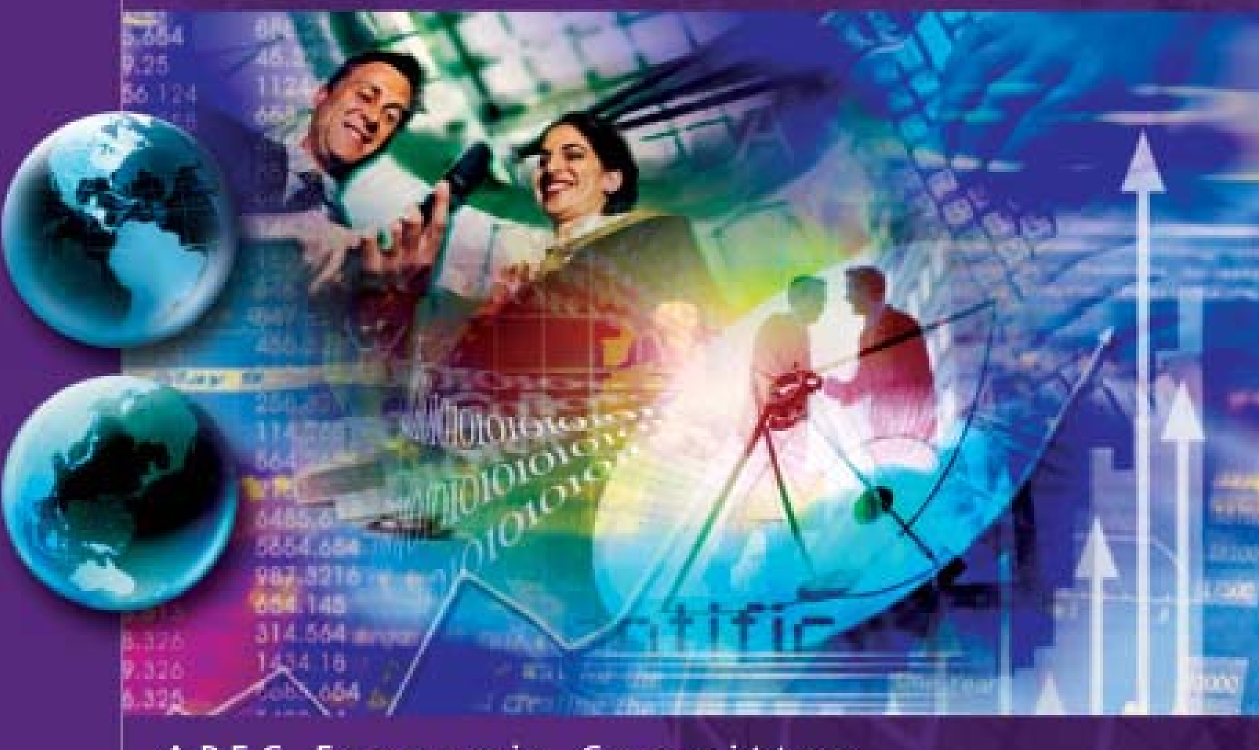
Asia-Pacific
Economic Cooperation

2003 The Drivers of New Economy in APEC

Innovation and Organizational Practices



APEC Economic Committee

Published by:
APEC Secretariat, 35 Heng Mui Keng Terrace, Singapore 119616
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Website: http://www.apec.org

APEC#203-EC-01.2 ISBN 981-04-9708-3

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FOREWORD

There is a widening recognition of the fact that a new factor of production, knowledge, is entering the production process, and this is not only changing how goods are produced, but is transforming entire economies. The Economic Committee has recognised the importance of this development, and supported research by member economies that seek to understand the nature and causes of the creation of knowledge-based economies (KBEs), and to consider how public policy can support KBEs. This volume, which is the fourth in the series, brings together research from Singapore and Canada, and asks the questions:

- What is the role of research and development (R&D) expenditure on productivity improvements? Are the macro-level benefits different from those at the firm level? What is role of public expenditure on R&D?

- What are the elements of a KBE, and how can they be quantified and evaluated?

- What role do innovative business strategies play in the development of a KBE? Are such business strategies necessary to realise the full value of information and communication technology (ICT) investments?

My special thanks go to Dr Surendra Gera, Vice Chair of the Economic Committee and to Dr Peter Thurlow, who brought these contributions together, and to all of the contributing researchers. The studies on the mapping of a KBE and on the role of R&D expenditures were conducted by a team from Singapore, headed by Adrian Choo. The paper on the role of innovative business strategies was completed by a Canadian team, which included Surendra Gera, Wulong Gu and Jenness Cawthray.

Choong Yong Ahn
Chair, APEC Economic Committee
Seoul, September 2003

CHAPTER ONE

THE DRIVERS OF THE NEW ECONOMY IN APEC: INNOVATION AND ORGANIZATIONAL PRACTICES

DRIVERS OF THE NEW ECONOMY: INNOVATION AND ORGANIZATIONAL PRACTICES

INTRODUCTION

How does a nation or economy create wealth? Economists agree that income is generated through the organization of the factors of production in a process that creates a desired good or service. This creates wealth as long as the factors of production were not detached from another productive process where they had higher value added. Thus, there are only two ways in which wealth can be created. The first is through the use of previously unemployed factors, such as labour, new natural resources, or capital. The other is through the improvement of the production process or the production of new, high-value goods or services. For the former method of wealth creation, there are often physical limits to the pool of unemployed factors. The latter method, however, is virtually limitless in its potential to create wealth. This, then, is the source of the interest in technological progress. In recent years technical progress has become a self reinforcing process, which has knowledge at its base. This is behind the excitement of the knowledge-based economy (KBE) or 'new economy' literature.

The term knowledge-based economy refers to an economy in which the production, distribution and use of knowledge are the main drivers of growth across *all* industries. "Knowledge" in this context refers to technical competence primarily related to information processing and high tech communications. In the KBE, the ability to create and exploit knowledge is critical to the success of all industries, including high tech and traditional industries. In KBEs, it is this capacity to translate ideas into useful products and processes that is increasingly becoming a major source of firms' competitive advantage. Firms that cannot acquire and effectively use knowledge are in danger of losing market share to their more innovative rivals.[1]

It is felt by some that 'knowledge' constitutes the main competitive advantage of industrialized economies. However, for economies that are in the process of industrialising, development of a KBE would seem to offer the possibility of vaulting into the ranks of the developed world. This takes tremendous investment in human, as well as physical capital.

In a traditional economy, the growth rate of potential output is the maximum long-run rate of economic growth. Potential output, a variable that cannot be directly observed, is the amount of output that would be forthcoming if all factors of production were fully employed. The output gap is the difference between potential and actual output. If the central bank's objective is to maintain a stable inflation rate, then monetary policy is conducted such that the output gap is closed (that is, set to zero) and actual growth is equal to potential growth. If actual output is allowed to exceed potential, then the result is a temporary burst of output above potential and an unleashing of inflationary pressures. The containment of those inflationary pressures can be very costly, often substantially in excess of the temporary surge of output above potential.

An increase in the rate of technical progress creates more rapid growth in total factor productivity (TFP). Just as importantly, much of the technical progress is imbedded in the capital stock, which creates greater incentive for investment and leads to capital deepening. This in turn leads to greater labour productivity (or simply, productivity) growth that can boost potential output growth, which would allow a higher rate of non-inflationary output to be forthcoming over the long run. Another important aspect of this dynamic is that globalization and expanded trade flows impose intense competitive pressures on producers, which in turn force the passing on of the benefits of increased productivity to the consumer (again supporting

[1] See, for example, *Towards Knowledge-based Economies in APEC,* Report by APEC Economic Committee, November 2000.

low inflation) and force the pace of further technological development. Thus, a KBE is very desirable from a macroeconomic perspective as well.

The term, 'new economy', is closely related to the KBE. In fact, many use these two terms synonymously. However, some associate the new economy more with the high-growth non-inflationary environment, where technical advances drive further investments in high-tech capital, which in turn drives productivity improvements, which reinforces the low inflation environment. An excellent example is the United States during the 1990s. Another connotation of the new economy is that TFP growth is driven by network externalities, in which each new addition to the network not only generates benefits to the added unit, but also to all of the other units already in the network.[2] The emergence and growth of the Internet is a classic example. Moreover, there is the sense that while this surge in technology originated in the computer industry and quickly spread into the communications sector, it has now penetrated into virtually every field of human endeavour, and the potential exists to fundamentally transform everything we do. Again we come to the sense that future growth possibilities are unlimited.

Therefore, given the unknown, and potentially vast, significance of the KBE or the new economy, it is vitally important to understand the processes at play. The Economic Committee (EC) at APEC takes this very seriously. This volume is the fourth in a series that attempts to encourage, pool and cross-fertilise the work of member economies in this line of economic research.

In this volume there are three contributions to the literature. The first, "Economic Contributions of Research and Development in Singapore" attempts to quantify the contributions of R&D to Singapore's economy. The second, "Mapping Singapore's Knowledge-based Economy" gives an assessment of where the strengths and opportunities for growth exist in Singapore's KBE. The third paper, "Innovative Business Strategies and Firm Performance in the New Economy" attempts to quantify the role of innovative business strategies in supporting productivity improvements, using Canadian data.

ORGANIZATION OF THE VOLUME AND OVERVIEW OF THE INDIVIDUAL PAPERS

1. Economic Contributions of Research and Development in Singapore

The aim of this study is to quantify the different ways in which research and development (R&D) has contributed to the Singapore economy. This quantitative framework can then be used as a reference to help refine Singapore's technology policy. Singapore's experience in building its national innovation system can serve as a useful case study for other APEC economies.

The existing literature suggests that R&D can contribute to the economy in several ways. Successful innovation at the firm level can result in totally new products, generating market growth for the firm as well as bringing about consumer satisfaction. R&D can also improve existing products and processes, thereby contributing to cutting costs and increasing the value-added for the firm. R&D by individual firms can also spill over to an entire industry as rival firms attempt to replicate the results of successful innovations. At the same time, backward and forward supporting industries may develop to support new products, contributing to the development of an industry cluster. Moreover, there may be spillovers to other industries as R&D results are adapted for use in other products and processes. Finally, the entire economy may benefit as the R&D innovations gain wider and wider application.

[2] See a recent study by the APEC Economic Committee, *The New Economy and APEC*, October 2001.

Studies of Singapore's electronics industry indicate that commercial R&D has played an increasingly important role in the development of Singapore's high-tech manufacturing in the past three decades. As Singapore's public research institutions grow in sophistication, they are increasingly able to successfully partner business R&D. Looking ahead, a strong R&D sector is likely to be even more important in fast growing manufacturing industries such as electrical and non-electrical machinery, and transportation equipment, which are increasingly characterised by high R&D intensity as well as the need for experienced, skilled researchers for both product invention and development.

Macroeconomic Contributions of R&D

To quantify the contributions of R&D at the aggregate level, a econometric equation is used, which regresses TFP growth on "R&D stock" in Singapore for the period 1978 to 2001. In this study the R&D stock is constructed as the cumulative R&D expenditure over three years, discounted by an annual knowledge "depreciation" rate. One additional dollar of R&D expenditure is estimated to yield a 20 percent return for the economy. This figure includes all spillover effects from firm-specific R&D to the entire economy.

Microeconomic Contributions of R&D

A firm level production model relating the firm's value added (VA) with its labour and capital inputs as well as its R&D stock is used to estimate the contributions of R&D at the firm level. Firms conducting R&D are found to derive a 14 percent return for one additional dollar of R&D expenditure. Across clusters, R&D expenditures are most highly rewarding for firms in the information-communications technology (ICT) and life-sciences clusters. While not directly comparable due to the different methodologies, the wide spread in returns to R&D at the macroeconomic and microeconomic level suggests substantial spillover effects from R&D. This provides economic justification for government's funding of R&D.

Using the same microeconomic model, it was found that firms which receive substantial R&D grants from the government register similar performance on their R&D compared with other firms which rely on other sources for R&D funding. Thus the Singapore government has been able to seed more R&D without impacting on market efficiency.

The model regressing value-added of public institutions to their R&D stock is not statistically robust. This may support the hypothesis that business private sector and public sector institutions have different organisational objectives for their R&D efforts. However, public institutions are found to generate 0.19 patent applications for every additional million dollars of R&D expenditure, compared with 0.07 for the business private sector. By this measure, public institutions are more effective than the business private sector in generating new knowledge.

Implications

As a long-term investment in Singapore, R&D has yielded high economic returns. As Singapore continues its development into a knowledge-based economy, R&D will become even more important for both the manufacturing and service sectors. There is therefore an economic imperative to continue to promote R&D in Singapore. The study concludes by identifying effective channels for government to promote R&D in Singapore.

2. Mapping Singapore's Knowledge-based Economy

This case study takes stock of Singapore's progress in building up its KBE and analyses how these developments have contributed to its economic competitiveness. The findings of the study will enable Singapore to identify gaps in strategically important areas, and thereby take steps to enhance its economic position in the years ahead. It is also hoped that the results could prove useful to other APEC economies in developing their own KBE strategies.

Measuring Singapore's KBE

Existing literature suggests that the strength of a KBE can be measured in terms of four capabilities: knowledge creation, acquisition, dissemination and application. In an effective KBE, these four capabilities interact with each other in the economy to create "the main driver of growth, wealth creation and employment across all industries" (APEC Economic Committee 2000).

Methodology. In order to study Singapore's KBE, the study first identifies appropriate indicators to measure the extent of Singapore's knowledge capabilities. Comparisons are made with the OECD economies and newly industrialised economies (NIEs) to allow us to gauge the stage of development of Singapore's KBE.

Three essential and distinct proxy indicators have been chosen to measure Singapore's progress in each of the four KBE capabilities. The reasons for choosing the indicators are tabulated below.

Indicators Selected for Mapping KBE

Proxy Indicator	Aspect Measured by Indicator
Knowledge Creation	
Percentage of GDP spent on R&D	Intensity of R&D conducted in the economy
Researchers per capita of population	Availability of human resources needed for R&D
US patents per capita of population	Overall quality of the national innovation system by the scientific output it creates
Knowledge Acquisition	
Imports in the technology balance of payments (BOP)[a]	Direct gauge of the cross-border transfer of knowledge
Number of head and regional offices in Singapore	Amount of firm-specific knowledge brought in by multi-national corporations (MNCs) and regional firms
Size of the knowledge intensive business services (KIBS) sector[b]	Provides intermediate products and services to firms, thereby perpetuating innovative practices and services from global sources
Knowledge Dissemination	
Info-communication technology (ICT) spending as a percentage of GDP	Intensity of resources put into developing information infrastructure
Internet access cost as a percentage of per capita GDP	Affordability of ICT services, which will determine the usage of an economy's ICT network
Percentage of workforce with at least secondary school education	Basic IT and linguistic skills to tap into ICT network
Knowledge Application	
Percentage of workforce with university education	Ability of workforce to seek out, process and use relevant information
Percentage of "knowledge workers" in workforce	Jobs that demand and allow workers to apply knowledge extensively
World Competitiveness Yearbook ranking of entrepreneurship	Ability of the economy to create new business models for generating, acquiring, diffusing and applying new ideas and processes

Notes:
a. Technology receipts and payments constitute the main form of technology diffusion and comprise four main categories: (i) transfer of techniques (through patents and licences, disclosure of know-how), (ii) transfer (sale, licensing, franchising) of designs, trademarks and patterns, (iii) services with a technical content, including technical and engineering studies, as well as technical assistance, (iv) industrial R&D.
b. OECD classifies IT and related services, management and business consulting as well as engineering and technical services under KIBS.

Status of Singapore's KBE

Knowledge Creation. Singapore has made good progress towards creating a stronger base for knowledge creation over the last ten years. Adjusting for its small economy and population, the level of R&D spending and number of researchers in Singapore has approached the levels existing in developed KBE economies. However, there is still a considerable gap between Singapore's R&D outputs and that of the more advanced KBEs.

Knowledge Acquisition. Singapore's KBE is characterised by a strong knowledge acquisition capability as a result of its industrial policy of attracting MNCs, the openness of its business environment as well as its excellent ICT infrastructure. Based on current trends, knowledge acquisition will continue to grow and it will remain Singapore's main source of new knowledge in at least the medium term.

Knowledge Dissemination. With the major/widespread emphasis on ICT infrastructure and education, Singapore has made good progress in enhancing its knowledge dissemination capability. However, Singapore still has some way to go before it can reach world-class standards. First, upgrading the country's education profile is a long-term undertaking that can only take place alongside demographic changes. Second, while ICT prices have dropped, particularly after the April 2000 liberalisation of the telecom sector, prices still remain high by international standards. This points to further opportunities for efficiency gains within the ICT sector.

Knowledge Application. In terms of knowledge application, Singapore is still less developed than the advanced KBEs. Entrepreneurship is the weakest link in Singapore's knowledge application capability and will require major efforts for improvement. Singapore also has to continue improving its tertiary education.

Contribution of KBE to Singapore's Economy

The development of Singapore's KBE has been critical to the economy's GDP and productivity growth. The study shows that:

a. The knowledge-based industries (KBIs), as defined by the Organisation for Economic Cooperation and Development (OECD), have contributed an increasing share to Singapore's GDP, from 48 percent between 1983 and 1985 to 56 percent in 2001. Multipliers computed from Singapore's 1990 input-output table also show that the KBIs have significantly higher productivity than non-KBIs. This is consistent with the expectation that KBIs benefit more from the availability of new technologies and knowledge.

b. The development of the KBE has been essential to Singapore's strategy of moving manufacturing industries up the value chain into more knowledge-intensive and high-tech products. Singapore's manufacturing exports went through a rapid technological transition from 1980 to 2000. The share of high and mid-high technology exports increased from 37.7 percent of total exports in 1980 to 84.1 percent in 2000. Average manufacturing productivity growth accelerated from 5.5 percent p.a. in the 1986–90 period to 7.2 percent p.a. in the 1991–95 period.

c. Singapore's knowledge capabilities are key to the success of future growth sectors as identified by the its Economic Review Committee (ERC), such as photonics, nanotechnology, ICT, education services and healthcare services. These sectors require high skills and are knowledge intensive.

Extending the KBE indicators framework for international benchmarking, the study finds that Singapore's KBE is generally competitive *vis-a-vis* the OECD economies. However, Singapore tends to be stronger in knowledge acquisition and weaker in other areas.

Policy Insights

Singapore's commitment to KBE development has enabled it to make a rapid and successful transition to a newly industrialised economy (NIE) over the past decade. As Singapore continues to move further up the value chain and approach the technological frontier, it will need to develop a more balanced KBE to sustain its economic development. Taking stock of Singapore's current KBE structure, it is assessed that further efforts need to be channelled towards enhancing its national innovation system, entrepreneurship and education capability. This will improve Singapore's knowledge creation, dissemination and application capabilities, complementing its strong knowledge acquisition capability.

3. Innovative Business Strategies and Firm Performance in the New Economy

A rapidly integrating global economy, technological change and shifting consumer preferences are together increasing competitive pressures for firms. Firms now face greater pressure to make better use of knowledge, technology and human resources to realize benefits from intangible investments and to respond to new demands from suppliers and customers. Consequently, firms are forced to rethink their business strategies, production processes and management practices to improve their functioning and to adapt to the changing business environment of the new economy. "Strategic business thinking has shifted away from products, plants and inventory towards employees, information and knowledge" (OECD, 2001).

To succeed in the new economy, firms may adopt one of a number of innovative business strategies or some combination thereof. A few examples are given below.

(1) Firms may adopt production and efficiency strategies such as outsourcing, business re-engineering and downsizing to improve their competitiveness. They may reorganise production and working practices to improve flexibility and reduce X-inefficiencies.

(2) They may adopt innovative human resource management (HRM), practices including new procedures for compensation, recruiting and selection, team-based work organisation, flexible job assignment, skills training and communication in order to maximise the benefits of new technologies, especially information and communication technologies (ICT).

(3) They may adopt quality-related strategies including improving product/service quality and improving co-ordination with customers/suppliers.

Innovative Business Strategies: A Framework

The term 'innovative business strategy' is relatively broad and includes strategic, structural and work practices of organizations. In this paper, we define innovative business strategies[3] to include three broad streams: 1) the restructuring of production processes, which include business re-engineering, downsizing, flexible work arrangements, outsourcing, greater integration among functional lines, and decentralisation; 2) human resource management (HRM) practices, which include performance-based pay, flexible job design and employee involvement, improving employees' skills, and institutional structures affecting labour-management relations; and 3) product/service quality-related practices emphasising total quality management (TQM) and improving coordination with customers/suppliers.

The existing empirical research from the US suggests that innovative business practices may improve economic performance of firms through their mutually reinforcing relationship with ICT. ICT is key to facilitating new business practices, from lean production, to teamwork, to customer relations. ICT enables firms to introduce significant organisational change in the areas of re-engineering, decentralisation, flexible work arrangements and outsourcing. It allows firms to produce with greater flexibility and shortened product cycles to satisfy shifting consumer preferences. In fact, new business practices 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 business approaches.

[3] To be consistent with the existing literature on the subject, we use the terms "innovative business strategies" and "organizational innovations" interchangeably.

The questions that are addressed in this study are,

- Is firm performance improved through the adoption of innovative business strategies and ICT?

- Are new business practices complementary to ICT in improving firm performance?

- How does the relationship between new business practices and ICT vary across manufacturing and services firms?

In the analysis, the authors use three binary measures of firm performance: productivity, sales growth, and unit production costs. All three measures of firm performance are subjective measures that are based on respondents' perception of firm performance. We find all three measures are highly correlated. This suggests that the three measures taken together capture overall success of the firms. To further examine the issue of whether ICT and innovative business strategies are related to firm performance, the authors also use two objective measures of firm performance: product and process innovation.

Empirical Findings

Using firm-level data, this study examines the issue of whether investment in ICT, combined with innovative business strategies and worker skill levels contribute to better performance in Canadian firms. We find that Canadian firms have been actively engaged in organisational changes in the areas of production and efficiency practices, human resource management (HRM) practices, and product/service quality-related practices. These practices, along with ICT use, are found to be related to better firm performance. The study finds that while ICT is productive on its own, it is more productive in firms that combine high levels of ICT with high levels of organisational change. The firms that combine ICT with organisational change have a high incidence of productivity improvement and have high rates of innovation. These findings seem to suggest that to be successful, firms typically need to adopt ICT as part of a "system" or "cluster" of mutually reinforcing organisational approaches. We also find that ICT and human capital are complements in the service sectors. The firms that combine high levels of ICT and high levels of worker skills have better performance.

