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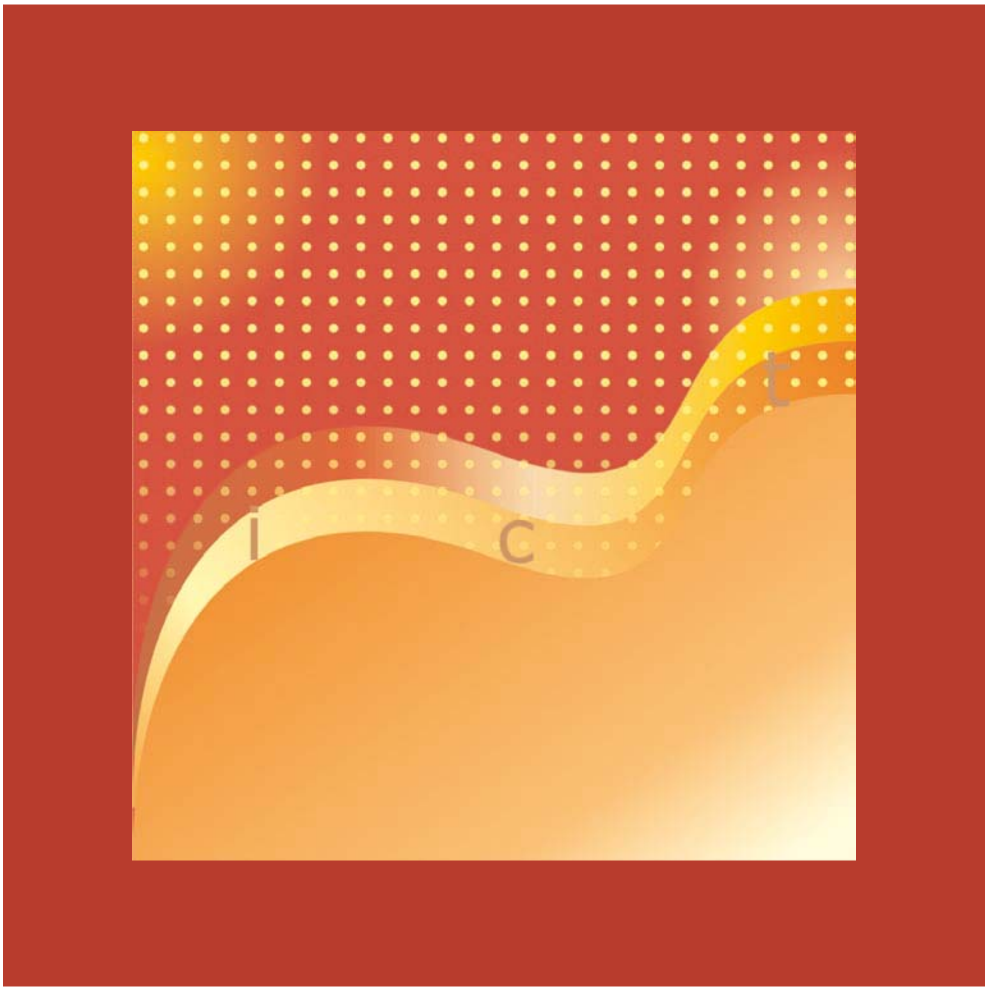
Science and technology for development: the new paradigm of ICT

Prepared by the UNCTAD secretariat



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Chapter 3

MEASURING THE IMPACT OF ICT ON PRODUCTION EFFICIENCY

A. Introduction

The economic impact of information and communication technologies is a complex subject of great interest to both developing and developed countries, particularly in the context of globalization. Previous editions of UNCTAD's *Information Economy Report*, formerly known as the E-Commerce and Development Report, have addressed this issue from a variety of angles in order to provide a comprehensive view of how and how much ICTs matter to economies and development. The first edition of the ECDR (2000) showed through its computable general equilibrium estimates that developing countries would be at a disadvantage in terms of income and welfare if they fell too much behind as regards ICT use. In the meantime, ICTs have evolved, improved and become more widespread and constitute a very dynamic sector of economic activity. Developing countries' exports of ICT goods and services have grown spectacularly, establishing new international specialization patterns.[1] At this stage it is important to establish to what extent ICTs have impacted on economic growth. The analysis of differences in economic gains from ICT between countries, industries and firms aims at revealing where most positive effects have occured and where new efforts should focus.

The introduction of this Report clarifies the role played by ICTs in the wider context of science and technology and the latter's contribution to growth and development. This chapter presents empirical results regarding the economic impact of ICT use from the productivity perspective. More specifically, it reviews quantitative results of empirical studies on the impact of ICT use on production efficiency.

The focus on productivity and the supply side is of interest to developing countries. In recent years, developing countries have continued to grow extensively by absorbing new investment and labour. In particular, the policy choice to build up and support an ICT-producing sector has generated jobs and attracted additional foreign investment and offshoring in several emerging economies. This chapter shows that in addition to recognizing the benefits of the ICT-producing sector, it is important to recognize the development potential of other sectors of economic activity where ICTs could be used intensively (ICT-enabled activities).

An important result of the intellectual debate initiated by Gordon (1999) was that in developed countries, while initial productivity gains from ICT accrued mainly from a fast growing ICT-producing sector, in the second stage there were additional gains deriving from increasingly widespread use of ICTs in many economic sectors. In developing countries, by contrast, productivity gains from ICT are still being largely generated by the ICT-producing industry.[2] This is because developing countries with tighter budget constraints have been spending less on ICT. In that context, developing countries wishing to increase their gains from ICT should take measures to extend the use of ICT from the ICT-producing sector to other economic sectors and to domestic consumers.

Researchers studying the impact of ICTs on productivity used different economic models of interpretation, depending on the type of ICT data made available and the issue researched. The analysis depended very much on the quality of measurements and the availability of data on ICT uptake. At the firm level, the specialized literature tended to move away from evaluating the impact of all-inclusive ICT investment and instead focused on the way in which specific ICT use resulted in higher production efficiency. As ICTs become more complex and widespread, more information is needed on how ICT use determines competitiveness, in addition to information on the amount spent on ICT investment. In developing countries as well, more information on how firms use ICT would help in refining policy decisions to scale up the most efficient enterprise practices.

In keeping with the conceptual structure adopted in past issues of this Report,[3] the present chapter proceeds with a literature review at the macroeconomic and microeconomic levels of the main empirical findings on ICT and production efficiency. The review of studies applied to developed country data is aimed at facilitating the interpretation of similar empirical exercises conducted with more recent data from developing countries. Also included in the review are a number of research papers that use developing country data. The literature review links three defining elements: the economic model of interpretation, the ICT or IT[4] variable used and the significance of results for developing countries.

Section D of this chapter draws on a commonly used theoretical framework (Cobb–Douglas production function) for studying the relationship between specific ICT use and labour productivity in firms. It provides an illustration of how information on ICT use by firms can be linked with economic data in order to quantify productivity gains associated with ICTs.[5] The study described is the outcome of a joint research project of UNCTAD and the Thai National Statistical Office. It is an application of a verified econometric model to a large sample of Thai manufacturing firms. The project is part of a broader international initiative to improve ICT measurement and the quality of data on ICT uptake in order to enable cross-country comparisons and allow the measuring of ICT impact. This initiative is promoted by UNCTAD through the Partnership on Measuring ICT for Development.[6]

B. Economic impact of ICT at the macroeconomic level

The macroeconomic impact of ICT on production efficiency is assessed in the context of growth accounting models. The introduction of this Report presents the theoretical assumptions underlying both neoclassical and endogenous growth models. Past issues of the UNCTAD IER and ECDR[7] have also reviewed the channels through which ICTs impact on economic growth. This section reviews the recent literature on the impact of ICT on growth and productivity in order to highlight the main factors that apply in the context of developing countries.

Chart 3.1 summarizes the way in which ICT use leads to productivity growth: first it increases the efficiency of factor inputs (capital and labour) and, second, it fosters technological innovation as a source of total factor productivity growth. Labour productivity in particular grows as a result of capital deepening through incorporating ICT capital inputs into the production process. In this case, ICT investment results in improved labour efficiency without changing the technology of production. When, in addition to capital deepening, economic agents are able to relocate resources in a way that improves technological efficiency and better incorporates ICTs into their production processes, ICT use can result in total factor productivity gains.

This section reviews the findings of the specialized literature on several research questions at the macroeconomic level related to ICT and growth in both developed and developing countries. One of the questions addressed in the specialized literature is whether ICTs have contributed to GDP growth as an ordinary production input or whether they generated, besides capital deepening, additional spillover effects, other positive externalities and technological innovations. This allows a comparison of the magnitude of gains from ICT production and from ICT use. The main purpose of the review is to show instances where results regarding ICT and productivity differed between developed and developing countries, in order to better understand how developing economies can maximize gains from ICT.

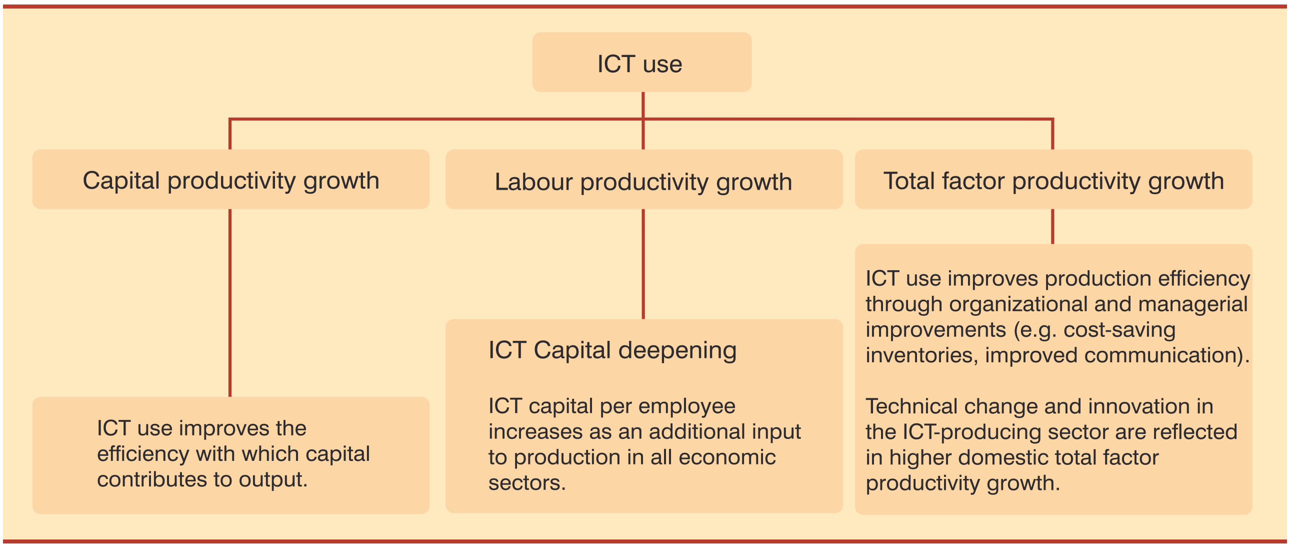
1. ICT capital, ICT use and growth

Measuring the amount of capital invested in ICT goods and services is one way of measuring the intensity of ICT uptake in an economy. Within the neoclassical growth accounting setting, ICT investment is assumed to contribute to labour productivity through capital deepening, this assumption being consistent with the logic that workers who have more computing and communication equipment are more efficient than workers who have only ordinary capital. Thus ICT capital contributes to GDP per capita growth as an additional input to the production function. This theoretical framework does not account for the contribution of ICT to total factor productivity arising from an ICT-enabled innovative reallocation and reorganization of production (such as the substitution of ICT capital for ordinary capital). Several such growth accounting exercises were conducted by a number of authors over different periods of time to estimate the contribution of ICT capital to GDP growth.

