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Abstract

This paper studies the mutually reinforcing effects on firm level productivity of certain combinations of information technologies and business practices, using a linked data set from the 1998 Survey of Advanced Technology in Canadian Manufacturing and the Annual Survey of Manufacturing. It shows that firms are bundling certain technologies with certain business practices and that adoption of the more commonly occurring bundles (for example, the bundle of the concurrent engineering practice and design and engineering technologies) is associated with higher productivity.

Key words: productivity, business practice, technology

Résumé

Les auteurs ont étudié les effets de renforcement réciproques sur le niveau de productivité de l'entreprise de certaines combinaisons de technologies de l'information et de pratiques commerciales, à l'aide d'un ensemble de données liées provenant de l'Enquête sur les technologies de pointe dans l'industrie canadienne de la fabrication de 1998 et de l'Enquête annuelle des manufactures. L'étude montre que les entreprises regroupent certaines technologies avec certaines pratiques commerciales et que l'adoption des regroupements les plus fréquents (par exemple le regroupement de la méthode d'ingénierie concurrente et des technologies de la conception et du génie) est liée à une plus grande productivité.

Mots clés : productivité, pratiques commerciales, technologie

1. Introduction

Canada, like most other OECD countries experienced a resurgence in labour productivity growth in the second half of the 1990s, apparently associated with the increased use of information technologies (IT, or ICT).[1] Costs for IT related equipment plunged and IT investment surged.[2] Some argue, however, that the full benefits of new technologies are only realized when these go together with investments in new business practices. "Simply investing in information technology is unlikely to provide a competitive advantage. Differences in economic performance should depend instead on how businesses use that technology" Atrostic and Nguyen (2006).

Brynjolfsson (1994, 2002) shows that IT-users that also invested in organizational capital exhibited both higher gains in multifactor productivity (MFP) and higher stock market values compared to firms that invested only in IT capital or only in adopting new organizational practices.[3] The idea is that investments in tangible and intangible assets reinforce one another. For example, Milgrom and Roberts (1990) find that at Ford, the adoption of a team approach rather than a sequential one along with Computer Aided Design/Computer Aided Manufacturing (CAD/CAM) techniques made it possible to greatly reduce development time.

Further empirical evidence that IT is most valuable when coupled with complementary changes in organizational design and business processes is provided by Brynjolfsson, Hitt and Yang (2002). They report that: "In addition to being correlated with IT, these practices are all correlated with each other." They constructed a composite variable following the lead of Brynjolfsson and Hitt (1995), and use this composite variable to "try to capture an organization's overall tendency to use this collection of work practices" and also to assess the productivity benefits of these combinations of work practices.

Using data for Canada, we explore alternative ways of empirically identifying combinations of business and high tech practices that are being adopted by businesses. We refer to these combinations generically as **BHIT bundles** in recognition also of the research of Brynjolfsson, and Hitt (1995, 2000) on which we build.[4]

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[1] See Atrostic et al. (2006), Baldwin and Sabourin (2001), Berndt and Morrison (1995), Colecchia and Schreyer (2001), Jorgenson (2001, 2004), Ho, Rao and Tang (2004), Stiroh (2002), and Van Ark, Inklaar and McGuckin (2003),

[2] Ho, Rao and Tang (2004) show that during 1995-2000, the price of computers fell by 18.3 percent in Canada and by 25.2 percent in the United States. See also Colecchia and Schreyer (2001, table 2).

[3] For Canada, Gera and Gu (2004) find that the adoption of ICTs along with organizational changes was perceived by firm managers to be positive for their performance. In France, Germany and the United Kingdom, McKinsey Global Institute finds that over the period of 1994-2002, IT adoption had little impact on productivity unless accompanied by management practices such as lean management, performance management and talent management (see Dorgan and Dowdy 2004). On this subject, see also Pilat (2003) and OECD (2004) and Arnal, Ok and Torres (2001).

[4] See also Hitt and Brynjolfsson (1997).