CHAPTER TWO

ECONOMIC CONTRIBUTIONS OF RESEARCH AND DEVELOPMENT IN SINGAPORE

ECONOMIC CONTRIBUTIONS OF RESEARCH AND DEVELOPMENT IN SINGAPORE

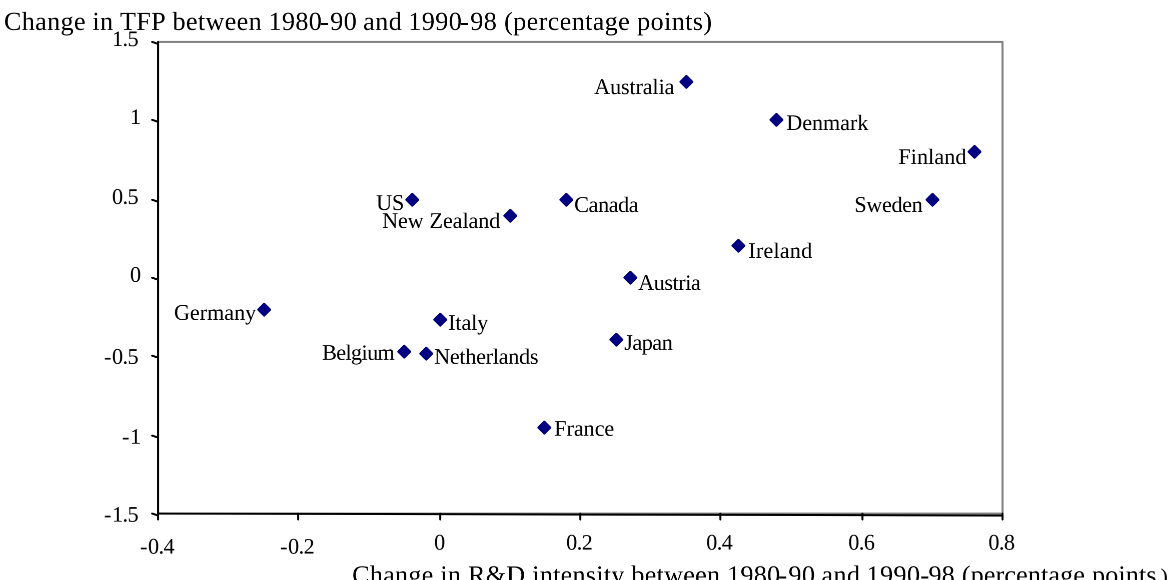
INTRODUCTION

1. As part of Singapore's strategy to become a globally competitive knowledge economy, the national resources devoted to research and development (R&D) have increased rapidly over the years. Gross expenditure on R&D increased from 0.86 percent of GDP in 1990 to 2.11 percent in 2001. The number of research scientists and engineers also multiplied, growing from 4,300 to 18,600 in the same period. As Singapore commits more of its resources to R&D, it has become more important to ensure that R&D is bringing net benefits to the economy. This paper will address this issue through an assessment of the economic contributions of R&D.

R&D AND THE ECONOMY

2. According to Mansfield (1996), R&D contributes to the economy in several ways. Successful innovation at the firm level can result in totally new products, generating market growth for the firm as well as bringing about consumer satisfaction. R&D can also improve existing products and processes, thereby contributing to cost-cutting and increasing value-added in the firm. R&D by individual firms can also spill over to the entire industry as rival firms attempt to replicate the results of successful innovations. At the same time, backward- and forward- supporting industries will develop to support new products, contributing to the development of an industry cluster. Finally, there will be spillovers to the entire economy as R&D results are adapted for use in other products and processes.

Exhibit 1: Correlation Between Total Factor Productivity (TFP) and R&D Intensity



Source: OECD

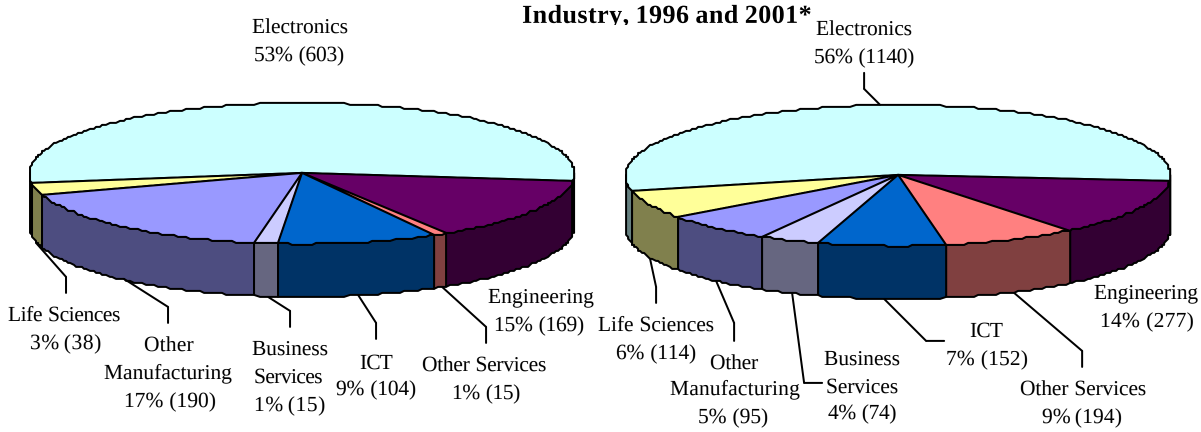
3. The economic contributions of R&D are supported empirically by the OECD countries' experience. At the macro level, Bassanini, Scarpetta and Visco (2000) have found an empirical link between total factor productivity (TFP) and R&D intensity (i.e., percentage of GDP spent on R&D) among the OECD countries from 1980 to 1998. As shown in exhibit 1, countries which registered the highest increase in R&D intensity, i.e., Finland and Sweden, also attained

the largest improvement in TFP growth. Correspondingly, countries such as France and Germany which showed little to no improvement in R&D intensity experienced a decline in TFP growth.

4. At the micro level, various studies (e.g., Griliches, 1986; Hall and Mairesse, 1995; Odagiri and Iwata, 1986; Wakelin, 2001) have generally found a positive relationship between firms' R&D expenditure and productivity in the advanced economies such as France, Japan, the UK and the US.

THE R&D LANDSCAPE IN SINGAPORE

Exhibit 2: Composition of Private Gross Expenditure on Research & Development by Industry, 1996 and 2001*



Private Sector GERD by Cluster, 1996

Private Sector GERD by Cluster, 2001

* Absolute figures (S$ million) in parentheses.
Source: *National Survey of R&D in Singapore*

5. Total private sector gross expenditure on research and development (GERD) had increased from S$1.1 billion in 1996 to S$2.0 billion in 2001. Public sector GERD had maintained its one-third share of R&D in Singapore, amounting to S$0.7 billion in 1996 and S$1.2 billion in 2001. Exhibit 2 compares the composition of private sector GERD by major industry clusters. Breakdown of public sector GERD by industry clusters is not applicable as most public institutions are inter-disciplinary and classified under other services.

6. The electronics cluster accounts for the majority of private sector R&D in Singapore, taking up 53 percent and 56 percent in 1996 and 2001 respectively. The engineering cluster has remained an important source of R&D, with a 15 percent share of total GERD in 1996 and a 14 percent share in 2001.

7. In other sectors, there have been some significant shifts in tandem with the continual restructuring of the Singapore economy. The life sciences cluster has doubled its share of business GERD as the biomedical science industry takes off in Singapore. R&D for the ICT sector remains relatively high at 7 percent, although it has declined from the all-time high of 9 percent in 1999 after the burst of the dot.com bubble. The other services cluster posted the strongest growth, from 1 percent in 1996 to 9 percent in 2001. This was led by the surge in R&D spending from wholesale firms.

R&D AND INDUSTRY DEVELOPMENT IN SINGAPORE

8. R&D has increasingly contributed to industry development in Singapore over the years. The most important example is the electronics industry. MNCs in the electronics sector began improving their experimental development capabilities alongside their growing manufacturing capabilities in the 1970s. Firm-level interviews by the Asian Development Bank (ADB)[4] of major MNCs in Singapore indicate that most of the R&D conducted in Singapore is used to solve manufacturing-based problems.

9. In-house product development capabilities in turn allow the MNCs to source more sophisticated components locally because they can interface better with their supporting industries. This fuels the growth of an increasingly high-tech electronics-supporting industry. Wong (1999) conducted a survey of supplier firms in the hard-disk industry and found that "product specification from customers" is regarded as the most important source of technological learning for these firms.

10. The National Science and Technology Board (NSTB), established in 1991, is now known as the Agency for Science, Technology and Research (A*STAR). Its purpose is to develop public technology infrastructure, and support the growth of private sector R&D as well as nurture R&D manpower. Three technology plans were implemented over the periods 1991–95, 1996–2000 and 2001–2005.

11. Under the national technology policy, the public sector research institutes (RIs) in Singapore expanded their capabilities rapidly during the 1990s. Companies to enlist the RIs to help them deal with manufacturing-based problems that they cannot solve within the context of experimental development. The RIs possess strategic basic research and applied research capabilities which complement MNCs' product development expertise.

12. The importance of R&D in industry development is not confined to electronics. As Chandler (1990) has observed, fast growing manufacturing industries such as electrical and non-electrical machinery, and transportation equipment are increasingly characterised by both high R&D intensity and the need for experienced, skilled researchers in both product invention and development. Localised R&D has become even more important for industry development due to several factors.

13. Firstly, a successful R&D sector will boost the technological and knowledge capabilities of the economy. This will help to attract, as well as anchor, high-tech and knowledge intensive businesses to Singapore, enabling progress as a knowledge based economy.

14. Secondly, the high R&D intensity in the industry means the global rate of technological change is very rapid. Cohen and Levinthal (1990) have found that a firm needs to be engaged in relevant research in order to possess the absorptive capacity to assimilate and commercialise the new technology quickly, before the new product becomes commoditised.

15. Thirdly, the availability of experienced scientific personnel has become a key factor in the location of new, high-tech product lines due to the closer integration between science and process engineering. Examples of this integration include the recent consolidation of both IBM and Sony's headquarters and R&D operations close to their high-tech plants in Singapore. A vibrant local R&D sector is necessary for training a sizeable pool of indigenous researchers and attracting foreign R&D talent.

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[4] Alice H. Amsden, Ted Tschang, Akira Goto (2001), *Do Foreign Companies Conduct R&D in Developing Countries?*, ADB Institute Working Paper 14.

16. Fourthly, the human resource aspect of R&D is even more important for Singapore's developing bio-tech industry. Zucker, Darby and Brewer (1998) have found the industrial involvement of "star scientists"[5] to be central to the ability of firms to make commercial breakthroughs in bio-technology. The presence of a strong local R&D sector is a prerequisite in attracting "star scientists" to operate in Singapore.

17. In parallel, the pay-offs for successfully developing new R&D intensive industries have increased. In such industries, the inventor has greater control over the knowledge underlying the innovation as it is technically more difficult and costly to reverse engineer the patented process. Accordingly, Gans and Stern (2002) have found intellectual property (IP) protection in the bio-technology sector to be both more effective and widespread, making patents much more valuable.

MACROECONOMIC CONTRIBUTIONS OF R&D

18. Both international studies as well as industrial trends suggest that individual firms benefit from conducting R&D in Singapore. In addition, there are significant spillovers to the economy. R&D by individual firms contributes to cluster development as innovations spill over to competing firms as well as prompt the development of supporting industries. R&D results can also be adapted for use in other products and processes.

19. Stokey (1995) describes how both firm-specific and spillover benefits from R&D translate into increases in TFP. New products and services introduced by R&D will result in higher value-added as production is shifted away from products with diminishing returns to new products with higher valuation by consumers. This will increase overall TFP. The development of industry clusters around new products and the ability of firms to assimilate external technology will enable further reallocation of production towards higher value-added. Cost-cutting innovations enable TFP to grow, as higher output can be achieved with the same level of labour and capital.

20. Consequently, the macroeconomic contributions of R&D can be measured by changes in TFP growth. Adopting a similar approach to Jones (1995) and Toh (2000), we construct a macroeconomic model, regressing TFP growth on R&D stock in Singapore over the period 1978 to 2001. R&D stock is constructed as the cumulative R&D expenditure over three years, discounted by an annual knowledge "depreciation" rate. Technical details of the model are attached in annex A. The regression analysis shows that R&D is a significant determinant of TFP growth. TFP growth translates directly to GDP growth on a one-to-one basis as TFP is measured in terms of percentage points of GDP. The results are summarised in exhibit 3.

Exhibit 3: Macroeconomic Contributions of R&D[a]

Short-Run Contribution of R&D to GDP (percent)	Long-Run Contribution of R&D to GDP (percent)	Internal Rate of Return to R&D (percent)
0.020	0.052	19.7

[a] *Average value from 1978 to 2001.*

21. Based on the regression results, a 1 percent increase in Singapore's R&D stock will contribute to a 0.020 percent increase in GDP in the short-run (one year). This is a significant return as Singapore's GDP is about 13 times bigger than R&D stock in dollar terms. A one dollar increase in R&D stock will yield S$0.26 (=0.020*13) of GDP value-added (VA) in the

[5] Star scientists are identified by their outstanding productivity in the discovery of genetic sequencing in the study by Zucker, Darby and Brewer (1998).

first year. In addition, a one dollar increase in R&D expenditure will result in S$2.71 worth of R&D stock[6] over three years due to the cumulative nature of knowledge. Hence the returns to R&D expenditure will be much higher than the contribution from one unit of R&D stock.

22. As the regression model is dynamic, the long-run contribution of R&D stock can also be derived. The long-run contribution of R&D is 0.052 percent of GDP, significantly higher than the short-run contribution. A one dollar increase in R&D stock will yield S$0.68 (=0.052*13) of GDP value-added (VA) in the long run.

23. The internal rate of return (IRR)[7] is used to gauge the effectiveness of R&D in Singapore on a financial accounting basis. It is commonly used by the corporate sector as it allows for direct comparison with the interest rate in any market. If the IRR of an investment project is higher than the interest rate that an investor will be charged for borrowing funds to finance the, then that project will be considered profitable.

24. The IRR of a one dollar increase in R&D expenditure in Singapore is 20 percent. This is substantially higher than most market rates for sourcing funds i.e., Singapore's inter-bank prime lending rate ranges from 5 percent to 6 percent. Hence, R&D investments in Singapore have been highly rewarding and brought substantial benefits to the economy.

MICROECONOMIC RETURNS OF R&D

25. R&D has been highly rewarding at the macroeconomic level, and should continue to be promoted in Singapore. Quantifying firm- and institution-specific returns to R&D in various industry clusters will allow the government and businesses to identify areas with the greatest returns to R&D. The quantitative analysis may also highlight trends undermining R&D effectiveness in certain clusters. Study of these trends can result in initiatives that can better facilitate the conduct of R&D in Singapore.

26. The economic returns to R&D are quantified for the seven major industry clusters: electronics, engineering, life sciences, other manufacturing, infocom-technology (ICT), business and finance services, and other services. These clusters leverage on distinct technological fields and possess different industrial characteristics. Hence returns to R&D are expected to vary by the cluster.

27. Firm-level data on parameters such as total sales revenue, R&D expenditure, total employment and value-added are available from the annual R&D survey conducted by A*STAR. The database is available for the period of 1996 to 2001, and 1176 different firms and public institutions have participated in the survey. To avoid complications arising from the different organisational characteristics[8] of the public and private sectors, regressions are performed separately on the data sets of 1091 private sector firms and 63 public institutions. Full details about data characteristics and limitations are attached in annex B.

Returns to R&D for Business Private Sector Firms

28. A firm-production model relating the firm's value-added (VA) with its labour and capital inputs as well as its R&D stock is constructed. The technical details of the model are attached

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[6] This figure is based on the knowledge "depreciation" rate of 10 percent assumed in the model. See Annex A for details.

[7] The IRR is the interest rate that sets the perpetual stream of revenue arising from one dollar of capital outlay, in this case R&D expenditure, to zero.

[8] Public sector conducts primarily upstream research, and most of their findings will not result in direct commercialisation.

in annex C. Regression analysis of the data set shows that R&D stock is a significant and robust contributor to private sector firms' VA. The results are summarised in exhibit 4.

Exhibit 4: Economic Impact of R&D Conducted from 1996 to 2001[a]

	Total VA of Cluster (S$ million)	VA Contribution of R&D Firms to Each Cluster[b] (percent)	Short-run Contribution to Firm Value Added (percent)	Long-run Contribution to Firm Value Added (percent)	Internal Rate of Return to R&D (percent)
Overall	120,468	17.2	0.037	0.121	14.4
Electronics	12,311	84.2	0.050	0.154	23.3
Engineering	6,894	52.5	0.055	0.171	16.4
Life Sciences	2,728	100.0	0.060	0.186	104.9
Other Manufacturing	9,055	27.4	0.035	0.107	13.4
ICT	11,712	23.2	0.058	0.181	46.2
Finance & Business Services	25,405	0.5	0.053	0.166	NA
Other Services[c]	52,363	0.5	0.046	0.143	4.2

[a] All figures are average annual values over 1996 to 2001.
[b] Figures are estimated from the Singapore Census of Industrial Production, Survey of Services and the A*STAR database.
[c] Major components of other services are retail and wholesale trade, hotels and restaurants, real estate activities, public administration, defence, education, and transport services.

29. The average contribution of a 1 percent increase in R&D stock in the short-run (first year) is 0.037 percent of the firm's VA. This is significant in absolute terms. A one dollar increase in R&D stock will yield S$0.21 (=0.037*5.6) of VA in the first year as the VA of R&D firms is 5.6 times larger than their R&D stock.

30. Due to the dynamic specification of the output equation, the long-run contribution of R&D stock can be estimated. The average long-run VA contribution of 0.120 percent is much greater than the short-run contribution. A one dollar increase in R&D stock will translate to S$0.67 (=0.120*5.6) of VA in the long-run. This is in line with the expectation that R&D projects have a long gestation period. The average internal rate of return is computed to be 14 percent, using the same methodology outlined for the macroeconomic model. This is much higher than the normal cost of capital in both Singaporean and international markets. Thus, individual firms have sufficient incentive to undertake R&D by themselves.

31. The electronics and engineering clusters have a high proportion of firms conducting R&D. R&D firms contribute 84 percent and 53 percent of total VA in the electronics and engineering clusters respectively. This trend is likely to persist, judging from the high IRR of 23 percent and 16 percent in electronics and engineering respectively. Although engineering R&D has a higher long-run contribution to firms' VA of 17 percent, compared with 15 percent in electronics, electronics firms are able to reap greater economies of scale. On average, firms' VA are 5.4 times bigger than their R&D stock in the electronics cluster, compared with 4.0 times in the engineering cluster. This leads to a lower IRR for engineering than electronics.

32. Among the clusters, life sciences have the highest percentage of firms conducting R&D. All life sciences firms conduct R&D, consistent with the nascent, technology-intensive status of the industry. R&D in this cluster has been the most rewarding, with an IRR of 105 percent.

33. R&D in other manufacturing has an IRR of 13 percent. This is a very diverse cluster, ranging from chemicals and textile processing to production of recorded media. Hence it is not surprising that the VA contribution of R&D firms is only 27 percent of VA in the entire cluster.

34. The IRR for the ICT cluster is 46 percent, the second highest among all the clusters. R&D firms only contribute 23 percent of total VA in the cluster, significantly less than other clusters with a high IRR to R&D. This could be because segments of the ICT cluster (such as computer components) are highly commoditised, and require little to no product development capabilities for market entry. However, firms which are able to conduct relevant R&D are highly successful, i.e., IBM and Dell.

35. Internal rates of return for the finance and business services cluster cannot be computed as the net returns are negative even in the long-run. Given the low returns, it is not surprising that R&D firms take up only 0.5 percent of the cluster's VA. On average, firms' VA are only 1.2 times larger than their R&D stock in this cluster. This suggests that incumbent R&D firms could have over-invested in R&D, or they may be too small to reap sufficient economies of scale in the commericalisation of R&D results. The average VA of firms which conduct R&D in the finance and business services cluster is only S$5.9 million, the smallest among all the clusters. This may be the reason behind the negative IRR.

36. R&D spending in the other services cluster took off rapidly, from S$15 million in 1996 to S$194 million in 2001. The low IRR of 4.2 percent suggest that results from more recent projects may not have materialised yet, and many firms may still be on the learning curve for their pilot R&D projects.

Effects of Government Funding on R&D Returns

Exhibit 5: R&D Returns for Firms with Substantial Government Funding[a]

	Short-run Contribution to Firm Value-Added (percent)	Long-run Contribution to Firm Value-Added (percent)	Internal Rate of Return to R&D (percent)
Firms with substantial govt. funding	0.043	0.141	19.8
Firms with little to no govt. funding	0.039	0.127	13.5

[a] *All figures are average annual values over 1996 to 2001.*

37. Government grants accounted for 8.5 percent of all R&D funding from 1996 to 2001. These grants have played a significant role in seeding R&D in Singapore. However, a key concern is whether firms would undertake additional projects with somewhat lower returns to leverage on the availability of government grants. Comparison is made between firms which receive substantial R&D funding from the government and other firms. Firms are considered to receive substantial government funding if at least 30 percent of their R&D funds come from the government.

38. The results are summarised in exhibit 5. Firms which receive substantial funding have an IRR of 20 percent to R&D, significantly better than the 13.5 percent for other firms. However,

the difference in performance is not statistically robust due to the small sample[9] of firms receiving substantial government funding each year. Nonetheless, the analysis indicates that R&D from firms with substantial government funding perform at least as well as other firms. The concern over market inefficiency induced by government grants is thus unfounded.

Returns to R&D by Public Institutions

39. The model regressing value-added of public institutions to their R&D stock is not statistically robust. This supports the hypothesis that business/private sector and public sector institutions have different organisational objectives for their R&D efforts. In their studies of R&D productivity in Europe and Japan respectively, Ernst (1998) and Kondo (1999) use the number of patent applications as a proxy of the volume of new knowledge generated in an institution. Patent applications are a better proxy than patents granted because patent law requires scope for immediate application before granting a patent. This would preclude a substantial portion of the upstream research work done by public institutions. Moreover, trivial patent applications are curbed by the prohibitive costs.[10]

Exhibit 6: Impact of Increase in R&D on Patents Applications[a]

	Short-run Contribution to Patent Applications (percent)	Long-run Contribution to Patent Applications (percent)	Patent Applications per S$ Million Increase in R&D Expenditure in Long Run	Average Patent Applications Per Year[11]
Public Sector	0.148	0.936	0.193	158
Private Sector	0.019	0.194	0.070	459

[a] *All figures are average annual values over 1996 to 2001.*

40. Accordingly, R&D stock is found to be a significant contributor to patent applications for public institutions, more so than for business/private sector firms. The summarised results are tabulated in exhibit 7. Given the emphasis of public institutions on more upstream research and training, it is not surprising that the contribution of R&D stock to patent applications is much higher for the public institutions.

41. In the long run, a 1 percent increase in R&D stock for public institutions induces a 0.94 percent increase in the number of patent applications, compared to 0.19 percent for the business/private sector. This translates to 0.19 of a patent application for every additional million dollars of R&D expenditure for the public institutions, compared to 0.07 in the private sector.

42. On average, the public sector applies for 158 patents each year, compared with 459 from the business/private sector. Public sector research plays an important role in the innovation system. Some innovations could not have occurred without the new theoretical and empirical findings as well as instrumentation from the more basic research conducted by the public sector. Mansfield (1991) has found that 17 percent of new products and processes in US industries received at least substantial aid from recent academic research. One would expect the figure to be even higher for Singapore's RIs which focus on "user inspired research".

9 On average, 53 firms receive substantial government funding each year.

10 Typically, applying for a patent will cost at least S$10,000 in Singapore and also involves substantial paperwork.

11 Patent applications are much higher for the business/private sector as its R&D expenditure is twice the size of public sector R&D expenditure.

43. In addition, the R&D conducted by public institutions provides training for research scientists and engineers (RSEs) who go on to development work in commercial firms. Singapore's higher education and research institutes employed 8,800 RSEs in 2001, accounting for 47 percent of the RSEs in Singapore.

44. Singapore's research institutes deploy their personnel and resources in numerous collaborative efforts with industry. This is cited by many MNCs as an important factor in their establishment of R&D facilities in Singapore.

POLICY IMPLICATIONS

45. There is a wide spread between the rates of return to R&D at the firm-specific and economy levels. This suggests significant spillover effects of R&D to the economy, and provides justification for government involvement in R&D activities. However, government efforts should not displace the business private sector from what they are best at doing– commercialising R&D results. Public R&D should remain focused in key niches not covered by the business/private sector as well as play an enabling role for private R&D.

46. The majority of upstream, or what A*STAR calls "user-inspired", research in Singapore is conducted by public institutions. Singapore's public institutions are more effectively organised than private firms to produce fundamental scientific discoveries, which private firms could later tap and possibly commercialise. These public institutions should therefore continue to be the key contributors to Singapore's basic research capabilities.