Gains to productivity from ICT have low values when ICTs are nascent in the economy. When ICT inputs have a very small share in total production, growth accounting models can detect only a feeble effect on productivity from those inputs. For example, early

Chart 3.1

Channels through which ICT contributes to productivity growth



results in developed countries derived for the 1980s and early 1990s showed that investment in computer equipment had a minimal impact on GDP growth. Research[8] estimating the impact of investment in computing equipment on GDP growth in the United States in the 1980s found a rather small contribution of just 0.2 per cent compared with an average GDP growth rate of 2.3 per cent. The ICT variable used in that research was the yearly variation in the stock of computer capital. The broader concept of ICT investment was developed later, in parallel with research and has been used only recently. It was suggested by several authors that inputs with a very small share in total output could not have a great impact on GDP even if investment in that input was growing at high rates (Triplett, 1999). Although computer investment had reached a sizeable amount in certain specialized sectors, at the national level investment in computing equipment represented only 0.5 per cent of the total capital stock in 1993 (Jorgenson and Stiroh, 1995[9]). This measurement problem was subsequently addressed by broadening the concept of computer capital to also incorporate other ICT goods and services, including software and communication equipment. Other measurement problems related to accurately capturing price changes in IT and composite IT goods and services since the rather insubstantial changes in nominal ICT investment were hiding much larger variations in real ICT investment (IMF, 2001).

Conversely, when specific ICTs such as computers become ubiquitous, especially in developed countries, they can no longer contribute to explaining variations in output between economic actors (Carr, 2003). In that case, it is necessary to find other measurements relating to a particular use of ICT (for example, establishing web presence) where significant differences in ICT use explain changes in output.

An additional insight into growth accounting for ICT was provided by the structural change in the mid-1990s and the shift in the trend of ICT investment. Table 3.1 shows the evolution of ICT investment as a share in total capital investment in OECD countries before and after the mid-1990s.[10] Some associated this structural change with the beginning of the Internet revolution, arguing that connected computers allowed a larger variety of combined ICT use among firms. Others attributed the structural change to an unusually rapid technological improvement in the semiconductor industry (Oliner and Sichel, 2002). Starting in 1995, there was a marked decline in global ICT prices and a considerable acceleration of investment in ICT. At first, this trend was apparent only in developed countries. With a time lag of almost a decade, developing countries also experienced a similar increase in their ICT capital investments.[11] In the mid-1990s developing countries started to invest in ICT at faster rates and some, notably from Asia,[12] have acquired a considerable stock of ICT capital that matches ICT capital intensity in the United States in the early 1990s. In that connection, the analysis of more recent data on ICT investment in developing countries benefits from comparisons with

Table 3.1

Share of ICT investment in non-residential fixed capital formation in selected OECD countries (5-year averages), 1980–2004

	1980–1984 (per cent)	1985–1989 (per cent)	1990–1994 (per cent)	1995–1999 (per cent)	2000–2004 (per cent)
United States	15.1	19.8	23.1	27.0	29.9
Sweden	11.9	16.1	20.1	24.9	27.6
Finland	8.3	11.6	18.9	24.5	26.6
Australia	8.4	11.4	17.4	20.7	23.8
United Kingdom	7.9	12.5	16.2	22.7	23.1
Belgium	13.1	18.1	17.4	19.8	21.9
New Zealand	8.6	12.7	16.8	16.7	20.0
Canada	9.6	12.0	15.4	18.2	19.4
Denmark	12.7	14.6	17.6	19.4	19.3
Rep. of Korea	N/A	N/A	N/A	14.3	18.3
France	8.7	11.4	10.8	15.5	17.6
Netherlands	9.3	11.9	13.1	15.5	17.5
Germany	N/A	N/A	13.3	14.8	16.5
Italy	10.5	13.8	14.4	15.5	16.1
Japan	N/A	N/A	9.0	13.0	15.5
Austria	8.9	12.0	12.0	12.8	14.0
Portugal	12.3	13.2	10.7	12.6	12.8
Spain	11.0	14.7	12.7	14.2	12.7
Greece	4.5	7.5	10.2	11.2	12.4
Norway	8.3	9.4	8.5	10.0	12.3
Ireland	6.8	7.5	5.6	9.4	10.8

Notes: ICT investment has three components: information technology equipment (computers and related hardware), communications equipment and software. Software includes acquisition of prepackaged software, customized software and software developed in house. The investment shares shown in the table are percentages of each country's gross fixed capital formation, excluding residential construction. Also, the figures shown here do not account for price falls since they are ratios of nominal investment values. Since the price of ICT goods and services fell considerably it is reasonable to assume that the share of ICT investment increased faster than this table shows.

N/A = not available.

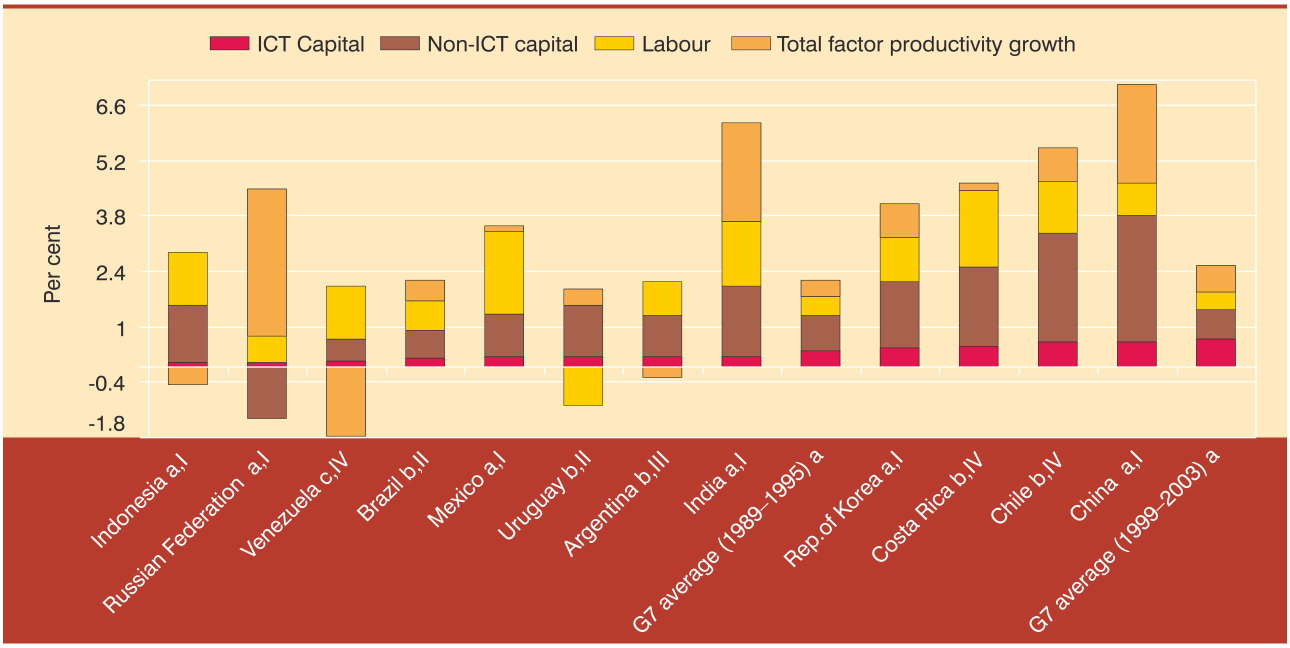
Source: OECD (2007).

ICT investment trends in developed countries in the 1980s and 1990s.

Using the new data from after 1995, Jorgenson and Vu (2005) found that the contribution of ICT capital to world GDP had more than doubled and now accounts for 0.53 per cent of the world average GDP growth of 3.45 per cent. The percentage was higher for the group of G7 countries, where ICT investments contributed with 0.69 per cent to a GDP growth of 2.56 per cent during 1995–2003. The Economic Commission for Latin America and the Caribbean has recently conducted a series of growth accounting exercises for Latin American countries. Their estimates are reflected below for a comparison with certain Asian developing countries.

Chart 3.2 shows the results of several growth accounting exercises in a number of developing countries in the period after the mid-1990s, benchmarked against estimates for the G7 countries before and after 1995. For each country, the various inputs broken down between ICT capital, non-ICT capital, labour and residual total factor productivity growth add up to average GDP growth. Economies appear in increasing order of the contribution of ICT capital to growth,

Chart 3.2
Sources of GDP growth, 1990–2003



Notes: Time period considered in analysis I: 1995-2003, II: 1995-2004, III: 1992-2004, IV: 1990-2004.
Source of estimates – a: Jorgenson & Vu (2005); b: de Vries et al. (2007), c: de Vries et al. (2006).

ranging from 0.09 per cent in Indonesia to 0.69 per cent in the G7 countries and reaching 0.38 per cent in G7 countries prior to 1995. In a number of developing countries, accelerated investment in ICT made a significant and positive contribution to GDP growth after the mid-1990s. However, owing to the low starting levels of ICT capital, this type of input could make only a reduced contribution, below 0.25 per cent in many cases. It was necessary for ICT capital stock to reach a certain level before greater benefits from investment in those technologies could be achieved. There were exceptions to that general finding, however. In the Republic of Korea, Costa Rica, Chile and China benefits from ICT investment were about 0.5 per cent, closer to the G7 average. In three out of those four developing countries, the ICT-producing sector had a large share in economic output.[13]

As shown in chart 3.2, several emerging economies have experienced strong growth in the last 10 years. In fast-growing developing countries ICT investment made only a small contribution to GDP growth. Other inputs such as ordinary capital investment and labour remained major contributors to the rapid GDP growth in emerging economies.[14] China and India stood out with some of the largest output growth in recent times, but their performance was led only partly by greater investment in ICT, as the other inputs distinguished by the model had a considerably higher share. Previous editions of the ECDR[15] have shown that the effect of ICT use on other fundamental variables of the economy such as labour was also significant. It is therefore possible that in emerging economies ICT use made a larger contribution to economic growth than suggested by the capital-deepening effect. Indeed, ICT use has also contributed to improving labour productivity in emerging economies (see section 3). However, as growth accounting estimates show, developing countries in which ICT investments had a greater impact on growth also managed to leverage more capital and to improve the skill mix of their labour force. Benefits from ICT capital did not occur in isolation from a general upturn in the economic evolution of emerging economies.

As mentioned in the introduction of this Report, ICT use is also reflected in multifactor productivity increases, which account for an important part of GDP growth in emerging economies.

2. The ICT-producing sector and the ICT using sectors

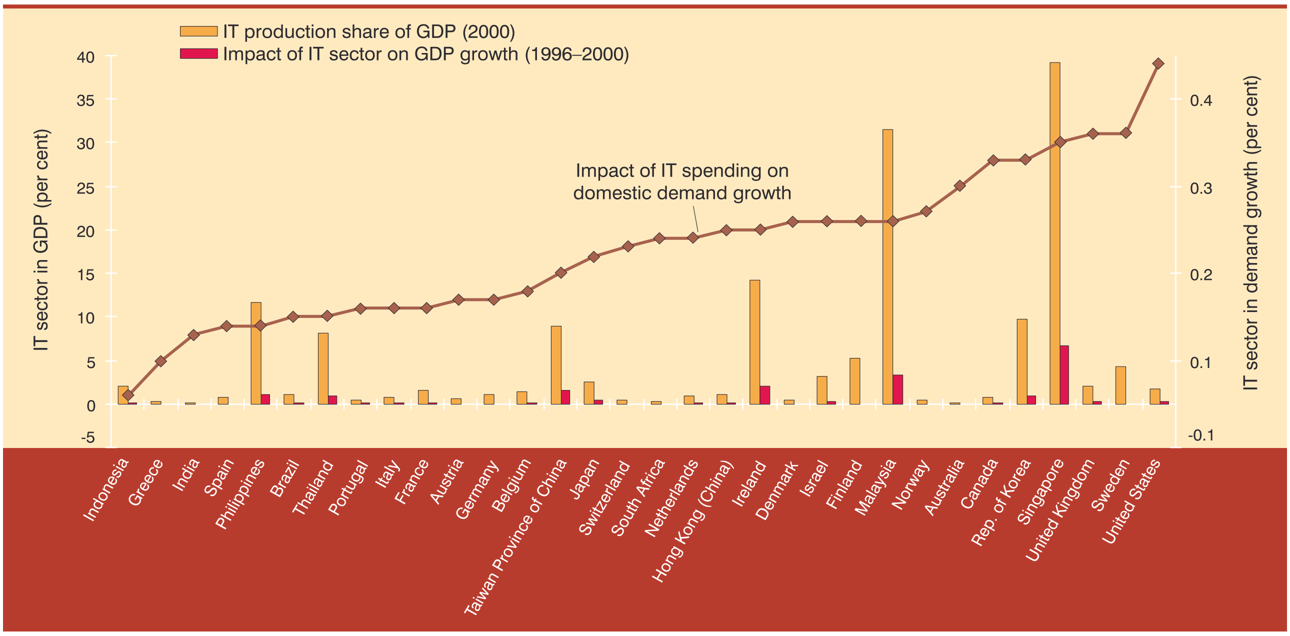
In a debate initiated by Gordon (1999), researchers asked whether there was proof of gains from the widespread use of ICTs in addition to gains to GDP from rapid technological advances in the ICT-producing sector. For the United States economy, Stiroh (2002) showed that gains from ICT investment in a broad range of economic sectors were positive and complementary to gains from the ICT-producing industry itself. Furthermore, in a comprehensive empirical study at the sectoral level comparing productivity growth in the United States with that in the European Union, van Ark, Inklaar and McGuckin (2003) found that the faster productivity growth in the United States is explained by the larger employment share in the ICT-producing sector and productivity growth in services industries with a highly ICT-intensive profile. Accordingly, wholesale and retail trade and the financial securities industry account for most of the difference in aggregate productivity growth between the EU and the United States.