The data used in this study are for 1998 and are taken from the Statistics Canada 1998 Survey of Advanced Technology in Canadian Manufacturing (sometimes referred to as SAT or as SATCM) linked with the 1998 Annual Survey of Manufacturing (ASM). The survey collected data for establishments (referred to as firms in this paper) on the use of 12 advanced business practices and 26 types of advanced technology processes.

First, alternative approaches are pursued for empirically identifying commonly occurring combinations of business practices and high tech processes. Second, we examine whether the firms that used the identified BHIT bundles are more productive.[5] We find that adoption of BHIT bundles is associated with higher productivity.

2. The Statistics Canada Surveys of Advanced Technology Data and Manufacturing

The 1998 Survey of Advanced Technology data has been linked to the Annual Survey of Manufacturing for 1998. We have data for a sample of 2,196 firms. Each of the sampled firms carries a population weight that represents the number of firms with similar industry characteristics in the population. The sample represents a subpopulation of 20,862 firms in the manufacturing sector.[6]

In the 1998 Survey of Advance Technology, managers were asked which ones they were currently using of 26 different technologies (see appendix A for the specifics) that fall under the following functional headings (hereafter referred to simply as technologies): (1) Design and Engineering; (2) Processing, Fabrication and Assembly; (3) Automated Material Handling; (4) Inspection; (5) Network Communications; and (6) Integration and Control. We designate each of the six technologies using a multi-point scale variable set equal for each firm to the number of specific technologies that were adopted, and equal to 0 otherwise; hence all the technology variables take on the value of 0 for a firm that has adopted none of the specific types of processes that information was collected about in the Survey of Advanced Technology.

The 1998 Survey of Advanced Technology also asked plant managers whether they were regularly using each of the following 12 business practices: (1) Cross-Functional Design Teams; (2) Concurrent Engineering, (3) Continuous Improvement (including TQM), (4) Benchmarking, (5) Plant Certification (e.g., ISO9000), (6) Certification of Suppliers, (7) Just-in-Time (JIT) Inventory Control, (8) Statistical Process Control (SPC), (9) Electronic Work Order Management, (10) Process Simulation, (11) Distribution Resource Planning, and (12) Quality Function Deployment (QFD). Each of the business practices is denoted by a binary (that is, a dummy) variable set equal to 1 if a firm used the practice and set equal to 0 otherwise.

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[5] This is not a causal analysis; we do not know when the business practices were adopted. See Leung (2004).

[6] The 1998 Survey of Advanced Technology provides a random sample of 4,200 Canadian manufacturing establishments (hereafter referred to as "firms"), taken from Statistics Canada's Business Register. It spans all but one manufacturing industry at the 3-digit NAICS level. Food processing firms were surveyed separately and are excluded from this survey. In addition, firms with fewer than 10 employees were not surveyed because of resource constraints. See Sabourin and Beckstead (1998). The linked database contains data on 2,273 manufacturing firms. However, this paper excludes from the sample 77 firms with negative value added.

3. The Linkage Between Advanced Technologies and Business Practices

What are the common combinations of business practices and technological processes? For our data**,** all pairs of the selected business practices and high tech processes are significantly and positively correlated. There are no obvious patterns in the values. Multivariate methods are needed to find combinations that are more prevalent.

3.1 Technologies and the Likelihood of Using a Business Practice

We estimated a simple logit model where the dependent variable for each estimating equation is the probability of using one business practice over that of not using it.[7] There are 12 estimated equations for the 12 mutually non-exclusive business practices we have data for. For each equation, the explanatory variables are the multi-point scale variables for the 6 technologies, and also a binary (dummy) variable set equal to 1 if a firm has a foreign head office and 0 otherwise, a dummy variable set equal to 1 if a firm engages in exporting and equal to 0 otherwise, a dummy variable set equal to 1 for large firms with more than 100 employees and equal to 0 otherwise, and industry dummy variables.[8] In table B1 in appendix B we report the derived elasticities for the odds ratios with respect to each included explanatory variable. The larger a derived elasticity, the greater the influence is of the associated explanatory variable on the odds of a business practice being used.

3.2 Business Practices and the Likelihood of Adopting an Advanced Technology

Next we explore the reverse question: whether the likelihood of a firm adopting an advanced technology is significantly associated with the use of specific business practices.