47. Unlike the business/private sector, public institutions do not have consistent records for commercialising their research results. This makes linkages between public institutions and businesses extremely important. Transfers of knowledge and collaborative projects between the two sectors are the key channels by which the economic potential of upstream research is exploited. The recent establishment of Exploit Technologies[12] in A*STAR, as well as new programmes such as Technology for Enterprise Capability Upgrading (TEC-UP)[13] and Small-and-Medium Enterprises Technology Upgrade (SMET-UP),[14] are therefore timely. They will further boost the linkages between public sector R&D and industry in Singapore.

48. Although the business private sector as a whole enjoys high returns to R&D, there is wide variation in the returns to individual firms. Without government incentives to encourage more R&D through schemes such as the RISC[15] and Local Industry Upgrading Programme (LIUP)[16], significantly less firms would be willing to innovate than is optimal for the economy.

49. Comparative analysis of the major industry clusters have revealed that the R&D landscape differs substantially across clusters. The results provide some broad directions for improving the contribution of R&D in each cluster. In-depth studies of each cluster could be conducted to build on these results. For instance, R&D in life sciences and ICT have been highly rewarding. The policy focus should be on how to further augment the R&D resources for these clusters.

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[12] Exploit Technologies promotes the commercial exploitation of intellectual property generated by all the RIs.

[13] TEC-UP aims to promote greater collaboration between the RIs and local industries as well as help firms build up their own R&D and technology capabilities.

[14] SMET-UP is specifically targeted at helping SMEs raise their technological capabilities by leveraging on expertise and resources in the public sector.

[15] The RISC is now administrated by EDB, and is open for application to both local and foreign companies conducting R&D in Singapore.

[16] LIUP assists local firms in the transfer and implementation of new technology into their operations as well as provide a platform for joint R&D projects with MNC partners.

50. On the other hand, returns in the finance and business services and, to a lesser extent, the other services clusters, have been dragged down by their low VA to R&D stock ratio, which suggests an inability to exploit economies of scale. This occurs in the two industries where the VA of R&D firms makes up only 0.5 percent of the clusters' VA, the lowest among all the industry clusters. This suggests ample room for more firms to undertake R&D. The R&D policy for these clusters should therefore examine the possibility of encouraging more firms to engage in collaborative R&D projects.

51. In addition, R&D in the other services cluster, especially in the wholesale segment, has taken off rapidly in the last few years, but a significant portion of the projects may not have yielded returns yet. The process for commercialising innovations in services may differ substantially from that in manufacturing. There may now be sufficient economies of scale for services firms to systemically learn from innovative practices in other economies. As a starting point, firms could leverage on work done by successful centres such as the US National Association of Wholesalers-Distributors.

CONCLUSION

52. R&D has yielded high economic returns as a long-term investment in Singapore. R&D has also played a key enabling role in the growth of Singapore's manufacturing industries. As Singapore continues its development into a knowledge-based economy, R&D will become even more important for both manufacturing and services. There is therefore an economic imperative to continue to promote R&D in Singapore.

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ANNEX A

MACROECONOMIC MODEL

The economy production function is commonly specified in the Cobb-Douglas functional form:

$$Y = AK^{\alpha}L^{\beta} \quad (1)$$

where Y is output; A is productivity; K is the stock of physical capital and L is labour employed.

If productivity can be explained by R&D stock and other factors, then the equation can be written as:

$$A = BS^{\gamma}Z^{\phi} \quad (2)$$

where S is R&D stock; Z is other factors affecting measured productivity (e.g. stock of foreign R&D, human capital) and B is a proportionality constant.

Substituting (2) into (1) and taking logarithms gives:

$$\log Y - \alpha \log K - \beta \log L = \log B + \gamma \log S + \phi \log Z \quad (3)$$

Or

$$TFP = \log B + \gamma \log S + \phi \log Z \quad (4)$$

since $TFP = \log Y - \alpha \log K - \beta \log L$ (by definition) (5)

APPLICATION TO SINGAPORE DATA

Physical capital stock is computed from the annual gross fixed capital formation figures tracked by the Department of Statistics (DOS), assuming a capital depreciation rate of 10 percent.[17] Annual GDP and labour figures are also available from the DOS. Substituting these data series into equation (5) yields the time series for TFP.

Adopting the timeframe used by Kelm (1995) as well as Tsang, Yip and Toh (2000), the discounted sum of the economy's annual R&D expenditures over a three-year period (i.e., current year plus two previous years) is used as a proxy for the economy's available R&D stock.[18] Singapore's annual R&D expenditure is available from the annual R&D survey conducted by A*STAR. The discount rate of 10 percent is used in weighing the R&D expenditure.[19]

For the other variables denoted Z in equation (4), the variables tested are:

i. Ratio of exports to GDP (to proxy openness of economy)

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[17] The results are not sensitive to the choice of a depreciation rate between 5 percent and 15 percent.

[18] The three-year discounted sum of R&D expenditures is a better proxy of the economy's available stock of knowledge than the current year R&D expenditure and gives a more precise estimate of the related coefficient. In general, the longer the lag in the discounted sum, the more precise the estimate will be. However, a longer lag would mean less years of observations in the estimation. Balancing these two factors, the three-year discounted sum is therefore chosen.

[19] The results are not sensitive to the choice of discount rate from 5 percent to 15 percent.

ii. Proportion of labour force with post secondary and tertiary education (to proxy human capital effect)

iii. Stock of FDI as a proportion of domestic capital stock (to proxy foreign R&D stock)

However, these variables are not significant in the regression model and are not included in the final model.

TFP and logS are found to be cointegrated. According to the Granger Representation Theorem, a set of cointegrated variables will have an error correction model (ECM) representation. Expressing the ECM as an autoregressive distributed lag (ADL) model, we "tested-down" to a model ADL(1,0) given by:

$$TFP_t = \beta + \lambda TFP_{t-1} + \gamma \log S_t \quad (6)$$

REGRESSION RESULTS

Exhibit 7: Regression Results for Macroeconomic Model[a]

Constant	0.093* (1.80)
$\log S_t$	0.020^ (1.70)
TFP_{t-1}	0.616*** (3.30)
R-squared	0.853
Adjusted R-squared	0.839
S.E. of regression	0.029
F-statistic	58.192

[a] t-statistics in parentheses.
^p < .15; *p < .10; **p < .05; ***p < .01 (two-tailed)

Ordinary least squares regression is performed on the model specified in equation (6), using annual data from 1978 to 2001. Exhibit 8 presents the results. There is a good fit of data points in the model, with an adjusted R^2 of 0.84. In addition, the standard error is low at 0.029.

ANNEX B

DATA SOURCE

The microeconomic study is based on the panel database provided by the Agency for Science, Technology and Research (A*STAR) of Singapore. The database is compiled from annual national surveys of R&D in Singapore conducted by the A*STAR. These surveys collect comprehensive data on R&D activities, including factors affecting R&D investments and the contributions of R&D. The surveys cover both the public and the business/private sectors. The former includes government bodies, higher education institutes, and public research institutions. The latter includes major private establishments in virtually all the ten two-digit Singapore Standard Industrial Classification (SSIC) industrial sectors. The surveys are based on the guidelines stated in the OECD *Frascati Manual*, and is therefore comparable with R&D surveys conducted by other economies that are based on the OECD methodology.

The study makes use of data collected in the 1997 to 2002 surveys (i.e., R&D activities conducted from 1996 to 2001). The surveys cover all organisations, public and private, that are reported to have R&D activities in Singapore. As completing the survey form is regarded as a legal obligation, the response rate in each year is above 90 percent for all the major R&D firms and institutions. Hence, the A*STAR database presents an accurate picture of R&D in Singapore.

To avoid complications associated with the different organisational characteristics of the business/private and the public sectors, the database has been partitioned into two sets for the purpose of analysis. The two data sets are comprised of 1091 private sector firms and 63 public institutions respectively. As a substantial proportion of firms and public institutions do not conduct R&D every year, the actual sample in each year is significantly smaller. Nonetheless, the sample is sufficiently large in all the clusters for regression analysis, as shown in exhibit 9.

Exhibit 8: Sample Size by Cluster and Year

	1996	1997	1998	1999	2000	2001
Electronics	104	97	113	96	93	83
Engineering	125	122	129	138	130	121
Life Sciences	44	50	53	53	42	48
Other Manufacturing	120	103	104	107	91	77
ICT	78	79	110	110	84	106
Finance & Business Services	10	15	17	27	31	31
Other Services	12	40	38	56	51	47
Public Sector	30	35	33	31	43	45

To fully utilise the observations available, we pool all the cross-sectional and time series data in both the business/private and public sector data sets into panel databases. Since not all the firms and public institutions participated in every survey conducted during the six-year period, the two panel databases are in fact unbalanced. Nevertheless, modern econometric software, such as Eviews 4, makes unbalanced panel data estimation fairly easy and routine.

DATA LIMITATIONS AND FURTHER RESEARCH

The VA of firms conducting R&D are computed using cluster level VA-output ratios due to the unavailability of firm-level data. Theory would suggest that firms conducting R&D would have higher VA-output ratios than the industry average. This is because a significant portion of commercial R&D is aimed at producing cost-savings through incremental improvement in processes. Thus, the R&D returns to firms may have been under-estimated. In addition, the relationships between R&D and other parameters such as firm age and product diversity are worth investigating should such data become available in the future.

In Singapore, separate surveys are conducted on firms' R&D, production and international activities by A*STAR, DOS, Economic Development Board respectively as well as International Enterprise Singapore. The absence of a common identification system across the databases prevent the horizontal integration of available firm level data. With the establishment of a common identification system, the effect of R&D on a firm's ability to compete in international markets and the interaction effects with international transfers of technology could be tracked. This would greatly expand the scope for further studies.

ANNEX C

ESTIMATION MODEL

Based on the data availability of the A*STAR database and the approach of Griliches (1986, 1995), the following production function is specified:

$$Q_{it} = A\, L_{it}^{\alpha'}\, K_{i.}^{\beta'}\, R_{it}^{\gamma'} \qquad i = 1, ..., N;\ t = 1, ..., T \qquad (1)$$

where Q_{it} is the output (value-added) of firm i at time t; A is a constant; L_{it} is firm i's labor input at time t; $K_{i.}$ is firm i's capital inputs; R_{it} is the firm's available stock of knowledge obtained by cumulating firm i's R&D expenditures over a relevant period of time up to and including time t. Using the production model of the firm allows the effect of firm size to be controlled through the variables of labour input, capital and stock of knowledge. The interaction effect of R&D with capital and labour resources can also be captured.

Taking the natural logarithm of the above equation, using a small letter to denote the logarithm of the corresponding variable, adding an error term ε_{it}, and using lagged dependent variables to pick up the time-invariant firm- and industry-specific effects as well as the partial adjustment effect, the following empirical version of the model is derived:

$$q_{it} = a + \phi_1 q_{it-1} + \dots + \phi_j q_{it-j} + \alpha l_{it} + \beta k_{i.} + \gamma r_{it} + \varepsilon_{it} \qquad (2)$$

where j is the number of lagged periods; $\alpha = \alpha'/(1 - \phi_1 - \dots - \phi_j)$; $\beta = \beta'/(1 - \phi_1 - \dots - \phi_j)$; $\gamma = \gamma'/(1 - \phi_1 - \dots - \phi_j)$. This type of dynamic specification can be rewritten as an equation with q_{it} being a function of an infinite series of lagged independent variables with the lagged coefficients following a certain kind of restrictions. For example, $q_{it} = \phi q_{it-1} + \beta x_{it}$ can be rewritten as $q_{it} = \beta(x_{it} + \phi x_{it-1} + \phi^2 x_{it-2} + \phi^3 x_{it-3} + \dots)$, i.e., as an infinite series of x_{it-j} with the coefficients restricted to be declining geometrically. Thus, the specification enables the estimation of the long-run contribution of R&D even with limited years of observations.

The value-added of each sample firm is computed by multiplying the sales revenue of the firm in the A*STAR database by the value-added to sales (VAS) ratio of the industry cluster to which the firm belongs. The VAS ratio of each industry cluster is compiled from the *Census of Industrial Production* and *Survey of Services* for the period between 1996 and 2001. There is significant variation in the VAS ratio across the clusters, suggesting that the industrial characteristics of each cluster are very different.

The total fixed assets and total employment of each sample firm are obtained directly from the A*STAR database. To impute capital inputs, a constant capital cost rate of 10 percent[20] is assumed, i.e., each sample firm obtains capital inputs equivalent to 10 percent of its total fixed assets every year.

Adopting the timeframe used by Kelm (1995) as well as Tsang, Yip and Toh (2000), the discounted sum of the firm's annual R&D expenditures over a three-year period (i.e., current year plus two previous years) is used as a proxy for the firm's available stock of knowledge.[21]

[20] The results are not sensitive to the choice of capital cost rate from 5 percent to 15 percent.

[21] The three-year discounted sum of R&D expenditures is a better proxy of the firm's available stock of knowledge than the current year R&D expenditure and gives a more precise estimate of the related coefficient. In general, the longer the lag in the discounted sum, the more precise the estimate will be.

Each firm's annual R&D expenditure is available from the A*STAR database. The discount rate of 10 percent is used in weighing the R&D expenditure.[22]

The A*STAR database also provides the breakdown of R&D funding by source, ownership type of R&D firm as well as patent statistics (i.e., number of patent applications and patents awarded each year). This enables testing of the effects of these parameters on R&D performance.

Exhibit 9: Regression Results for Business/Private Sector Firms [a]

	Model 1	**Model 2**
Constant	1.770*** (5.17)	0.661*** (4.74)
l_{it}	0.196*** (5.84)	0.174*** (4.98)
k_{it}	0.106*** (5.76)	0.130*** (6.65)
r_{it}	0.037^ (1.78)	
q_{it-1}	0.425*** (14.79)	0.404*** (14.04)
Q_{it-2}	0.267*** (9.91)	0.274*** (10.22)
$El_i \times r_{it}$		0.05** (3.00)
$En_i \times r_{it}$		0.055** (3.18)
$Ls_i \times r_{it}$		0.060*** (3.36)
$Om_i \times r_{it}$		0.035** (3.13)
$Ic_i \times r_{it}$		0.058*** (3.53)
$Fb_I \times r_{it}$		0.053* (2.48)
$Os_i \times r_{it}$		0.046* (2.54)
R-squared	0.850	0.854
Adjusted R-squared	0.849	0.852
S.E. of regression	0.922	0.396
F-statistic	1326.679	568.283

	Model 3
Constant	0.750*** (5.03)
l_{it}	0.194*** (5.75)
k_{it}	0.105*** (5.71)
q_{it-1}	0.425*** (14.78)
q_{it-2}	0.269*** (9.92)
$Gov_i \times r_{it}$	0.043* (2.00)
$N\_Gov_i \times r_{it}$	0.039^ (1.89)
R-squared	0.850
Adjusted R-squared	0.849
S.E. of regression	0.400
F-statistic	1105.540

[a] t-statistics in parentheses.
^p < .10; *p < .05; **p < .01; ***p < .001 (two-tailed)

Ordinary least squares regression is performed on the model specified in equation (2), using the data from all business private sector firms. Exhibit 9 presents the results. Model 1 is the basic model represented by equation 2 with variables lagged up to two periods. There is good fit of the data points in the regression model, with an adjusted R^2 of 0.85.

Model 2 is an extension of model 1, partitioning R&D expenditure by industry clusters. The electronics, engineering, life sciences, other manufacturing, infocom-technology, business and finance services as well as other services clusters are denominated by the variables El, En, Ls, Om, Ic, Fb and Os respectively. The standard error in model 2 improves significantly to 0.40 from 0.92 in model 1. This stems from structural differences between returns to R&D among the various clusters.

Model 3 regresses value-added against R&D conducted by firms which receive at least 30

However, a longer lag would mean less years of observations in the estimation. Balancing these two factors, the three-year discounted sum is chosen.
[22] The results are not sensitive to the choice of discount rate from 5 percent to 15 percent.

percent of their R&D funding from government sources (Gov_i x r_{it}) and firms which receive less than 30 percent of their funding from the government (N_Gov_i x r_{it}). The contribution of R&D conducted by firms receiving substantial R&D grants is marginally higher at 0.043 compared to 0.039 from other R&D firms. A formal test of equality between the two coefficients gives a Wald statistic of 0.37 with a probability of 0.541. Hence, the two coefficients are not statistically different.

Exhibit 10: Regression Results for Public Institutions and Comparison of Patents Applications[a]

	Model 4
Constant	6.572** (3.13)
l_{it}	1.681*** (4.00)
k_{it}	-0.157 (-0.61)
r_{it}	-0.840** (-3.35)
q_{it-1}	0.336*** (4.78)
q_{it-2}	0.159* (2.15)
R-squared	0.422
Adjusted R-squared	0.402
S.E. of regression	2.165
F-statistic	20.757

	Model 5	Model 6
Constant	-0.663* (-2.52)	-0.082** (-2.49)
l_{it}	0.026 (0.53)	0.011 (1.41)
k_{it}	-0.042 (-1.35)	-0.005 (-1.02)
r_{it}	0.148*** (4.51)	0.019*** (3.40)
pa_{it-1}	0.575*** (7.29)	0.651*** (27.27)
pa_{it-2}	0.267** (3.08)	0.253*** (9.37)
R-squared	0.749	0.600
Adjusted R-squared	0.741	0.599
S.E. of regression	0.259	0.151
F-statistic	84.913	644.205

[a] t-statistics in parentheses.
^p < .10; *p < .05; **p < .01; ***p < .001 (two-tailed)

The model specified in equation 2 is separately applied to the public institutions in the database. Exhibit 10 presents the results under model 4. The poor regression result, i.e., low adjusted R^2 of 0.40, suggests that the value-added objective specified in equation 2 is not an accurate representation of public institutions.

Taking into account the emphasis of public institutions on more upstream research and training, the objective variable of firm value-added is replaced with annual patent applications (pa_{it}) instead. The modified model is tested on public sector institutions in model 5. The regression results are much more robust than in model 4, with adjusted R^2 of 0.74.

Model 6 regresses patents applications on R&D conducted by business/private sector firms. The results are less rigorous with an adjusted R^2 of 0.60. This is consistent with the observation that business/private sector firms conduct primarily downstream research and seek to maximise value-added rather than knowledge *per se*.

REFERENCES

Amsden, A.H; T. Tschang and A. Goto (2001), *Do Foreign Companies Conduct R&D in Developing Countries?*, ADB Institute Working Paper 14.

Bassanini, A.; S. Scarpetta and I. Visco (2000), *Knowledge, Technology and Economic Growth: Recent Evidence from OECD Countries*, OECD, Economics Department Working Paper 259.

Gans, J.S. and S. Stern (2002), "Managing Ideas: Commercialisation Strategies for Biotechnology", *Kellogg Biotechnology Review*, Vol.1.

Chandler Jr., A.D. (1990), *Scale and Scope. The Dynamics of Industrial Capitalism.*, Cambridge, MA: Harvard University Press.

Cohen, W.M. and D. Levinthal (1990), "Absorptive Capacity: A New Perspective on Learning and Innovation", *Administrative Science Quarterly*, Vol 35, 128-152.

Ernst, H. (1998), "Industrial Research as a Source of Important Patents", *Research Policy*, Vol 27, 1-15.

Griliches, Z. (1986), "Productivity, R&D and Basic Research at the Firm Level in the 1970s", *American Economic Review*, Vol 76, 141-154.

Griliches, Z. (1995), "R&D and Productivity: Econometric Results and Measurement Issues," in P. Stoneman (ed), *Handbook of the Economics of Innovation and Technological Change*. Oxford, England: Blackwell.

Guellec, D. and B. Potterie (2001), *R&D and Productivity Growth, Panel Data Analysis of 16 OECD Countries*, OECD, STI Working Papers 2000/4.

Hall, B.H. and J. Mairesse (1995), "Exploring the Relationship Between R&D and Productivity in French Manufacturing Firms", *Journal of Econometrics*, Vol 65, 263-293.

Kelm, K.M.; V.K. Narayanan and G.E. Pinches (1995), "Shareholder Value Creation During R&D Innovation and Commercialization Stages", *Academy of Management Journal*, Vol 18, 770-786.

Kondo, M. (1999), "R&D Dynamics of Creating Patents in the Japanese Industry", *Research Policy*, Vol 28, 587-600.

Mansfield, E. (1991), "Academic Research and Industrial Innovation." *Research Policy*, Vol 20, 1-12.

Mansfield, E. (1996), "Contributions of New Technology to the Economy", in B. Smith and C.E. Barfield (eds), *Technology, R&D & the Economy*. Washington, D.C.: Brookings Institution and American Enterprise Institute.

Odagiri, H. and H. Iwata (1986), "The Impact of R&D on Productivity Increase in Japanese Manufacturing Companies", *Research Policy*, Vol 15, 13-19.

OECD (1993), *The Measurement of Scientific and Technological Activities: Proposed Standard Practice for Surveys of Research and Experimental Development*, Paris: OECD.

Stokey, N.L. (1995), "R&D and Economic Growth," *Review of Economic Studies*, Vol. 62, 469-489.

Toh Mun Heng, (2000), *The Impact of R&D on the Singapore Economy : An Empirical Evaluation*, Faculty of Business Administration, National University of Singapore.

Tsang, W.K.; S.L. Yip, and Toh Mun Heng (2000), "Does Knowledge Creation Create Value? A Contrast of R&D Performance between Domestic and Foreign Firms in a Newly Industrialised Economy", Nanyang Technological University, Working Paper.

Wakelin, K. (2001), "Productivity Growth and R&D Expenditure in UK Manufacturing Firms", *Research Policy*, Vol 30, 1079-1090.

Wong Poh Kam (1999), *The Dynamics of HDD Industry Development in Singapore*, National University of Singapore, Centre for Management of Innovation and Technopreneurship.

Zucker, L.G.; M.R. Darby and M.B. Brewer (1998), "Intellectual Human Capital and the Birth of US Biotechnology Enterprises", *American Economic Review*, Vol 88, No. 1, 290-306.

CHAPTER THREE

MAPPING SINGAPORE’S KNOWLEDGE-BASED ECONOMY

MAPPING SINGAPORE'S KNOWLEDGE-BASED ECONOMY

AIM

1. The formation of the National Science and Technology Board in 1991 marked a milestone in deliberate government policy to promote the development of science and technology (S&T). Singapore's S&T efforts have made much progress since then, with gross expenditure on R&D growing from S$757 million in 1991 to S$3 billion in 2000. Singapore's manufacturing base has continued to move up the value-chain to more high-tech and knowledge-intensive products. Underpinning this S&T effort is a growing and comprehensive education system that has progressively improved the skill sets of the labour force. All these are indicative of Singapore's shift to the next stage of knowledge-based economic development.

2. This paper aims to take stock of the progress Singapore has made in building up its knowledge-based economy (KBE) and analyses how these developments have contributed to the economic competitiveness of Singapore. Findings in this paper will allow Singapore to be better positioned through the identification of gaps in strategically important areas.

