The Effect of Organizational Innovation and Information and Communications Technology on Firm Performance

Surendra Gera
Industry Canada
Wulong Gu[1]
Statistics Canada

DO COMPUTERS CONTRIBUTE TO productivity growth? Much evidence suggests that investment in information and communications technology (ICT) is making an important contribution to economic growth and labour productivity growth in OECD countries. At the same time, the OECD argues that ICT improves productivity by enabling organizational innovations. In this paper, we examine whether ICT and organizational innovation are associated with better performance in Canadian firms. The paper extends the previous studies in Canada to include firms in both manufacturing and service sectors. While most ICT investment is made in the service sector, there is little evidence on the contribution of ICT to the performance of the firms in the service sector in Canada. We have three objectives in this article:

- Is firm performance improved through ICT, worker skills and organizational innovations?
- Are organizational changes and worker skills complementary to ICT in improving firm performance?
- How does the relationship between productivity, ICT, worker skills and new organizational practices vary across manufacturing and services?

Our article has three novel features. First ,it uses a comprehensive micro data set, namely Statistics Canada's Workplace and Employee Survey (WES). The survey is a cross-section of 6,351 business establishments covering the entire spectrum of the Canadian economy in 1999. It provides a rich set of measures on organizational changes and firm performance that allow us to examine the relationship between ICT use, organizational practices and firm performance.

Second, the article examines the role of complementarities between ICT use, organizational changes in the areas of production practices, human resource management practices and product/service related practices, and human capital as drivers of better firm performance in the knowledge-based economy.

Third, and more importantly, the analysis extends beyond manufacturing to include the service sector.

1 Surendra Gera is Senior Research and Policy Advisor, Micro-Economic Policy Analysis Branch, Industry Canada and Wulong Gu is Chief of Research, Micro-Economic Analysis Division, Statistics Canada. Views expressed in the article do not necessarily represent those of Industry Canada or Statistics Canada. The unabridged version of this article, available at www.csls.ca under Publications and the *International Productivity Monitor*, contains a more detailed presentation of the data, analytical methods and results. The authors would like to thank John Baldwin, Andrew Sharpe, Julie Turcott and two anonymous referees for helpful comments. Email: gera.surendra@ic.gc.ca and wulong.gu@statcan.ca.

This article is divided into five main sections. The first provides a brief review of the growth accounting literature and its findings concerning the effects of ICT on productivity growth, and also of studies discussing the complementarities between ICT and organizational innovations. The second section provides a framework for analyzing and measuring organizational innovations. The third and fourth sections provide a discussion of data and empirical results, and the final section concludes.

Literature Review on ICT, Productivity Growth and Organizational Innovation

Most of the aggregate-level evidence shows that investment in ICT is making an important contribution to economic growth and labour productivity growth across OECD countries (OECD, 2000; Oliner and Sichel, 2000; Jorgenson and Stiroh, 2000). These studies find that technological progress, particularly the rapid advances in semiconductor technology, and ICT-capital deepening are the primary factors behind the acceleration in the U.S. growth in recent years.

Harchaoui et al. (2002) describe the similarities between Canada and the United States in the late 1990s. Like the United States, Canada experienced dramatic increases in both GDP growth and multifactor productivity growth in the post-1995 period. As in the United States, ICT growth was the largest contributor to the growth in capital services in Canada. Subsequent studies confirm that Canada shows trends similar to those in the United States, but in somewhat attenuated form (Rao, Ho and Tang, 2003; Gu and Wang, 2003).

OECD (2002) argues that ICT improves productivity by enabling organizational innovations. ICT is key to facilitating new organizational approaches, from lean production to teamwork to customer relations. ICT enables firms to introduce significant organizational changes in the areas of re-engineering, decentralization, flexible work arrangements and outsourcing. It allows firms to produce with greater flexibility and shortened product cycles to satisfy shifting consumer preferences. In fact, organizational innovation and ICT may be regarded as complementary factors. To be successful, firms typically need to adopt ICT as part of a "system" or "cluster" of mutually reinforcing organizational approaches (Milgrom and Roberts, 1990). Empirical evidence, mostly from U.S. studies, confirms that organizational changes improve economic performance of firms through their mutually-reinforcing relationship with ICT (see, for example, Bresnahan, Brynjolfsson and Hitt, 2002).