This debate is of relevance to development because in many developing countries ICT investment has remained largely concentrated in the ICT-producing sector. Several studies[16] have shown that while in developed countries, the impact of ICT use was an important element accounting for growth, in most developing countries productivity gains were generated predominantly by the ICT-producing industry itself. On a global scale, developing countries managed to attract investment and started to produce a large share of global ICT goods and services. However, demand for ICTs originated predominantly from developed countries. This pattern has recently changed in the case of certain developing countries. For example, after a rapid development, China became in 2006 the world's second largest importer of ICT goods, with a large share of those imports originating from developing economies of Asia (see chapter 2).

Bayoumi and Haacker (2002) compared gains to real GDP from the IT-producing sector with gains to total consumption from domestic IT spending (1996–2000).[17] They found that several developing economies received a smaller demand boost from IT spending even if they were relatively specialized in IT production (chart 3.3). Because ICT use in several developing economies is limited to a few economic sectors those economies gained less from ICT. A comparison between developed and developing ICT producers in chart 3.3 shows that IT spending had a proportionately greater impact on demand in Ireland and Finland as compared with the effect in the Philippines and Thailand, for example. Among developing countries specialized in the production of ICTs, the Republic of Korea, Singapore and to a certain extent also Malaysia had a larger contribution of IT spending to domestic demand growth. However, as the authors suggest,

Chart 3.3

Impact of the IT sector on GDP growth and domestic demand, 1996–2000



Note: The definition of IT used here includes hardware, software and telecommunications equipment.

Source: Bayoumi and Haacker (2002).

developing countries gained from IT mostly as IT producers, while developed countries gained relatively more as IT consumers.

There are several factors that can explain why firms in developing countries use ICT less. Data on ICT use by firms in Thailand (see section D), for example, show that the main factors hindering the adoption of ICT applications are high costs and lack of knowledge about how to apply ICTs for improving performance in a particular type of business. Undoubtedly, the lack of knowledge about how to apply ICT to business goes hand in hand with the reduced size of e-markets in specific sectors. Certain domestic producers continue to be confronted with lower levels of ICT penetration among domestic suppliers and consumers. Owing to lack of knowledge about how to implement ICT in order to boost sales, domestic producers find it best to refrain from adopting ICTs. Furthermore, data on Thai firms show that exporting firms connect their computers to the Internet and establish web presence more often than firms producing for domestic markets, so as to access information and reach consumers in foreign markets. This is confirmed by research findings in Clarke and Wallsten (2004), which show that the Internet affects exports from developing countries in an asymmetric manner. Their study measures ICT adoption by the number of Internet users within a country (the Internet penetration rate). They find that developing countries with higher Internet penetration rates tend to export more merchandise to partners from developed countries, while there was no significant relationship between Internet access and trade in goods between developing countries. This finding indicates that in developing countries the Internet has been used more effectively in trade relations with developed countries.

3. ICT impact on total factor productivity growth

Models reviewed in this section estimate a two-sided impact of ICT on labour productivity growth: the effect of ICT capital investment as an additional input into production, and the share of total factor productivity growth explained by technological change in the ICT-producing sector.

Atkinson and McKay (2007) describe three ways in which ICT can contribute to total factor productivity: network externalities, complementary improvements generated by ICT adoption, and improved access to knowledge. All three suggest that the positive effect of ICTs on productivity will occur with a time lag. ICTs can generate network externalities in the same way as connecting a popular service provider to the telephone network will increase the satisfaction of all telephone subscribers. However, it goes without saying that building valuable networks of ICT users takes time and the process is not without difficulties. For example, the different technologies involved are not always compatible and interconnections may fail. The same applies to organizational change – which is costly, time-consuming and sometimes unsuccessful – and also to accessing information: not all ICTs are equally user-friendly and users may find it hard to identify the best source of information available.

Estimates of the effect of ICT on total factor productivity growth are provided either by growth accounting models or by other regression models explaining total factor productivity growth. As seen in the introduction of this Report, total factor productivity growth reflects technical change in the economy that cannot be explained by mere increases in capital and labour, but it also captures other factors such as policy and institutions. There are several ways in which ICTs could contribute to total factor productivity growth, but so far there is no agreement on the size of this contribution. More rapid technological progress in the ICT-producing sector is one way in which ICTs influence total factor productivity. For example, Oliner and Sichel (2002) ran a sectoral growth accounting model on data corresponding to the non-farm business sector in the United States and found that both the contribution of IT use to labour productivity and the total factor productivity growth arising from the IT-producing sector are positive and statistically significant. Table 3.2 provides a summary of their results. Accordingly, IT capital investment accounted for the larger share of labour productivity growth in the United States through a general IT capital deepening effect in several economic sectors. The IT-producing sector had a relatively lower contribution to labour productivity in the United States, which was above all influenced by productivity gains in the semiconductor industry.

Other growth accounting exercises were performed with European data (van Ark et al., 2003) and with East Asian data (Lee and Khatri, 2003). As the results in chart 3.4 indicate, the ICT-producing sector had a sizeable positive effect on total factor productivity growth in several East Asian economies specialized in the production of ICT, and also in Ireland. In those economies, productivity growth in the ICT sector was the main source of technological improvement and

Table 3.2

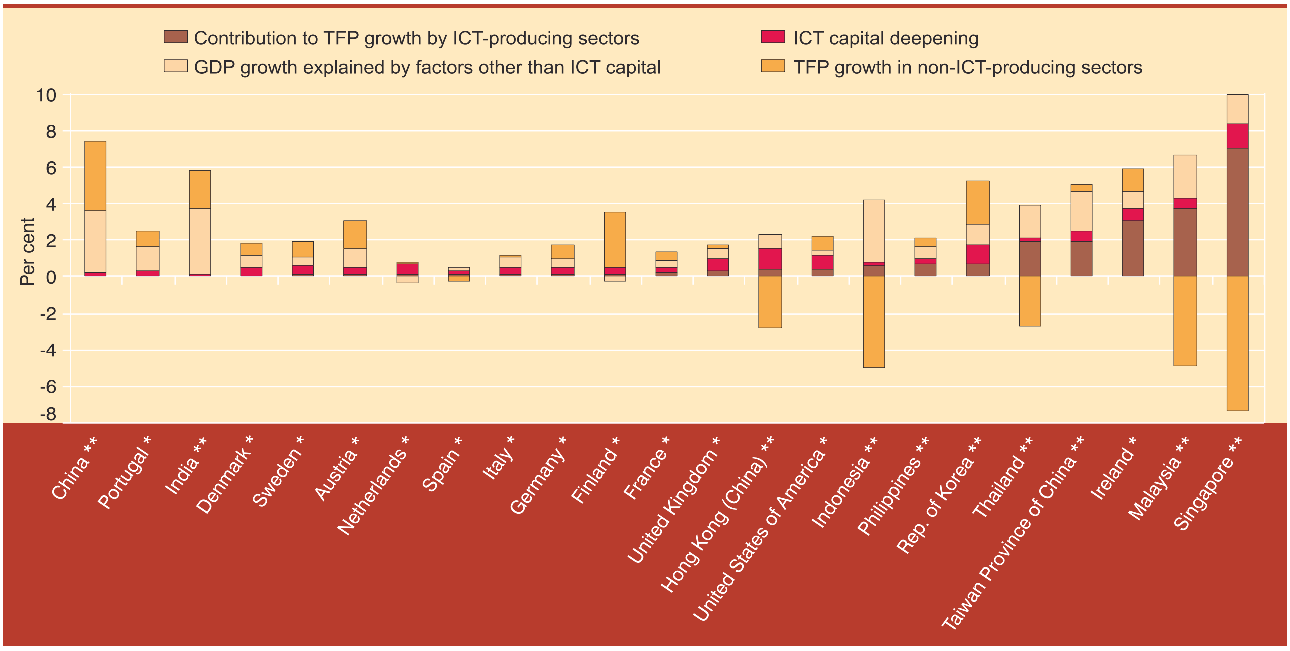
Oliner and Sichel (2002) estimates for the IT contribution to labour productivity growth in the United States (per cent)

	1974–1990	1991–1995	1996–2001
Growth of labour productivity (non-farm business sector)	1.4	1.5	2.4
Percentage contributions from:			
• IT capital (IT capital deepening), of which:	0.4	0.5	1.0
Computer hardware	0.2	0.2	0.5
Software	0.1	0.2	0.4
Communication equipment	0.1	0.1	0.1
• Other capital (capital deepening)	0.4	0.1	0.2
• Labour quality	0.2	0.4	0.3
• Total factor productivity (TFP), of which:	0.4	0.6	1.0
IT-producing sector contribution to TFP, of which:	0.3	0.4	0.8
Semiconductors	0.1	0.1	0.4
Computer hardware	0.1	0.1	0.2
Software	0.0	0.1	0.1
Communication equipment	0.0	0.1	0.1
Other sectors	0.1	0.2	0.2
Total IT contribution to labour productivity	0.7	0.9	1.8

Source: Oliner and Sichel (2002).

Chart 3.4

Contribution of ICT capital to labour productivity, and of ICT production to total factor productivity



Note: Countries are in increasing order of the contribution of the ICT-producing sector to total factor productivity growth. An ICT-related TFP growth estimate was not available for China.
Source: * van Ark et al. (2003) for 1995–2000; ** Lee and Khatri (2003) for 1995–1999.

gains to GDP from ICT production exceeded gains from ICT use (capital deepening).

Research has also investigated whether ICT-using industries have contributed to total factor productivity growth. Schreyer (2000), for instance, developed a growth accounting model in which ICT capital contributed to GDP growth through both capital deepening and spillover effects as a source of technological improvement. However, to date there is no agreement about whether ICT investment has a significant effect on total factor productivity growth in developing countries. More research is needed on this topic.

There is an emerging literature attempting to estimate the contribution of ICT to total factor productivity growth in developing countries. For example, Shiu and Heshmati (2006) estimated the impact of foreign direct investment and ICT investment on total factor productivity growth in China over the last decade (1993–2003). While Chinese total factor productivity grew at an average rate of 8.86 per cent to 9.22 per cent during that decade, ICT investment was found to contribute to it to a lesser extent: a percentage increase in ICT investment resulted in 0.46 per cent total factor productivity growth, compared with foreign direct investment that generated 0.98 per cent.

Seo and Lee (2006) estimated a model of total factor productivity growth during 1992–1996 in 23 OECD and 15 non-OECD developing economies as a function of GDP growth, human capital, openness, domestic ICT capital intensity, ICT spillover effects and a linear trend. In their model, ICTs can have a double effect on total factor productivity growth – through higher domestic investments and through network effects. The ICT network variable is calculated as the ICT capital intensity of foreign countries. Their analysis compared two samples of OECD economies and developing economies.[18] Findings suggest that in developed economies total factor productivity growth is more strongly correlated with domestic ICT investments, while in developing countries it is not significantly linked to domestic investments in ICT but rather to ICT investments in OECD countries.