THE KNOWLEDGE-BASED ECONOMY

3. There is no authoritative definition of what a KBE really is. However, there is general consensus that it embodies the ability to constantly innovate through accessing, processing, using and creating knowledge. These key characteristics are well summed up by APEC[23] as follows:

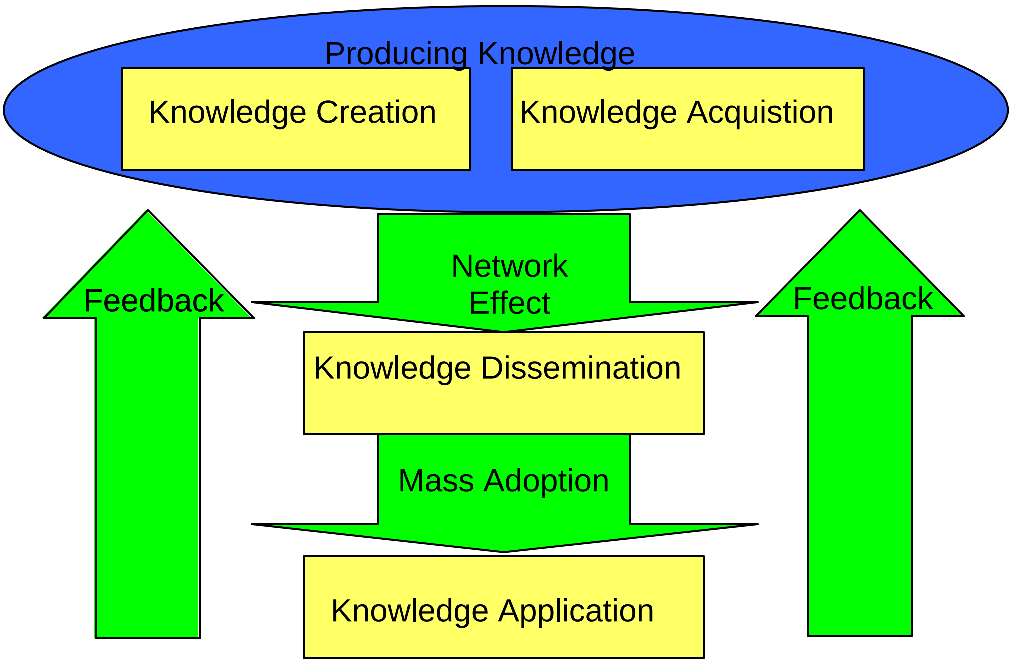
> "A knowledge-based economy is an economy in which the production, distribution, and use of knowledge is the main driver of growth, wealth creation and employment across all industries."

4. This definition encapsulates the two key perspectives we need to address in mapping Singapore's KBE. First, we need to understand "the production, distribution, and use of knowledge" in Singapore. This will allow us to have a systematic overview of Singapore's KBE capabilities. Second, we need to quantify how knowledge activities are benefiting the economy, as these activities evolve into "the main driver of growth, wealth creation and employment across all industries".

5. As the Singapore economy develops, it can no longer rely on the accumulation of capital and labour to sustain economic growth. Singapore needs to further develop its KBE, deriving its driver of growth from the production, dissemination and application of knowledge. The linkages between the knowledge capabilities identified by the APEC study are illustrated in exhibit 1.

[23] APEC Economic Committee (2000), *Towards Knowledge-Based Economies in APEC*, APEC Secretariat.

Exhibit 1: Linkages between KBE Capibilities



Source: Adapted from World Bank (1998/99), World Development Report–Knowledge for Development, New York: Oxford University Press.

6. Knowledge Creation and Acquisition. The production of knowledge is the fundamental driver in the growth of KBE for it provides new ways of increasing efficiency in the production of goods and services. The developed economies have traditionally been the main sources of knowledge creation. The alternative path used by less developed economies is to acquire knowledge from the developed economies. Singapore continues to rely primarily on knowledge transfers through the attraction of MNCs and foreign talent. However, with the emphasis on science and technology since 1990, Singapore has begun to build a systematic capability in knowledge creation. Hence it is necessary to look at both knowledge creation and acquisition capabilities to measure the extent of the knowledge base in Singapore.

7. Knowledge Dissemination. The ICT revolution has vastly expanded the frontier of possibilities for the KBE by enabling existing and new knowledge to be disseminated at ever faster speeds, larger volumes and lower costs. Moreover, the usefulness of knowledge-intensive products such as software is subject to network economies, i.e., they become more useful as the user-base increases.[24] The culmination of these developments is the "network effect" which multiplies the benefits of a fixed knowledge base many-fold through dissemination.

8. Knowledge Application. The economic benefits of an expanding knowledge base and network dissemination are realised when they are adopted and applied by the labour force in the production of goods and services. The constant stream of technological advances in an advanced KBE compresses product cycles and speeds up the depreciation of human capital, making knowledge application even more critical. The commercial benefits from applying

[24] Shapiro, Carl and Hal R. Varian (1999), *Information Rules: A Strategic Guide to The Network Economy*, Harvard Business School Press.

knowledge will provide feedback to the knowledge production community, driving the next round of innovation and absorption.

MAPPING SINGAPORE'S KBE CAPABILITIES

9. Three proxy indicators have been chosen to map each of the four KBE capabilities. While a host of indicators exist for each capability and they may be applicable across multiple capabilities, the three indicators chosen for each capability are essential and distinct. Comparisons are made with the OECD economies and NIEs to allow us to gauge the stage of development of Singapore's KBE. The selected basket of indicators is summarised in exhibit 2.

Exhibit 2: Indicators Selected for Mapping KBE

Proxy Indicator	**Aspect Measured by Indicator**
Knowledge Creation	
Percentage of GDP spent on R&D	Intensity of R&D conducted in the economy
Researchers per capita	Availability of human resources needed for R&D
US patents[25] per capita	Overall quality of the national innovation system by the scientific output it creates
Knowledge Acquisition	
Imports in the technology balance of payments (BOP)[a]	Direct gauge of the cross-border transfer of knowledge
Number of head and regional offices in Singapore	Amount of firm-specific knowledge brought in by MNCs and regional firms
Size of the knowledge intensive business services (KIBS) sector[b]	Provides intermediate products and services to firms, thereby perpetuating innovative practices and services from global sources[26]
Knowledge Dissemination	
Info-communication technology (ICT) spending as a percentage of GDP	Intensity of resources put into developing information infrastructure
Internet access cost as a percentage of per capita GDP	Affordability of ICT services, which will determine the usage of an economy's ICT network
Percentage of workforce with at least secondary school education	Basic IT and linguistic skills to tap into ICT network
Knowledge Application	
Percentage of workforce with university education	Ability of workforce to seek out, process and use relevant information
Percentage of "knowledge workers"[27] in workforce	Jobs that demand and allow workers to apply knowledge extensively

[25] Singaporean patents registered in the US.
[26] Den Hertog, P. (2000), "Knowledge-Intensive Business Services as Co-Producers of Innovation", *International Journal of Innovation Management* 4(4), pp. 491-528.
[27] OECD and APEC consider the following classifications by International Labour Organisation as "knowledge workers": managers and senior government officials, professional workers, and "associate professionals".

World Competitiveness Yearbook ranking of entrepreneurship	Ability of the economy to create new business models for generating, acquiring, diffusing and applying new ideas and processes

Notes:

a. Technology receipts and payments constitute the main form of technology diffusion and comprise four main categories: (i) Transfer of techniques (through patents and licences, disclosure of know-how), (ii) Transfer (sale, licensing, franchising) of designs, trademarks and patterns, (iii) Services with a technical content, including technical and engineering studies, as well as technical assistance, (iv) Industrial R&D.

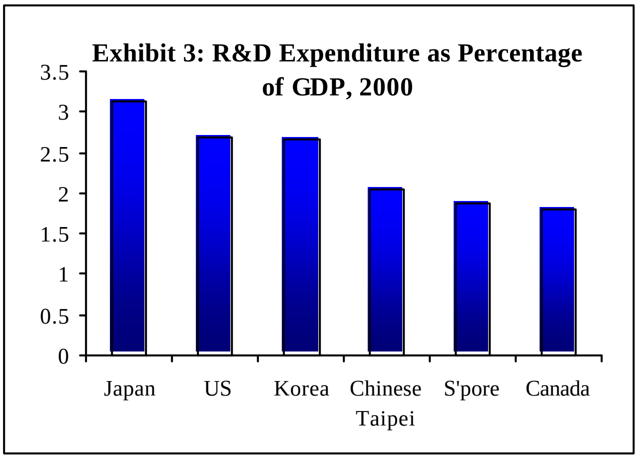
b. The OECD classifies IT and related services, management and business consulting as well as engineering and technical services under KIBS

Knowledge Creation

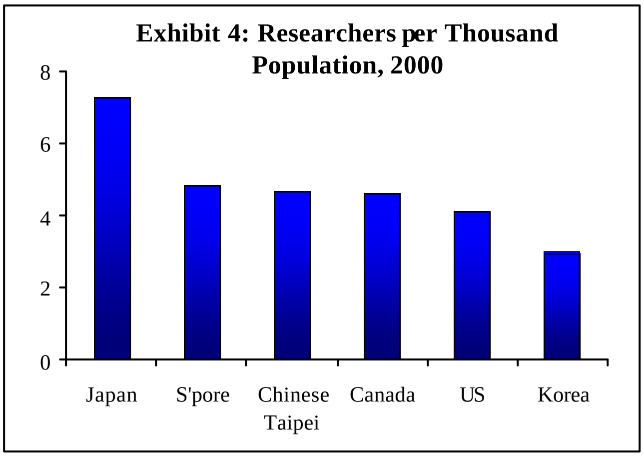
10. Singapore has made good progress towards creating a stronger base for knowledge creation over the last ten years. Adjusting for its small economy and population, the level of R&D spending and number of researchers in Singapore has approached the levels existing in developed KBE economies. However, there is still a considerable gap between Singapore's R&D outputs and that of the more advanced KBEs.

11. Singapore's R&D expenditure, expressed as a percentage of GDP, has risen steadily from 0.86 percent to 1.88 percent between 1990 and 2000. This indicates that Singapore has made significant progress in creating an R&D base. Exhibit 3 also shows that this level of R&D spending is comparable to that of Chinese Taipei and Canada, but lags close to a full percentage point behind the US, Japan and Korea.

12. Exhibit 4 shows the number of researchers per thousand population across the selected group of economies. Singapore's figure of 4.82 is much higher than Korea's, and is comparable to those of the US, Canada, and Chinese Taipei.

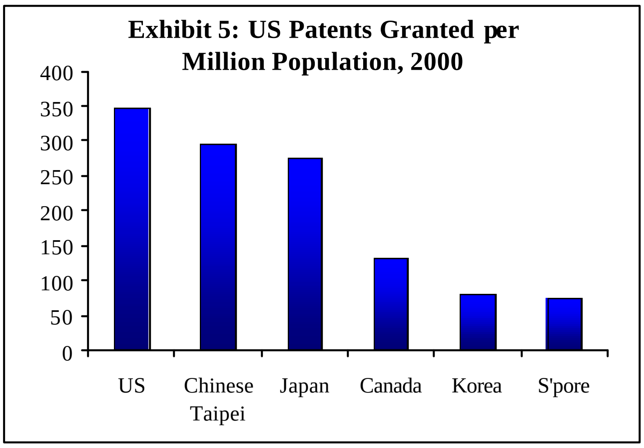


Source: *World Competitiveness Yearbook 2002*



Source: *World Competitiveness Yearbook 2002*

13. Singapore's patents record has improved steadily over the last decade, from 25 US patents in 1990 to 304 patents in 2001. However, Singapore's performance is still weak by international standards. Singapore registered 74 new US patents per million population in 2001, whereas Canada and Chinese Taipei had 131 and 294 patents respectively as shown in exhibit 5 The US ranks even higher in terms of patent registration rates.

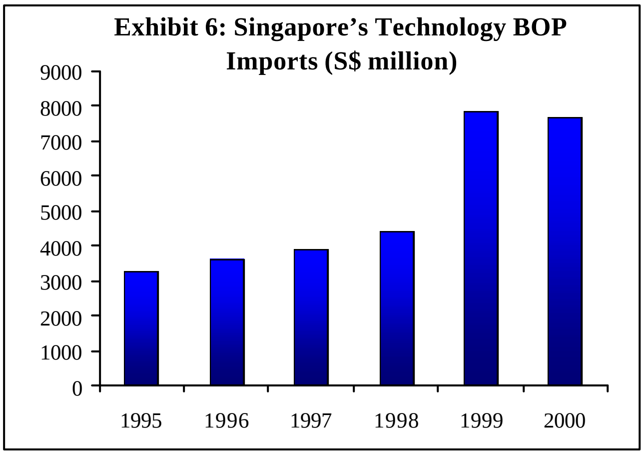


Source: *US Patents & Trademark Office*

Knowledge Acquisition

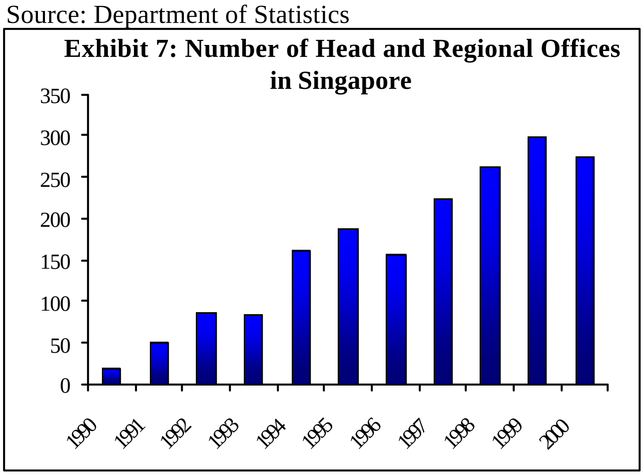
14. Singapore's KBE is characterised by a strong knowledge acquisition capability as a result of: its industrial policy of attracting MNCs, the openness of its business environment, as its excellent ICT infrastructure. Based on current trends, knowledge acquisition will continue to grow and will remain Singapore's main source of new knowledge in at least the medium-term.

15. As shown in exhibit 6, the value of Singapore's technology imports have risen steadily over the years, from S$3.3 billion in 1995 to S$7.7 billion in 2000. In 2000, technology payments constituted 3.3 percent of Singapore's total imports, several times higher than the average level of 1.2 percent in the OECD economies. This high level is reflective of the importance of acquired knowledge to the Singapore economy.



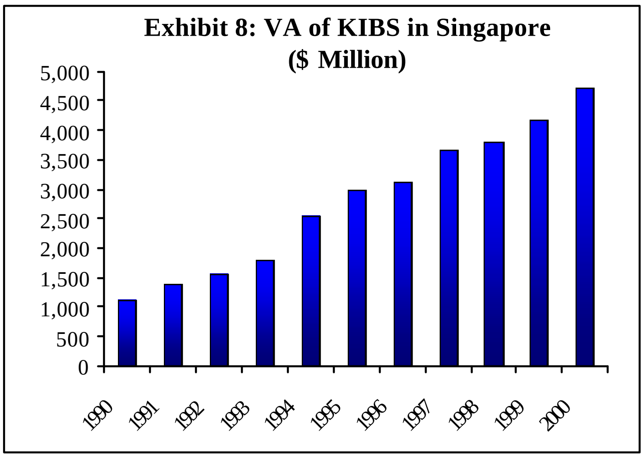
Source: Department of Statistics

16. Exhibit 7 shows that Singapore has continued to develop as a hub where companies base their headquarters and regional offices. The number of such set-ups has increased rapidly, from 19 in 1990 to 274 in 2000. This enhances Singapore's knowledge acquisition capability as these firms bring in best practices as well as awareness of new technologies around the world.



Source: Department of Statistics

17. The knowledge intensive business services (KIBS) sector in Singapore has grown rapidly from S$1.1 billion in 1990 to S$4.7 billion in 2000 as shown in exhibit 8. Renowned KIBS firms such as McKinsey, Anderson Consulting and Reuters have increased their presence in Singapore over the years. Local enterprises have also increased their usage of KIBS, leading to more rapid and wider diffusion of global innovative practices throughout the economy.

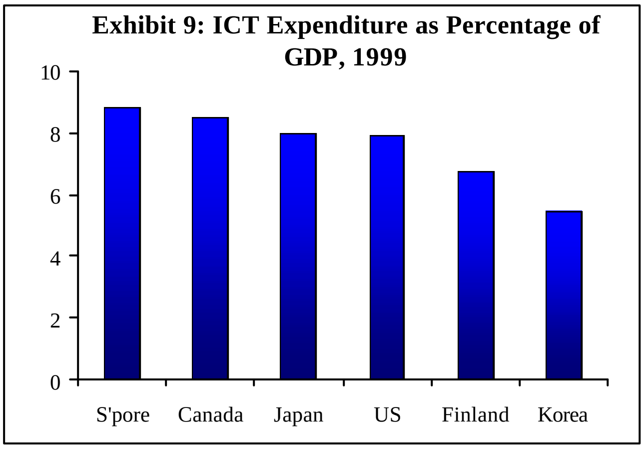


Source: Department of Statistics

Knowledge Dissemination

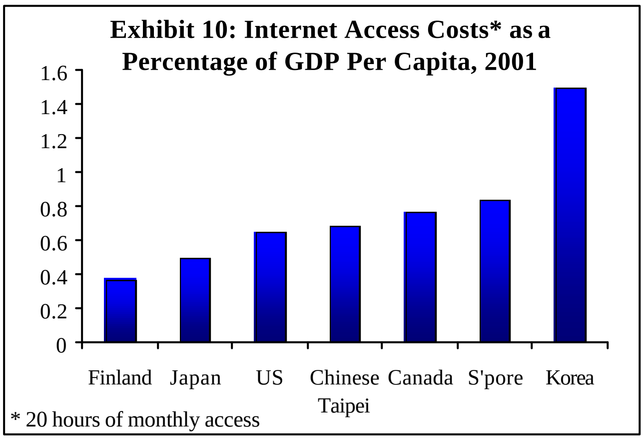
18. With its emphasis on ICT infrastructure and education, Singapore has made good progress in enhancing its knowledge dissemination capability. However, Singapore still has some way to go before it can reach world-class standards. There are two key issues Singapore needs to continue to address. First, upgrading its education profile is a long-term undertaking which can only take place alongside demographic changes. Second, while ICT prices have dropped, particularly after the April 2000 liberalisation of the telecom sector, prices still remain high by international standards. This points to further opportunities for efficiency gains within the ICT sector.

19. Exhibit 9 shows that Singapore spent 8.8 percent of its GDP on ICT in 1999, higher than the 8 percent in Japan and 7.9 percent in the US. As a result of maintaining this emphasis on ICT throughout the years, Singapore has one of the best ICT infrastructures in the world, as evidenced by its top rankings in the *World Competitiveness Yearbook* and *Global Competitiveness Report*.



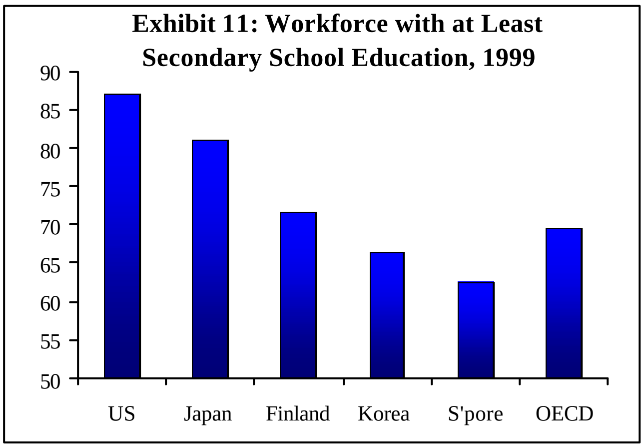
Source: OECD, Infocomm Development Authority

20. Exhibit 10 shows that ICT usage costs are about 30 percent higher in Singapore when to the US. A survey[28] by the Infocomm Development Authority on firms' ICT usage has also highlighted costs as the biggest impediment to computerisation in the workplace.



Source: Global Information Technology Report 01/02

21. Workers with at least secondary education are equipped with the potential to pass the knowledge acquired in their jobs on to other workers. The proportion of Singapore's workforce with at least secondary education has improved steadily over the years, from 50.6 percent in 1990 to 62.5 percent in 1999. Singapore is approaching the OECD average of 69.6 percent as shown in exhibit 11.

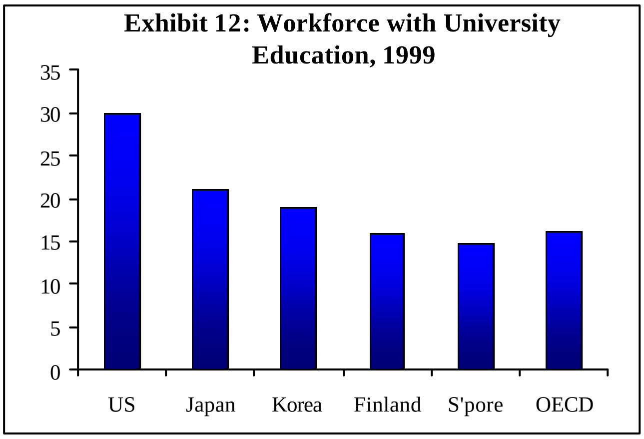


Source: Ministry of Education, Ministry of Manpower, OECD

Knowledge Application

22. In terms of knowledge application, Singapore is still less developed than the advanced KBEs. Entrepreneurship is the weakest link in Singapore's knowledge application capability and will require major efforts for improvement. Singapore also has to continue improving its tertiary education.

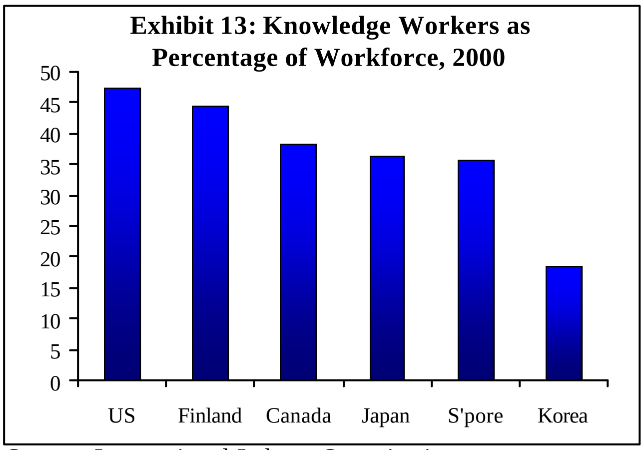
23. The proportion of the Singapore workforce with university education has increased steadily over the years from 6.2 percent in 1990 to 14.7 percent in 1999. But Singapore still lags significantly behind developed countries such as the US and Japan as shown in exhibit 12.



Source: Ministry of Manpower, OECD

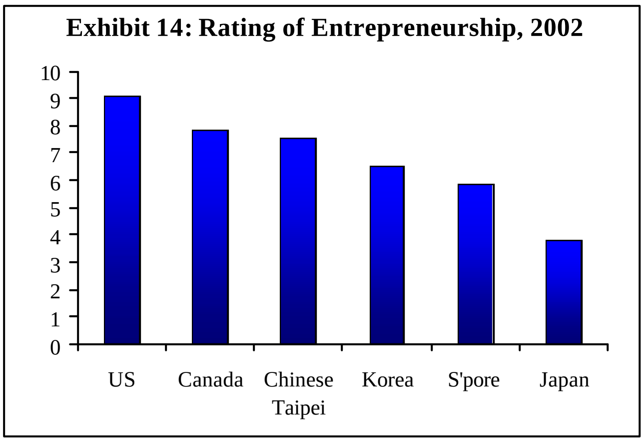
[28] Infocomm Development Authority of Singapore (1999), *Key Findings of ICT Usage Survey 1999 on the ICT Adoption by Businesses in Singapore.*

24. Exhibit 13 shows that knowledge workers[29] constitute 36 percent of the labour force in Singapore, compared with 47 percent in the US, 36 percent in Japan and 18 percent in Korea. By this measure, Singapore is almost comparable with the developed economies.



Source: International Labour Organisation

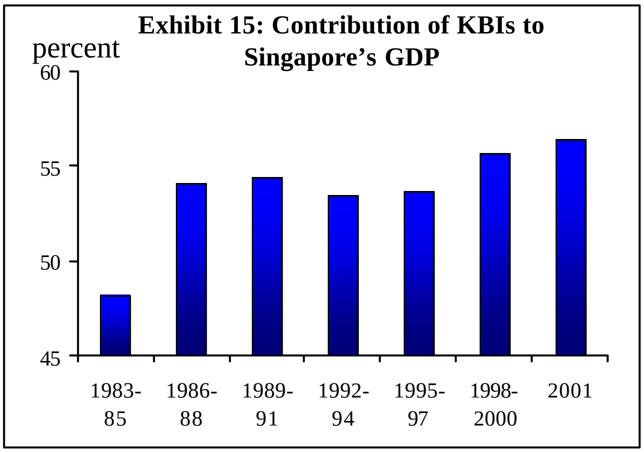
25. The *World Competitiveness Yearbook* (WCY) is one of numerous studies[30] that point to the dearth of entrepreneurship in Singapore. Exhibit 14 summarises Singapore's position relative to the other KBEs. We are substantially behind the other NIEs, as well as the US and Canada.