Over the last decade, there have been many firm-level studies in the United States examining the relationship between ICT investment and firm performance. The evidence is mixed.[2] Studies using 1980s data found no evidence that computers contributed positively to output growth (see, for example, Barua, Kriebel and Mukhopadhyay, 1995). In contrast, studies such as Brynjolfsson and Hitt (1995, 1996) and Lichtenberg (1995) employing more recent data over the 1988-1992 period have found a positive relationship between ICT investment and labour productivity.

Another study by Brynjolfsson and Hitt (1997) also explores the relationship between computers and productivity growth. The study uses data that includes more than 600 large U.S. firms over the period 1987 to 1994. The findings show that computers make a positive contribution to output growth. More interestingly, the study concludes that, "as a general purpose technology, the pattern of growth contribution appears to suggest that computers are a part of a larger system of technological and organizational changes that increased productivity over time".

Not many studies have examined the relationship between ICT and firm performance in the

2 For a comprehensive literature review of firm-level studies, see Brynjolfsson and Hitt (2000).

service sector. While the evidence from the available studies seems to be mixed, Brynjolfsson and Hitt (1995) report an important result. They find the contribution of ICT to output growth is as high in the service sector as in the manufacturing sector.

In Canada, a number of studies find strong evidence of a link between the use of ICT technologies and performance of plants in the manufacturing sector. Baldwin, Diverty and Sabourin (1995) and Baldwin and Sabourin (2002) link technology surveys to longitudinal data on the performance of manufacturing plants. They find that plants that use advanced technologies are more likely to experience productivity growth and that the superior productivity growth is then reflected in market share gains. Among the advanced technologies examined, communications technology is associated with the best performance. But they also point out that it is not ICT use alone that matters. Plants that combine ICT with other advanced technologies tend to do better than those using only one or two isolated technologies.

Baldwin and Sabourin (2002) raise an important caveat that must be kept in mind when interpreting the results of these studies. They argue that simply purchasing advanced technologies does not necessarily lead to success. Firm performance critically depends on how these technologies are implemented. Successful implementation of these technologies requires a human resource strategy to develop the necessary worker skills. It requires that firms overcome financing problems associated with acquiring new and untried technologies. And, it requires innovation accompanied by the development of best practices in quality control and engineering.

In a study for the food processing sector, Baldwin, Sabourin and Smith (2003) link technology use to plant performance and find that plants that were using new computer-driven advanced technologies experienced greater growth in labour productivity and market share during the period 1988 to 1997. Interestingly, the study finds that a plant's performance is related not just to its technological stance, but to other areas of competencies. In particular, plants that gave greater stress both to the use of advanced technologies and to human resource strategies such as training experience superior productivity gains. Organizations that continuously improve quality, train workers and recruit skilled workers do better than others.

Previous studies also suggest that dynamic services are more innovative and require a higher share of knowledge workers than the manufacturing sector. Investment in intangible activities, diffusion of knowledge, new technologies and high-quality human capital are the main factors contributing to the growth of this sector. At the same time, ICT has become a main determinant of productivity growth in transport, wholesale and retail trade (Pilat, 2001).

Organizational Innovation: A Framework

"Organizational innovation" is a broad concept that includes strategies, structural, and behavioural dimensions. It includes competitive strategy (i.e. role of innovation and costs); structural characteristics of the organization such as hierarchy, functional lines, and organizational boundaries; work processes including the use of different production inputs, the flow of work, job design, work allocation, and use of suppliers and subcontractors; human resource management (HRM) practices including hiring and firing; and industrial relation practices involving the strategies and institutional structures affecting the labour-management relationship.

Following OECD (2002), we define organizational changes to include three broad streams:

- the restructuring of production processes, which includes business re-engineering, downsizing, flexible work arrangements,

Table 1
Types of Organizational Innovation

Production and Efficiency Practices	Human Resources Management Practices	Product/service Quality-related Practices
• Business re-engineering • Downsizing • Flexible work arrangement • Outsourcing • Greater integration among functional areas • Decrease in the degree of centralization	• Performance-based pay • Flexible job design and employee involvement • Developing employee's skills • Labour-management cooperation	• Total quality management (TQM) • Improving coordination with customers/suppliers • Improving customer satisfaction

outsourcing, greater integration among functional lines, and decentralization;

- human resource management practices, which include performance-based pay, flexible job design and employee involvement, improving employees' skills, and institutional structures affecting labour-management relations; and
- product/service quality-related practices emphasizing total quality management (TQM) and improving coordination with customers/suppliers. A framework for our discussion of organizational innovation is shown in Tables 1 and 2.