As stated in section 2, we have information on six technologies. An ordered logit model is estimated since our technology variables are on a multi-point scale.[9] We use this model to explore for each of the six technologies whether the probability that firm i adopts technology k is related to a set of factors that may influence the probability. The probability of adopting each technology is related to the set of 12 business practices controlling as well for head office location, export orientation, firm size and industry fixed effects. More specifically, the dependent variable in this model is the probability of a firm adopting a technology over that the probability of not adopting it. The explanatory variables are the dummy variables for the different business practices, and also, as in the previous business practice logit models, we include dummy variables for a foreign head office, for whether a firm engages in exporting, and for whether a firm is large (with 100 employees or more). Table B2 displays the derived elasticities: estimates of the strength of an association controlling for the other factors that are included in our estimating equations.

[7] See appendix B for further details.

[8] The industry dimension is captured by separating firms into 20 industries based on the 3-digit NAICS codes.

[9] See appendix B for details.

3.3 BHIT Bundles

We experiment with four alternative definitions of BHIT bundles based on the derived elasticities in tables B1 and B2:[10]

Case 1: BHIT bundles are identified by the technology that has the strongest association, based on table B1, with the likelihood of use of a business practice.

Case 2: BHIT bundles are identified by the two business practices that have the strongest association, based on table B2, with the likelihood of the adoption of a technology.

Case 3: BHIT bundles are the groups of business practices and high tech processes that satisfy the criteria for either case 1 or case 2.

Case 4: BHIT bundles are the groups of business practices and high tech processes that satisfy the criteria for both cases 1 and 2.

The BHIT bundles are summarized in table 1. By design, 12 are identified by the technology that has the strongest association with the use of each business practice (case 1), and 12 more are identified by the two business practices with the strongest association with each technology (case 2). All together, 20 BHIT bundles are identified for case 3, but only four for case 4.

Most of the BHIT bundles are expected. For instance, firms using the business practice of Electronic Work Order Management would be expected to adopt Network Communications technologies, and firms that adopt Design and Engineering would be expected to use Cross-Functional Design Teams. It is interesting to note that Network Communications, and Integration and Control technologies are in BHIT bundles with many business practices, and the business practice of Continuous Improvement is part of BHIT bundles involving many technologies.

4. Technology Adoption, Business Practice and Productivity Performance

In the previous section, results were presented indicating that firms seem to use certain combinations of business practices and high tech processes: what we termed BHIT bundles. Presumably firms choose the bundles they believe will help improve their productivity and competitiveness. But do firms using one or more BHIT bundles actually realize higher productivity performance compared to other firms? That is the question examined in this section.

[10] The cut-off line is arbitrary. The main concern is to choose to a cut-off line that results in the size of the group consisting of firms with at least a BHIT bundle is comparable to the size of the other group consisting of firms adopting technologies or business practices but having no BHIT bundle, which has implications for the productivity analysis. The sizes of the two groups being comparable in a regression is important since it minimizes the potential estimation bias of one group against the other (Lee and Tang, 2001).

Table 1. Commonly Adopted Business Practice and High Tech (BHIT) Bundles

	Advanced Technologies					
Business practices	Design and Engineering	Processing, Fabrication and Assembly	Automated Material Handling	Inspection	Network Communi-cations	Integration and Control
Cross-Functional Design Teams	◄▲					
Concurrent Engineering	◄▲	▲				
Continuous Improvement		▲	▲		◄▲	▲
Benchmarking				▲	◄	
Plant Certification					◄	
Certification of Suppliers					◄	
Just-in-Time (JIT) Inventory Control						◄
Statistical Process Control			▲			◄
Electronic Work Order Management					▲	◄▲
Process Simulation						◄
Distribution Resource Planning		◄				
Quality Function Deployment				▲		◄

Note: ▲ denotes the bundles identified by the two business practices that have the largest influences on the likelihood of the adoption of a technology. ◄ denotes the bundles identified by the technology that has the largest influence on the likelihood of the use of a business practice.