Source: *World Competitiveness Yearbook 2002*

ECONOMIC CONTRIBUTIONS OF SINGAPORE'S KBE

26. The size of Singapore's KBE can be estimated by looking at the value-added of the knowledge-based industries (KBIs). The detailed breakdown of KBIs is shown in annex A. The GDP contribution of these KBIs in aggregate is summarised in Exhibit 15. KBIs have contributed about 53 percent of Singapore's GDP between 1983 and 2001, reaching 56 percent in 2001.[31] In comparison, these sectors accounted for around 50 percent of total value-added in Australia, the European Union and the United States.[32]



Source: Department of Statistics, Singapore

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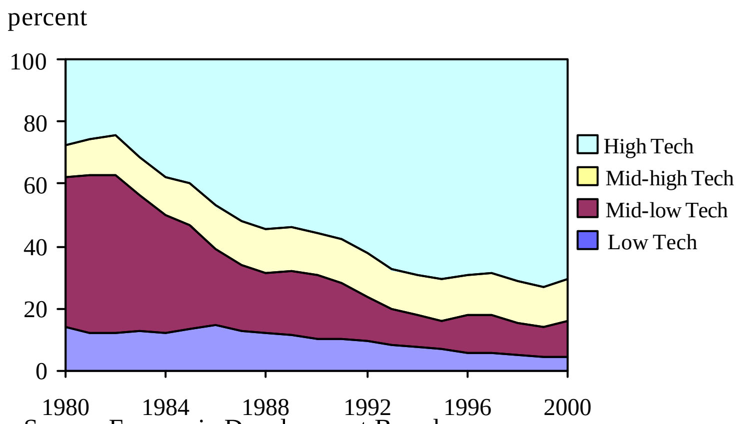
[29] See table 2.1 for definition.

[30] These include the *Global Competitiveness Report* and the *Global Entrepreneurship Monitor 2000*.

[31] The low level in the 1983-85 period was due to the construction boom. The construction sector's share of GDP rose to 11% during that time.

[32] OECD (2001), *Science, Technology and Industry Outlook*, Paris: OECD.

Exhibit 16: Technology Profile of Singapore's Direct Manufacturing Exports



Source: Economic Development Board,

27. In the manufacturing sector, the Economic Development Board has been moving the industries up the value chain into more knowledge-intensive and high-tech products. This allows the economy to continue growing even as the build-up of labour and capital resources slows down. Exhibit 16 shows that the technology profile of Singapore's manufacturing base, as reflected by the composition of its manufacturing exports, went through a rapid technological transition from 1980 to 2000. The share of high and mid-high technology exports increased from 37.7 percent of total exports in 1980 to 84.1 percent in 2000. Average manufacturing productivity growth accelerated from 5.5 percent p.a. in the 1986–90 period to 7.2 percent p.a. in the 1991–95 period. High productivity growth was sustained at an average of 7.8 percent p.a. from 1996 to 2000. This could be attributed to the higher level of capital investments and total factor productivity as the manufacturing base became more technology-intensive.

28. In the process of upgrading its manufacturing base, Singapore has become specialised in a few industries. Electronics rose from contributing 18 percent of manufacturing VA in 1983 to a high of 48 percent in 2000. However, specialisation has made the economy vulnerable to sectoral cyclical swings. To make the economy more robust, it is necessary to nurture new pillars of manufacturing. The Economic Review Committee (ERC) Manufacturing Sub-Committee has recommended the high value-added activities in photonics, nanotechnology, alternative fuels and performance materials as areas Singapore could move into. These areas would require Singapore to broaden and deepen its knowledge capabilities.

29. For the services sectors, the ERC has identified ICT, education services, healthcare services, tourism, financial services, trading and logistics services as well as professional services as the segments having growth potential These segments currently contribute 23.6 percent of GDP. Their share of GDP is projected to grow to between 28.7 percent and 31.8 percent in 2012 if the Sub-Committee's target of 7.3 percent to 8.7 percent growth per annum in value-added is met.[33] The quality of these services is highly dependent on the skills and knowledge of the workforce. Improving Singapore's knowledge capabilities is the key to the future success of these new growth engines.

[33] Computed from Services Sub-Committee Report.

30. We can use the Input-Output tables to analyse how the increasing shift to KBIs has affected the performance of the economy. The VA multiplier of a sector indicates the amount of value-added generated directly as well as indirectly (as an intermediate good in another industry) due to the sale of one unit of the industry output to the final demand. The output multiplier reflects the direct and indirect output required to satisfy one unit of sale to the final demand.[34] The ratio of VA multiplier to the output multiplier is an overall "productivity" measure for each sector. It measures the proportion of output that is attributable to value-added produced as well as induced (through forward and backward linkages) by the sector. To illustrate, Singapore's KBIs had an average productivity measure of 0.43 in 1990. This means that every unit of final output produced by the KBIs generated 0.43 of value-added in the entire economy. The average multipliers for the KBIs and non-KBIs are shown in exhibit 17.[35]

Exhibit 17: Production and Productivity Multipliers for Singapore

	KBIs, 1990	**Non-KBIs, 1990**	**KBIs, 1995**	**Non-KBIs, 1995**
Output multiplier	1.37	1.45	1.30	1.45
VA multiplier	0.59	0.54	0.58	0.56
Productivity measure*	0.43	0.38	0.45	0.39

31. The KBIs had significantly higher productivity than non-KBIs. Moreover, the productivity gap widened between 1990 and 1995, although productivity measures in both segments improved over this period. While the comparison is not conclusive, this is consistent with the expectation that KBIs benefit more from the availability of new technologies and knowledge.

32. This gap in productivity growth between KBIs and non-KBIs is expected to widen in the years ahead due to the ICT revolution. According to the World Bank[36], the three major ICT-induced transformations are as follows:

a. *Emergence of product classes with network economies and low marginal cost of distribution*. The classic example is application software whose utility and portability increase as more people use it (network economies), and it is rather cheap to distribute online. This has provided the economic viability for companies such as Microsoft to consolidate and enlarge market share, driving down unit costs and increasing profit margins.

b. *Integration of inventory data systems*. This allows greater optimisation and responsiveness in horizontal and vertical supply chains, both within the firm and across companies. This will result in a significant lowering of costs, as experienced by the Detroit automobile companies.

c. *Mass customisation of products and services.* This is now achievable with interactive data interfaces and improvement in data mining capabilities. Particularly, the ability to customise services on a large scale has the potential to revitalise services' productivity growth. They would derive economic benefits from investing in ICT systems for customer

[34] Toh Mun Heng, Low, Linda (1994), *Input-Output Tables 1988: Models and Applications*, Department of Statistics.
[35] The structure of the I-O analysis follows the same framework as Toh Mun-Heng (2000), *The Development of Singapore as a Knowledge Based Economy: Size of KBE and Its Economic Impact*, Faculty of Business Administration, National University of Singapore.
[36] Sahid Yusuf, Simon J. Everett (2002) *Can East Asia Compete?*, World Bank
[37] Major components of this indicator are the KIBS as well as the rental of machinery and equipment.

relationship management, marketing and e-services. Thus, productivity growth in services can be driven by an upswing in capital deepening.

COMPETITIVENESS OF SINGAPORE'S KBE

33. This section assesses Singapore's international competitiveness in terms of its KBE capabilities. The indicators that are used to benchmark Singapore's KBE with the OECD countries are summarised in exhibit 18.

Exhibit 18: List of Indicators Used to Benchmark KBE Competitiveness

Knowledge Creation	**Knowledge Acquisition**
GERD (% of GDP)	Technology BOP imports (% of Imports)
Researchers per capita.	FDI (% of GDP)
US patents per capita.	VA of business services (% of GDP)
Knowledge Dissemination	**Knowledge Application**
ICT expenditure (% of GDP)	Percentage of workforce with university education
Affordability of internet access	Percentage of knowledge workers in workforce
Percentage of workforce with at least secondary education	World Competitiveness Yearbook ranking of entrepreneurship

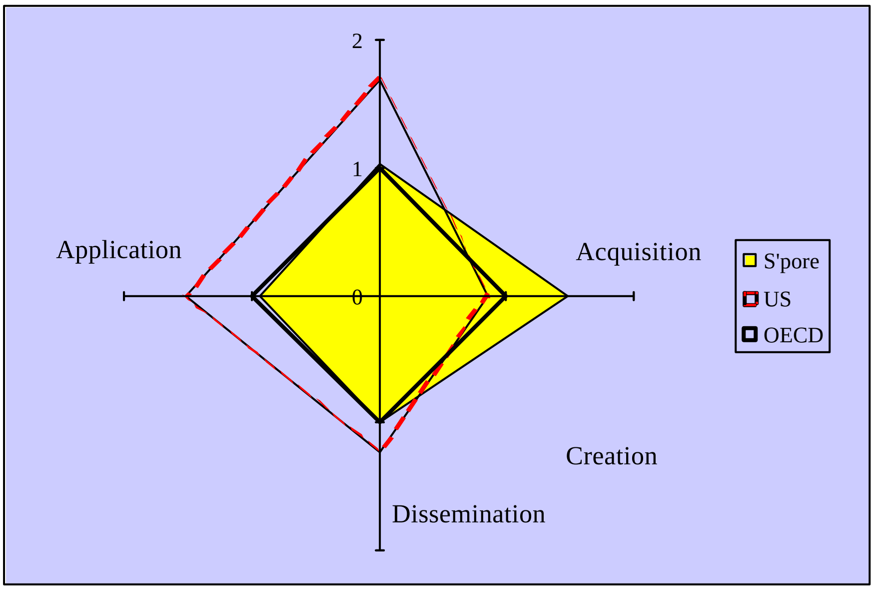
Notes: Ten of these indicators have already been used earlier. The number of head and regional offices has been replaced due to the unavailability of international data. We have adopted the OECD convention of using the broader indicator of FDI/GDP as a proxy of MNC presence. As not all OECD economies track the size of their KIBS sector, the size of business services (excluding real estate services)[37] is used.

34. A composite index for each knowledge capability is compiled from the indicators, with the OECD average being set as the base index of one. The indices are shown in exhibit 19. exhibit 20 shows the overall structure of Singapore's KBE relative to the OECD and the US. The methodology and computations for the indices are detailed in annex B.

Exhibit 19: Composite Knowledge Indices for Selected Countries, 2000

	OECD	**S'pore**	**US**	**Japan**	**Korea**
Knowledge Creation Index	1.00	1.03	1.69	1.96	0.98
Knowledge Acquisition Index	1.00	1.49	0.86	0.65	0.98
Knowledge Dissemination Index	1.00	1.05	1.24	1.35	0.77
Knowledge Application Index	1.00	0.93	1.52	0.96	0.90

Exhibit 20: Comparison of Singapore's KBE with OECD and the US, 2000



35. With a knowledge creation index of 1.03, Singapore is on par with the OECD average. Among the OECD economies, only a handful of countries such as the US, Japan and Sweden have become successful innovative nations. Most economies are, like Singapore still developing their R&D clusters.

36. Singapore relies predominantly on its strength in knowledge acquisition to upgrade its KBE. Its knowledge acquisition index of 1.49 is the second highest compared to the OECD economies, only behind Ireland. Ireland and Singapore have been able to absorb much foreign technology due to the extensive presence of MNCs in their economies. The US and Japan have low acquisition indices as they are the largest producers of new knowledge in the world. Consequently, their dependence on foreign sources of knowledge is low.

37. Singapore has a comparable index ranking of 1.05 with the OECD economies in knowledge dissemination. Although Singapore has a stronger policy emphasis on ICT infrastructure than many other developed economies, its rating is only slightly higher than the OECD average due to the late liberalisation of the ICT sector relative to the OECD as well as the weaker education profile.

38. Singapore has almost caught up with the OECD economies in terms of knowledge application, as reflected in its index of 0.93. Much progress has been made in the area of education, which is now approaching first world standards. This is, however, moderated by the low level of entrepreneurship in Singapore.

SINGAPORE'S KBE – THE NEXT LAP

39. Singapore's KBE is generally competitive with the OECD countries. However, it has so far relied mainly on knowledge acquisition as the source of competitive advantage to drive its KBE to the next lap. Going forward, Singapore will need to position its domestic policies to nurture a more broad-based KBE to sustain economic growth. In particular, the mapping of Singapore's KBE has highlighted three particular areas which will require greater policy emphasis.

40. Domestic innovation system. The quality and type of innovation system Singapore has in place will determine whether it can make the best use of resources devoted to R&D. To this end, the Agency for Science, Technology and Research (A*STAR) is actively fostering closer linkages between public sector R&D and industry cluster development as well as promoting the creation, ownership and exploitation of intellectual capital at its research institutes. Recent progress includes an increase in collaborative R&D projects with industry as well as the establishment of Exploit Technologies Pte Ltd to centrally manage and commercialise intellectual property created by the research institutes.

41. Commercialisation of new knowledge. To maximise the commercialisation of new knowledge, Singapore needs entrepreneurs to create new business models and challenge existing firms to innovate. The ERC Sub-Committee on Entrepreneurship and Internationalisation has proposed a comprehensive set of initiatives for nurturing entrepreneurship. Key recommendations include allowing for greater creativity in the education system, attracting global entrepreneurial executives to Singapore as "mentors", development of the venture capital market as well as making the legal environment more conducive for new start-ups.

42. Education and training of workforce. The upgrading of Singapore's workforce is fundamental to the development of the KBE, for it is a key determinant of all four knowledge capabilities. The ERC Working Group on Education has suggested a master plan for increasing the development capability of Singapore's education system. This entails a 3-tiered system of universities to provide a broader tertiary education base as well as to cater to specialised niches. A core of quality commercial schools should also be fostered for on-the-job upgrading. In addition, attracting MNCs to set up regional training facilities in Singapore will lead to greater dissemination of organisational and technological knowledge.

CONCLUSION

43. The KBE has become increasingly important to Singapore over the years. The global market of products and services has become more technology- and knowledge-intensive. At the same time, the Singapore economy is maturing. The build-up of capital and labour will slow down and become less important drivers of economic growth. Singapore's ability to create, acquire, disseminate and apply knowledge will be key to sustaining its economic growth.

44. Taking stock of Singapore's current KBE structure, it is assessed that further efforts need to be channelled towards enhancing its national innovation system, entrepreneurship and education capability. While the policy recommendations are not new, the KBE mapping has allowed us to understand the underlying linkages between these three areas and the entire KBE system. Greater efforts to address the needs in these three areas are central to sustaining Singapore's economic growth and competitiveness in the long-run.

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Annex A

Knowledge Based Industries in Singapore (Based on SSIC Classification)

Knowledge Based	Non-Knowledge Based
Services	
Communication/Port Services	Construction
Finance Services	Utilities
Business Services	Wholesale and Retail Trade
Education	Transport
Healthcare	Other Services
Manufacturing	
Publishing, Printing, Reproduction of Recorded Media	Food, Beverages and Tobacco
Refined Petroleum Products	Textiles and Textile Manufactures
Chemicals and Chemical Products	Wearing Apparel except Footwear
Machinery and Equipment	Leather, Leather Products and Footwear
Electrical Machinery and Apparatus	Wood and Wood Products
Electronic Products and Components	Paper and Paper Products
Medical, Precision and Optical Instruments, Watches and Clocks	Rubber and Plastic Products
Transport Equipment	Non-Metallic Mineral Products
	Basic Metals
	Fabricated Metal Products excluding Machinery and Apparatus
	Other Manufacturing Industries

Notes: This classification of KBIs and non-KBIs is based on that used in the OECD Science, Technology and Industry Outlook 2000.

Annex B

Computation of Knowledge Indices for Selected Economies

Knowledge Creation	**OECD**	**S'pore**	**US**	**Japan**	**Korea**
Researchers per capita.	3.10	4.82	4.10	7.25	2.96
Normalised Figures	1.00	1.55	1.32	2.34	0.95
GERD (% of GDP)	1.79	1.88	2.69	3.12	2.65
Normalised Figures	1.00	1.05	1.50	1.74	1.48
US Patents (per million population)	153.70	73.59	346.28	274.52	78.93
Normalised Figures	1.00	0.48	2.25	1.79	0.51
Creation Index	**1.00**	**1.03**	**1.69**	**1.96**	**0.98**

Knowledge Acquisition	**OECD**	**S'pore**	**US**	**Japan**	**Korea**
Tech BOP Imports (% of Imports)	1.15	3.30	1.28	1.32	2.54
Normalised Figures	1.00	2.87	1.11	1.15	2.21
FDI (% of GDP)	0.08	0.07	0.03	0.00	0.02
Normalised Figures	1.00	0.90	0.38	0.02	0.25
VA of Business Services (% of GDP)	9.00	6.33	9.80	7.00	4.20
Normalised Figures	1.00	0.70	1.09	0.78	0.47
Acquisition Index	**1.00**	**1.49**	**0.86**	**0.65**	**0.98**

Knowledge Dissemination	**OECD**	**S'pore**	**US**	**Japan**	**Korea**
ICT Expenditure/GDP	7.28	8.80	7.94	8.00	5.47
Normalised Figures	1.00	1.21	1.09	1.10	0.75
Affordability of Internet Access	0.87	0.84	0.65	0.49	1.50
Normalised Figures	1.00	1.04	1.34	1.78	0.58
% Secondary School Education	69.60	62.50	89.70	82.40	67.20
Normalised Figures	1.00	0.90	1.29	1.18	0.97
Dissemination Index	**1.00**	**1.05**	**1.24**	**1.35**	**0.77**

Knowledge Application	**OECD**	**S'pore**	**US**	**Japan**	**Korea**
% University Education	16.20	14.67	30.04	21.04	19.00
Normalised Figures	1.00	0.91	1.85	1.30	1.17
% Knowledge Workers	36.00	35.76	47.33	36.41	18.43
Normalised Figures	1.00	0.99	1.31	1.01	0.51
Entrepreneurship (WCY)	6.50	5.83	9.11	3.80	6.51
Normalised Figures	1.00	0.90	1.40	0.58	1.00
Application Index	**1.00**	**0.93**	**1.52**	**0.96**	**0.90**

Notes: The indicators for each individual economy are normalised with the OECD average as the basis. The composite index for each knowledge capability is computed by taking the average of the three relevant normalised indicators. This approach works out with the composite index for the OECD average being set to unity. This makes interpretation of the index intuitive. For instance, a knowledge acquisition index of 1.1 for Singapore means Singapore is 1.1 times better than the OECD average in acquiring knowledge.

REFERENCES

APEC Economic Committee (2000), *Towards Knowledge Based Economies in APEC*, APEC Secretariat.

APEC Economic Committee (2001), *The New Economy and APEC*, APEC Secretariat.

Den Hertog, P. (2000), "Knowledge-Intensive Business Services as Co-Producers of Innovation", *International Journal of Innovation Management* 4(4), pp. 491-528.

Economic Development Board (1999), *Knowledge: The Way Forward*, Industry 21 Seminar Proceedings. Singapore: Economic Development Board.

Economics and Statistics Administration (2002), *Digital Economy 2002*, US Department of Commerce.

EMF Foundation (2002), *World Competitiveness Yearbook*, Lausanne: International Institute for Management Development.

Huggins, Robert (2002), *World Knowledge Competitiveness Index 2002*, Cardiff, Wales: Robert Huggins Business & Economic Policy Press.

Infocomm Development Authority of Singapore (1999), *Key Findings of ICT Usage Survey 1999 on the ICT Adoption by Businesses in Singapore*.

Landfeld J. Steven; Barbara M. Fraumeni (2000), *Measuring the New Economy*, Bureau of Economic Analysis.

National Science and Technology Board (1996), *National Science and Technology Plan – Towards 2000 and Beyond*, Singapore: National Science and Technology Board.

OECD (2000, 2001), *Science, Technology and Industry Outlook*, Paris: OECD.

OECD (2001), *Science, Technology and Industry Scoreboard*, Paris: OECD.

OECD (2001), *The New Economy: Beyond the Hype*, Paris: OECD.

OECD-EUROSTAT (1997), *Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, Paris: OECD.

Atkinson Robert D.; Paul D. Gottlieb (2001), *The Metropolitan New Economy Index*, Progressive Policy Institute.

Atkinson Robert D.; Rick Coduri (2002), *The 2002 State New Economy Index*, Progressive Policy Institute.
Sahid Yusuf, and Simon J. Everett (2002), *Can East Asia Compete ?*, World Bank.

Shapiro, Carl and Hal R. Varian (1999), *Information Rules: A Strategic Guide To The Network Economy*, Harvard Business School Press.

Toh Mun Heng, and Low, Linda (1994), *Input-Output Tables 1988: Models and Applications*, Department of Statistics.

Toh Mun Heng (2000), *The Development of Singapore as a Knowledge Based Economy: Size of KBE and Its Economic Impact*, Faculty of Business Administration, National University of Singapore.

Wong Poh Kam, and He Zi Lin (2002), *Determinants of KIBS Innovation: The Impacts of Client Linkages and Strategic Orientations*, working paper, Centre for Entrepreneurship, National University of Singapore.

Wong Poh Kam; Foo Maw Der; Wong, Finna (2001), *Global Entrepreneurship Monitor: Singapore Country Report 2000*, Singapore: Centre for Management of Innovation and Technopreneurship.

Wong Poh Kam (2001), *Leveraging Multinational Corporations, Fostering Technopreneurship: The Changing Role of S&T Policy in Singapore*, International Journal of Technology Management, Vol 22, Nos. 5/6.

World Bank (1998/99), *World Development Report – Knowledge for Development*, New York: Oxford University Press.

World Economic Forum (2002), *The Global Competitiveness Report*, Geneva: World Economic Forum.

CHAPTER FOUR

INNOVATIVE BUSINESS STRATEGIES AND FIRM PERFORMANCE IN THE NEW ECONOMY*

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ABSTRACT

This paper examines the issue of whether investment in information and communication technology (ICT), innovative business strategies and worker skills contribute to better performance in Canadian firms. We consider innovative business strategies in the areas of production and efficiency practices, human resource management (HRM) practices, and product/service quality-related practices. In the literature, these practices are also termed as "organizational innovation" or "organizational changes". We find that Canadian firms have been actively engaged in innovative business strategies in the areas of production and efficiency practices, human resource management (HRM) practices, and product/service quality-related practices. These practices, along with ICT use, lead to improved firm performance. We find that while ICT is productive on its own, it is more productive in firms that combine high levels of ICT with high levels of organizational change. The firms that combine ICT with new organisational practices have a high incidence of productivity improvement and have high rates of innovation. These findings seem to suggest that to be successful, firms typically need to adopt ICT as part of a "system" or "cluster" of mutually-reinforcing organisational approaches. We also find that ICT and human capital are complements in the services sector. The services firms that combine high levels of ICT and high levels of worker skills have better firm performance.

INNOVATIVE BUSINESS STRATEGIES AND FIRM PERFORMANCE IN THE NEW ECONOMY

INTRODUCTION

A rapidly integrating global economy, technological change and shifting consumer preferences are together increasing competitive pressures for firms. Firms now face greater competitive pressures to make better use of knowledge, technology and human resources to realize benefits from intangible investments and to respond to new demands from suppliers and customers. Consequently, firms are forced to rethink their business strategies, production processes and management practices to improve their functioning and adapt to a changing business environment in the new economy. "Strategic business thinking has shifted away from products, plants and inventory towards employees, information and knowledge" (OECD, 2002).