Production and Efficiency Practices

Production and efficiency practices allow a firm to design, produce and market its products more efficiently than its competitors. Reducing the cost of doing business, increasing the speed of delivery, enhancing the flexibility of the organization, and achieving economies of scale are the main characteristics of production and efficiency practices. These activities work together to achieve better productivity performance, lower cost of production, higher quality, and better customer service. In practical terms, production and efficiency practices are often associated with making production processes "lean" and more responsive to market changes. These practices include a return to "core business", "re-engineering" and "outsourcing". All these practices entail a concentration of the activities of the firm on essential parts of the business, where its comparative advantage lies. Additional practices such as "just-in-time" production and "benchmarking" are expected to make the firm more responsive to the market while at the same time encouraging the adoption of successful practices in other organizations. Other practices such as "decentralization" involve the decentralization of management responsibility and empowering of employees in order to achieve enhanced flexibility (OECD, 2002).

Human Resource Management Practices

In the knowledge-based economy, there is a greater tendency to forge more explicit links between HRM practices and overall corporate strategy (Newton, 1996). Firms use HRM practices as a strategic tool to achieve business objectives such as cost reduction and product development. HRM practices produce a skilled and motivated work force that can adapt to and take advantage of new technologies and changing markets. HRM practices cover a range of personnel management areas including performance-based pay, job rotation, flexible job designs, employee involvement, skills training, and communication procedures (Table 2).

In empirical literature, there is ample evidence on the effects of individual HRM practices on productivity performance.[3] Importantly, regardless of size, those employers who have adopted

Table 2
Elements of Human Resources Management Practices

Human Resources Management Practices	Strategies
Performance-based Pay	• Individual incentive systems • Productivity/quality gain sharing & other group incentives • Profit sharing plan • Merit pay and skill-based pay
Flexible Job Design & Employee Involvement	• Employee suggestions programs • Flexible job design • Greater reliance on job rotation and multi-skilling • Information sharing with employees • Quality circles, problem-solving teams • Self-directed work groups • Joint labour management committees
Developing Worker Skills	• Formal job-related training • On-the-job training • Participation in training subsidies program • Participation in other training program
Labour-management Cooperation	• Enhancing labour-management cooperation

some of the practices associated with what have been called "high performance workplaces" are more likely to have formal training programs. There are significant and positive effects on establishment productivity associated with investments in human capital.[4]

Product/Service Quality-Related Practices

Over the past twenty years, the composition of the business sector has shifted from traditional industries (e.g. steel, chemicals) with long product cycles and an emphasis on process R&D to more innovative, faster-changing industries, often with short product cycles (e.g. computer equipment). Shorter product cycles increase the need to constantly renew products and improve the quality of goods (OECD, 2000). To respond to this challenge, businesses increasingly focus on practices such as total quality management (TQM), improving coordination with customers/suppliers, and improving customer satisfaction. There is widespread recognition of TQM as a critical competitive strategy and thus, a primary concern of all levels of management, including senior management (Easton and Jarrell, 1998).[5]

Data

Data for our analysis are taken from the 1999 WES, a survey developed by Statistics Canada and Human Resource Development Canada. The WES is a linked employer-employee survey. The employer survey provides comprehensive information on 6,351 business establishments across a

3 Some notable studies include profit sharing (Kruse, 1993) and information sharing (Kleiner and Bouillon, 1988). HRM practices such as teamwork and job rotation seem to raise skill demands primarily for behavioural and interpersonal skills such as the ability to get along with others and work in teams (Cappeli and Neumark, 1999). Lynch and Black (1995) find that smaller establishments are much less likely to provide formal training programs than larger establishments.

4 Ichniowski, Shaw and Prennushi (1997) find that interaction effects are important determinants of productivity. Firms realize the largest gains in productivity by adopting clusters of complementary HRM practices, and benefit little from making marginal changes in any one HRM practice. Black and Lynch (2000, 2001) find that unionized establishments that promote joint decision making coupled with incentive-based compensation have higher productivity than other similar non-union plants, while those businesses that are unionized but maintain more traditional labour-management relations have lower productivity

5 Evidence from surveys of managers and the case study literature shows that the most important reasons for investing in ICT are product quality improvements, especially customer service, timeliness, and convenience (Bresnahan, Brynjolfsson and Hitt, 2002).

complete cross-section of the Canadian economy. This study utilizes the employer workplace survey on innovative business strategies, organizational changes, training and other HRM practices, and quality-related strategies. The reference period for the WES is the 12-month period ending in March 1999. We have removed non-profit operations from the data for the analysis in the paper. The final sample used consists of 5,501 firms in the business sector.