The results reviewed confirm that gains from ICT to GDP occurred both in developed and in developing countries, with a lower intensity in countries that started to invest in ICT later and at a slower pace. The positive macroeconomic impact of ICT coincided with a marked contribution to growth deriving from other factors such as increased ordinary capital investment, improved skills and a better allocation of resources. A number of developing countries, particularly Asian ones, have specialized in the production and exporting of ICTs. As a result, it is estimated that ICT production increased GDP by as much as 7 per cent in Singapore and 3 per cent in Malaysia yearly (1996–2000). Developed countries gained more than developing countries from the consumption of ICTs. In terms of impact of ICT investment on total factor productivity, as a sustainable factor for growth, research results do not always confirm the existence of significant effects. However, when a positive effect is verified, it is explained by a more efficient use of ICT in specific sectors (the case of wholesale and retail trade services in the United States). It is therefore necessary to study in detail how the specific use of ICT leads to greater business efficiency.

The next section looks further at how private firms have managed to leverage gains from ICT use.

C. Firm-level impact of ICTs

This section draws on a growing number of empirical studies at the firm level conducted in a number of OECD countries. Annex 3.1 provides a summary of results in selected research on ICT and productivity. In the context of the Partnership on Measuring ICT for Development, several international institutions have pledged to work on improving the information available on ICT measurement and the quality of the data, and to make ICT statistics cross-country-comparable. As the next step, the OECD and Eurostat are promoting research to estimate the economic impact of ICTs at the macroeconomic, industry and firm levels. Initiated in 2003, the EU KLEMS project aims at building a comprehensive time series database, including measures of economic growth and productivity derived through the use of growth accounting techniques.

Through the Partnership on Measuring ICT for Development, UNCTAD has worked to improve the measurement of ICT use by businesses in developing countries. In those countries there is little research estimating the impact of ICT on production efficiency at the firm level. In order to conduct that type of study, statistical offices or research institutes need to collect data on the use of ICTs[19] and link this information with output and productivity data at the firm level. While several developing countries have made important progress in measuring and producing data on ICT use, linking this information to other economic variables often has remained a challenge.

Investing in ICTs makes a difference to firms' sales and labour productivity. Although ICT investment cannot confer long-term competitive advantage, not investing in ICT clearly leaves firms at a disadvantage (Carr, 2004).

Several recent studies[20] highlight the need to complement data on ICT investment with more information on the way in which firms use specific ICT. Particularly in a developed country context, investment in ICT has become nearly universal and spending more on acquiring additional and more complex technology may not lead to increased market shares in firms (Carr, 2004). Accordingly, it became increasingly relevant to study the way in which ICT use by firms is related to higher sales per employee. In developing countries, the percentage of companies with access to ICTs remained lower on a national scale (see chapter 1), even though for certain economic sectors or geographical regions indicators showed higher ICT penetration. Further to the overview of the modelling framework, section D presents an empirical application quantifying the relationship between ICT and labour productivity in a large sample of Thai manufacturing firms. In developing countries as well, more information on the way in which specific ICTs are used by firms can help in assessing the relationship between ICT and productivity. UNCTAD recommends that countries give priority to gathering statistical data on the core ICT indicators (United Nations, 2005).[21]

1. ICT use and firm labour productivity

The different dimensions of firm-level analyses considerably increase the complexity of research results on this topic. If previously presented models focused mostly on ICT investments, the studies reviewed here go into greater detail about specific ICT technologies or applications and interactions between them. Moreover, variables on ICT use have different productivity effects in conjunction with other control measures such as firm age, the share of foreign capital participation or access to more skilled human resources. To make it easier to keep track of the different empirical model variants, this section groups the many dimensions into three categories, by elements of the regression equation (table 3.3).

Labour productivity is commonly measured either as value added per employee or as sales per employee. Criscuolo and Waldron (2003) derive results for both measures of productivity and find that the impact of e-commerce[22] was slightly stronger on value added than on sales. Conversely, Atrostic and Nguyen (2002) rely on the findings of Baily (1986) to argue that using value added as a measure of labour productivity yields systematically biased estimates of the theoretically correct growth model. Outside the context of empirical models, value added is a more precise measure of labour productivity since it subtracts from the value of sales the costs incurred with intermediate consumption. However, as suggested by Carr (2003), firms take

Table 3.3

Key variables for measuring ICT impact on labour productivity

Labour productivity variables	ICT variables	Complementary / control variables
• Sales per employee • Gross output per employee • Value added per employee • Or recalculations of the above variables based on effective hours worked by employees	Binary (dummy) variables: these take on value 1 if the firm has access to a specific technology and 0 otherwise. Numerical variables: • Spending on specific ICTs • ICT capital stock • Share of employees using ICTs • Number of computers available in the firm	• Firm age • Ownership • Affiliation to a multi-unit firm • Skill mix (share of employees working directly in production) • Level of education • Industry sector of activity (corresponding to ISIC codes) • Geographical region • Typical factors of Cobb–Douglas production functions (ordinary capital stock, employment, spending on materials)

decisions to adopt ICTs on the basis of expectations about maintaining or increasing market share and competitiveness. For those considerations, analysing about the impact of ICT on sales per employee is more appropriate.

The empirical models presented here draw on several types of variables for describing the use of ICT. Binary variables, which distinguish between firms with and without access to, for example, Internet, are easy to collect and provide input for analyses of differences between the haves and the have nots. Empirical studies also test for the effect of intensity in ICT uptake – for example, the share of capital devoted to computer investments – and intensity of ICT use, such as the number of computers available or the share of employees using e-mail. From a theoretical point of view, findings based on numerical rather than binary variables are more powerful. Maliranta and Rouvinen (2006) proposed a slightly different modelling structure in which they estimate the net effects of several complementary features of computers: processing and storage capacity, portability and wireless and wireline connectivity. In their model, the positive labour productivity effect associated to the portability of computers is complementary to that of the basic processing and storage capacity of any computers whether portable or not.

The different variables of intensity in ICT use by enterprises analysed by the specialized literature are not the ideal measurements. As some have emphasized,[23] ICT use becomes increasingly relevant to productivity when combined with soft skills such as good management and superior marketing abilities. Unfortunately, such soft skills and soft technology inputs cannot be quantified directly and therefore their effect is hard to assess. Empirical research usually corrects for this unknown effect by accounting for different economic results in foreign-owned firms, in exporting companies, in establishments belonging to multi-unit corporations or simply in more experienced firms. Therefore, policy implications derived from such research do not directly recommend that the intensity of ICT use be scaled up (for example by increasing the number of computers per employee). Rather they recommend investigating how the combined use of ICT and superior managerial capabilities can account for variations in ICT gains between firms with different characteristics.

ICTs can generate higher market shares either by reducing input costs and thus allowing firms to produce more of the same products, or by improving the quality of products or product packages, with, as a result, additional sales or higher-priced products. Empirical results presented here cannot distinguish between those two effects. More information on the evolution of prices in different sectors is needed in order to assess which effect prevailed in defined periods of time.

2. Complementary factors explaining the ICT–productivity relationship

Control variables are additional elements in the growth equation. They also give a different dimension to results relating to ICT use and productivity when interacted with measures of ICT.

In several studies, firm age has proved to be an important element explaining productivity effects. The European Commission's Enterprise and Industry Directorate General showed in a report (Koellinger, 2006) that the dynamic evolution of new firms is a source of economic growth and employment and that new firms also contribute significantly to the diffusion of e-business applications in Europe. In terms of econometric results, Maliranta and Rouvinen (2003) estimate that young manufacturing firms in Finland, unlike older ones, have 3 per cent higher productivity gains from the use of computers. Also, young Finnish services firms appeared to be 1 per cent more productive thanks to access to the Internet. In a different study, Farooqui (2005) runs four different growth models on young and older British firms in manufacturing and services taken separately. Results show that ICT indicators such as investment in IT hardware and software and the share of ICT-equipped employment have a more pronounced impact on young manufacturing firms as compared with older ones. The same finding did not apply to young British services companies, however, on that issue, Atrostic and Nguyen (2005) draw attention to the fact that the measure of capital input used in most papers – the book value of capital – is a more accurate proxy in the case of the new firms. Older firms' capital input is not properly captured by book values because this measure is evaluated at initial prices when capital assets were acquired as opposed to current asset prices. The first best proxy to use would be the current value of the capital stock computed by means of the perpetual inventory method by using information on yearly capital investments, depreciation and current asset prices. But in many cases, data are not available on all the above-mentioned variables. Regression results using the book value of capital assets are likely to give biased results for older firms and more accurate results for younger ones.

Firms with foreign capital participation seemed to have higher labour productivity. With regard to developed countries, Bloom, Sadun and van Reenen (2005) estimated that in their large sample of UK firms from all business sectors, US-owned establishments had significantly higher productivity gains from IT capital than other foreign-owned firms or domestically owned firms. This result can be linked with macro-level findings which indicated that the United States had acquired greater labour productivity from investment in ICT than all other developed countries, especially since the mid-1990s. More productive US-owned firms appear to be better managed or have access to more efficient ICT solutions.

Similarly, firms belonging to multi-unit networks of affiliates may have greater labour productivity since they dispose of additional resources to draw from in the subsidiary–headquarters management structure. A multi-unit corporate configuration may justify benefits from network effects (a success story replicated in several subsidiary branches) and access to superior management resources.

The skill mix of production and non-production workers and the level of education in the regions where companies are located were considered by some studies to be complementary to the measures of ICT use by firms. Better-skilled workers are more likely to be able to develop, use and maintain more advanced technology. Maliranta and Rouvinen (2003) comment that growth models need to control for the human capital characteristics of employment and labour because these variables are essentially complementary to ICT uptake and omitting them would inflate the labour productivity gains from ICT.

Last but not least, when quantifying the relationship between ICTs and labour productivity one needs to control for differences in demand and supply factors. For example, in many countries businesses located in the vicinity of the capital benefit from higher demand than those located in isolated provinces simply because there is a high concentration of the population in capitals. In a similar way, different industries have distinct labour productivity averages owing to both demand and supply factors. For example, an oil-producing company is very likely to have higher sales per employee than a light industry manufacturer specialized in food and beverages of the same size (because of industry characteristics such as price, labour intensity and type of consumer good). It is therefore necessary to take into account regional and industry-specific characteristics when accounting for the contribution of ICT to labour productivity growth.

The ICT-producing sector itself benefited from ICT use that considerably exceeded domestic industry averages. Maliranta and Rouvinen (2003) estimate that in Finland firms belonging to the ICT-producing sector had 3 to 4.5 per cent higher labour productivity gains from ICT use than the rest of the manufacturing and services companies in the sample. This may be because ICT producers have a know-how advantage over other ordinary users in terms of how to best put to work specific technology to enhance labour productivity.

3. Impact of specific ICTs on productivity

Use of computer networks (such as the Internet, intranet, LAN, EDI and Extranet) had an estimated 5 per cent positive effect on labour productivity in a large sample of American manufacturing businesses (Atrostic and Nguyen, 2002). The model considered a theoretical framework in which use of computer networks made a "disembodied" contribution to technological change other than that of capital and labour. Atrostic and Nguyen (2005) take up again the impact of computer networks in a slightly modified empirical model. The novelty of their approach consists in using two different computer-related measures in the labour productivity regression: computer capital, as distinct from ordinary capital, and the computer network binary variable used previously. In their view, having separate measures for the presence of computers (computer investment) and for how computers are used (computer networks) is crucial for estimating accurately the two effects on labour productivity. When using a sample composed only of newly registered US manufacturing firms, they find that the contribution of computer networks added 5 per cent to labour productivity while investment in computers added 12 per cent. Within the entire data set of older and younger US manufacturing firms, the contribution of computer capital dropped to 5 per cent and there was no evidence of a positive effect on computer networks any more. However, as mentioned before, most empirical studies tend to find that ICT use has less impact on older manufacturing firms, and this may be due to a measurement bias as explained in Atrostic and Nguyen (2005).