4.1 Regression Model for Productivity Analysis

To gain insight into how BHIT bundles are associated with productivity, we divide firms into three groups: BHIT adopters, no-BHIT adopters and non-adopters. A BHIT adopter is a firm with at least one BHIT bundle. A no-BHIT adopter is a firm that adopts at least one technology or business practice, but has no BHIT bundles. And a non-adopter is a firm that adopts none of the stated technologies or business practices.

We estimated the following weighted linear regression model for firm productivity that includes dummy variables for whether a firm is classified as a BHIT adopter or a no-BHIT adoptor:[11]

[11] The regression model is based on a production function in value added concept, which suggests that labour productivity is a function of capital intensity and an efficiency parameter. This paper hypothesizes that firms differ in efficiency due to different characteristics.

$$\ln(P_{i,98}) = \beta_0 + \beta_1 \ln(F_{i,98}) + \beta_2 Y_i + \beta_3 N_i + \beta_4 O_i + \beta_5 E_i + \beta_6 S_i + \sum_{j=1}^{19} \beta_{6+j} I_{i,j} + \varepsilon_i . \quad (1)$$

In (1), $\ln(P_{i,98})$ is defined as value-added per worker in 1998 (in logarithm); $\ln(F_{i,98})$ is fuel and power consumption per worker (in logarithm);[12] Y_i is a dummy variable equal to 1 for BHIT adopters and equal to 0 otherwise; N_i is a dummy variable equal to 1 for no-BHIT adopters and equal to 0 otherwise; O_i is a dummy variable equal to 1 if the head office is foreign and equal to 0 otherwise;[13] E_i is a dummy variable equal to 1 if the firm is exporting and equal to 0 otherwise;[14] S_i is a large firm size dummy based on employment in 1995, and set equal to 1 for firms with 100 or more employees and equal to 0 otherwise; $I_{i,j}$ is a dummy equal to 1 if firm *i* belongs to industry *j* and equal to 0 otherwise; and ε_i is the error term. At the core of the regression are the two dummy variables associated with technology adoption and the use of business practices.

4.2 Empirical Results on Productivity

Model (1) was estimated using the case 1-4 definitions of BHIT bundles. The resulting coefficient estimates are shown in columns 1-4, respectively, of table 2. From rows 1 and 2 of the table, we see that the estimated coefficients are significantly positive for both the BHIT and the no-BHIT dummy variables. Thus, we find that firms that adopted one or more of the business practices or high tech processes that information was collected on in the Survey of Advanced Technology are more productive than non-adopters, whether or not they have adopted any of the BHIT bundle combinations.

In addition, we see that the coefficients in row 1 are systematically larger than those in row 2. This result is consistent with the hypothesis that the most productive firms are BHIT adopters.[15] This results suggest that the bundling activities more commonly undertaken by firms are associated with higher productivity.[16]

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[12] Capital intensity, defined as capital stock per worker, is an important determinant of labour productivity, but there is no capital stock or investment data available in the dataset. To overcome this problem, proxy variables for capital intensity are used: the consumption of fuel and power per employed person. These sorts of proxy variables for capital intensity are also used in the studies of Globerman, Ries and Vertinsky (1994) and Tang and Wang (2005). These proxy variables are chosen on the basis of theories and empirical evidence suggesting that the working capital stock is highly correlated with fuel and power consumption. (Industry differences in energy intensity are accounted by industry dummies.)

[13] See Baldwin and Gu (2005), Globerman, Ries and Vertinsky (1994), and Rao and Tang (2002).

[14] See Baldwin and Gu (2004).

[15] All of the estimated equations are statistically significant with at least a 99 percent level of confidence, and all are based on 2196 observations (see section 2).