Constructing Key Variables

The key variables for our analysis include ICT use, human capital, organizational innovation, and firm performance. In this section, we discuss how these variables are constructed from the WES employer survey.

ICT Use

We have constructed two measures of ICT use from the WES: the share of workers using computers; and the level of ICT investment per worker. The former is calculated as the number of employees using a micro-computer, minicomputer, mid-range computer or mainframe computer as a share of the total number of employees. The latter is constructed as the expenditure on new software and hardware plus computer-controlled or computer-assisted technologies per worker. The share of workers using computers captures the outcomes of all ICT investment activities by establishments, past and present, while ICT investment represents current investment activities only. As such, the ICT investment variable is a less comprehensive measure than the share of workers using computers.

Human Capital

Human capital is measured as the share of knowledge workers in the total number of workers. We define knowledge workers as managers plus professional workers (see, for example, Gera, Gu and Lin, 2001; Lavoie, Roy and Therrien, 2003).

Organizational Innovations

The WES provides a rich set of measures of organizational innovations, as listed in Tables 1 and 2. The variable for an element of organizational innovation takes the value of one if the workplace adopted the organizational innovation. Otherwise, it is equal to zero.

Firm Performance

The WES provides a rich set of measures on firm performance. We use five such measures: productivity changes, sales growth, profit changes, product innovation, and process innovation. In our empirical analyses, the measures for productivity, sales growth and change in profit are equal to one if the establishment reported an increase in productivity, sales or profit during the period between April 1, 1998 and March 31, 1999. The variable for product innovation takes the value of one if the workplace introduced new or improved products. The variable for process innovation is set to one if the workplace introduced new or improved processes.[6] The five measures of firm performance are highly correlated and capture different aspects of the overall success of the firms. While none of the above measures is perfect, the five measures taken together should capture the overall success of the firms.

Summary Statistics

Table 3 presents sample means for ICT use, share of knowledge workers, and firm performance in the Canadian business sector, by establishment size and industrial sector. A number of interesting findings emerge:

6 Process innovation is often introduced in conjunction with new technologies (ICT and non-ICT) such as robots, advanced manufacturing cells, automated process control and many similar state-of-the-art technologies, all of which are integral to new processes. ICT as a general purpose technology should facilitate the introduction of process innovations.

Table 3
Sample Means of ICT, Human Capital and Firm Performance

Variables	All	Manuf.	Dyn. Services	Distrib. Services	Large Establish-ments	Small Establish-ments
Share of Workers using Computers	0.46	0.34	0.66	0.38	0.44	0.46
ICT Investment per worker (current $)	1,629	1,252	3,388	616	1,663	1,629
Share of Knowledge Workers	0.24	0.18	0.27	0.25	0.16	0.25
Increase in Productivity	0.39	0.51	0.38	0.38	0.55	0.39
Increase in Profits	0.36	0.44	0.37	0.35	0.51	0.35
Increase in Sales	0.46	0.57	0.42	0.48	0.57	0.46
Product Innovation	0.45	0.55	0.41	0.50	0.62	0.45
Process Innovation	0.32	0.47	0.32	0.30	0.62	0.31

Source: Workplace and Employee Survey, Statistics Canada.

Note: Dynamic services industries include the communication, finance, insurance & real estate, business services, education & health, and information & cultural industries. Distributive services industries include wholesale, retail and transportation services. Large establishments are defined as those with more than 100 employees. Small establishments employ 100 or fewer workers.

- the share of workers using computers is higher among dynamic services (66 per cent) than in distributive services (38 per cent) and manufacturing industries (34 per cent), while the share of workers using computers is similar between large establishments (44 per cent) and small establishments (46 per cent);
- ICT expenditure per worker is similar between large and small establishments ($1,663 vs.$1,629 per worker);
- the share of knowledge workers is highest in services industries, which along with their higher share of workers using computers suggests that firms that employ more knowledge workers are more likely to have higher levels of computer use;
- a higher proportion of manufacturing establishments (51 per cent) and large establishments (55 per cent) report increases in productivity than do small establishments (39 per cent), dynamic services establishments (38 per cent) and distributive services establishments (38 per cent); and
- about half of the establishments report introducing new products or improved products (45 per cent) in the business sector, while the fraction of large and manufacturing establishments that introduced product and process innovations is greater than that of small and non-manufacturing establishments.

