBC diffusion has diminished the use of owner-operators. By allowing firms to monitor how drivers drive, OBCs have eliminated an important incentive advantage of owneroperators, and have led trucking firms to subcontract fewer hauls out to such individuals.

Residential Real Estate The Internet vastly increases the amount of information on housing vacancies that is readily available to consumers. Previous research had shown that high costs of information and lack of access to information limited housing searches. The best information available to consumers tended to be for properties near their current location. In addition, research found that information intermediaries such as real estate agents influenced the options that consumers considered. The increased information that the Internet makes available to consumers potentially reduces or eliminates those limits.

Consumers can readily learn about properties far from their current locations, and can do so relatively directly (there still may be some influence exerted in how web sites are set up, for example, and consumers may not immediately, or ever, get to the best web site for their needs). Two recent studies use micro data to assess the effect of using the Internet to search for housing. In these cases, micro data from the public-use Current Population Survey provide basic information on what kinds of consumers use the Internet to search for housing. However, the CPS does not have information about the homes that Internet users purchased.

To address questions about the kinds of homes purchased, the researchers surveyed a sample of recent home purchasers in a county in North Carolina. Characteristics of buyers who used the Internet as a source of information about housing vacancies were generally similar to those of buyers who only used conventional information sources, except that Internet users were younger. The researchers conclude that using the Internet to shop for housing does not seem to effect geographic search patterns, or to lead consumers to pay lower prices for comparable homes.

Although using the Internet might be expected to decrease the number of homes buyers visited, because they would have more information about the houses and neighborhoods, the studies G. Baker and T. Hubbard, " Contractibility and Asset Ownership: On-Board Computers and governance in U. S. Trucking," http://gsbwww. uchicago. edu/fac/thomas. hubbard/research/papers/paper_424. pdf (April 2003). 16 72 DIGITAL ECONOMY 2003 instead find that homebuyers who use the Internet as an information source make personal visits to more houses. 7 The Impact of IT on Wages Do " knowledge workers" receive wage premiums because they use computers? Does the use of IT increase the demand for more-educated workers? Does the growing use of computers by workers in some sectors of the economy explain shifts in the distribution of wages? Initial micro data research answered the first question with a resounding " yes. " One early study, for example, found that the pay of workers who used computers was 10 to 15 percent higher than the pay of similar workers who did not. 8 However, more recent studies that make use of more detailed information about workers and jobs over multiple periods find that the answer is more nuanced. IT potentially affects many aspects of the performance of businesses. It also may affect the wages, and other characteristics of jobs. Asking how IT affects wages is actually asking two questions. The first question is whether jobs where workers use computers pay higher wages. If the answer is yes, the second question is why. As with IT use in businesses, determining cause and effect of IT use on wages is hard.

The jobs might pay higher wages because they require high skill levels. Some IT-using jobs, such as computer programmers and systems analysts, clearly require high skill levels, as do jobs such as architects who use computer-assisted design programs. However, computers appear throughout many workplaces. Workers may use computerizeddiagnosticequipment and programmable logic controllers, for example, in production applications. Office and service workers may use word processors and spreadsheets, e-mail, computerized billing systems, and so forth.

Such jobs might pay higher wages if using a computer makes a worker with a given skill level more productive, but they generally do not require the workers to know much about principles of programming, or system or network design. Finally, the use of IT may allow computers to substitute for low-skilled workers performing repetitive tasks. Micro data studies in the United States, Europe, and Canada all find that workers using computers at work have much higher wages than workers who do not. The difference typically is on the order of 10 to 20 percent.

However, these studies all used data from a single period, and many of them lack information about other aspects of the job, the worker, and the employer. This makes it hard to determine whether the workers have higher wages because they use a computer, or because important unobserved characteristics of the employer (is it highly productive regardless of the use of computers?) or the worker (is the worker already highly skilled before using a computer?) may affect managers' decisions on investing in computers and R. Palm and M.