[16] As expected, fuel and power consumption per employed person, as a proxy for capital intensity, is one of the most significant factors associated with labour productivity. This is consistent with the fact that the higher the capital intensity, the higher the level of labour productivity. In addition, the estimation shows that firms with head offices abroad are on average more productive than others. This finding is consistent with results of others showing that foreign-controlled firms in Canada are more productive than domestic-controlled firms (e.g., Globerman, Ries and

Table 2. Technology Adoption, Business Practices and Productivity Performance

Independent variables	BHIT Definition Used: Technology associated: Case 1	Business practice associated: Case 2	Technology and business practice associated: Case 3	Technology or Business practice associated: Case 4
1. BHIT adopter (adopted technology and business practice, with at least one BHIT bundle)	0.329[a]	0.337[a]	0.366[a]	0.317[a]
2. No-BHIT adopter (Adopted technology or business practice, without any BHIT bundle)	0.251[a]	0.239[a]	0.223[a]	0.263[a]
3. Fuel and power consumption per worker (as a proxy for capital per worker)	0.184[a]	0.184[a]	0.184[a]	0.185[a]
4. Foreign head office	0.442[a]	0.444[a]	0.440[a]	0.446[a]
5. Exporting	0.155[a]	0.158[a]	0.153[a]	0.159[a]
6. Large firm size	0.119[a]	0.113[a]	0.099[a]	0.125[a]
Adj. R-square	0.36	0.36	0.37	0.36

Note: The reference group is the group of firms that adopt neither technology nor business practice. For Case 1, the BHIT bundles are identified by the technology that has the largest influence on the likelihood of the use of a business practice. For Case 2, the BHIT bundles are identified by the two business practices that have the largest influences on the likelihood of the adoption of a technology. For Case 3, the BHIT bundles are jointly identified in case 1 and case 2. And for Case 4 the BHIT bundles are identified in either case 1 or case 2. A super a, b or c indicates significance at the 1%, 5% or 10% level, respectively. Industry fixed effects terms (dummy variables) are included, but the coefficient estimates are not reported.

5. Conclusions

There is growing interest in the potential importance of the mutually reinforcing effects on firm level productivity of certain combinations of business practices and high tech processes. We empirically explore these effects for Canadian manufacturing firms using a linked data set from the 1998 Survey of Advanced Technology in Canadian Manufacturing and the Annual Survey of Manufacturing. Our results show that firms are bundling certain business practices and high tech processes, and that adoption of the more commonly occurring bundles is associated with higher productivity.

Vertinsky 1994). Furthermore, it is found that firms with export orientation are more productive, which is consistent with the finding of Baldwin and Gu (2004). Finally, firm size matters for productivity. Large-sized firms tend to be more productive. This finding is also consistent with the literature for Canadian manufacturing firms (e.g., Tang and Wang, 2005).

Findings of complementarities between business practices and high tech processes lend support to the proposition that there are also important complementarities between the largely intangible practice and process assets of firms -- assets that are mostly being ignored in official statistics and the national accounts -- and the tangible assets that are being measured by national statistics agencies.[17] These results underscore the importance of improving the available firm level data on business practice and high tech process assets, including when these investments were made, and the utilization of these mostly intangible assets.

[17] See Appendix C for a discussion of unmeasured assets in the national accounts.

Appendix A Specific Advanced Technologies in Our Six Functional Groups

1) Design and Engineering
   a) Computer aided design/engineering (CAD/CAE)
   b) Computer aided design/manufacturing (CAD/CAM)
   c) Modelling or simulation technologies
   d) Electronic exchange of CAD files

2) Processing, Fabrication, and Assembly
   a) Flexible manufacturing cells or systems (FMC/FMS)
   b) Programmable Logic Control (PLC) machine(s) or process(es)
   c) Lasers used in materials processing (including surface modification)
   d) Robot(s) with sensing capabilities
   e) Robot(s) without sensing capabilities
   f) Rapid Prototyping Systems (RPS)
   g) High speed machining
   h) Near net shape technologies

3) Automated Material Handling
   a) Part identification for manufacturing automation (e.g. bar coding)
   b) Automated Storage and Retrieval System (AS/RS)

4) Inspection
   a) Automated vision-based systems used for inspection/testing of inputs and/or final products
   b) Other automated sensor-based systems used for inspection/testing of inputs and/or final products

5) Network Communications
   a) Local Area Network (LAN) for engineering and/or production
   b) Company-wide computer networks (including Intranet and WAN)
   c) Inter-company computer networks (including Extranet and EDI)