E-commerce also has a significant impact on labour productivity in firms, with a marked difference between businesses that buy and those that sell online.

Criscuolo and Waldron (2003) analyse a panel of UK manufacturing firms and find that the positive effect of placing orders online ranged between 7 and 9 per cent. On the other hand, they estimate that firm labour productivity was lower 5 per cent for those that used e-commerce for receiving orders online (online sellers). Lower labour productivity associated with selling products online is likely to be due to price effects. The prices of products sold online are considerably lower than the prices of similar goods sold through different channels. Additionally, firms which specialize in selling online may have difficulties in finding suppliers from which to buy online as much as they would want. Larger firms with a stronger position in the market may be able to better cope with balancing the extent of e-buying and e-selling. In a larger and updated UK data set of manufacturing and services firms, Farooqui (2005) finds again that e-selling negatively impacts on labour productivity in manufacturing, while e-buying has a larger and positive effect. In particular, Farooqui (2005) finds that in distribution services e-buying boosts labour productivity by 4 per cent.

Several studies show that measures of ICT use by employees are also reflected in enhanced firm productivity. Within a large panel of Finnish firms Maliranta and Rouvinen (2003) compare the impact of computer use on labour productivity in manufacturing and services sectors. A 10 per cent increase in the share of computer-equipped labour raises productivity by 1.8 per cent in manufacturing and 2.8 per cent in services. On the other hand, a higher share of employees with Internet access was found to have a significant impact only on services firms (2.9 per cent). The study considers Internet use as a proxy for external electronic communication and LAN use as a measure of internal electronic communication. Findings show that manufacturing firms benefit more from better internal communication, while services firms gain more from improved external electronic communication. A 10 per cent higher share of employees using LAN in the manufacturing sector results in 2.1 per cent higher labour productivity. A similar study on a mixed sample of Swedish manufacturing and services firms estimated that a 10 per cent higher share of computer-equipped labour boosts productivity by 1.3 per cent (Hagén and Zeed, 2005). The Swedish study also estimates productivity effects deriving from access to broadband of 3.6 per cent. With the help of a composite ICT indicator, Hagén and Zeed (2005) show that adopting an ever-increasing number of ICT solutions has positive but decreasing effects on labour productivity in Swedish firms. Each additional level of ICT complexity seems to add less to firm productivity. Farooqui (2005) also identifies the use of computers and the Internet by employees as a proxy of work organization and skills. In the United Kingdom, a 10 per cent increase in the share of employees using computers raised productivity by 2.1 per cent in manufacturing and 1.5 per cent in services. These effects are additional to the impact of ICT investment, also accounted for in the Farooqui (2005) model. Similar estimates for Internet use by British firm employees showed 2.9 per cent for manufacturing and no significant impact for services.

Maliranta and Rouvinen (2006) estimate the impact of different complementary computer features on labour productivity in a 2001 sample of Finnish services and manufacturing firms. Their computer variables are measured in terms of share of employees using computers with one or several of the following features: processing and storage capabilities, portability and wireline or wireless connectivity. They find that a 10 per cent higher share of labour with access to basic computer attributes such as providing processing and storage capabilities increases labour productivity by 0.9 per cent. In addition, computer portability boosts output per employee by 3.2 per cent, wireline connection to the Internet adds 1.4 per cent, while wireless connectivity adds only 0.6 per cent.

There is an emerging literature estimating the impact of broadband on firm productivity. Gillett et al. (2006) were the first to quantify the economic impact of broadband and found that there were positive and significant effects on the number of workers and the number of businesses in IT-intensive sectors. Chapter 6 of this Report reviews the economic impact of mobile phones, with a focus on the African region.

4. ICT investment, soft technologies and total factor productivity gains

Brynjolfsson and Hitt (2002) explore the impact of computerization on multi-factor productivity and output growth in a panel data set of 527 large US firms over a period of eight years (1987-1994). They compare the short-run and long-run effects of computerization on total factor productivity growth by taking first and five- to seven-year differences of the log-linear output function. The aim of their analysis is to understand the mechanism through which private returns from computerization accrue, since they are the ultimate long-run determinants of decisions to invest in ICTs.

They model production as a function of computer capital and other inputs, and assume that in the presence of computers, the efficiency of employees, internal firm organization and supply-chain management systems are improved. They find that, in the short run, investments in computers generated an increase in labour productivity primarily through capital deepening, and found little evidence of an impact on total factor productivity growth. However, when the analysis is based on longer time differences, results show that computers have a positive effect on total factor productivity growth. In the long run, the contribution of computer capital to growth rises substantially above computer capital costs, and this is then reflected in terms of total factor productivity. Their interpretation is that computers create new opportunities for firms to combine input factors through business reorganization. Brynjolfsson and Yang (1999) had previously estimated that computer adoption triggers complementary investments in "organizational capital" up to 10 times as large as direct investments in computers.

More research, based on developing country data, is needed in order to ascertain how and when ICT use increased production efficiency in firms and which ICT was used. A comparison of estimation results across different countries, industry sectors and technologies can provide policymakers with additional information for fine-tuning ICT policy master plans. As an illustration, section D presents the results of a firm-level growth model for manufacturing firms in Thailand.

D. Measuring ICT use and productivity in Thai manufacturing firms

1. Background and objectives of the project

Measuring ICT access and use is an important element in the Thai national ICT policy. ICT indicators chosen were ones that made it possible to provide the necessary data to monitor progress in the Thai ICT Master Plan, to compare with ICT developments in other countries and to help in further policy decision-making (Smutkupt and Pooparadai, 2005). To analyse and monitor ICT use by businesses, the National Statistical Office (NSO) of Thailand gathered a valuable pool of information through a series of surveys such as the ICT Survey (2004 and 2005), the Manufacturing Industry Survey (1999, 2000 and 2003) and the Business Services Survey (1999 and 2003). More than 66,000 firms were covered in the general ICT Survey 2005, approximately 8,800 manufacturing firms in the Manufacturing Survey 2003 and some 25,000 services firms in the Business Services Survey 2004. The information provided by those surveys helped build up a thorough description of the main recent patterns of ICT use in the Thai economy at a microeconomic level.[24] On the basis of the information provided by the surveys, the Thai NSO has published yearly reports describing in detail the use of ICT by the whole economy, by sectors of economic activity and by regions.

Using a firm-level data set of combined ICT uptake and several economic variables, the NSO and UNCTAD have conducted a joint research project. A well-known empirical model (the Cobb–Douglas production function) was used to assess the relationship between ICT use and productivity of Thai manufacturers. In that context, UNCTAD has conducted a training course for NSO staff on applying econometric methods to ICT data analysis and provided additional technical assistance to facilitate the analysis throughout the research phase. On the Thai side, the impact analysis was carried out by the NSO's Economic Statistics Analysing and Forecasting Group. The study is one of the first using official data from a developing country to analyse the economic impact of ICT in the business sector.[25]

The aim of the project was to evaluate the intensity of ICT use by firms and to quantify empirically the relationship between ICT uptake and productivity in a developing country. More specifically, the project aimed at studying the link between ICT use in firms and labour productivity by applying the theoretical framework used by similar studies conducted with developed country data. The relationship between ICT use and economic efficiency in firms has different magnitudes, depending on a series of factors specific to the economic environment and time span under consideration. For example, as suggested by other studies (in section C), ICT uptake is reflected in higher productivity gains at the firm level when complemented with superior know-how and managerial skills. Therefore, the analysis also identified differences in the ICT use–productivity relationship based on geographic location, industry sector, firm size and age.

To study the relationship between ICT uptake and economic output it is necessary to bring together ICT and economic variables in a firm level-data set. This was possible only for a 2002 cross-section of Thai manufacturing firms. The empirical study was therefore limited to the available sample of data. When more data become available, research could be based on larger data sets with information on more years and sectors.

The first part of this section reviews the use of basic ICTs such as computers, the Internet and the web by Thai manufacturing firms. That is followed by a brief presentation of the theoretical framework employed in the econometric application. The study ends with a detailed presentation of empirical results, a summary and conclusions.

2. ICT use by manufacturing firms in Thailand

The Manufacturing Industry Survey 2003 covered a large sample of more than 8,800 firms representative of the Thai manufacturing sector of approximately 360,000 establishments. By using weights corresponding to a stratified sampling by regions, employment size and industry sectors it was possible to represent the characteristics of the entire population[26]. The information provided below illustrates the use of ICTs in Thai manufacturing firms in 2002[27].

The study took into account small, medium-sized and large manufacturing firms with more than 10 employees. In the Thai manufacturing sector firms with more than 10 employees account for 98 per cent of revenues and 96 per cent of value added. This characteristic is common in other economies as well[28] and usually research is conducted separately for micro-enterprises (fewer than 10 employees).

Among firms with more than 10 employees, 60 per cent use computers, 35 per cent access the Internet and 12 per cent have a website presence (table 3.4). According to the sample information, 99 per cent of the firms with access to the Internet also had computers on their premises; similarly, all businesses present on the web also had Internet access. The analysis therefore compared the economic performance of firms not using ICT with that of firms using computers, firms using both computers and the Internet, and firms using computers, the Internet and the web[29]. Accordingly, there is a gradual increase in the share of businesses with website presence, Internet access and computers (table 3.4). Many more firms employ computers in their daily routine work and considerably fewer have a website presence.

Adoption of websites by Thai manufacturers was at an early stage in 2002. Even among Internet-connected firms relatively few had opted in favour of a website presence (slightly more than one third). A considerable proportion of large firms that had computers and Internet connection had not established a web presence (27 per cent of businesses with more than 1,000 employees).

In larger firms with computers, access to the Internet was more often available than in smaller firms using computers. This may suggest that cost factors prevented

Table 3.4

Computer, Internet and website presence in Thai manufacturing businesses

Proportion of businesses using computers	59.8
Proportion of businesses using the Internet	35.1
Proportion of businesses with a web presence	12.3
Proportion of businesses connected to the Internet among businesses using computers	58.3
Proportion of businesses with a web presence among businesses using the Internet	35.2

Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Table 3.5

Intensity of computer use in Thai manufacturing businesses

Average number of employees using computers per 100 employees	7.8
Average number of computers per 100 employees	6.5

Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

smaller firms from connecting to the Internet even when they already had computers.

The intensity of computer use remains relatively low in manufacturing in Thailand. On average, for each 100 employees[30] there are approximately seven computers available. For each 100 employees there are on average eight that use computers regularly in their work (table 3.5). Moreover, while in smaller firms the ratio of computers to employees using computers is closer to 1, in larger firms there are relatively more employees using computers for each physical computer machine. In other words, on average, there are more employees using computers than available computers. This suggests that Thai firms have, to a certain extent, valuable human capital resources (i.e. computer-literate staff) that would allow them to increase the use of computers.

Larger firms have on average more computer resources available per employee. A comparison with information from the ICT survey of all economic activities in Thailand shows that in manufacturing, firms use computers less intensively than in services, where businesses have more computers available per employee.

Most businesses connect to the Internet through regular ISP subscriptions (52 per cent of businesses) or through prepaid Internet packages (51 per cent of businesses) (table 3.6). Internet cafés are not a common solution for accessing the Internet since only 3 per cent of businesses choose it. Prepaid Internet packages and Internet cafés are modalities for Internet connection that are more often used by small firms.

Table 3.6

Modality of Internet connection (in manufacturing businesses using the Internet)

Proportion of businesses accessing Internet through ISP subscriptions	51.7
Proportion of businesses accessing Internet through Internet cafés	3.3
Proportion of businesses accessing Internet through prepaid Internet packages	50.7
Proportion of businesses accessing Internet through other modalities	3.9

Note: Shares presented here do not add up to 100 per cent. A firm could access the Internet in different ways.

Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Table 3.7
Type of activity performed while using the Internet (in manufacturing businesses using the Internet)

Proportion of businesses sending and receving e-mail	84.7
Proportion of businesses obtaining information	85.2
Proportion of businesses placing orders online	47.4
Proportion of businesses carrying out business promotion	23.6
Proportion of businesses performing other activities	5.7

Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Table 3.8
Type of activity performed on the web (in manufacturing businesses with web presence)

Proportion of businesses advertising own business	83.1
Proportion of businesses receiving orders online	52.3

Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Manufacturing firms with Internet access indicated that they used it mainly for retrieving information (85 per cent) and e-mailing (85 per cent) (table 3.7). Only a limited number of businesses engage in other Internet activities such as placing orders online (48 per cent) and business promotion (24 per cent). Information search was the most popular activity on the Internet for all size groups, but larger firms were able to engage in it more often than smaller firms. Large and middle-sized firms used the Internet more often for e-mailing compared with small firms.