To succeed in the new economy, firms may adopt a number of innovative business strategies or any combination thereof. For example,

(1) Firms may adopt production and efficiency strategies such as outsourcing, business re-engineering and downsizing to improve their competitiveness. They may reorganise production and work to improve flexibility and reduce X-nefficiencies;

(2) They may adopt innovative human resource management practices (HRM), including compensation, recruiting and selection, team-based work organization, flexible job assignment, skills training and communication procedures in order to maximise the benefits of new technologies, especially information and communication technologies (ICT);

(3) They may adopt quality-related strategies including improving product/service quality and improving co-ordination with customers/suppliers.

At the firm level, many empirical studies find that organizational innovations[38] are related to better firm performance. More important, these studies find that new organizational practices may improve economic performance of firms through their mutually-reinforcing relationship with ICT. OECD (2002) argues that 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).

Black and Lynch (2000) find a positive and significant relationship between the proportion of non-managers using computers and productivity of establishments. The findings also show that firms that reengineer their workplace to incorporate more high performance practices are more

[38] Throughout this paper, we use terms such as innovative business strategies, organizational innovations and organizational changes inter-exchangeably.

productive. Profit sharing and/or stock options are also associated with improved productivity performance. And, employee voice has a larger positive effect on productivity when it is done in the context of unionized establishments.

In a subsequent study, Black and Lynch (2001) examine how workplace practices, human capital investments, and ICT are related to establishment productivity. The results show that what appears to matter the most for productivity is how human resource management (HRM) systems are implemented. Greater employee voice in decision-making is what seems to matter most for productivity–rather than total quality management (TQM) *per se*. In addition, unionized establishments that have adopted HRM practices 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. Finally, productivity is higher in plants with more-educated workers or greater computer usage by nonmanagerial employees.

Bresnahan, Brynjolfsson and Hitt (2002) surveyed about 300 large firms to obtain information on organizational practices and worker characteristics and combine the survey data with a panel detailing ICT capital levels and mix over the 1987–1994 period. The major findings include 1) skilled labour is complementary with a cluster of three distinct changes at the firm level: ICT, new work organization, and new products and services and 2) interactions between ICT, new workplace practices and human capital positively predict firm productivity. Firms that adopt decentralized organizational structures do appear to have a higher contribution of ICT to productivity. The most interesting finding is that new work practices are associated with improved firm performance only when the practices are implemented as a bundle–and not separately. In other words, successful firms adopt ICT as part of a system or cluster of mutually reinforcing organizhational changes (Brynjolfsson and Hitt, 2000).

A number of Canadian studies find strong evidence of a link between the use of ICT technologies and performance of plants. Baldwin, Diverty and Sabourin (1995), Baldwin and Sabourin (2002) and Baldwin, Sabourin and Smith (2003) 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. Amongst 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 use with other advanced technologies tend to do better than those using only one or two isolated technologies.

This study also points out that the various measures of performance are related. Plants that adopt more advanced technologies experience faster productivity growth. Those that experience faster productivity growth gain market share. Thus advanced technology use is positively related to both measures of performance. Finally, the paper observes that there are various business practices that involve considerable organizational change that have an independent effect on market share growth. Plants that make use of cross-functional design teams, concurrent engineering, total quality management, just-in-time inventory control, process simulation, and quality function deployment all experienced market-share growth. Organizational change matters.

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.

They raise this issue because of the findings that emerge from a number of associated studies that do not just examine the technological stance of a firm. A large number of firm-level studies in Canada have linked surveys on the emphasis given to business strategies to longitudinal data on firm performance (e.g., Baldwin, Johnson, 1995; Baldwin and Johnson, 1996; Baldwin and Johnson, 1997; Baldwin and Johnson, 1998). These studies find that the firms with comprehensive innovation strategies tend to be the most successful, outperforming firms that only have individual strategies in terms of their growth in market share and profitability. But in these surveys, the innovator is always a complete firm. Marketing, financing, management and innovation strategies are all well developed within those most successful firms.

A recent study by Baldwin, Sabourin and Smith (2003) that links technology use to plant performance in the food processing sector also finds 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—but, more importantly for this paper, that the use of advanced technologies is associated with the adoption of such business practices associated with improving product quality (continuous quality improvement), material management (materials requirement planning, just-in-time inventory control) and various process/product development practices (rapid prototyping, concurrent engineering). Technology use is not conducted in isolation from other best practices in a firm.

Perhaps equally important for our purposes, Baldwin, Sabourin and Smith (2003) find 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.

In a similar vein, OECD (2002) argues that ICT improves productivity by enabling "organizational innovation". The greatest benefits from ICT appear to be realised when ICT investment is combined with other organizational assets, such as new strategies, new business processes, new organizational structures and better worker skills.

In this paper, we examine the issue of whether ICT combined with innovative business strategies such as the restructuring of production processes, human resource management (HRM) practices, and better worker skills contribute to better firm performance.

Objectives of the Paper

In this paper, we attempt to address three questions:

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

Our study has three novel features. First it uses a comprehensive establishment-level micro data set–Statistic Canada's 1999 *Workplace and Employee Survey* (WES). The survey, a cross-sectional survey of 6,351 business establishments across the entire spectrum of the Canadian economy[39],enables us to empirically assess the relationship between ICT use, organizational practices and firm performance.

Second, the paper examines the role of complementarities between ICT use, new organizational practices in the areas of production practices, HRM practices and product/service related practices and human capital as drivers of better firm performance in the knowledge-based economy (KBE).

Third, the analysis extends beyond manufacturing to include service sectors such as dynamic service and distributive service sectors (wholesale trade, retail trade and transportation). Previous studies suggest that dynamic services are more innovative and require a higher share of knowledge workers. 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).

INNOVATIVE BUSINESS STRATEGIES: A FRAMEWORK

"Organizational innovation" is a broad concept that includes strategies, structural, and behavioural dimensions. It includes competitive strategy (i.e., role of innovation, costs, people etc.); 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; HRM practices including hiring and firing; and industrial relation practices involving the strategies and institutional structures affecting the labour-management relationship.

In this paper we define innovative business strategies or new organizational practices as the OECD (2002) does, to include three broad streams: 1) the restructuring of production processes, which include business re-engineering, downsizing, flexible work arrangements, outsourcing, greater integration among functional lines, and decentralization; 2) human resource management (HRM) practices, which include performance-based pay, flexible job design and employee involvement, improving employees' skills, and institutional structures affecting the labour-management relations; and 3) product/service quality-related practices emphasizing total quality management (TQM) and improving coordination with customers/suppliers. A framework for our discussion of new organizational practices is shown in table 2 and table 3.

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.

[39] More precisely, The WES is a cross-sectional survey of workplaces. For our discussion in the rest of the paper, we will use the terms workplace, establishment, and firm interchangeably.

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).

Firms re-engineer their business process in order to achieve efficiencies in the form of lower costs, higher product quality and better customer service. Business re-engineering covers the entire range of business activities including manufacturing-distribution coordination, reduced time to market, improved or just-in-time manufacturing, improved inventory management, lower procurement costs, reduced processing errors, extended business reach and better customer service. More extensive use of ICT can help firms achieve the potential gains of re-engineering (OECD, 2002).

Outsourcing can be a key element of production and efficiency practices. This allows firms to leverage talent and resources and gain the potential benefits of advanced skills and technologies without having to directly invest in them.

Decentralization of management responsibility and more diffused decision-making structures can help firms achieve enhanced flexibility. It is argued that flatter hierarchies and devoted decision-making diffuse information quickly within firms, and help improve the innovative and creative abilities of staff and a firm's responsiveness to clients.

Cost-reduction strategies are generally associated with "downsizing" and "flexible work arrangement." Cappelli (2000) argues that the distinctiveness of downsizing, as opposed to more traditional layoffs, is that in the former case the job cuts do not necessarily appear to be driven by shortfalls in demand but instead appear to be driven by the search for operating inefficiencies.

Firm flexibility may also involve using part-time, temporary, or contract workers. Flexible work arrangements can increase the "numerical" flexibility of firms, referred to as the ability of firms to vary labour inputs. This allows firms to adjust their workforce to business cycles and demand trends. For workers, such practices can facilitate their mobility between different careers, jobs and markets.

Human Resource Management (HRM) Practices

In the KBE, 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. Baldwin (1999) describes the findings of a number of Canadian studies that find an emphasis on HRM practices is closely related to the innovation stance of the firm.

Performance-based pay links workers' pay in part to either the performance of the firm, or individual performance. It is designed to strengthen employee incentives and increase trust and commitment. There are many ways to relate pay to performance: individual incentive systems, productivity/quality gain sharing and other group incentives, profit sharing and merit pay, and skill-based pay. There is ample evidence to suggest that performance-based pay can help motivate, attract and retain outstanding performers (Lawler *et. al.*,1998). Performance-based pay is being used by a substantial number of firms in OECD economies, particularly companies which are implementing a range of organizational changes (OECD, 2002).

Flexible job design and employee involvement: A key objective of HRM policies is to get employees more involved in their jobs. Freeman, *et al.* (2000) argue that many American firms use such HRM policies as self-directed teams, quality circles, profit sharing, and diverse other programs, to involve employees in their jobs. 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 (Cappelli and Neumark, 1999). In this paper, we consider a number of individual HRM practices including employee suggestion programs, flexible job design and job rotation, job enrichment/enlargement, job redesign, information sharing with employees, quality circles and problem-solving teams, self-directed work groups, and joint labour management committees.

Previous studies find that flexible job design and employee involvement (EI) are associated with increased benefits to employers.[40] Cappelli and Neumark (1999) find that work practices that transfer power to employees, may raise productivity, although the statistical case is weak. Similarly, Freeman *et al.*, (2000) find that EI that is more likely to be associated with profit-sharing and other forms of shared compensation could do more for workers than for firms. EI is found to have an effect on labour productivity.

Developing Employee Skills: HRM practices focus on "high skill" strategies that make better use of and continuously renew human capital (OECD, 1998). In the KBE, work requires creative thinking, self-motivation, and academic basics. Problem-solving, decision-making, business, financial, negotiating, and interpersonal skills, in addition to technical skills are essential for workers (Newton, 1996). A recent OECD (2002) study notes that firms are now developing their own customized training strategies, which are increasingly on-line. Some large firms are involved in setting up corporate universities using ICT technologies and offering some combinations of satellite-based learning, web-based training, virtual reality and virtual campuses, sometimes in conjunction with more traditional methods.

Lynch and Black (1995) find that smaller establishments are much less likely to provide formal training programs than larger establishments. Importantly, regardless of size, those employers who have adopted some of the practices associated with what have been called "high performance workplaces" are more likely to have formal training programs. And, there are significant and positive effects on establishment productivity associated with investments in human capital.

In empirical literature, there is ample evidence of the effects of individual HRM practices on productivity performance. Some notable studies include: profit sharing (Kruse, 1993); training (Bartel, 1995); and information sharing (Kleiner and Bouillon, 1988).

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. The study investigates the productivity effects of innovative HRM practices using data from a sample of 36 homogeneous steel production lines owned by 17 companies.

[40] See for example, Minister of Industry, 2001

The findings show that lines using a set of innovative HRM practices, which include incentive pay, teams, flexible job assignments, employment security, and training, achieve substantially higher levels of productivity than do lines with more traditional approaches, which includes narrow definitions, strict work rules, and hourly pay with close supervision.

Labour–management Cooperation: Many studies find that an effective labour-management relationship is key to fostering organizational change and raising productivity. Unions may raise productivity by lowering the costs of introducing new HRM practices and encouraging employee participation. Black and Lynch (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. In our analyses, we consider enhancing labour-management cooperation to be an important objective of industrial relations strategy in the new economy.

Product/Service Quality-Related Practices

Over the past 20 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 increased 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). Baldwin and Johnson (1998) report that it is closely related to the success of small and medium-sized firms in Canada.

TQM is based on: 1) customer focus which includes elements such as emphasis on customer requirements and customer satisfaction and changes in processes; 2) systematic improvement meaning a wide-spread systematic organizational focus on quality improvement, cycle-time reduction, waste reduction and the adoption of prevention-based orientation; 3) supplier performance and supplier relationships, which means choosing suppliers on the basis of product quality rather than solely on price; 4) employee involvement and development, meaning teams to identify and solve quality problems; and 5) statistical tools such as control charts for monitoring and continuous control.

Competition in the market places the importance on customer relations and customer satisfaction. To satisfy customers, firms must design, manufacture, and deliver products and services that meet their tangible and intangible needs better than their competitors, and provide superior value. In order to retain and maintain customers and build loyalty, firms provide quality after-sales and other services (Monga, 2000).

ICTs are playing a key role in the growth of customer relations management (CRM) practices. For example, to communicate with clients, sales forces in the field are supplemented by interactive web sites and call centres. In addition, advanced database technology, world-wide web integration, sales force automation and multi-media-based front office applications are emerging as key elements of CRM. Evidence from surveys of managers and case study literature shows that the most important reasons for investing in ICT are product quality improvements, especially customer service, timeliness, and convenience (Bresnahan *et.al.*, 2002).

Individual organizational practices (e.g., TQM, on-the-job training, etc), have positive effects on firm performance (Easton and Jarrell, 1998). However, studies show that higher productivity gains are realized when firms implement bundles of high performance practices, as opposed to single practices (OECD, 2002). Black and Lynch (2000) find that bundling of production and HRM practices is particularly effective. Mavrinac and Siesfeld, (1998) found that synergies exist between flexible employee management and compensation programs and TQM.

DATA SOURCE

Data for our analysis was taken from the 1999 *Workplace and Employee Survey* (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 about 6,351 business establishments across a complete cross-section of the Canadian economy. This study utilizes the employer workplace survey of innovative business strategies, organizational changes, training and other HRM practices, and quality-related strategies. The reference period for the WES is the twelve month period ending in March 1999. The WES is essentially a survey of small firms: over 85 percent of the establishments surveyed employ less than 20 employees. We have removed non-profit operations from the data for the analysis in this paper. The final sample used consists of 5,501 firms in the business private sector.

Constructing Key Variables

The variables for our analysis include ICT use, human capital, innovative business strategies, 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 share of ICT investment in total machinery and equipment (M&E) equipment. The former is calculated as the number of employees using a micro-computer, minicomputer, mid-range computer or mainframe computer (Q43) as a share of the total number of employees (Q4a). The latter is constructed as the share of expenditures on new software and hardware plus computer-controlled or computer-assisted technologies (Q44b and Q45b) in total expenditures on M&E (Q44b, Q45b, Q46b). The share of workers using computers captures the outcomes of all ICT investment activities by establishments, past and present, while the ICT investment share represents current investment activities only. As such, the ICT investment share 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, 2000; Roy *et. al.*, 2001).

Innovative business strategies

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

Firm Performance

The objective of the paper is to examine whether ICT and new organizational practices are related to firm performance. In our analysis, we use three binary measures of firm performance: productivity, sales growth, and unit production costs. The measures for productivity and sales growth are equal to one if the establishment reports an increase in productivity or sales growth. The measure for unit production costs is equal to one if the establishment reported a decrease.

All three measures of firm performance are subjective measures that are based on respondents' perception of firm performance. As shown in appendix table A1, three measures are highly correlated. This suggests that the three measures taken together capture overall success of the firms.

To further examine the issue of whether ICT and new organizational practices are related to firm performance, we will also use two objective measures of firm performance: products and process innovation. The variable for product innovation takes a value of one if the workplace introduced new or improved products over the survey reference year (between 1 April 1998 and 31 March 1999). The variable for process innovation is set at one if the workplace introduced new or improved processes.

Summary Statistics

Table 4 presents sample means for ICT use, share of knowledge workers, and firm performance in Canadian business private sector, by firm size and industrial sector. A number of interesting findings emerge from this table.

- The share of workers using computers is higher among dynamic services[41] (66%) than in wholesale and retail trade and transportation (38%), and manufacturing industries (34%). The share of workers using computers is similar between large firms (44%) and small firms (46%).
- The share of ICT in total M&E investment is much higher among large firms (54%) in comparison to small firms (24%).
- 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 firms (51%) and large firms (55%) report increases in productivity than do small firms (39%), dynamic services firms (38%) or wholesale and retail trade firms (38%).
- About half of the firms report introducing new products or improved products (45%) in the Canadian business private sector. The fraction of large and manufacturing firms that introduce product and process innovations is greater than that of small and non-manufacturing firms.

[41] The dynamic service industries include communication and other utilties, FIRE, business services, education and health care and information and cultural industries.

Table 5 shows the fraction of workplaces adopting various elements of innovative business strategies: the restructuring of production process; HRM practices; and product/service quality-related practices. Our results show the following:

Among production and efficiency practices, the incidence of firms adopting flexible work arrangements (24%) and business re-engineering (19%) is much higher than other individual practices.

Within HRM practices, the incidence of practices such as increasing employee involvement/participation (63%) and enhancing labour-management cooperation (55%) are highest. Additionally, a high proportion of firms also report adopting individual incentive systems (31%), formal job-related training (29%) and classroom training (20%).

Among product/service quality-related practices the incidence is higher for firms adopting the improving product quality (78%) and improving coordination with customers/suppliers (66%) practices than for those adopting TQM (13%).

EMPIRICAL METHODS AND RESULTS

Innovative business practices consist of three main types: production and efficiency practices; human resource management practices; and product/service quality- related practices. In turn, each of these organizational practices consists of various single practices, as listed in tables 2 and 3.

To examine the relationship between new organizational practices and firm performance, we first construct an overall measure of "organizational innovation" as the first principal component of the variables that reflect the importance of the various single practices that comprise the organizational innovation. The measure of organizational innovation is calculated as a weighted sum of the standardized variables, using the weights as determined from the principal components analysis.

The measures for three organizational innovations (production and efficiency practices; HRM practices, and product/service quality practices) are constructed as:

(1) **Production and Efficiency Practice (PEP)** = β_1 (PE1) + β_2 (PE 2) + β_3 (PE 3) + β_4 (PE4) + β_5 (PE 5) + β_6 (PE 6)

(2) **HRM Practice (HRM)** = γ_1 (HRM1) + γ_2 (HRM 2) + γ_3 (HRM 3) + γ_4 (HRM 4) + γ_5 (HRM 5) + γ_6 (HRM 6) + γ_7 (HRM 7) + γ_8 (HRM 8) + γ_9 (HRM 9) + γ_{10} (HRM 10) + γ_{11} (HRM 11) + γ_{12} (HRM 12) + γ_{13} (HRM 13) + γ_{14} (HRM 14) + γ_{15} (HRM 15) + γ_{16} (HRM 16) + γ_{17} (HRM 17)

(3) **Product/Service Quality Practice (PQP)** = η_1 (PSQ1) + η_2(PSQ2) + η_3(PSQ3)

where β, γ, and η represent the weights determined by the principal component analysis. The variables and the weights assigned to them are shown in appendix tables A3 andA4. As shown in these tables, all variables receive positive weights. The measures of all three organizational changes are standardized by subtracting means and dividing by standard errors.

ICT, New Organizational Practices and Firm Performance

In this section, we present regression results for the relationship between ICT, new organizational practices, human capital and firm performance.

Our empirical specification is a Probit model that relates firm performance to the measures of ICT, new organizational practices (OC) and human capital (HK):

(4) $$y_i^* = a_o + b_1 ICT_i + b_3 OC_i + b_4 HK_i$$

$$+g_1 SIZE_i + g_2 OWNERSHIP_i + g_3 INDUSTRIES_i + e_i\ ,$$

where y_i^* is 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 firm reports an increase in productivity, introducing product innovations or introducing process innovations. Otherwise, it is equal to zero.

$y_i = 1$, if y_i^* >0, and
$y_i = 0$, if $y_i^* \leq 0$

In our regression analysis, we control for firm size, foreign ownership and industry fixed effects, which have been found to be important determinants of firm performance in previous empirical studies. The error term e_i follows a normal distribution. In all estimations, we weight observations by sampling weights.

To examine the magnitude of the effects of ICT and new organizational practices on firm performance, we will present marginal effects from the Probit model, evaluated at the sample means.

Empirical Results for Total Business Sector

Table 6 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 the share of ICT investment in total M&E investment. And, we also include the share of knowledge workers in all specifications.

In the first three specifications, we individually introduce three new organizational practices (PEP, HRM and PQP). In the last specification, we introduce three organizational practices 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 percent 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 computer is associated with a 1 percentage-point increase in probability of productivity improvement. However, as we will find in the next section, the contribution of ICT to firm performance becomes quite large when combined with innovative business strategies.

The share of ICT is found to have little effect on productivity performance in Canadian business sectors. This may reflect the fact that productivity improvements due to ICT investments occur only after a certain time lag or with initial adjustment costs.

Our results show that three organizational innovations (the restructuring of the production process, HRM practices, and product/service quality related practices) are all positively related to firm performance. The effects are quite large. The estimates in specification (4) show 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 are 11 and 5 percentage points increase respectively in the incidence of productivity improvement.

The story for knowledge workers is more ambiguous. The coefficient on the share of knowledge workers is small and negative and statistically insignificant. Findings in the previous work suggest that firms which are ICT-intensive are likely to have more managers and professionals relative to their industry competitors (Bresnahan *et. al.*, 1999). We interpret our result as suggesting that the share of knowledge workers has little additional effect on firm productivity after the measures of organizational innovations and ICT use are taken into consideration.

Table 7 examines the issue of whether ICT and new organizational practices 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.

While new organizational practices are found to be related to better firm performance in Canadian industries, the importance of organizational innovation for firm performance differs across various practices, as shown in table 8.

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, our results 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 practice, our results show that total quality management and improving product quality matter more for firm performance. The firms that adopt these practices have higher incidence of productivity improvement and higher rates of innovation.

Empirical Results by Industry Sectors

A number of previous studies show that the services sector in Canada has invested heavily in ICT and it accounts for most of ICT investment over the past decade. The service sector has 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 service sectors. The OECD (2002) finds that the fraction of firms that introduced organizational changes is highest in service sectors across OECD economies. A study by McKinsey Institute suggests that service firms often have difficulty improving performance by using organizational practices devised for manufacturing firms (Barkin *et.al.*, 1998). For example, reducing costs and changing management may be less effective in service firms than in manufacturing firms, since critical elements for services firms are customer service, innovation and product quality improvement.

Manufacturing firms tend to focus on the introduction of new production approaches. The effective use of ICT in the auto industry is closely related to the implementation of just-in-time delivery. In services, organizational changes such employee participation and teamwork are more important for improving product quality and customer relations. Sundbo and Gallouj (1998) suggest that services may be better suited to deal with modern demands for flexible organizations than manufacturing, as their functions and tasks are often less specialized. Similar evidence is provided by other studies on the management of ICT in service firms (Pilat, 2001).

Consequently, in our subsequent analyses, we examine the relationship between ICT, innovative business strategies and firm performance separately for manufacturing and service sectors. We further divide the service sector into the dynamic services sector and the wholesale, retail trade and transportation sector. The dynamic service sector includes communication and other utilities, FIRE (finance, insurance and real estate), business services, education and health care, and information and cultural industries. These two service sectors differ in terms of their use of ICT, worker skills and capacity for organizational innovations.

The results in table 9 show that the relationship between ICT, new organizational practices and firm performance is somewhat different across industrial sectors. For the manufacturing sectors, 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 (wholesale and retail trade, and transportation service) is very much similar to that of the dynamic service sector. For the distributive service sector, production and efficiency practices, HRM practices, the share of workers using computers matters for productivity performance. ICT investment and product/service quality-related strategies have little impact on performance.

We have also examined the issue of whether ICT and new organizational practices 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 service sectors. Second, we find that product/service quality-related strategies are important for firm performance in dynamic service sectors, while these strategies are less important in manufacturing and distributive service sectors. 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.

Complementarities between ICT and New Organizational Practices

In this part of the paper, we test the hypothesis that ICT and organizational innovations 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.

The underlying argument behind the bundling of ICT and organizational innovations is the following. ICT enables firms to introduce organisational changes in the areas of re-engineering, decentralisation, flexible work arrangements, outsourcing, lean production, teamwork and customer relations. It also allows firms to produce with greater flexibility and shortened product cycles to satisfy shifting consumer preferences. In turn, these organizational changes are essential for realizing the full benefits of ICT (Brynjolfsson and Hitt, 2000; OECD, 2002).