Danis, " Residential Mobility: The Impacts of Web-Based Information on the Search Process and Spatial Housing Choice Patterns," Urban Geography, Vol. 22, No. 7 (2001); and R. Palm and M. Danis, " The Internet and Home Purchase," Journal of Economic and Social Geography, Vol. 93, No. 5 (2002). A. Krueger, " How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989," Quarterly Journal of Economics, Vol. 108 No. 1 (February 1993). 18 17 73 DIGITAL ECONOMY 2003 assigning them to which employees. A new study reviewing recent research on the impact of IT on employment, skills, and wages concludes that the story is complex. 9 Studies find that having information on plant characteristics and work practices matters. For example, a study finding that workers using computers in Germany had higher wages than workers who did not also found that a similar wage differential accrued to workers using telephones or pencils, or who worked sitting down. 20 The implication is that the wage differential really reflected the fact that workers using computers, telephones, or pencils, or who work sitting down, receive higher wages because they have higher skills.

This research suggests that IT is associated with substantial wage differentials, but does not cause them. Studies for France and Canada find similar wage differentials. 21 Researchers using French and Canadian micro data also have matched sets of data on employers and workers in those countries, and have two or more years of data. Studies using these matched data all find that substantial cross-section returns to computer use fall sharply when they make use of information about changes in both the worker and employer characteristics.

Estimates differ by country and study, but the final differentials are modest, 1 to 4 percent. 22 These studies also find that the relatively modest wage differential associated with computer use varies markedly across occupations and among workers with different levels ofeducation. For example, a study for Canada finds that more highly educated workers, white-collar workers, and those adopting the computer for scientific applications receive higher than average wage premiums, while other workers do not receive wage premiums when they start using computers on the job. The reasons for such differences remain unresolved.

It may be more costly to teach some groups of workers to use computers, or groups may differ in the proportion of computer training costs that they share with the employer (with lower employer shares resulting in higher wages). The researchers find that controlling for training increases the small or zero wage premiums they otherwise find for many low-skilled groups. They speculate that, if appropriate data were available to test for long-run effects, controlling for training and other worker characteristics might show positive wage differentials for most workers using computers. 3 Some detailed case studies (studies of specific businesses, usually anonymous) suggest another reason for differences in the wage differential associated with using computers at work. One M. Handel, “ Implications of Information Technology for Employment, Skills, and Wages: A Review of Recent Research,” SRI International, SRI Project Number P10168, Final Report (July 2003). J. DiNardo and J. Pischke, “ The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too? ” The Quarterly Journal of Economics, Vol. 112 No. 1 (February 1997). H. Entorf, M. Gollac, and F.

Kramarz, “ New Technologies, Wages, and Worker Selection. ” Journal of Labor Economics (1999), and H. Entorf, and F. Kramarz, “ Does Unmeasured Ability Explain the Higher Wages of New Technology Workers? ” European Economic Review, Vol. 41 (1997); and C. Zoghi and S. Pabilonia, “ Which Workers Gain from Computer Use? ” Paper presented at NBER Summer Meetings (July 2003). 22 23 21 20 19 E. g. , Entorf and Kramarz 1997. C. Zoghi and S. Pabilonia 2003. 74 DIGITAL ECONOMY 2003case studyexamined the effect of introducing computers into the operations of a financial organization.

For some occupations, the case study found that computers substitute for the routine work that individuals previously performed, reducing the need for such workers. In other occupations, however, computers appear to take on routine tasks and free workers to perform more complex, higher skilled, problem-solving activities. 24 If IT also allows the business to alter the way it works and organize itself more productively, it may raise the skill requirements for all workers in the business, even if they do not directly use computers.

Insights from the International Micro Data Initiative A wave of new literature in plant- or firm-level research on the effects of IT has been conducted in countries participating in the OECD. 25 (See box 5. 1.) As with research using U. S. micro data, the micro data research conducted in other countries also find links between IT and productivity. Where information on computer networks is available, or other measures of how computers are used, the research again suggests that it is not just having IT, but how IT is used that effects economic performance measures such as productivity.