Table 4 shows the fraction of workplaces adopting various elements of organizational innovations: the restructuring of production process; HRM practices; and product/service quality-related practices. Our data show that:

- among production and efficiency practices, the incidence of establishments adopting flexible work arrangements (24 per cent) and business re-engineering (19 per cent) is much higher than other individual practices;
- within HRM practices, the incidence of practices such as increasing employee involvement/participation (63 per cent) and adopting individual incentive systems (31 per cent), formal job-related training (29 per cent) and classroom training (20 per cent) was highest; and
- among product/service quality-related practices the incidence of establishments adopting improving product quality (78 per cent)

Table 4
Mean Incidence of Organizational Innovation

Organizational Innovations	Mean (per cent)
Production and Efficiency Practices	
Business re-engineering	0.19
Downsizing	0.09
Flexible work arrangement	0.24
Outsourcing	0.12
Greater integration among different functional areas	0.13
Decrease in the degree of centralization	0.03
Human Resources Management (HRM) Practices	
Performance-based pay	
Individual incentive systems	0.31
Productivity/quality gain sharing and other group incentives	0.08
Profit sharing plan	0.08
Merit pay and skilled-based pay	0.17
Flexible job design and employee involvement	
Employee suggestion programs	0.07
Flexible job design	0.07
Information sharing with employees	0.11
Quality circles, problem solving teams	0.06
Joint labour management committees	0.04
Self-directed work groups	0.02
Greater reliance on job rotation and multiskilling	0.15
Increase employee involvement/participation	0.63
Human resource investment policies	
Formal job-related training	0.29
Classroom training	0.20
Participating in training subsidies program	0.05
Participating in other training program	0.03
Product/Service Quality-related Practices	
Improving product quality	0.78
Improving coordination with customers/suppliers	0.66
Total quality management	0.13

and improving coordination with customers/suppliers (66 per cent) practices is higher than that of establishments adopting TQM (13 per cent).

While organizational changes are found to be related to better firm performance in Canadian industries, the importance of organizational changes for firm performance differs across various practices.[7] Among various types of productivity and efficiency practices, we find that downsizing is the least important for firm performance. The implementation of downsizing is associated with the smallest increase in the incidence of productivity improvement and the rate of innovation. For HRM practices, the data show that flexible job design and employee involvement are more important for firm performance than performance-based pay or improving industrial relations. The introduction of flexible job design and employee involvement is associated with the largest increase in the incidence of productivity improvement and the rates of product and process innovation. For product/service quality-related practices, our results show that total quality management and improving product quality matter more for firm performance. The establishments that adopt these practices have a higher incidence of productivity improvement and higher rates of innovation.

Empirical Methods and Results

As has been mentioned previously, organizational innovation, as defined in this article, consists of three main types: production and efficiency practices (PEP); human resource management (HRM) practices; and product/service quality-related practices (PQP), as listed in Table 1.

To examine the relationship between organizational innovation and firm performance, we first construct an overall measure of each type of organizational practice as the first principal component of the variables that reflect the importance of the various individual practices. The measures for the three organizational innovations – production and efficiency practices, HRM practices and product/service quality practices – are calculated as a weighted sum of the standardized variables, using the weights as determined from principal component analysis.

7 See, for example, Table 7 in the unabridged version of the paper.

Table 5
Effects of ICT and Organizational Innovation on Productivity Performance
Probit Estimation Results

Variables	(1)	(2)	(3)	(4)
Production and efficiency practices	0.207 (10.29)			0.153 (6.92)
HRM practices		0.211 (8.99)		0.114 (4.64)
Product/services quality practices			0.105 (6.45)	0.046 (2.68)
Share of workers using computers at work	0.140 (3.13)	0.132 (2.85)	0.139 (2.96)	0.117 (2.52)
ICT investment per worker	0.002 (0.07)	0.023 (0.60)	0.036 (1.01)	-0.016 (-0.45)
Share of knowledge workers	-0.067 (-1.18)	-0.011 (-0.17)	-0.043 (-0.72)	-0.054 (-0.95)

Note: The dependent variable is the incidence of productivity improvement. The number of observations for each specification is 5,501 establishments. Estimates are not the probit coefficient estimates, but are rather marginal effects calculated at the sample means. T-statistics, which refer to the probit coefficient estimates, are in parentheses. All regressions control for industry fixed effects, firm size and foreign ownership. T-statistics are adjusted for heteroscedasticity using the Huber-White method.