Manufacturing firms with a website presence use it mostly for advertising their business (83 per cent) and less for selling goods and services online (52 per cent) (table 3.8).

Analysing the use of ICT in micro-enterprises was beyond the scope of this study. While overall in micro-firms ICT penetration rates are considerably lower, there are aspects where the use of ICT differs between micro-enterprises and the rest of the firms (for example, a larger share of micro-firms uses web presence for advertising their business). A separate study could further analyse the economic implications of ICT in micro-enterprises.

Economic performance is stronger in firms that use ICT and even more so in firms that use a combination of several ICTs. Manufacturers using computers have on average 10 times higher sales per employee than manufacturers without computers (chart 3.5). The order of magnitude is higher when comparing sales per employee in firms with and without a website presence.

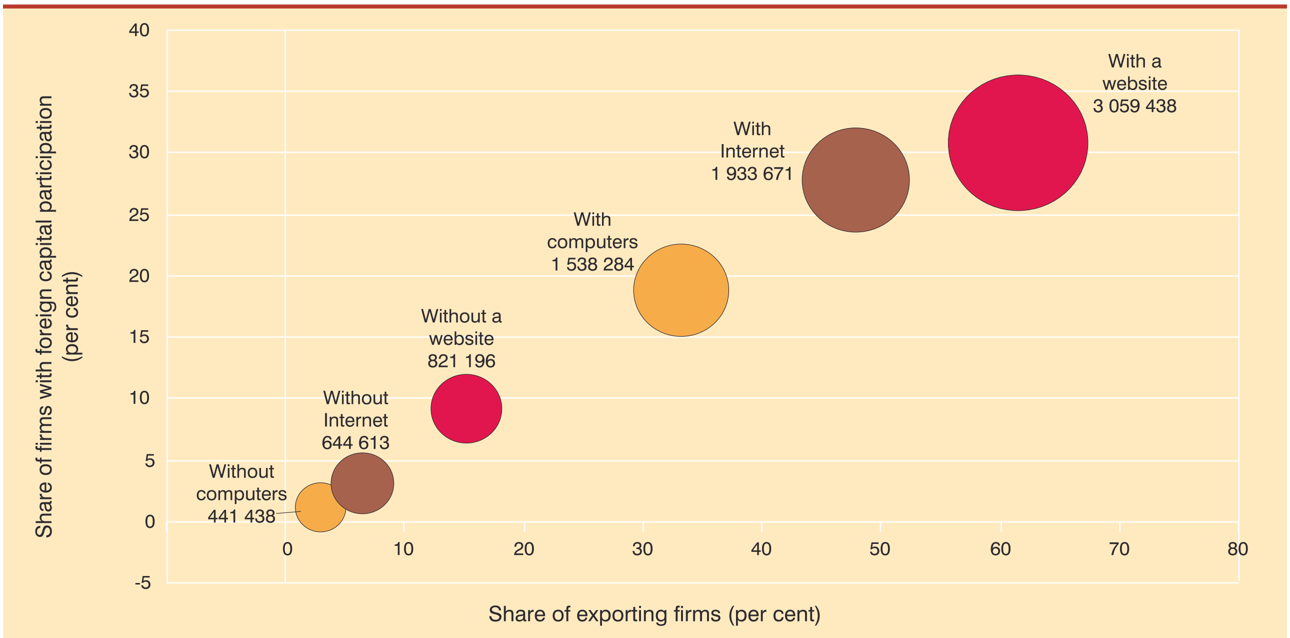
In 2002, exporting firms generated three quarters of total sales in the Thai manufacturing sector, while firms with foreign capital participation accounted for 62 per cent of that total industry revenues. There were very few Thai manufacturing firms without computers that were able to export or to attract foreign capital investment. On average, of 100 exporting Thai manufacturers, 91 had at least one computer, 77 were also connected to the Internet and only 35 had a website presence.

Chart 3.5 illustrates average sales per employee in firms with computers, Internet and web presence in terms of their export position and foreign capital participation. A typical manufacturer with at least one computer receives revenues of 1,538,284 baht per employee yearly. A total of 33 per cent of businesses with computers are exporters and 19 per cent benefit from foreign capital participation. This confirms that computers are distributed through Thai manufacturing and are not used exclusively by foreign-owned firms or by exporting firms.

Among firms with Internet access and website presence, exporting and foreign-owned firms had a higher

Chart 3.5

Average sales per employee in manufacturing Thailand (baht per employee)



Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

participation. A typical manufacturer with at least one computer connected to the Internet earns on average more than firms with computers only (1,933,671 baht per employee); but 48 per cent of Internet-connected businesses are exporters and 28 per cent receive foreign capital. The shares of exporting and foreign-owned firms are even higher among website-present manufacturers (61 per cent and 31 per cent). This suggests that websites are used more frequently by exporting firms, possibly for the purpose of following foreign market developments (information search).

Manufacturers with foreign capital participation do not establish web presence as frequently as exporting firms. Foreign capital participation seems to make more difference in terms of Internet access and less in terms of web presence, possibly owing to the existence of different management practices and requirements in foreign firms. The high share of exporters among manufacturers present on the web could be related to the language used or the relative scarcity of Internet content in the Thai language. However, available data provided no information on the language used by firms on the websites.

3. The model and a few theoretical considerations

The primary goal of the analysis was to quantify the relationship between ICT use and labour productivity in Thai manufacturing firms in 2002. In the analysis, which built on methods employed in similar studies, firm productivity was modelled on the assumptions of a Cobb–Douglas production function with three input factors: capital, labour and spending on materials (see box 3.1).

The analysis also identified differences based on geographical location, industry sector, firm size and age and their influence on the ICT use–productivity relationship. This was done by estimating interactions of ICT measures with control variables within the same Cobb–Douglas theoretical framework.

Box 3.1

The empirical model

The regression equation is based on a linearized version of the Cobb–Douglas function (equation 1). Labour productivity is regressed on factor inputs (capital, labour, spending on materials), one or several ICT variables and a set of controls for industry and regional attributes of demand and supply, the presence of foreign capital participation and the activity of multi-unit firms (head offices or branches).

$$\ln\left(\frac{sales_j}{L_j}\right) = \beta_0 + \beta_1 ICTVariable_j + \beta_2 \ln\left(\frac{K_j}{L_j}\right) + \beta_3 \ln\left(\frac{M_j}{L_j}\right) + \beta_4 \ln(L_j) + \beta_5 Multi\_unit_j + $$
$$+ \beta_6 Foreign\_capital_j + \sum_r \beta_r region\_r_j + \sum_i \beta_i Industry\_i_j + u_j$$

,where K is capital, L is employment and M is spending on materials. (equation 1)

With the data available from the Manufacturing Survey 2003 it was possible to construct two similar models based on the same Cobb–Douglas framework: one using total employment as a common denominator and the other using total effective employment. Effective employment is obtained by multiplying total employment times the declared number of hours effectively worked during 2003. Results derived from the two models could be used as a check for the robustness of the estimates. From a theoretical point of view, the effective labour productivity model is more accurate since it accounts for variations in the hours effectively worked by employees rather than assuming that all employees worked on average an equal number of hours. The model employed for effective labour productivity is described by equation 2.

$$\ln\left(\frac{sales_j}{L\_effective_j}\right) = \beta_0 + \beta_1 ICTVariable_j + \beta_2 \ln\left(\frac{K_j}{L\_effective_j}\right) + \beta_3 \ln\left(\frac{M_j}{L\_effective_j}\right) + \beta_4 \ln(L\_effective_j)$$
$$+ \beta_5 Multi\_unit_j + \beta_6 Foreign\_capital_j + \sum_r \beta_r region\_r_j + \sum_i \beta_i Industry\_i_j + u_j$$

,where K is capital, L_effective is effective employment and M is spending on materials. (equation 2)

White (1980) heteroskedasticity consistent standard deviations were calculated.

By looking at the performance of firms with and without specific ICTs the analysis was able to quantify the extent to which during 2002 Thai manufacturers with similar characteristics had higher productivity when using ICTs. Further research with comparable data on several years could investigate the impact of past decisions to adopt ICTs on current labour productivity. The analysis could not establish whether beyond correlation, there is a causal relationship between ICT use and firm labour productivity. To deal with that shortcoming, other specialized papers applied instrumental variable estimation techniques in data sets covering several years.[31]

In the light of the discussion in Atrostic and Nguyen (2002) (see section C) the preferred dependent variable for measuring labour productivity was total sales per employee.

A set of additional variables was used in each equation to control for the effect of foreign capital participation, for the multi-unit firm organizational aspect and also for unknown demand and supply factors across industries and regions. Firm age appeared not to play a significant role as a control variable for explaining variations in labour productivity. Information on firm age, however, was used for testing if among ICT users more experienced firms had superior labour productivity as compared with younger firms. Most regression estimates showed that establishments with foreign capital participation have on average 7 to 8 per cent higher sales. Firms belonging to multi-unit organizational structures have 2 to 4 per cent higher sales, presumably because they can more easily gain access to a larger pool of resources. Also, there appeared to be decreasing returns to scale: larger firms had on average 0.5 to 3 per cent lower labour productivity given the set of controls.

4. Results

Firstly, the study evaluated the relationship between computer, Internet and website presence and the value of sales per employee. The three measures of ICT were regarded as progressive steps adding to the complexity of ICT uptake since all firms using the Internet also had computers on their premises and all firms present on the web also had Internet access. Accordingly, estimates on the Internet factor are interpreted as additional to computer-related gains; similarly, website-related gains are complementary to those from Internet and computer use. Results are shown in table 3.9.

After controlling for a series of firm-specific economic characteristics, as well as industry and regional aspects of demand and supply, estimated results showed that firms with a combined use of computers, the Internet and the web had on average 21 per cent higher sales than firms without any of the ICTs considered. Among the three ICTs considered, computers contributed with 14 per cent, Internet access with 3 per cent and web presence with 4 per cent. Similar estimates were also obtained with the effective labour productivity variant of the model (table 3.9, second column). Atrostic and Nguyen (2005) estimated that in 1999 computer networks (such as the Internet, intranet, LAN, EDI, extranet or other) had a 5 per cent positive impact on labour productivity in a large sample of United States manufacturing firms. In comparison, the results derived in this study show that computer presence was more closely associated with labour productivity in Thailand than Internet connectivity.

Table 3.9

Estimation results for computer, the Internet and website presence

	OLS (White heteroskedasticity – consistent standard errors)	
Independent variables	Dependent variable: log (sales per employee)	Dependent variable: log (effective sales per employee)
	$R^2 = 0.923877$ Number of observations included: 5 877	$R^2 = 0.893852$ Number of observations included: 5 651
Computer presence	0.1359***	0.1346***
Internet access	0.0322*	0.0365*
Web presence	0.0418**	0.0491***

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

Studies based on developed country data rarely estimate the impact of computer presence on labour productivity because in many developed countries computer penetration rates in the business sector have already reached levels of as much as 95 per cent. However, in developing countries the share of firms that use at least one computer for business purposes has remained lower (60 per cent in manufacturing Thailand in 2002). Furthermore, data from the 2003 Manufacturing Survey in Thailand show that in absence of computers firms cannot access the Internet and establish web presence. This explains why in developing countries computer presence in firms is more closely related to economic performance than in developed countries.

Because the use of at least one computer seemed to account for a large share of the variation in sales per employee, it was interesting to estimate also the relationship between the intensity of computer use and labour productivity (tables 3.10 and 3.11). Results show that an increase of 10 per cent in the share of employees using computers is associated with 3.5 per cent higher sales per employee in Thai manufacturing firms. For the same variable, the estimated coefficient in Maliranta and Rouvinen (2003) was only 1.8 in a panel of Finnish firms (1998–2000). Since the variation in the intensity of computer use in Thailand was greater – with many firms not having computers – computer use was associated with larger differences in labour productivity in that country. Similarly, a 10 per cent improvement in the number of computers available per employee was correlated with a 4.5 per cent increase in sales per employee (table 3.11).