Two kinds of studies are being undertaken. Some studies base their research on new data on IT for a single country. They make use of as much information as they can, and choose empirical techniques best suited to their data. Studies such as these contribute important insights, particularly when one country has information that other countries do not, or researchers are able to use techniques that help ensure that the measured effects indeed are due to IT. However, this strength also makes it hard to compare such estimates across countries.

Studies from individual OECD countries find that IT has an impact on productivity and economic performance. Significant effects of IT on productivity are found in the service sector in Germany. 26 Recent research for France finds that one specific kind of network, the Internet, is associated with productivity gains, but other kinds of networks, which have been in use much longer, are not. 27 Canadian research finds that adopting IT is associated with growth in both productivity and market share. 8 Use of computers in Australia also is associated with productivity growth, with effects that vary across industries and are intertwined with other factors, such as the skill of a business' work force, its organization and re-organization, and its innovativeness. 29 24 D. Autor, F. Levy and R. Murnane, " Upstairs, Downstairs: Computer-Skill Complementarity and Computer-Labor Substitution on Two Floors of a Large Bank," Industrial & Labor Relations Review 55(3) (2002). Research to date is summarized in D.

Pilat, ICT and Economic Growth: Evidence from OECD Countries, Industries, and Firms (Paris: OECD, 2003). T. Hempell, " What's Spurious, What's Real? Measuring the Productivity Impacts of ICT at the Firm-Level," Discussion Paper 02-42, Centre for European Economic Research (Zentrum fur Europaische Wirtschaftsforschung GmbH; ZEW, 2002), ftp://ftp. zew. de/pub/zew-docs/dp/dp0242. pdf. B. Crepon, T. Heckel, and N. Riedinger, http://www. nber. org/CRIW/papers/crepon. pdf, Paper presented at " R&D, Education, and Productivity," NBER CRIW conference in honor of Zvi Griliches (Paris: August 2003). 8 29 27 26 25 J. Baldwin and D. Sabourin 2001. G. Gretton, J. Gali, and D. Parham, " Uptake and impacts of ICTs in the Australian economy," paper presented at OECD, Paris, December 2002. 75 DIGITAL ECONOMY 2003 Another group of studies tries to use as many variables and analytical techniques as possible that are similar to those used by researchers in a few other countries. 30 This approach may exclude some variables and some analytical techniques, if researchers in several countries cannot use them.

On the other hand, this kind of coordination makes it more likely that similar empirical findings are actually due to IT, and that differences in empirical findings are due to differences in economic conditions and other factors among countries. An example is a group of researchers conducting parallel analyses for the United States, Denmark, and Japan. 31 Preliminary findings are that IT is positively related to productivity in all three countries, but that the relationship depends on the type of IT used, the sector, and time period.

Early results for Denmark show a significant correlation between several measures of the firm’s performance and use of the Internet, but not for other uses of IT. For Japan, productivity levels are consistently higher for firms using IT networks. However, growth in labor productivity varies by type of network and how the network is used, and the effect of Internet use is higher for retail trade firms than for manufacturing firms. For U. S. manufacturing plants, there is a strong relationship between use of computer networks and labor productivity. Better Micro Data Research Requires Better Micro Data

Because the micro data are typically collected for other purposes, such as constructing key economic indicators, we almost always find that they lack some (often, much) of the information needed to address questions such those about the pervasiveness of IT and its effect. These gaps simply do not allow us to draw firm conclusions about the effect of IT. For example, research exploring the micro-level link between IT and economic performance may not always be able to separate the role of IT from other related but unobserved characteristics of the plant.

Well-managed plants may use IT as one of many tools to achieve performancegoals. If we have information about IT, but not about management practices, the research may attribute performance effects to IT that really are due to good management. Estimating plant-level relationships among computers, computer networks, and productivity also is hard to do with existing data because many of the most important concepts—what a business produces (output), and all the factors it uses to make its product (such as labor, capital, energy, etc. known as " inputs"), as well as IT itself—are difficult to define, and data based on these concepts are hard to collect. 32 Continuing research on these concepts leads to improve- For example, researchers in several countries are using the approach taken by U. S. researchers (Atrostic and Nguyen 2002), and using its findings as the benchmark against which they are comparing research findings using their own countries' data. B. K. Atrostic, P. Boegh-Nielsen, K. Motohashi, and S. Nguyen, " Information Technology, Productivity, and Growth in Enterprises: Evidence from New International Micro Data," L'acutalite economique (forthcoming 2004).