ICT, Organizational Changes and Firm Performance

In this section, we present regression results for the relationship between ICT, organizational change, human capital and firm performance. Our empirical specification is a probit model that relates firm performance to the measures of ICT, organizational changes (OC) and human capital (HK):[8]

$$y_i^* = \beta_0 + \beta_1 ICT_i + \beta_2 OC_i + \beta_3 HK_i + \beta_4 SIZE_i + \beta_5 OWNERSHIP_i + \beta_6 INDUSTRIES_i + \varepsilon_i$$

where y_i^* is an unobserved performance measure for firm i. The observed counterpart y_i to the unobserved firm performance measure is change in productivity, introduction of product innovations or introduction of process innovations during the reference year. The variable y_i takes the value of one if the establishment reports an increase in productivity, introduces product innovations or introduces process innovations. Otherwise, it is equal to zero. This can be expressed as $y_i = 1$ if $y_i^* > 0$, and $y_i = 0$ if $y_i^* \leq 0$.

In the regression analysis, we control for establishment size, foreign ownership, all industry fixed effects, which have been found to be important determinants of productivity changes in previous empirical studies. The error term ε_i assumes a normal distribution. In all estimations, we weight observations by sampling weights. To examine the magnitude of the effects of ICT and organizational changes on firm performance, we will present marginal effects from the probit model, evaluated at the sample means.

Empirical Results for the Total Business Sector

Table 5 presents probit model regression results for productivity performance. In all specifications, we introduce two measures of ICT use, the share of workers using computers at work and ICT investment per worker. And, we also include the share of knowledge workers in all specifications. In the first three specifica-

8 The measure of organizational innovation is calculated as a weighted sum of individual practices, using the weights as determined from the principal component analysis. The use of the principal component produces a comprehensible summary of all individual practices.

tions, we individually introduce three organizational changes (PEP, HRM and PQP). In the last specification, we introduce three organizational innovations in the same equation.

We find strong and robust evidence that the share of workers using computers is positively related to productivity performance. The coefficient on the variable is positive and statistically significant at the 5 per cent level in all specifications. However, the magnitude of the effect is quite small. Our results show that a 10 percentage point increase in the share of workers using computers is associated with a 1 percentage point increase in the probability of productivity improvement. However, as we discuss later in the article, the contribution of ICT to firm performance becomes quite large when combined with organizational changes. The ICT measure is found to have little effect on productivity performance in the Canadian business sector. This may reflect the fact that productivity improvements due to ICT investment occur only after a certain time lag or with initial adjustment costs.[9]

Our results show that the three organizational changes (the restructuring of production processes, HRM practices, and product/service quality-related practices) are all positively related to productivity performance. The effects are quite large. The estimates in specification (4) show that a one standard deviation increase in the measure of production and efficiency practices is associated with a 15 percentage point increase in the incidence of productivity improvement. For HRM practices and product/service quality practices, the effects on the incidence of productivity improvement are 11 and 5 percentage points respectively.

The story for knowledge workers is more ambiguous. The coefficient on the share of knowledge workers is small, negative and statistically insignificant. We interpret our result as suggesting that the share of knowledge workers has little additional effect on firm productivity after the measures of organizational changes and ICT use are taken into consideration. The share of knowledge workers may be linked to better productivity performance through its effect on ICT and organizational innovation.

We also examine the issue of whether ICT and organizational changes are related to other measures of firm performance such as sales growth, profit changes and innovativeness. Overall, our results show that ICT and organizational changes are positively associated with these various measures of firm performance. We find that for product and process innovations, it is the ICT investment that matters, whereas for sales and profit growth, the share of workers using computers appears to matter more.[10]

Empirical Results for the Manufacturing and Service Sectors

A number of previous studies show that the services sector in Canada has invested heavily in ICT and that this sector accounts for most of ICT investment over the past decade. Many service sector industries have also experienced rapid productivity growth (Rao and Tang, 2001; Gu and Wang, 2003). A number of studies conclude that the nature and extent of organizational changes differ between manufacturing and the service sector. OECD (2002) finds that the fraction of firms that introduced organizational changes is highest in the service sector across OECD countries. Consequently, we examine the relationship between ICT, organizational changes and firm performance separately for manufacturing and the service sector. We further divide the service sector into the

9 The two measures of ICT use have a correlation coefficient of 0.20. When we introduce the two measures separately in our regression, the coefficient on the share of workers using computers is positive and significant, and the coefficient on ICT investment is not significant.