6) Integration and Control
   a) Manufacturing Resource Planning (MRP II)/Enterprise Resource Planning
   b) Computer(s) used for control on the factory floor
   c) Computer Integrated Manufacturing
   d) Supervisory Control and Data Acquisition (SCADA)
   e) Use of inspection data in manufacturing control
   f) Digital, remote controlled process plant control (e.g. Fieldbus)
   g) Knowledge-based software

Appendix B The Logit Estimating Equations

The estimating equation for the results shown in table B1 below is:

(B1)
$$\ln\left[\frac{\text{Prob}(B_i = k)}{\text{Prob}(B_i = 0)}\right] = \alpha_{0,k} + \sum_{j=1}^{6} \alpha_{j,k} T_{j,i} + \alpha_{7,k} O_i + \alpha_{8,k} E_i$$
$$+ \alpha_{9,k} S_i + \sum_{m=1}^{19} \alpha_{m+9,k} I_{m,i} + \varepsilon_{i,k}, \quad k = 1, 2, \ldots, 12$$

where, for firm *i*, $\text{Prob}(B_i = k)$ denotes the probability of using the k^{th} business practice; $T_{j,i}$ indicates the adoption of type *j* technology; O_i is a dummy variable for the location of the head office of the controlling firm, taking the value 1 if the head office is foreign and 0 otherwise; E_i is a dummy variable for exporting activity, taking the value 1 if the firm exports and 0 otherwise; S_i is a firm size dummy based on employment, taking the value 1 for large firms and 0 otherwise; $I_{m,i}$ is the dummy for industry *m*; and ε_i is the error term.

The dependent variable in this model is the probability of using one business practice over that of not using the business practice. There are 12 mutually non-exclusive business practices that a firm might choose to use. Hence 12 logit equations were estimated.

The logit model is estimated, making use of the population weights that mentioned in section 2. The elasticity of the odds ratio, $\text{Prob}(B_i = k) / \text{Prob}(B_i = 0)$, with respect to a variable, say, x_i, is $\hat{\beta}_i \bar{x}_i$, implying that a change in x_i by one percent is associated with a change in the odds of using a business practice by $\hat{\beta}_i \bar{x}_i$ percent, where $\bar{x}_i$ represents the mean value of variable x_i across the manufacturing firms.

Table B1. Derived Elasticities of the Odds of Using a Business Practice

Technologies and other independent variables	Estimated Equation: 1 Cross-functional design teams	2 Concurrent engineering	3 Continuous improvement	4 Benchmarking	5 Plant certification	6 Certification of suppliers
Design and Engineering	0.55[a]	0.63[a]	0.13[a]	-0.10[a]	0.09[a]	-0.11[a]
Processing, Fabrication and Assembly	0.23[a]	0.45[a]	0.20[a]	0.20[a]	0.01	0.14[a]
Automated Material Handling	0.01	-0.03[a]	0.15[a]	0.14[a]	0.07[a]	0.06[a]
Inspection	0.11[a]	0.01	0.17[a]	0.15[a]	0.14[a]	0.15[a]
Network Communications	0.27[a]	-0.32[a]	0.32[a]	0.31[a]	0.18[a]	0.37[a]
Integration and Control	-0.14[a]	0.32[a]	0.17[a]	0.30[a]	0.13[a]	0.15[a]
Foreign head office	0.02[a]	-0.04[a]	0.02[a]	0.04[a]	0.05[a]	0.03[a]
Exporting	0.10[a]	-0.00	-0.11[a]	-0.07[a]	-0.07[a]	-0.00
Large size	0.10[a]	0.05[a]	0.11[a]	0.10[a]	0.10[a]	0.04[a]
	Estimated Equation:					
	7 Just-in-Time Inventory Control	8 Statistical Process Control	9 Electronic Work Order Management	10 Process Simulation	11 Distribution Resource Planning	12 Quality Function Deployment
Design and Engineering	-0.15[a]	0.12[a]	0.33[a]	0.29[a]	-0.25[a]	0.11[a]
Processing, Fabrication and Assembly	0.15[a]	0.04[b]	0.12[a]	0.19[a]	0.46[a]	0.13[a]
Automated Material Handling	0.03[a]	0.19[a]	-0.01	-0.03[b]	0.03[b]	0.06[a]
Inspection	-0.04[b]	0.22[a]	-0.11[a]	0.17[a]	0.04[a]	0.18[a]
Network Communications	0.27[a]	0.13[a]	0.34[a]	-0.09[b]	0.31[a]	0.07[a]
Integration and Control	0.30[a]	0.39[a]	0.58[a]	0.63[a]	0.43[a]	0.34[a]
Foreign head office	0.01[b]	0.04[a]	0.01	-0.03[a]	0.01[a]	0.01[a]
Exporting	0.02[b]	0.01	0.01	0.04[b]	-0.01	0.03[a]
Large size	0.06[a]	0.04[a]	0.06[a]	0.03[a]	0.02[a]	-0.03[a]