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

Correlation

Previous studies for OECD economies show that changes in organization and workplace practices are introduced hand-in-hand with investment in ICT (Arnal *et.al.*, 2001). Our results from the WES confirm these findings for Canada. We find that the incidence of organizational innovations is much higher in the firms that invest in ICT or have a high share of workers using computers than is the case in the firms that do not invest in ICT or have a low share of workers using computers.

Figures 1, 2 and 3 show the fractions of firms that introduce new organizational practices for ICT-investing firms and non-ICT investing firms.

- The incidence of production and efficiency practices is much higher in firms that invest in ICT than is the case for non-ICT investing firms. For example, 35 percent of the firms that invest in ICT report introducing flexible work arrangement, compared with 20 percent of non-ICT investing firms. It appears that ICT allowed significant organizational innovations in the areas of business re-engineering, flexible work arrangement, outsourcing and greater integration among different functional areas (figure 1).

- Incidence of HRM practices is much higher among ICT-investing firms than in non-ICT investing firms. Firms investing in ICT are more prone to use profit sharing plans, individual incentive systems and merit pay. Information sharing with employees, job rotation and multi-skilling, and increased employee involvement/participation schemes are found to complement investment in ICT. The link between formal job-related training and classroom training and investment in ICT are particularly strong (figure 2).

- The implementation of product/service quality related practices does not appear to be much different between the firms that invest in ICT and those that do not (figure 3).

Table 10 presents correlation coefficients between ICT, organizational innovations and the share of knowledge workers across firms in Canadian business sectors.[42] We find that ICT investment share and the fraction of workers using computers are positively correlated with the share of knowledge workers. This suggests that firms that invest 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 innovations in the areas of production and efficiency practices, HRM practices and product/service quality-related practices, supporting the view that ICT and new organizational practices are complements.

Table 11 presents the correlation coefficients between the share of workers using computers and various elements of organizational changes. With the exception of two HRM practices (participating in training subsidies programs and enhancing labour management cooperation), we find that ICT use is positively correlated with all types of organizational changes. While the overall conclusion from the table is consistent with the finding from table 10 and figures 1 to 3 that ICT, organizational changes and human capital are complements, a number of findings for individual organizational practices are worth noting.

We find that that ICT use is higher in firms that implement business re-engineering, flexible work arrangements and greater integration among different functional areas than in other firms. ICT use is also greater in organizations that are decentralized.

Our results also show that while the correlation with ICT use is positive for all individual HRM practices, it is stronger for practices such as individual incentive systems and job rotation and multi-skilling. In addition, firms with a larger share of workers using computers tend to invest more in human resources such as formal job-related training and classroom training.

Regression Results

Our finding of a positive correlation between ICT, new organizational practices and human capital is consistent with the view that all three are complements. In this section, we bring firm performance measures into our analysis. If ICT and new organizational practices are complements, the firms that combine these changes should perform better than those that do not.

Specifically, we re-estimate the Probit equation (4) and examine how various combinations of ICT, new organizational practices (OC) and human capital are related to firm performance. For instance, to examine the complementarities between ICT and organizational practices (OC), we divide our sample of firms into four quadrants: High-ICT and High-level of organizational practices (OC); High-ICT and Low-OC; Low-ICT and High-OC; and Low-ICT and Low-OC. We introduce dummies (D) denoting the four quadrants and run a regression as shown in equation (5).

(5) $$y_i^* = a_o + b_1 ICT_i + b_2 HK_i + d_1 D_{i,high-ICT,high-OC} + d_2 D_{i,low-ICT,high-OC} + d_3 D_{i,high-ICT,low-OC}$$

[42]. We find small but negative correlation coefficient between the measure of HRM practices and the share of knowledge workers.

$$+g_1 SIZE_i + g_2 OWNERSHIP_i + g_3 INDUSTRIES_i + e_i$$

Our 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 is important for productivity performance. We define High- and Low-ICT firms accordingly. For the service sector, we define High-ICT as those firms that have an above-medium share of workers using computers. Low-ICT firms are defined as those firms that have a below-medium share of workers using computers. For the manufacturing sector, High-ICT include those firms with positive ICT investment whereas Low-ICT firms include those with no ICT investment. For firm innovation performance, our results indicate that it is ICT investment that matters. Therefore, for our regression analysis on innovation performance, we use ICT investment to divide the firms into High- and Low-ICT groups.

High-OC firms in equation (5) are defined as those firms that have an above-median measure of organizational innovations. Low-OC firms are defined those firms that have a below-medium measure of organizational innovations.

We have run regression equation (5) using all five measures of firm performance: productivity improvement, sales growth, profit growth, product innovation and process innovation. However, we will present the results for productivity and innovation performance only. The results for sales and profit growth are similar to those for productivity performance.

Complementarity between ICT and Production and Efficiency Practices

The results in table 12 show that the firms that have a high level of ICT 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 firms that have a high level of ICT and do not adopt production and efficiency practices have poor performance. And the differences are quite large. The incidence of productivity improvement for firms that have high level of ICT and adopt production and efficiency practices is 34 percentage points higher that that for firms that have a low level of ICT and do not adopt new organizational practices. The rates of product innovation are 40 percentage points higher, and the rates of process innovation are 47 percentage points higher.[43]

We find that this inter-relationship between ICT and production practices exists for both manufacturing and service sectors. The firms that combine a high level of ICT and production practices have the highest incidence of productivity improvement and have the highest rates of product and process innovations for both manufacturing and service sectors. We find that the use of ICT does not lead to better productivity and innovation performance if firms do not combine ICT with production and efficiency practices. This suggests that the adoption of production and efficiency practices is essential if firms are to realize the full potential from ICT.

Complementarity between ICT and HRM practices

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 and adopt HRM practices (table 13). The rates of product and process

[43] A study of Danish firms also finds that firms that combined ICT and new organizational practices had higher rates of innovation (Danish Ministry of Business and Industry, 1996)

innovations are also higher. Shifting from low levels of ICT to high levels is associated with greater improvement in firm performance for High-HRM firms than for Low-HRM firms.

For the distributive service sector, the adoption of HRM practices is not associated with better firm performance for firms with low levels of ICT. Lack of attention to ICT can undermine HRM investment.

Complementarity between ICT and Product/Service Quality-Related Practices

Examining the interrelationship between ICT and product/service quality-related practices leads to a similar story. Firms that combine high levels of ICT and product/service quality-related practices have the best performance among Canadian firms (table 14). Shifting from low levels of ICT to higher levels of ICT is associated with greater improvement in productivity for high-PQP 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 significant factor for firm performance in this sector.

In the services sector, however, PQP is among the main drivers of firm performance. Our 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 service sectors.

Complementarity between ICT and Human Capital

Finally, we examine the complementarity of ICT and knowledge workers. Our findings fail to detect a positive relationship between the share of knowledge workers and measures of firm performance used. However, the story is different when we examine the complementarity hypothesis. Our results in table 15 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. Shifting from low levels to high levels of human capital is associated with an improvement in firm performance for firms with high levels of ICT. This is consistent with previous findings at the industry level that ICT and human capital are complements (Autor, Katz and Krueger, 2002; Gu and Wang, 2003). For the manufacturing sector, our findings do not show evidence of complementarity between ICT and human capital.

CONCLUSION

Concerns about an ICT "productivity paradox" were raised in the late 1980s. Since then a large number of studies have emerged both at the industry and firm level that have substantially improved our understanding of the relationship between ICT and firm performance. In particular, the firm-level studies have argued than an explanation for the so-called "productivity paradox" can be attributed to an insufficient response of organizational changes to adapt to changing business environment, to make better use of knowledge, technology and human resources, to respond to new demands from suppliers and customers, and to use ICT effectively (OECD, 2002; Sharpe, 1999).

Firm-level studies in both the US and Canada show that ICT investment, when accompanied by new organizational practices and investment in human capital, has a significant impact on productivity and economic performance (Brynjolfsson and Hitt, 2000; Bresnahan, Brynjolfsson and Hitt, 2002; Black and Lynch, 2000, 2001; Baldwin and Sabourin, 2003; Baldwin, Sabourin and Smith, 2003)). The most interesting finding is that new work practices are associated with improved firm performance only when the practices are implemented as a bundle–and not separately. In other words, successful firms adopt ICT as part of a system or cluster of mutually reinforcing organizational changes.

In this paper, we examine the issue of whether investments in ICT combined with organizational innovations 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. In particular, we examine the role of complementarities between ICT use, new organizational practices and human capital as drivers of firm performance. And, more importantly, we extend the analyses beyond manufacturing to include dynamic services and distribution service sectors. Previous studies suggest that the dynamic services sector is playing a key role in spurring productivity throughout industrial economies.

Our findings are broadly consistent with the previous empirical work on ICT and new organizational practices. In particular, our analysis suggests that Canadian firms have been actively engaged in new organizational practices 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 adopt organizational innovations and introduce ICT have a higher incidence of productivity improvement and higher rates of innovation.

We find that the roles of ICT and new organizational practices are different between industrial 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 dynamic service firms in Canada are enjoying the benefits of ICT and technological and organizational innovations. These firms focus more on new organizational practices that are related to product/service quality-related practices. The story for the distribution service sector is very similar to that of the dynamic service sector except for the lack of significance of product/service quality-related practices in this sector.

Our analysis shows that ICT use is correlated with worker skills suggesting that firms that use high levels of ICT also employ more knowledge workers. 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 new organizational practices 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. We find that while ICT is productive on its own, it is more productive in firms that combine high levels of ICT with high levels of organizational innovations in the areas of production and efficiency practices, HRM practices, and product/service quality-related practices. The firms that combine ICT with organizational innovations have a high incidence of productivity improvement and have high rates of innovation. Our results also suggest that ICT and human capital are complements in the 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.

REFERENCES

Autor, D., L. Katz and, A. Krueger (1998), "Computing Inequality: Have Computers Changed the Labor Market", *Quarterly Journal of Economics,* CXIII, 1169-1214.

Baldwin, J. R., (1999) *Innovation, Training and Success*. Analytical Studies Research Paper Series No 137. 11F0019MIE1999137. Analytical Studies Branch. Ottawa: Statistics Canada

Baldwin, J.R. B. Diverty; D. Sabourin (1995), "Technology Use and Industrial Transformation," in T. Courchene (ed.) *Technology Information and Public Policy.* The Bell Canada Papers on Economic and Public Policy, Volume 3. John Deutsch Institute for the Study of Economic Policy. Queen's University.

Baldwin, J.R. and J. Johnson (1995), "*Business Strategies in Innovative and Non-Innovative Firms in Canada*," Analytical Studies Research Paper Series 11F0019MIE1995073. Analytical Studies Branch. Ottawa: Statistics Canada, published in *Research Policy*, 25, 785-804.

Baldwin, J.R. and J. Johnson (1996), "Human Capital Development and Innovation: A Sectoral Analysis," In *The Implications of Knowledge-Based Growth for Micro-Economic Policies*, Peter Howitt (ed.). Calgary: University of Calgary Press.

Baldwin, J.R. and J. Johnson (1997), "*Differences in Strategies and Performances of Different Types of Innovators*," Analytical Studies Research Paper Series 11F0019MIE1997102. Analytical Studies Branch. Ottawa: Statistics Canada.

Baldwin, J.R. and J. Johnson (1998), "Innovator Typologies, Related Competencies and Performance," In *Microfoundations of Economic Growth*, edited by G. Eliasson and C. Green. Ann Arbor: University of Michigan. 227-53.

Baldwin, J. R. and D. Sabourin (2002), "Advanced Technology Use and Firm Performance in Canadian Manufacturing in the 1990s," *Industrial and Corporate Change* 11 (4): 761-89.

Baldwin, J. R., D. Sabourin; David Smith (2003), "Impact of Advanced Technology Use on Firm Performance in the Canadian Food Processing Sector," Economic Analysis Research Paper Series. No. 12. 11F0027MIE20030012. Analytical Studies Branch, Ottawa: Statistics Canada.

Barkin, T.I.; J. J. Nahirny; E.S. Van Metre (1998), "Why are Service Turnarounds So Tough," *McKinsey Quarterly*, No. 1, pp. 46-54.

Bartel, A. (1995), "Formal Employee Training Programs and Their Impact on Labour Productivity," NBER Working paper No. 3026.

Black, S.E. and L.M. Lynch (2000), "What's Driving the New Economy: The Benefits of Workplace Innovation," NBER Working Paper No. 7479.

Black, S.E. and L.M. Lynch (2001), "How to Compete: The Impact of Workplace

Practices and Information Technology on Productivity," *The Review of Economics and Statistics*, Vol. LXXXIII, 3: 434-445.

Bresnahan, F. B.; E. Brynjolfsson; L. Hitt (2002), "Information Technology, Workplace Organization and the Demand for Skilled Labour: Firm-Level Evidence," *The Quarterly Journal of Economics*, February, pp. 339-377.

Bresnahan, F. B.; E. Brynjolfsson; L. Hitt (1999), "Information Technology, Workplace Organization and the Demand for Skilled Labour: Firm-Level Evidence," NBER Working Paper No. 7136, May.

Brynjolfsson, E. and L. Hitt (2000), "Beyond Computation: Information Technology, Organization Transformation and Business Performance," *Journal of Economic Perspectives*, 14: 23-48.

Brynjolfsson, E. and L. Hitt (1997), "Information Technology and Organizational Design," MIT Sloan School Working Paper.

Brynjolfsson, E. and L. Hitt (1996), "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending," *Management Science*, 42(4), pp. 541-558.

Brynjolfsson, E. and L. Hitt (1995), "Information Technology as a Factor of Production: The Role of Differences among Firms," *Economics of New Innovation and New Technology*, 3(4), pp. 183-200.

Brynjolfsson; E., L. Hitt; S. Yang (2000), "Intangible Assets: How the Interactions of Information Systems and Organizational Structure Affects Stock Market Valuations," mimeo, MIT and Wharton.

Brynjolfsson, E. and S. Yang (1997), "The Intangible Benefits and Costs of Computer Investments: Evidence from Financial Markets," in Proceedings of International Conference on Information Systems, Atlanta, GA.

Cappelli, P. (2000), "Examining the Incidence of Downsizing and its Effect on Establishment Performance," NBER Working Paper No. 7742.

Cappelli, P. and D. Neumark (1999), "Do High-Performance Work Practices Improve Establishment-level Outcomes?" NBER Working Paper No. 7374.

Council of Economic Advisors (2000), *Economic Report of the President*, United States, Government Printing Office.

Danish Ministry of Business and Industry (1996), *Technological and Oraganizational Change: Implications for Labour Enterprise Performance and Industrial Policy*, Country Report Denmark.

Easton, G.S. and S.L. Jarrell (1998), "The Effects of Total Quality Management on Corporate Performance: An Empirical Investigation," *Journal of Business*, Vol. 71, No. 2, pp. 253-307.

Freeman, R.B.; M.M. Kleiner; C. Ostroff (2000), "The Anatomy of Employee Involvement and its Effects on firms and Workers," NBER Working Paper No. 8050, December.

Gera, S.; W. Gu; and X. Lin (2001), "Technology and the Demand for Skills in Canada: An Industry-Level Analysis" *Canadian Journal of Economics*, Vol. 34 No. 1, February, 132-148.

Gu, W. and W. Wang (2003), "ICTs and Productivity Growth in Canadian Industries," paper presented at the annual Canadian Economic Association Meeting, 2003.

Hitt, L. and E. Brynjolfsson (1997), "Information Technology and Internal Firm Organization: An Exploratory Analysis," *Journal of Management Information Systems*, 14: 77-99.

Ichniowski, C.; K. Shaw; G. Prennushi (1997), "The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines," *American Economic Review*, Vol. 87, No. 3, pp. 291-313.

Kleiner, M. and M. Bouillon (1988), "Providing Business Information to Production Workers: Correlates of Compensation and Profitability," *Industrial and Labor Relations Review*, July, 41(4), pp. 605-17.

Kruse, D. L. (1993), *Profit Sharing: Does It Make a Difference?* Kalamazoo, MI: Upjohn Institute.

Lawler, E.; S.A. Mohrman; G.E. Ledford (1998), *Strategies for High Performance Organizations – the CEO Report: Employee Involvement, TQM and Reengineering Programs in Fortune 1000 Corporations*, Jossey-Bass, San Francisco.

Lichtenberg, F. R. (1995), "The Output Contributions of Computer Equipment and Personal: A Firm-level Analysis," *Economics of Information and New Technology*, 3: 212-223.

Lynch, L. and S. Black (1995), "Beyond the Incidence of Training: Evidence from a National Employers Survey," NBER Working Paper No. 5231, August.

Mavrinac, S. and T. Siesfeld (1998), "Measures that Matter: an Exploratory Investigation of Investors' Information Needs and Value Priorities," in *Enterprise Value in the Knowledge Economy: Measuring Performance in the Age of Intangibles*, OECD and Ernst and Young Centre for Business Innovation.

Milgrom, P. and J. Roberts (1990), "The Economics of Modern Manufacturing: Technology, Strategy, and Organization," *American Economic Review*, 80(3), pp. 511-528.

Ministry of Industry (2001), "Employer and Employee Perspectives on Human Resource Practices", Statistics Canada and Human Resources Development Canada Catalogue No. 71-584-MPE, No. 1.

Monga, R.C. (2000), "Managing Enterprise Productivity and Competitiveness," ILO Working Paper PMD-3.

Newton, K. (1996), "The Human Factor in Firms' Performance: Management Strategies for Productivity and Competitiveness in the Knowledge-Based Economy," Industry Canada, Occasional Paper No. 14, Nov.

OECD (1998), *High-Performance Workplaces and Intangible Investment*, Paris.

OECD (2000), *A New Economy?: The Changing Role of Innovation and Information Technology in Growth*, DSTI/IND/STP/ICCP(2000)/Final, Paris.

OECD (2002), *Organisational Change and Firm Performance*, DSTI/DOC(2002)14, Paris.

Pilat, D. (2001), "Innovation and Productivity in Services: State of the Art," in OECD, *Innovation and Productivity in Services*, Paris [Proceedings of a joint OECD-Australia workshop, Sydney, November 2000], 2001.

Rao, S. and Jianmin Tang (2001), "The Contribution of ICTs to Productivity Growth in Canada and the United States in the 1990s," *International Productivity Monitor*, No. 3, Fall, pp. 3-18.

Sharpe, A. (1999), "Organizational Structure, Information Technology and Productivity: Can Organizational Change Resolve the Productivity Paradox?" Report prepared for the Applied Research Branch, Human Resources Development Canada, January.

Sundbo, J. and F. Gallouj (1998), *Innovation in Services – SI4S Project Synthesis*, STEP Group.

Table 1: Selected Firm-level Studies on the Impact of ICT and New Organizational Practices on Firm Performance

Study	Sample	Issues	Main Findings
Lichtenberg (1995)	US firms, 1998-91	Output contribution of capital and labour deployed in information systems	One information systems employee can be substituted for six non-information systems employees without affecting output.
Hitt and Brynjolfsson (1997); Brynjolfsson and Hitt (1997)	More than 600 large US firms, 1987–1994	The impact of ICT adoption and organizational decentralization on productivity	Firms that adopt both ICT and organizational decentralization are on average 5 percent more productive than that adopt only one of these.
Black and Lynch (2000 and 2001)	US firms, 1987–1993, and 1993–1996	The impact of work practices, ICT and human capital on productivity	The adoption of certain newer work practices, higher educational levels, and the use of computers by production workers have a positive impact on plant productivity.
Brynjolfsson and Yang (1997)	Fortune 1000 US firms, 1987–1994	The impact of ICT and intangible assets on firm performance	The market value of US$1 of ICT capital is the same as that of US$10 of capital stock. This may reflect the value of intangible investment associated with ICT.
Brynjolfsson, Hitt and Yang (2000)		The impact of ICT adoption and organizational decentralization on productivity	The market value of US$1 of ICT capital is higher by US$2 to 5 in decentralized firms than in centralized firms.
Bresnahan, Brynjolfsson and Hitt (2002)	300 large firms, 1987–1994	Complementarities between ICT, human capital and decentralized organizational structures	ICT combined workplace practices such as higher skills, new products and services, greater use of delegated decision making lead to higher productivity. Successful firms adopt ICT as part of a system or cluster of mutually reinforcing organizational changes.

Source: OECD (2000) and authors' updates.

Table 2: Types of Innovative Business Strategies

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

Table 3: Elements of Human Resources Management Practices

Human Resources Management Practices	Strategies
Performance-based Pay	• Individual incentive systems • Productivity/quality gain sharing and other group incentives • Profit sharing plan • Merit pay and skill-based pay
Flexible Job Design and 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

Table 4: Sample Means of ICT, Human Capital and Firm Performance

Variables	All	Manuf.	Dyn. Services	Distrib. Services	Large Firms	Small Firms
Share of Workers using Computers	0.46	0.34	0.66	0.38	0.44	0.46
ICT Investment Share	0.24	0.27	0.32	0.21	0.54	0.24
Share of Knowledge Workers	0.24	0.18	0.27	0.25	0.16	0.25
Increases in Productivity	0.39	0.51	0.38	0.38	0.55	0.39
Increases in Profitability	0.36	0.44	0.37	0.35	0.51	0.35
Increases in Sales Growth	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

Note: Dynamic services industries include the communication; finance, insurance & real estate; business services, education and health, and information and cultural industries. Distributive services industries include wholesale, retail and transportation services.

Table 5: Mean Incidence of Organizational Innovations

Organizational Innovations	Mean (%)
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 multi-skilling	0.15
Increased 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
Improving industrial relations	
Enhancing labour-management cooperation	0.55
Product/Service Quality – related Practices	
Improving product quality	0.78
Improving coordination with customers/suppliers	0.66
Total quality management	0.13

Table 6: Effects of ICT and Organizational Innovations on Productivity Performance

Probit model estimates

Variables	**(1)**	**(2)**	**(3)**	**(4)**
Production and efficiency practices	0.207			0.153
	(10.29)			(6.92)
HRM practices		0.211		0.114
		(8.99)		(4.64)
Product/services quality practices			0.105	0.046
			(6.45)	(2.68)
Share of workers using computers at work	0.140	0.132	0.139	0.117
	(3.13)	(2.85)	(2.96)	(2.52)
Share of ICT in M&E investment	0.002	0.023	0.036	-0.016
	(0.07)	(0.60)	(1.01)	(-0.45)
Share of knowledge workers	-0.067	-0.011	-0.043	-0.054
	(-1.18)	(-0.17)	(-0.72)	(-0.95)
No. of observations	5501	5501	5501	5501

Note: t-statistics 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.

Table 7: Effects of ICT and Organizational Innovations on Firm Performance

Probit model estimates

Variables	Dependent Variables			
	Sales Growth	**Profit Changes**	**Product Innov.**	**Process Innov.**
Production and efficiency practices	0.064 (2.63)	0.032 (1.47)	0.153 (5.27)	0.114 (5.06)
HRM practices	0.096 (3.49)	0.124 (5.16)	0.143 (4.64)	0.133 (5.91)
Product/services quality practices	0.082 (4.75)	0.047 (2.75)	0.140 (8.03)	0.098 (6.25)
Share of workers using computers at work	0.070 (1.44)	0.061 (1.27)	-0.012 (-0.23)	-0.002 (-0.04)
Share of ICT in M&E investment	-0.006 (-0.16)	0.020 (0.56)	0.148 (3.69)	0.214 (6.25)
Share of knowledge workers	-0.054 (-0.84)	0.038 (0.62)	0.062 (0.95)	-0.013 (-0.21)
No. of observations	5501	5501	5501	5501

Note: t-statistics 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.