10 The regression results are reported in Table 6 of the unabridged version of the paper.

dynamic services sector and the distributive services sector. The dynamic service sector includes communication & other utilities, FIRE (finance, insurance and real estate), business services, education and health care, and information & cultural industries. The distributive service sector includes wholesale trade, retail trade and transportation. These two service sectors differ in terms of their use of ICT, worker skills and capacity for organizational change.

The results in Table 6 show that the relationship between ICT, organizational changes and firm performance is somewhat different across sectors. For the manufacturing sector, production and efficiency practices, HRM practices, and ICT investment emerge as strong predictors of productivity performance. However, organizational innovations related to product/service quality practices are not related to productivity improvement in the manufacturing sector. In contrast, for the dynamic services sector, product/service quality-related practices, along with production and efficiency practices and HRM practices are important for productivity performance. For the dynamic service sector, our results also show that the share of workers using computers matters for productivity performance while ICT investment has little effect. These results are consistent with the previous findings that service firms tend to focus more on organizational changes that are related to product/service quality to reap productivity benefits (Pilat, 2001)

The story for the distributive service sector is very much similar to that of the dynamic service sector. For the distributive service sector, production and efficiency practices, HRM practices and the share of workers using computers matter for productivity performance. ICT investment and product/service quality-related strategies have little impact on performance.[11]

Table 6
Effects of ICT and Organizational Innovation on Productivity Performance by Industry Sector
Probit Estimation Results

Variables	Manuf.	Dynamic Services	Distributive Services
Production and efficiency practices	0.104 (3.47)	0.082 (2.82)	0.212 (5.12)
HRM practices	0.129 (3.57)	0.103 (3.00)	0.104 (2.38)
Product/services quality practices	0.036 (1.46)	0.078 (3.87)	0.035 (1.06)
Share of workers using computers at work	-0.004 (-0.06)	0.188 (3.46)	0.157 (1.90)
ICT investment per worker	0.114 (2.19)	-0.027 (-0.57)	-0.028 (-0.41)
Share of knowledge workers	-0.101 (-0.89)	-0.076 (-1.07)	-0.054 (-0.52)
No. of observations	1,368	2,072	1,192

Note: The dependent variable is the incidence of productivity improvement. Estimates are not the probit coefficient estimates, but are rather marginal effects calculated at the sample means. T-statistics, which refer to the probit coefficient estimates, are in parentheses. All regressions control for industry fixed effects, firm size and foreign ownership. T-statistics are adjusted for heteroscedasticity using the Huber-White method.

Complementarities between ICT and Organizational Changes

In this part of the paper, we test the hypothesis that ICT and organizational changes are complements. Milgrom and Roberts (1990) argue that to be successful, firms typically need to adopt ICT as part of a "system" or "cluster" of mutually reinforcing organizational approaches. To examine this complementarity hypothesis

11 We have also examined the issue of whether ICT and organizational changes are related to alternative measures of firm performance such as sales growth, profits changes and innovation among industrial sectors. Overall, our results from these alternative measures of firm performance are similar. First, we find that organizational innovations related to production and efficiency practices and HRM practices are related to better firm performance for both manufacturing and the service sector. Second, we find that product/service quality-related strategies are important for firm performance in dynamic services, while these strategies are less important in manufacturing and distributive services. Third, we find that for product and process innovation, ICT investment matters more than the share of workers using computers in both manufacturing and service sectors.

between ICT and organizational changes, we first look at correlations between ICT and various measures of organizational changes. If ICT and organizational changes are complements, we should observe a positive correlation between them. The incidence of organizational changes should be higher in those firms that use ICT more intensively. Second, we use regression analysis to compare performance of firms with various combinations of ICT and organizational changes. If these practices are complements, then firms that adopt these practices as a system should outperform the firms that fail to combine ICT and organizational changes.

We find that the incidence of organizational changes is much higher in the firms that invest heavily in ICT or have a high share of workers using computers than is the case in the firms that invest less in ICT or have a low share of workers using computers. Furthermore, ICT investment per worker and the fraction of workers using computers are positively correlated with the share of knowledge workers. This suggests that firms that invest heavily in ICT or have a large share of workers using computers tend to have a large share of knowledge workers. We also find that ICT use is correlated with the measures of organizational changes in the areas of production and efficiency practices, HRM practices and product/service quality-related practices, supporting the view that ICT and organizational changes are complements.[12]

If ICT and organizational changes are complements, the firms that combine these changes should have better performance than those that do not. Specifically, we re-estimate probit equation (4) from Table 5 and examine how various combinations of ICT, organizational changes and human capital are related to firm performance.[13] Our regression results suggest that ICT investment matters more for productivity performance in the manufacturing sector whereas for the service sector the fraction of workers using computers matters more. For innovation performance of firms, we find that it is ICT investment that matters.