Note: The estimation is based on an ordered logit model. The elasticity with respect to a variable x_i is $\hat{\beta}_i \bar{x}_i$, where $\hat{\beta}_i$ and $\bar{x}_i$ represent the estimated coefficient and the mean value of variable x_i across the manufacturing firms, respectively. A super a, b or c indicates significance at the 1%, 5% or 10% level, respectively. Industry fixed effects terms (dummy variables) are included.

The estimating equation for the results shown in table B2 below is:

(B2)
$$\ln\left[\frac{\text{Prob}(T_i = k)}{\text{Prob}(T_i = 0)}\right] = \alpha_{0,k} + \sum_{j=1}^{12} \alpha_{j,k} B_{j,i} + \alpha_{13,k} O_i + \alpha_{14,k} E_i$$
$$+ \alpha_{15,k} S_i + \sum_{m=1}^{19} \alpha_{m+15,k} I_{m,i} + \varepsilon_{i,k}, \quad k = 1, 2, \dots, 6$$

where $\text{Prob}(T_i = k)$ denotes the probability of adopting the k^{th} technology; $B_{j,i}$ indicates the use of type *j* business practice by firm *i*; O_i is a dummy variable for location of the head office of the firm, taking the value 1 if the head office is foreign and 0 otherwise; E_i is a dummy variable for exporting activity, taking the value 1 if the firm exports and 0 otherwise; S_i is a firm size dummy based on employment, taking the value 1 for large sized firms and 0 otherwise; $I_{i,j}$ is the dummy for industry *j*; and ε_i is the error term. The dependent variable in this model is the probability of adopting a technology over that of not adopting the technology. There are six mutually non-exclusive technologies. In this model, the probability of adopting a technology is related to the set of 12 business practices and the same control variables as for equation (B1).

Table B2. Derived Elasticities of the Odds of Adopting a Technology

	Estimated Equation:					
	1	2	3	4	5	6
	Design and Engineering	Processing, Fabrication and Assembly	Automated Material Handling	Inspection	Network Communications	Integration and Control
Cross-Functional Design teams	0.26[a]	0.14[a]	0.10[a]	0.11[a]	0.16[a]	-0.03[b]
Concurrent Engineering	0.36[a]	0.28[a]	-0.07[a]	-0.02	-0.08[a]	0.15[a]
Continuous Improvement	0.13[a]	0.20[a]	0.35[a]	0.24[a]	0.30[a]	0.19[a]
Benchmarking	-0.07[a]	0.11[a]	0.22[a]	0.32[a]	0.12[a]	0.15[a]
Plant Certification	0.02	-0.07[a]	-0.01	-0.01	-0.02	0.06[a]
Certification of Suppliers	0.00	0.07[a]	0.02	0.18[a]	0.24[a]	0.07[a]
Just-in-Time Inventory Control	-0.13[a]	0.00	-0.06[a]	-0.19[a]	0.01	0.06[a]
Statistical Process Control	0.08[a]	0.08[a]	0.30[a]	0.28[a]	0.06[a]	0.15[a]
Electronic Work Order Management	0.22[a]	0.13[a]	0.02[c]	-0.07[a]	0.24[a]	0.29[a]
Process Simulation	0.03[a]	0.04[a]	0.01[b]	0.08[a]	0.00	0.10[a]
Distribution Resource Planning	-0.01	0.10[a]	0.03[a]	0.01[c]	0.07[a]	0.06[a]
Quality Function Deployment	0.07[a]	0.02[b]	0.12[a]	0.28[a]	0.03[a]	0.11[a]
Foreign Head Office	-0.02[a]	0.00	-0.02[b]	-0.01[c]	0.10[a]	0.05[a]
Exporting	0.32[a]	0.24[a]	0.18[a]	0.30[a]	0.36[a]	0.22[a]
Large Size	0.12[a]	0.10[a]	0.12[a]	0.10[a]	0.17[a]	0.07[a]