A large literature lays out major data gaps in estimating the impact of information technology on economic performance. For example, conferences conducted by the NBER Conference on Research in Income and Wealth

(CRIW) addressing capital and labor measurement over the last 20 years include D. Usher, The Measurement of Capital (NBER CRIW Volume 45 (Chicago University Press, 1980)); J. Triplett, The Measurement of Labor Cost (NBER CRIW Volume 48 (Chicago University Press, 1983)); and C. Corrado, J. Haltiwanger, and D. Sichel, Measuring Capital in the New 32 31 0 76 DIGITAL ECONOMY 2003 ments in what statistical agencies collect, but a dynamic and evolving economy continually presents new challenges. Even when concepts are well defined, it is costly for statistical agencies to collect data and for respondents to provide the requested information. As a result, some key information needed for analysis may not be collected often or at all. Examples include information such as the number of computers and computer networks that businesses have, how they use them, and how much businesses invest in computers and other IT.

The divergent findings in the resulting empirical literature on the effects of IT are likely related to these data gaps, and to differences in the techniques researchers use to try to deal with them. 33 One way to improve the micro data available for research would be by better integrating aggregate economic indicators and their underlying micro data. It currently is not always easy to reconcile movements in the aggregate statistics with changes observed in the micro data. Aggregate indicators often are constructed from multiple micro data sources, and different sources of data for any concept (such as employment or payroll) may disagree.

Collecting more of the data underlying aggregate statistics in ways that enrich their value as micro data, such as using common sampling frames and keeping information that allows linkage of same economic unit over time and across surveys, would improve both the micro data and our ability to understand changes in the aggregate economic indicators. Conclusion Micro data research conducted in the United States and in OECD countries shows that IT is related to economic performance and productivity. Careful research also shows that the relationships are complex.

IT emerges as a multifaceted factor. The kind of IT that is used and how it is used appear to matter in many (but not all) settings, including the ownership structure of trucking markets, the relative dynamism of retailing, and the relative risk taking and innovativeness of manufacturing sectors across countries. At the same time, the use of IT alone does not appear to be enough to affect economic performance. When researchers have information about the characteristics of businesses, workers, jobs, and markets, they find that IT appears to work instead in tandem with those factors.

Economy (NBER CRIW Volume 65 (Chicago University Press, forthcoming)). A series of meetings of international experts, known as the " Canberra Group," addressed capital measurement issues during the late 1990s (http:// unstats. un. org/unsd/methods/citygroup/capitalstock. htm). An excellent manual describing how to calculate productivity devoted considerable text to issues in measuring capital can be found in P. Schreyer, Measuring Productivity: Measurement of Aggregate and Industry-Level Productivity Growth—OECD Manual (Paris: OECD 2001).

Measuring intangible capital, potentially important in both IT and non-IT capital, received much attention recently (see for example B. Lev, Intangibles: Management, Measurement, and Reporting (Brookings Institution Press: 2001)). 33 See, for example, Dedrick et al. (2003); D. Pilat, 2003; B. K. Atrostic, J. Gates, and R. Jarmin, 2000, “ Measuring the Electronic Economy: Current Status and Next Steps,” Working Paper CES-WP-00-10, Center for Economic Studies, U. S. Bureau of the Census, Washington DC; and J. Haltiwanger, and R.

Jarmin (2000), “ Measuring the Digital Economy,” in E. Byrnjolfsson and B. Kahin (eds.), Understanding the Digital Economy (MIT Press 2000). 77 DIGITAL ECONOMY 2003 Separating out the effect of IT remains difficult because the analysis requires detailed information, and requires it for multiple periods. However, such detailed and repeated information is rare. Most business micro data contain only the information needed to calculate important economic indicators. The micro data are most sparse for the sectors outside manufacturing—the most IT-intensive sectors.