Computer intensity in firms, as captured by the number of physical computers per employee, can be interpreted as a measure of investment in computer capital.

Table 3.10

Estimation results for the share of employees using computers, the Internet and website presence

	OLS (White heteroskedasticity – consistent standard errors)	
Independent variables	Dependent variable: log (sales per employee)	Dependent variable: log (effective sales per employee)
	R^2 = 0.923260 Number of observations included: 5 863	R^2 = 0.893054 Number of observations included: 5 637
Share of employees using computers	0.3492***	0.3969***
Internet access	0.0561***	0.0582***
Web presence	0.0160	0.0229

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

Table 3.11

Estimation results for the share of computers per employee, the Internet and website presence

	OLS (White heteroskedasticity – consistent standard errors)	
Independent variables	Dependent variable: log (sales per employee)	Dependent variable: log (effective sales per employee)
	R^2 = 0.923570 Number of observations included: 5 871	R^2 = 0.893028 Number of observations included: 5 645
Number of computer per employees	0.4466***	0.5185***
Internet access	0.0545***	0.0562***
Web presence	0.0147	0.0213

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

Similarly, the share of employees using computers also represents a proxy for computer capital investment, including investment in human capital and training for work with computers. As estimates in tables 3.10 and 3.11 show, Internet access contributed as a significant factor additional to computer intensity in explaining differences in labour productivity among firms. At the same time, when accounting for the intensity of computer use, it is noted that web presence is no longer significantly contributing to higher sales per employee. This suggests that a greater intensity of computer use and Internet access are factors facilitating the decision to establish web presence in the businesses analysed.

Both the labour productivity and the effective labour productivity models produced similar estimates for the overall use of computers, the Internet and the web in Thai manufacturing firms.

The study also estimated coefficients relating labour productivity to the different modalities of accessing the Internet (ISP subscribers, prepaid Internet package, Internet café, etc.), as well as to the different activities carried out on the Internet (e-mailing, information search, placing orders online, business promotion, etc.) and on the web (advertising own business, receiving orders online). However, results did not show significant differences in the way in which those factors were reflected in the value of sales per employee. More analysis would be needed to assess the role of the different modalities of Internet access and of the different activities carried out online in explaining firms' economic performance. This was beyond the scope of the present analysis.

In the second stage, the analysis aimed at identifying firms' characteristics that influenced the relationship between specific ICTs and labour productivity. For that purpose, the regression equation was slightly modified to estimate the effect of ICT uptake in groups of firms with different size, age, located in different regions and belonging to different industry branches. The next subsection analysed whether firm size contributed to explaining the ICT–labour productivity relationship.

Differences between employment size groups

To analyse the implications of firm size in determining the ICT–productivity relationship, three employment size groups were considered: small firms (11 to 25 employees), medium-sized firms (26 to 80 employees) and larger firms (more than 80 employees). The groups chosen have equal numbers of firms. Table 3.12 summarizes the results of three different empirical specifications. In the first column the estimation model took into account information on the presence of computers in firms, Internet access and web presence. In the second and third columns additional information was included on the intensity of computer use as measured by the share of employees using computers (the third column) and the number of computers per employee (the fourth column). Accordingly, results in the first column show that Internet access matters more to labour productivity in small firms and computer presence is correlated with higher productivity in middle-sized firms, while what makes a difference in large firms is web presence. The link between ICT use and labour productivity is stronger in large and middle-sized firms, with a high contribution from the presence of computers.

The third and fourth columns of table 3.12 show the estimated relationship between the intensity of computer use and productivity. Both measures of computer intensity, the share of employees using computers and the number of computers per employee yielded similar results. Most productivity gains associated with the intensity of computer use occur in large firms. A 10 per cent higher share of employees using computers leads on average to 4.2 per cent higher sales per employee in large firms and 2.9 per cent higher sales in middle-sized firms. Similarly, 10 per cent more computers per employee are correlated with 5.9 per cent higher sales per employee in large firms and 4.3 in middle-sized firms respectively. For smaller firms, variations in the intensity of computer use did not translate into significantly greater labour productivity. Also, in accounting for the intensity of computer use, the Internet and web presence no longer had a significant effect. This indicated that most middle-sized and large firms with greater intensity of computer use also had Internet access and web presence.

Differences between age groups

Several studies reviewed in the previous section found that firm age was an additional factor explaining how much enterprises gain from ICT. To analyse whether the same effect appeared in manufacturing Thailand, this study grouped businesses according to their founding year and hence experience in the market. There are three groups with an equal number of firms: young (founded between 1997 and 2002), middle-aged (founded between 1991 and 1996) and old (founded

Table 3.12

Estimation results by employment size groups

OLS (White heteroskedasticity – consistent standard errors)			
Dependent variable: log (sales per employee)			
	R2 = 0.923573 Number of observations included: 5 873	R2 = 0.922656 Number of observations included: 5 858	R2 = 0.923411 Number of observations included: 5 867
Computer presence in small firms	-0.0047	-	-
Computer presence in medium-sized firms	0.1200***	-	-
Computer presence in large firms	0.0981***	-	-
Share of employees using computers in small firms	-	0.1596	-
Share of employees using computers in medium-sized firms	-	0.2917**	-
Share of employees using computers in large firms	-	0.4139***	-
Number of computers per employee in small firms	-	-	0.1908
Number of computers per employee in medium-sized firms	-	-	0.4310**
Number of computers per employee in large firms	-	-	0.5947***
Internet access in small firms	0.0809**	0.0443	0.0427
Internet access in medium-sized firms	-0.0271	0.0427	0.0374
Internet access in large firms	-0.0339	-0.0021	-0.0055
Web presence in small firms	0.0097	-0.0005	0.0022
Web presence in medium-sized firms	0.0533	0.0368	0.0341
Web presence in large firms	0.0764*	0.0656	0.0619

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

before 1991). The applied estimation technique was the same as in the case of firm size. Results are shown in table 3.13 with the first column showing the effect of computer presence, Internet access and web in the different age groups, while in the third and fourth columns the analysis also takes into account the intensity of computer use.

In young firms computer presence is associated with the greatest value of gains in terms of sales per employee, a fact that suggests that young firms use computers more effectively. However, older firms seem to gain most from the combined use of computers, the Internet and the web. In older firms the presence of computers also matters, albeit less than in the younger ones, while there is an additional contribution to productivity from Internet access and the web.

With regard to accounting for the intensity of computer use, results confirm that for larger firms, with more experience in the market, there was a stronger correlation between ICT uptake and labour productivity. Results also show that younger firms with a lower intensity of computer use achieve higher sales per employee when they have access to the Internet.

Both firm age and employment size influence the magnitude of the relationship between ICT use and labour productivity. Larger and more experienced firms appear to gain more from the combined use of the three specific ICTs analysed here (computers, Internet and web). The presence of computers and the intensity of computer use contribute substantially to explaining those differences. However, in smaller and younger firms Internet access matters more in the sense that a lower intensity of computer use can be compensated

Table 3.13
Estimation results by firm age groups

OLS (White heteroskedasticity – consistent standard errors)			
Dependent variable: log (sales per employee)			
	R^2 = 0.924005 Number of observations included: 5 877	R^2 = 0.923348 Number of observations included: 5 863	R^2 = 0.923653 Number of observations included: 5 871
Computer presence in young firms	0.1729***	-	-
Computer presence in middle-aged firms	0.1498***	-	-
Computer presence in old firms	0.0902***	-	-
Share of employees using computers in young firms	-	0.1786	-
Share of employees using computers in middle-aged firms	-	0.4286***	-
Share of employees using computers in old firms	-	0.3713***	-
Number of computers per employee in young firms	-	-	0.2500*
Number of computers per employee in middle-aged firms	-	-	0.5188***
Number of computers per employee in old firms	-	-	0.4922***
Internet access in young firms	0.0313	0.1203***	0.1146***
Internet access in middle-aged firms	0.0144	0.0449*	0.0465*
Internet access in old firms	0.0484*	0.0260	0.0236
Web presence in young firms	0.0372	0.0206	0.0226
Web presence in middle-aged firms	0.0220	-0.0021	-0.0039
Web presence in old firms	0.0613**	0.0323	0.0292

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

for by use of the Internet. Chinn and Fairlie (2006) analysed the factors leading to higher computer and Internet penetration rates and show that income has a greater influence on decisions to acquire computers than does Internet access. Small and young firms with computers may find it easier to buy Internet access rather than additional computers. This study shows that small firms with at least one computer gain most from Internet access, while young firms use computers more effectively.

Regional and industry characteristics also have a bearing on the strength of ICT's impact on firm performance. These are further explained in the next two subsections.

Regional differences

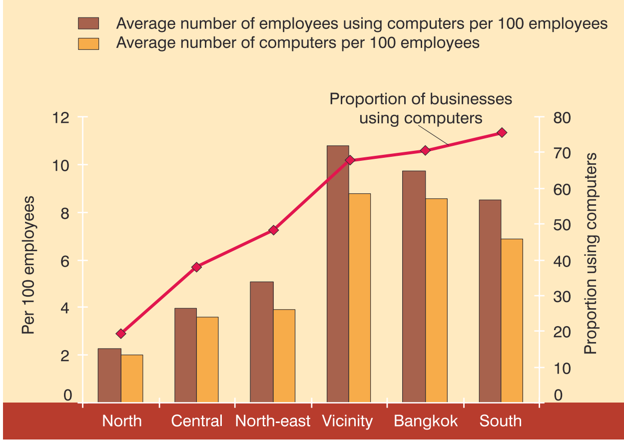
Owing to factors such as infrastructure, labour force training and qualifications and market size, firms located in different geographical regions use ICTs differently.

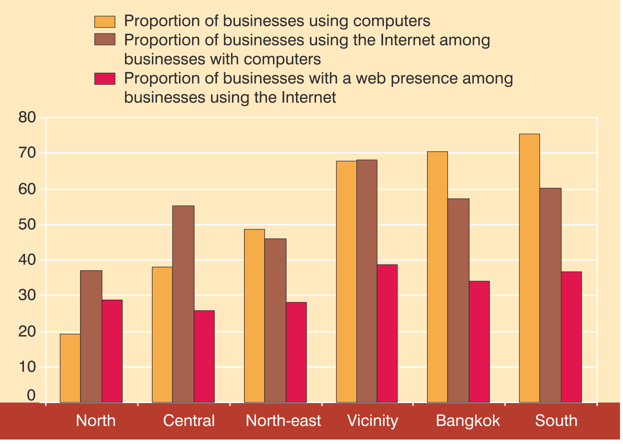
Dominated by larger manufacturing firms, the south had the highest share of computer-equipped firms and a relatively high intensity of computer use. The northern region had different characteristics: more small enterprises, fewer firms with computers and a more reduced intensity of computer use (see charts 3.6 a and b).

In terms of Internet access, Bangkok and the southern region had the two highest Internet penetration rates.

Charts 3.6 a and b

Computer, Internet and website use by regions in manufacturing Thailand





Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Not surprisingly, this region, together with Bangkok, has the highest proportion of ISP regular subscribers. Access through Internet cafés and prepaid Internet packages is more popular among manufacturers located in the north. However, in the north and the centre, there is a greater proportion of businesses with computers connected to the Internet. For example, in the north only 20 per cent of businesses have computers but among those with computers almost 40 per cent have also acquired Internet access. This confirms that the use of computers is an important source of differentiation among firms located in different geographical regions. Among businesses with computers, the proportion of businesses using the Internet and present on the web varied less across regions (chart 3.6 b).

Table 3.14 shows the results of two different models estimating the relationship between ICT use and labour productivity in businesses from different regions. The first one takes into account computer presence, Internet access and the web, while the second one also considers the intensity of computer use as measured by the share of employees using computers.