Note: The estimation is based on an ordered logit model, given the dependent variables are on multi-point scale. The elasticity with respect to a variable x_i is $\hat{\beta}_i \bar{x}_i$, where $\hat{\beta}_i$ and $\bar{x}_i$ represent the estimated coefficient and the mean value of variable x_i across the manufacturing firms, respectively. A super a, b or c indicates significance at the 1%, 5% or 10% level, respectively. Industry fixed effects terms (dummy variables) are included.

Appendix C Unmeasured Assets in the National Accounts

It is widely agreed that the asset holdings of businesses that yield services used in current production include more than the physical capital stocks that official statistics agencies currently attempt to measure. This is not a serious problem if the unmeasured asset stocks are systematically correlated with the measured ones, they are not being mistakenly counted instead as part of consumption, and any interactions between the unmeasured and the measured asset stocks are either unimportant or stable. However, Diewert, Mizobuchi and Nomura (2005) argue that important components of the stock of assets are going unmeasured in the national accounts:

> "[I]n each accounting period, the business unit combines the capital stocks and goods in process that it has inherited from the previous period with 'flow' inputs purchased in the current period (such as labour, materials, services and additional durable inputs) to produce current period 'flow' outputs as well as end of the period depreciated capital stock components which are regarded as outputs from the perspective of the current period (but will be regarded as inputs from the perspective of the next period).
> All of the 'flow' inputs that are purchased during the period and all of the 'flow' outputs that are sold during the period are the inputs and outputs that appear in the usual definition of cash flow. These are the flow inputs and outputs that are very familiar to national income accountants. But this is not the end of the story: the firm inherits an endowment of assets at the beginning of the production period and at the end of the period, the firm will have the net profit or loss that has occurred due to its sales of outputs and its purchases of inputs during the period. As well, *it will have a stock of assets that it can use when it starts production in the following period*."

Diewert, Mizobuchi and Nomura conclude: "Just focusing on the flow transactions that occur within the production period will not give a complete picture of the firm's productive activities."

Furthermore, Brynjolfsson and Hitt (2000) point out that intangible business practice and technology process asset stocks are mostly not being counted for official statistics purposes. They present evidence that there are important differences in the extent to which firms invest in these types of assets along with making investments in the sorts of capital that are being counted for official statistics purposes, that there are important interaction effects, and that some of the missed asset accumulation is being mistakenly treated as current expenses rather than as investment, leading to potentially important distortions of measured productivity. In a 2000 *Journal of Economic Perspectives* article, Brynjolfsson and Hitt write:

> "Changes in multifactor productivity growth, in turn, depend on accurate measures of final output. However, nominal output is affected by whether firm expenditures are expensed, and therefore deducted from value-added, or capitalized and treated as investment. As emphasized throughout this paper, information technology is only a small fraction of a much larger complementary system of tangible and intangible assets. However, current statistics typically treat the accumulation of intangible capital assets, such as new business processes, new production systems and new skills, as expenses rather than as investments. This leads to a lower level of measured output in periods of net capital accumulation. Second, current output statistics disproportionately miss many of the gains that information technology has brought to consumers such as variety, speed, and convenience…. The magnitude of investment in intangible assets associated with computerization may be large. Analyses of 800 large firms by Brynjolfsson and Yang (1997) suggest that the ratio of

intangible assets to information technology assets may be 10 to 1. Thus, the $167 billion in computer capital recorded in the U.S. national accounts in 1996 may have actually been only the tip of an iceberg of $1.67 trillion of information technology-related complementary assets in the United States."

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