More definitive research on the impact of IT requires that producing micro data sets becomes a statistical agency priority. 78 DIGITAL ECONOMY 2003 Appendix 5. A. Conducting Micro Data Research on the Impact of IT THE CENTER FOR ECONOMIC STUDIES, U. S. CENSUS BUREAU The Center for Economic Studies (CES) is a research unit of the Office of the Chief Economist, U. S. Bureau of the Census, established to encourage and support the analytic needs of researchers and decision makers throughout government, academia, and business. CES currently operates eight Research Data Centers (RDCs) throughout the United States.

RDCs offer qualified researchers restricted access to confidential economic data collected by the Census Bureau in its surveys and censuses. CES and the RDCs conduct, facilitate, and support research using micro data to increase the utility and quality of Census Bureau data products. The best way for the Census Bureau to assess the quality of the data it collects, edits, and tabulates is for knowledgeable researchers to use micro records in rigorous analyses. Each micro record results from dozens of decisions about definitions, classifications, coding rocedures, processing rules, editing rules, disclosure rules, and so on. Analyses test the validity of all these decisions and uncover the data's strengths and weaknesses. Research projects at CES and its RDCs are examining how facets of the electronic economy affect productivity, growth, business organization, and other aspects of business performance using both new data collected specifically to provide new information about IT, and existing data. Projects using existing Census Bureau micro data on businesses include McGuckin et al. 998; Dunne, Foster, Haltiwanger and Troske, 2000; Stolarick 1999; and Doms, Jarmin, and Klimek, 2002). Research making use of the new 1999 supplement to the Annual Survey of Manufactures linked to existing Census Bureau micro data include Atrostic and Gates 2001; Atrostic and Nguyen 2002; Haltiwanger, Jarmin, and Schank 2002; and Bartelsman et al. 2002. Research findings from many of these projects are discussed in this chapter. The research also helps the Census Bureau assess what current data collections can say about the electronic economy so that we can more efficiently allocate resources to any new measurement activities.

More information about CES, RDCs, requirements for access to data, and examples of research produced at the RDCs is at http://www. ces. census. gov/ces. php/home. DATA SOURCES AT CES Researchers at CES and the RDCs built, and use, a longitudinal data set linking manufacturing plants over time. The data are based on surveys and economic censuses, and contain detailed data on shipments and factors used to produce them, such as materials and labor, as well as characteristics of the plant, such as whether it exports. Recent CES research broadens the range of available micro data beyond manufacturing.

A new micro data set, the Longitudinal Business Database, currently contains the universe of all U. S. business establishments with paid employees from 1976 to present. It allows researchers to examine entry and exit, gross job flows, and changes in the structure of the U. S. economy. The LBD can be used alone or in conjunction with other Census Bureau surveys at the establishment 79 DIGITAL ECONOMY 2003 and firm level. In addition, micro data from surveys and censuses of the retail, wholesale, and some service sectors is now becoming available.

The National Employer Survey, conducted by the Census Bureau for the National Center on the Educational Quality of the Workforce, collects detailed information about work practices, worker training, and the use of computers. Restricted access to confidential data from the survey is available to qualified researchers through the RDCs. Information about the National Employer Survey can be found at http://www. census. gov/econ/overview/mu2400. html. PUBLIC-USE DATA This chapter also refers to research conducted using two other sets of micro data collected by the Census Bureau.

The Current Population Survey (CPS) is a survey of households that is collected by the Census Bureau for the Bureau of Labor Statistics. The CPS periodically collects information about people’s use of computers at work and at home. More information can be found at http://www. census. gov/population/www/socdemo/computer. html. The Truck Inventory and Use Surveys collect information about on-board trip computers and electronic vehicle management systems as part of the Census of Transportation. Information about the Census of Transportation can be found at http://www. census. gov/econ/www/tasmenu. html. 80