The regression results also show that the firms that have a high level of ICT investment per worker and make intensive use of production and efficiency practices (business re-engineering, outsourcing and flexible work arrangements) have the best performance among Canadian firms. The incidence of productivity improvement for firms that have a high level of ICT and adopt production and efficiency practices is 34 percentage points higher than that for firms that have a low level of ICT and do not adopt the organizational change. The rate of product innovation is 40 percentage points higher, and the rate of process innovation is 47 percentage points higher.[14] We find that this interrelationship between ICT and production practices exists for both the manufacturing and service sectors.

Much the same story is evident when we examine the complementarity between ICT and HRM practices such as performance-based pay, flexible job design, employee involvement and human resource investment policies. The incidence of productivity improvement is higher in firms that use ICT more intensively and adopt HRM practices. The rates of product and process innovations are also higher.

Examining the interrelationship between ICT and organizational changes in product/service quality-related practices leads to a similar story. Firms that combine high levels of ICT investment per worker and product/service quality-

12 See Tables 9 and 10 in the unabridged version of the paper.

13 For methodology and detailed regression results, see Tables 11-14 in the unabridged version of the paper.

14 See Table 11 in the unabridged version of the paper. A study for Denmark also find that firms that combined ICT and organizational changes had higher rates of innovation (Danish Ministry of Business and Industry, 1996).

related practices have the best performance among Canadian firms. Surprisingly, our results do not detect evidence of complementarity between ICT and PQP in the manufacturing sector. The results, however, are consistent with our previous findings that PQP work practices do not emerge as a significant factor for firm performance in this sector. For the services sector, however, the results show that firms that adopt PQP practices have better firm performance if they also have a high level of ICT. These firms have a higher incidence of productivity improvement and higher rates of innovation. This is true for both dynamic services and distributive services.

Finally, we examine the complementarity of ICT and knowledge workers. Our results show that firms that have a high level of ICT and a high share of knowledge workers have the best performance among firms in the dynamic service and distributive service sectors. These firms have a high incidence of productivity improvement and high rates of product and process innovations. For the manufacturing sector, we do not find any evidence of complementarity between ICT and human capital.

Conclusion

In this article, we have examined the issue of whether investments in ICT combined with organizational changes such as the restructuring of production process, human resource management (HRM) practices and product/service quality-related practices and worker skills contribute to better firm performance among Canadian firms. Our findings are broadly consistent with the previous empirical work in the United States on ICT and new organizational practices. Our analysis suggests that Canadian firms have actively engaged in organizational changes in the areas of production and efficiency practices, HRM practices and product and quality-related practices. These practices combined with ICT are strongly associated with better firm performance. We find that the firms that implement organizational changes and introduce ICT have a higher incidence of productivity improvement, and also of sales and profit increase and product and process innovation.

We find that the role of ICT and new organizational practices are different between sectors. In the manufacturing sector, production and efficiency practices, HRM practices, and ICT investment emerge as strong predictors of firm performance. Product/service quality-related practices and the share of workers using computers, however, do not emerge as strong predictors of firm performance in this sector. In contrast, for the dynamic services sector, product/service quality-related practices and the share of workers using computers along with production and efficiency practices and HRM practices emerge as strong predictors of better firm performance. These findings suggest that the dynamic service firms in Canada are enjoying the benefits of ICT and technological and organizational innovations.

Finally, our analysis shows that ICT use is correlated with workers skills, suggesting that firms that are ICT-intensive also employ more knowledge workers. Our results also suggest that ICT and human capital are complements in dynamic service and distribution service sectors. The firms that combine high levels of ICT and high levels of human capital have a higher incidence of productivity improvement and higher rates of innovation in this sector. ICT use is also found to be correlated with organizational innovations in production and efficiency practices, HRM practices and product/service quality related practices, supporting the view that ICT and organizational changes are complements. More important, our findings seem to suggest that to be successful, firms typically need to adopt ICT as part of a "system" or "cluster" of mutually reinforcing organizational approaches.

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