Table 8: Fraction of Firms Reporting Productivity Improvement or Innovation by ICT and Organizational Innovations (%)

	Productivity Improvement			Product Innovation			Process Innovation		
	Yes	No	Diff.	Yes	No	Diff.	Yes	No	Diff.
ICT									
High share of workers using computers	45.94	33.01	12.93	50.15	41.11	9.04	36.52	27.88	8.64
High-ICT investment	48.32	35.65	12.67	63.28	39.07	24.21	55.84	23.64	32.2
Production and Efficiency Practices									
Business re-engineering	67.12	32.31	34.81	81.1	36.89	44.21	66.51	23.75	42.76
Downsizing	45.38	38.2	7.18	52.39	44.47	7.92	38.46	31.11	7.35
Flexible work arrangement	62.25	31.41	30.84	73.21	36.28	36.93	53.88	24.75	29.13
Outsourcing	72.93	34.07	38.86	76.76	40.76	36	62.48	27.47	35.01
Greater integration among different functional areas	67.84	34.71	33.13	77.94	40.52	37.42	66.17	26.87	39.3
Decrease in the degree of centralization	73.32	37.85	35.47	81.11	44.15	36.96	72.25	30.6	41.65
HRM Practices									
Performance-based pay									
Individual incentive systems	52.2	32.76	19.44	59.05	38.87	20.18	43.17	26.59	16.58
Productivity/quality gain sharing and other group incentives	65.89	36.48	29.41	70.01	43.02	26.99	58.11	29.48	28.63
Profit sharing plan	60.01	36.97	23.04	68.37	43.13	25.24	46.53	30.47	16.06
Merit pay and skilled-based pay	57.97	34.9	23.07	65.53	40.99	24.54	50.94	27.82	23.12
Flexible job design and employee involvement									
Employee suggestion programs	59.42	37.27	22.15	75.71	42.84	32.87	65.87	29.15	36.72
Flexible job design	65.85	36.76	29.09	73.25	43.03	30.22	60.28	29.58	30.7
Information sharing with employees	58.17	36.37	21.8	72.54	41.68	30.86	64.87	27.53	37.34
Quality circles, problem solving teams	67.16	37.14	30.02	79.64	43.11	36.53	72.65	29.31	43.34
Joint labour management committees	62.58	37.8	24.78	70.7	44.06	26.64	67.69	30.19	37.5
Self-directed work groups	71.91	38.09	33.82	73.48	44.54	28.94	69.47	30.91	38.56
Greater reliance on job rotation and multiskilling	66.97	33.84	33.13	75.53	39.78	35.75	58.74	26.97	31.77
Increase employee involvement/participation	46.17	38.85	7.32	57.06	25.21	31.85	41.23	15.83	25.4
Human resource investment policies									
Formal job-related training	53.61	32.74	20.87	63.1	37.79	25.31	51.44	23.65	27.79
Classroom training	54.87	34.75	20.12	62.16	40.84	21.32	50.62	26.95	23.67
Participating in training subsidies program	58.78	37.87	20.91	69.73	43.98	25.75	49.89	30.89	19
Participating in other training programs	64.49	38.07	26.42	72.79	44.35	28.44	61.66	30.87	30.79
Improving industrial relations									
Enhancing labour-management cooperation	45.12	31.07	14.05	54.79	33.28	21.51	40	21.58	18.42
Product/Service Quality-related Practices									
Improving product quality	43.79	21.63	22.16	54.55	12.55	42	38.89	8.71	30.18
Improving coordination with customers/suppliers	43.93	29.09	14.84	54.39	27.49	26.9	38.8	18.28	20.52
Total quality management	69.37	34.14	35.23	78.91	39.39	39.52	66.61	26.4	40.21

Table 9: Effects of ICT and Organizational Innovations on Productivity Performance by Sector

Probit model estimates

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)
Share of ICT in M&E investment	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	1368	2072	1192

Note: t-statistics 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.

Table 10: Correlation Coefficients between ICT, Organizational Innovations and Human Capital

	Production and efficiency practices (PEP)	HRM Practices (HRP)	Product/ service quality-related practices (PQP)	Share of knowledge workers	ICT Investment share	Share of workers using computers
Production and efficiency practices (PEP)	1					
HRM practices (HRP)	0.4516*	1				
Product/service quality-related practices (PQP)	0.4010*	0.3748*	1			
Share of knowledge workers	0.0810*	-0.0155*	0.0420*	1		
ICT Investment share	0.2119*	0.2155*	0.1429*	0.0759*	1	
Share of workers using computers	0.1522*	0.1681*	0.1081*	0.2012*	0.3239*	1

Note. One asterisk denotes statistical significance at the 5 percent level

Table 11: Correlation between Computer Use and ICT investment, Human Capital and New Organizational Practices

Correlation between computer use and:	Correlation coefficients	Correlation between computer use and:	Correlation coefficients
<u>ICT Use</u>		***<u>HRM Practices</u>***	
Share of ICT in M&E investment	0.3239*	Performance-based pay	
		Individual incentive systems	0.2199*
<u>Human Capital</u>			
Share of knowledge workers	0.2012*	Productivity/quality gain sharing and other group incentives	0.1068*
		Profit sharing plan	0.0985*
<u>Production and Efficiency Practices</u>			
Business re-engineering	0.1115*	Merit pay and skilled-based pay	0.1144*
Downsizing	0.0107*		
		Flexible job design and employee involvement	
Flexible work arrangement	0.1011*	Employee suggestion programs	0.0505*
Outsourcing	0.0876*	Flexible job design	0.0714*
Greater integration among different functional areas	0.1388*	Information sharing with employees	0.0850*
Decrease in the degree of centralization	0.0925*	Quality circles, problem solving teams	0.0367*
		Joint labour management committees	0.0191*
		Self-directed work groups	0.0450*
<u>Product/Service Quality – related Practices</u>			
Improving product quality	0.1049*	Greater reliance on job rotation and multi-skilling	0.1482*
Improving coordination with customers/suppliers	0.0509*	Increase employee involvement/participation	0.0878*
Total quality management	0.0874*	Human resource investment policies	
		Formal job-related training	0.1881*
		Classroom training	0.1766*
		Participating in training subsidies program	-0.0332*
		Participating in other training programs	0.0184*
		Improving industrial relations	
		Enhancing labour-management cooperation	-0.0290*

Note. One asterisk denotes statistical significance at the 5 percent level

Table 12: Complementarities between ICT and Production and Efficiency Practices and their Impact on Firm Performance

Marginal effect estimates from Probit models

	All industries	Manuf.	Dynamic Services	Distributive Services
Dependent Variable: Productivity Improvement				
High ICT, high PE	0.336	0.262	0.290	0.488
	(6.67)	(3.74)	(3.98)	(5.25)
Low ICT, high PE	0.196	0.204	0.154	0.274
	(3.64)	(3.29)	(2.52)	(2.71)
High ICT, low PE	0.069	0.135	0.154	0.110
	(1.62)	(2.12)	(2.70)	(1.38)
Dependent Variable: Product Innovation				
High ICT, high PE	0.395	0.304	0.379	0.403
	(7.69)	(4.57)	(5.08)	(4.35)
Low ICT, high PE	0.254	0.213	0.187	0.322
	(5.23)	(3.39)	(2.95)	(3.75)
High ICT, low PE	0.152	0.159	0.165	0.127
	(3.15)	(2.56)	(2.48)	(1.45)
Dependent Variable: Process Innovation				
High ICT, high PE	0.472	0.365	0.378	0.578
	(8.79)	(5.36)	(5.28)	(5.94)
Low ICT, high PE	0.221	0.201	0.084	0.321
	(4.65)	(3.14)	(1.54)	(3.88)
High ICT, low PE	0.251	0.192	0.236	0.260
	(5.46)	(2.93)	(3.93)	(2.91)

Note: t-statistics are in parentheses. All regressions control for industry fixed effects, firm size and foreig n ownership. t-statistics are adjusted for heteroscedasticity using the Huber-White method.

Table 13. Complementarities between ICT and HRM Practices and their Impact on Firm Performance

Marginal effect estimates from Probit models

	All Industries	Manuf.	Dynamic Services	Distributive Services
Dependent Variable: Productivity Improvement				
High ICT, high HRM	0.248	0.262	0.344	0.276
	(4.47)	(3.85)	(4.66)	(2.72)
Low ICT, high HRM	0.113	0.227	0.154	0.070
	(2.22)	(3.32)	(2.49)	(0.57)
High ICT, low HRM	0.086	0.147	0.136	0.164
	(2.09)	(2.40)	(2.44)	(2.22)
Dependent Variable: Product Innovation				
High ICT, high HRM	0.317	0.304	0.365	0.305
	(6.42)	(4.39)	(4.91)	(3.27)
Low ICT, high HRM	0.122	0.175	0.238	0.021
	(2.29)	(2.50)	(3.68)	(0.21)
High ICT, low HRM	0.142	0.146	0.179	0.090
	(2.94)	(2.37)	(2.76)	(1.01)
Dependent Variable: Process Innovation				
High ICT, high HRM	0.455	0.381	0.467	0.481
	(9.16)	(5.41)	(6.46)	(5.18)
Low ICT, high HRM	0.201	0.281	0.257	0.109
	(4.29)	(3.97)	(4.07)	(1.31)
High ICT, low HRM	0.241	0.220	0.255	0.224
	(5.21)	(3.62)	(4.43)	(2.57)

Note: t-statistics are in parentheses. All regressions control for industry fixed effects, firm size and foreig n ownership. t-statistics are adjusted for heteroscedasticity using the Huber-White method.

Table 14: Complementarities between ICT and Product and Service Quality-related Practices and their Impact on Firm Performance

Marginal effect estimates from Probit models

	All Industries	Manuf.	Dynamic Services	Distributive Services
<u>Dependent Variable: Productivity Improvement</u>				
High ICT, high PSQ	0.274 (4.14)	0.134 (1.43)	0.289 (3.27)	0.386 (3.10)
Low ICT, high PSQ	0.007 (0.11)	0.031 (0.36)	0.097 (1.27)	-0.123 (-0.97)
High ICT, low PSQ	0.076 (1.99)	0.106 (1.95)	0.139 (2.65)	0.127 (1.82)
<u>Dependent Variable: Product Innovation</u>				
High ICT, high PSQ	0.290 (4.19)	0.075 (0.71)	0.337 (3.14)	0.277 (2.18)
Low ICT, high PSQ	0.145 (2.14)	0.021 (0.25)	0.214 (2.69)	0.161 (1.16)
High ICT, low PSQ	0.160 (3.83)	0.154 (2.86)	0.193 (3.51)	0.124 (1.61)
<u>Dependent Variable: Process Innovation</u>				
High ICT, high PSQ	0.352 (5.23)	0.289 (3.20)	0.398 (4.26)	0.339 (2.66)
Low ICT, high PSQ	0.149 (2.12)	0.239 (2.73)	0.230 (3.17)	0.101 (0.74)
High ICT, low PSQ	0.263 (6.49)	0.217 (3.93)	0.285 (5.50)	0.263 (3.37)

Note: t-statistics are in parentheses. All regressions control for industry fixed effects, firm size and foreig n ownership. t-statistics are adjusted for heteroscedasticity using the Huber-White method.

Table 15. Complementarities between ICT and Human Capital and their Impact on Firm Performance

Marginal effect estimates from Probit models

	All Industries	Manuf.	Dynamic Services	Distributive Services
Dependent Variable: Productivity Improvement				
High ICT, high HK	0.102	0.097	0.086	0.205
	(2.26)	(1.39)	(1.42)	(2.52)
Low ICT, high HK	0.029	0.006	-0.011	0.070
	(0.67)	(0.12)	(-0.20)	(0.84)
High ICT, low HK	0.114	0.129	0.199	0.145
	(2.32)	(1.75)	(3.13)	(1.30)
Dependent Variable: Product Innovation				
High ICT, high HK	0.210	0.127	0.262	0.158
	(4.10)	(1.79)	(3.56)	(1.69)
Low ICT, high HK	0.028	0.030	0.010	0.003
	(0.68)	(0.56)	(0.20)	(0.03)
High ICT, low HK	0.116	0.180	0.109	0.068
	(2.00)	(2.57)	(1.53)	(0.49)
Dependent Variable: Process Innovation				
High ICT, high HK	0.286	0.205	0.331	0.256
	(5.89)	(2.87)	(5.00)	(2.87)
Low ICT, high HK	0.019	0.056	0.053	-0.032
	(0.50)	(0.98)	(1.10)	(-0.47)
High ICT, low HK	0.223	0.227	0.239	0.182
	(4.23)	(3.10)	(3.65)	(1.53)

Note: t-statistics are in parentheses. All regressions control for industry fixed effects, firm size and foreig n ownership. t-statistics are adjusted for heteroscedasticity using the Huber-White method.

Figure 1: Incidence of Production and Efficiency Practices

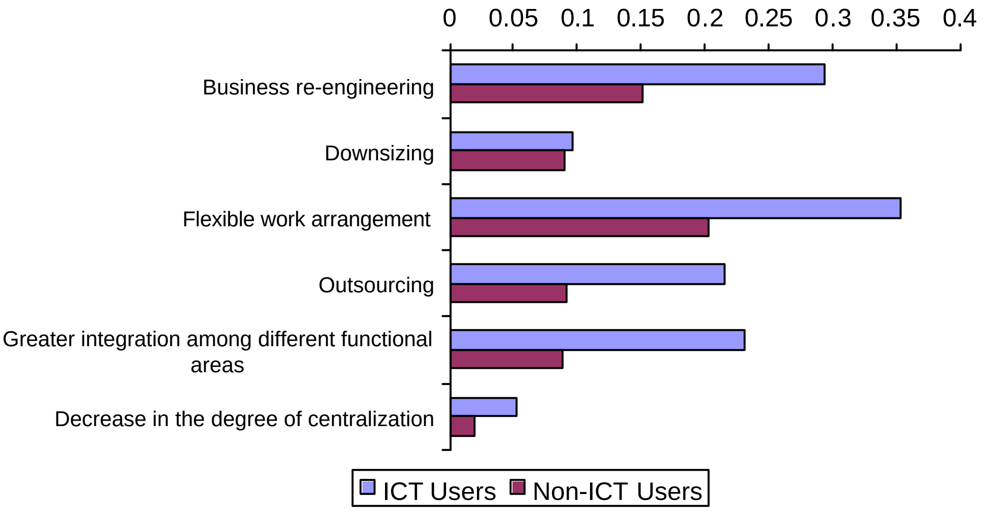
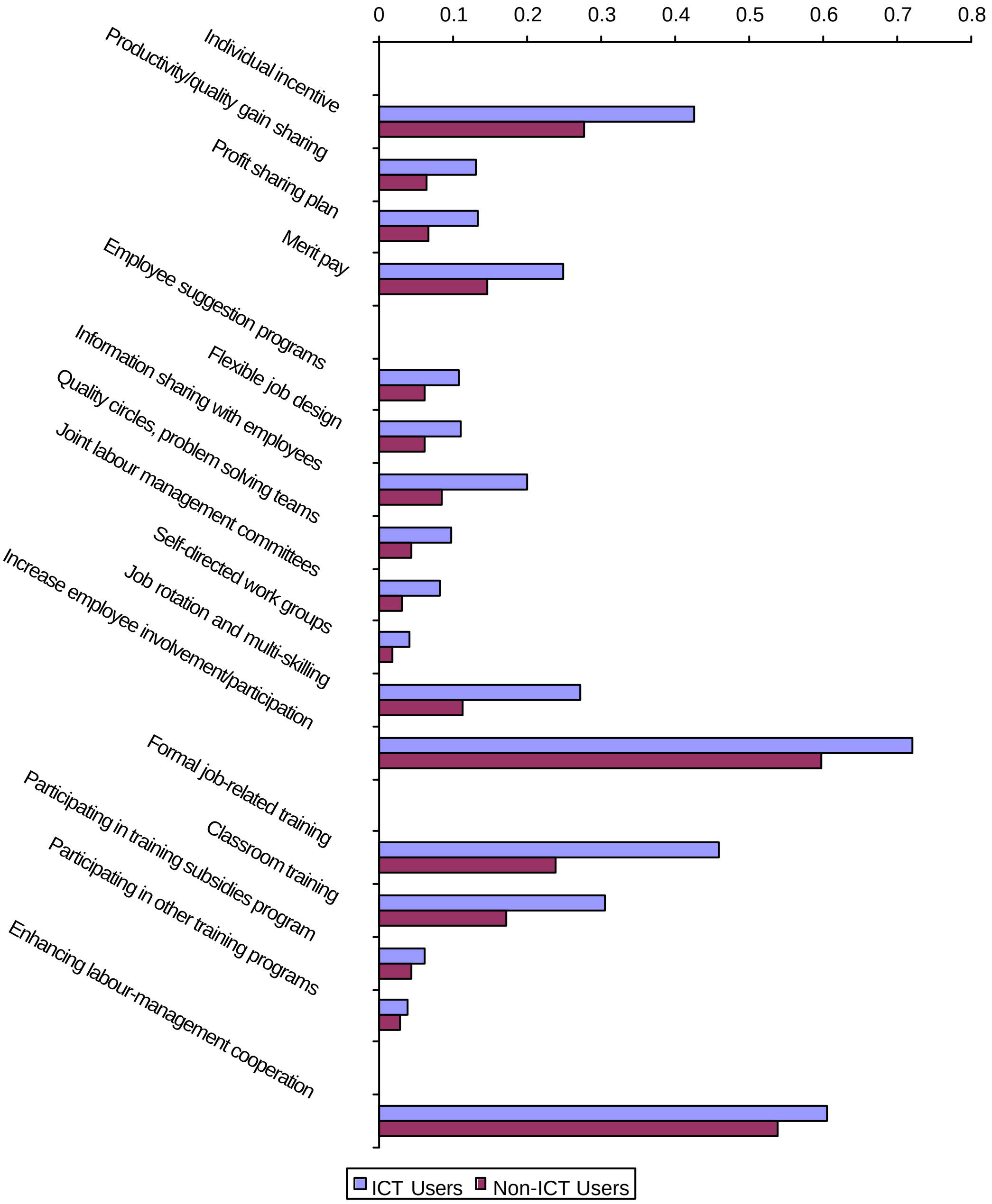


Figure 2: Incidence of HRM Practices



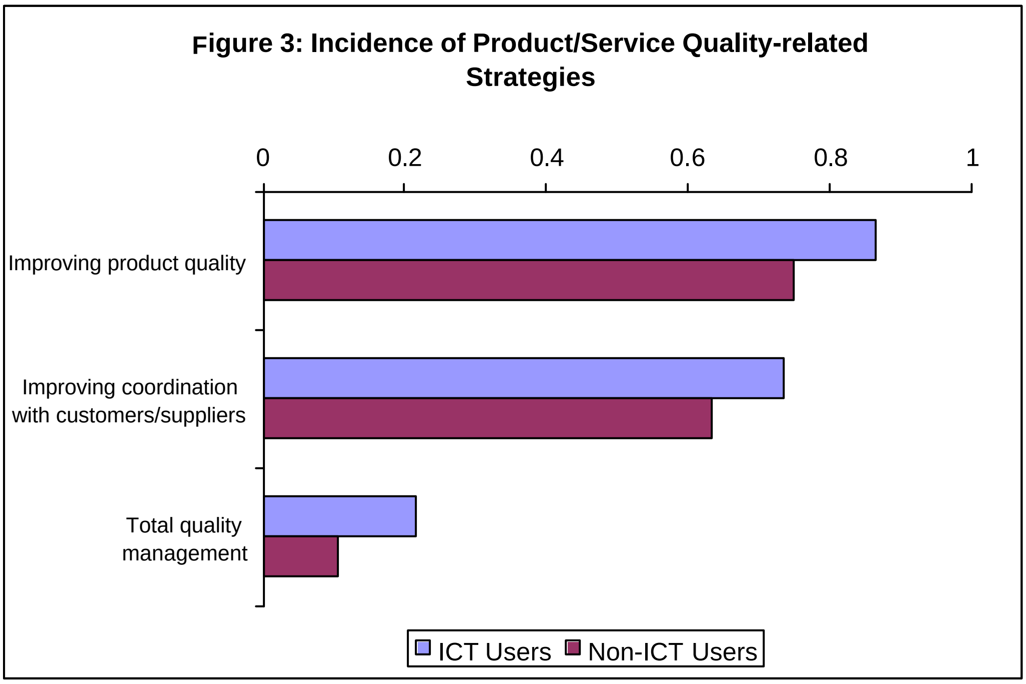


Figure 3: Incidence of Product/Service Quality-related Strategies
0
0.2
0.4
0.6
0.8
1
Improving product quality
Improving coordination with customers/suppliers
Total quality management
ICT Users
Non-ICT Users

Appendix A1: Correlation between Productivity Performance and Other Measures of Firm Performance

Performance Measures	Correlation Coefficients
Unit Production Costs	0.26
Sales Growth	0.57
Product Quality	0.44
Profitability	0.47
Productivity relative to your main competitors	0.21
Sales growth relative to your main competitors	0.28
Profitability relative to your main competitors	0.21

Table A2: Weights Assigned to Individual Practices for Constructing a Measure of Production and Efficiency Practices

	Weights
Business re-engineering (PE1)	0.48848
Downsizing (PE2)	0.24599
Flexible work arrangements (PE3)	0.45577
Outsourcing (PE4)	0.44609
Greater integration among different functional areas (PE5)	0.46626
Decrease in the degree of centralization (PE6)	0.27705

Table A3: Weights Assigned to Individual Practices for Constructing a Measure of HRM Practices

	Weights
Performance-based pay	
Individual incentive systems (HRM1)	0.17924
Productivity/quality gain sharing and other group incentives (HRM2)	0.18501
Profit sharing plan (HRM3)	0.18163
Merit pay and skilled-based pay (HRM4)	0.20926
Flexible job design and employee involvement	
Employee suggestion programs (HRM5)	0.33009
Flexible job design (HRM6)	0.32941
Information sharing with employees (HRM7)	0.3737
Quality circles, problem solving teams (HRM8)	0.32306
Joint labour management committees (HRM9)	0.26918
Self-directed work groups (HRM10)	0.24865
Greater reliance on job rotation and multi-skilling (HRM11)	0.19786
Increase employee involvement/participation (HRM12)	0.17418
Human resource investment policies	
Formal job-related training (HRM13)	0.27585
Classroom training (HRM14)	0.27096
Participating in training subsidies program (HRM15)	0.08772
Participating in other training programs (HRM16)	0.10006
Improving industrial relations	
Enhancing labour-management cooperation (HRM17)	0.15613

Table A4: Weights Assigned to Individual Practices for Constructing a Measure of Product/Service Quality-related Practices

	Weights
Improving product quality (PSQ1)	0.6460
Improving coordination with customers/suppliers (PSQ2)	0.65301
Total quality management (PSQ3)	0.3953

ACRONYMS

A* STAR	Agency for Science, Technology And Research
ADB	Asian Development Bank
ADL	Autoregressive Distributed Lag
CRM	Customer Relations Management
DOS	Department of Statistics (Singapore)
EC	Economic Committee
ECM	Error Correction Model
ERC	Economic Review Committee (Singapore)
FIRE	Finance, Insurance and Real Estate
GDP	Gross Domestic Product
GERD	Gross Expenditure on Research and Development
HRM	Human Resource Management
ICT	Information and Communication Technology
IP	Intellectual Property
IRR	Internal Rate of Return
KBE	Knowledge-Based Economy
KIBS	Knowledge Intensive Business Services
LIUP	Local Industry Upgrading Programme
NIE	Newly Industrialised Economy
NTSB	National Science and Technology Board (Singapore)
OECD	Organization for Economic Cooperation and Development
PEP	Production and Efficiency Practice
PQP	Product/Service Quality Practice
R&D	Research and Development
RIs	Research Institutes
RSEs	Research Scientists and Engineers
S&T	Science and Technology
SMET-UP	SME Technology Upgrading
TEC-UP	Technology for Enterprise Upgrading
TFP	Total Factor Productivity
TQM	Total Quality Management
VA	Value-Added
WES	Workplace and Employee Survey