Table 3.14

Estimation results by regional location

OLS (White heteroskedasticity – consistent standard errors)						
Dependent variable: log (sales per employee)						
	R^2 = 0.924005 Number of observations included: 5 877			R^2 = 0.923348 Number of observations included: 5 863		
	Computer presence	Internet access	Web presence	Share of employees using computers	Internet access	Web presence
Bangkok	0.1298***	0.0892*	0.0254	0.4735***	0.0844**	-0.0007
Vicinity	0.1411***	0.0511	0.0731*	0.2037**	0.0852***	0.0496
Central	0.1553***	0.0121	0.1533**	0.2851	0.0730**	0.1372**
North	0.1921***	0.0302	-0.1720**	0.5234**	0.0954	-0.2187**
North-east	0.1187***	0.0669	-0.0101	0.2029	0.0865	-0.0394
South	0.1436***	0.0236	0.0400	0.5642***	0.0285	0.0089

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

Both sets of results confirm that computers are more important among the ICTs considered here in accounting for variations in sales per employee. That is shown by the highly significant coefficients for presence of computers and share of employees using computers. For firms located in the centre, website presence matters more than in other regions. In Bangkok higher sales per employee are generated in businesses with computers and Internet access. In the vicinity of Bangkok similar results apply, but Internet access is relatively more important. In the north, sales per employee are correlated much more with computer use than with the Internet and the web. The negative coefficient estimated for web presence shows that in the northern region businesses with computers, the Internet and the web have lower sales than businesses equipped only with computers. This finding can be explained by the fact that there is a very small share of web-present firms in the north (only 2 per cent) and that the use of web presence leads to fewer efficiency gains in this region than in others. A similar problem seems to occur in the north-east for the web-present firms, but the estimated negative effect is much smaller and not significant. A more detailed study of the web-present firms in the northern and north-eastern regions is needed in order to find out why these firms have lower sales per employee than competitors that use only computers. In the south higher labour productivity is recorded in the most computer-intensive firms

Industry differences

In order to simplify the analysis, industries were classified into 14 broader categories of manufacturing activity (for reference purposes ISIC Rev. 3 codes are provided in parentheses). As expected, ICT use also varied considerably across industries (chart 3.7). Measures of ICT uptake in particular sectors of activity are a reflection of industry characteristics and the degree to which particular business types are able to integrate computers, the Internet and the web in their production process. The computing, electrical and precision instruments sector emerges as the most frequent user of the Internet and web presence. The paper and printing industry has the highest share of businesses with computers but lags behind in terms of the Internet and website presence. The chemical industry and machinery and transport equipment follow closely behind with high penetration rates for computers, the Internet and the web. In coke and petroleum an unusually high share (70 per cent) of the firms with computers and the Internet also find it useful to establish web presence. Computerized firms in the group of other manufacturing industries (such as furniture, jewellery and musical instruments) and textiles, clothing and leather are connected to the Internet in a higher proportion than in other sectors. This indicated that Internet access is considered more relevant in those industries than for example in coke and petroleum.

Chart 3.8 shows information regarding the intensity of computer use in businesses. Coke and petroleum stands out as the industry with the highest intensity of computer use. The least computer-intensive sectors are the recycling industry but also the wood industry, textiles, clothing and leather, the processed food, beverages and tobacco industry. Typical of the last three manufacturing sectors was the very high share of small businesses.

Table 3.15 shows for comparison the results of two empirical exercises: one taking into account computer presence, the Internet and the web, and the other estimating the importance of the intensity of computer use as captured by the share of employees using computers. Estimation results identified four sectors where the use of particular ICTs was correlated with higher than average sales per employee: machinery and equipment, basic metal industry, computing, electrical and precision instruments and processed food, and beverages and tobacco.

The combined use of computers, the Internet and the web was associated with the highest gains in:

- Machinery equipment;
- Basic metal industry; and
- Computing, electrical and precision instruments.

Internet access was more significantly related to higher sales per employee in:

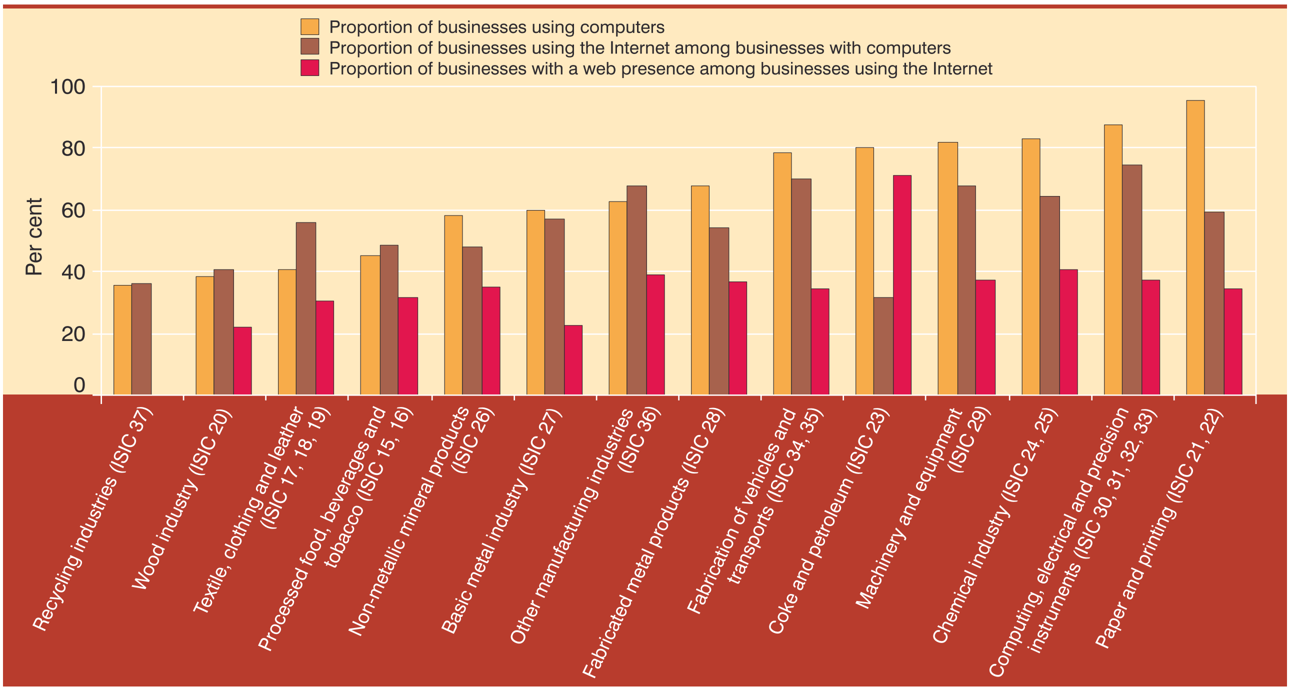
- Machinery equipment;
- Computing, electrical and precision instruments; and
- Processed food, beverages and tobacco.

Website presence seemed to add significantly to gains from computers and the Internet in:

- Machinery equipment;
- Basic metal industry; and
- Processed food, beverages and tobacco.

Chart 3.7

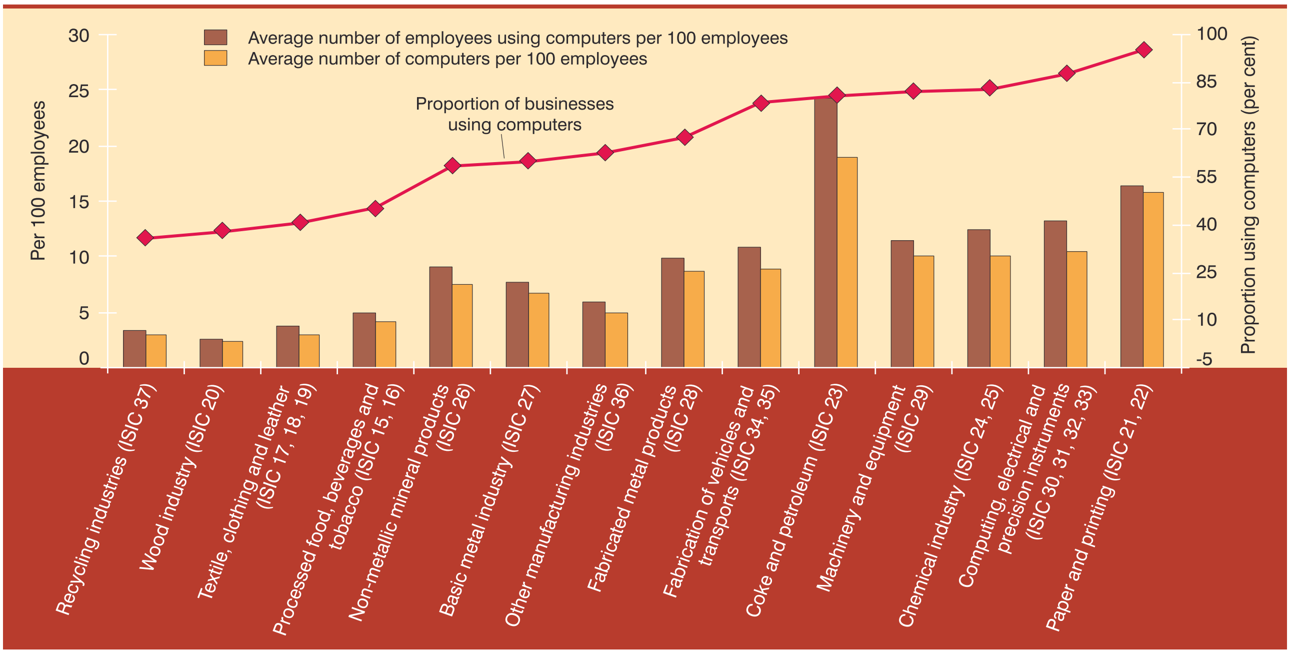
Computer, Internet and website presence across manufacturing industries in Thailand



Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Chart 3.8

Computer use by manufacturing industries in Thailand



Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Table 3.15

Estimation results by industry affiliation

OLS (White heteroskedasticity – consistent standard errors)						
Dependent variable: log (labour productivity)						
	$R^2 = 0.922725$ Number of observations included: 5 877			$R^2 = 0.922234$ Number of observations included: 5 863		
	Computer presence	Internet access	Web presence	Share of employees using computers	Internet access	Web presence
Processed food, beverages and tobacco (ISIC 15, 16)	0.1409***	0.0492*	0.0745*	0.4735***	0.0739**	0.0486
Textile, clothing and leather (ISIC 17, 18, 19)	0.1912***	0.0222	-0.0219	0.3728**	0.0609*	-0.0369
Wood industry (ISIC 20)	0.1354***	0.0563	0.0443	1.0008**	0.1056	0.0504
Paper and printing (ISIC 21, 22)	0.1357***	0.0132	0.0635	0.3009**	0.0172	0.0044
Coke and petroleum (ISIC 23)	0.2550**	-0.0038	-0.1637	0.5608***	-0.1150	-0.3177
Chemical industry (ISIC 24, 25)	0.1148***	-0.0128	0.0189	0.3487***	0.0049	-0.0201
Non-metallic mineral products (ISIC 26)	0.1123***	0.0285	0.0331	0.1943	0.0431	-0.0222
Basic metal industry (ISIC 27)	0.1558***	0.0775	0.1672**	0.2751	0.0764	0.1202
Fabricated metal products (ISIC 28)	0.1810***	0.0638*	0.0522	0.5150***	0.0865***	0.0298
Machinery and equipment (ISIC 29)	0.2090***	0.0998**	0.1619*	0.6667***	0.1203***	0.1384
Computing, electrical and precision instruments (ISIC 30, 31, 32, 33)	0.2283***	0.0745**	0.0292	0.4350***	0.0819***	-0.0061
Fabrication of vehicles and transports (ISIC 34, 35)	0.1134***	0.0315	0.1038	0.3983**	0.0488	0.0734
Other manufacturing industries (ISIC 36)	0.0744**	-0.0057	-0.0055	0.3118	0.0448	-0.0006
Recycling industries (ISIC 37)	-	-	-	-	-	-

Note: The regression included controls for employment size, capital, costs incurred with materials, foreign capital participation, multi-unit firms, and industry- and region-specific characteristics. (Level of significance at *** 1 per cent, ** 5 per cent and * 10 per cent).

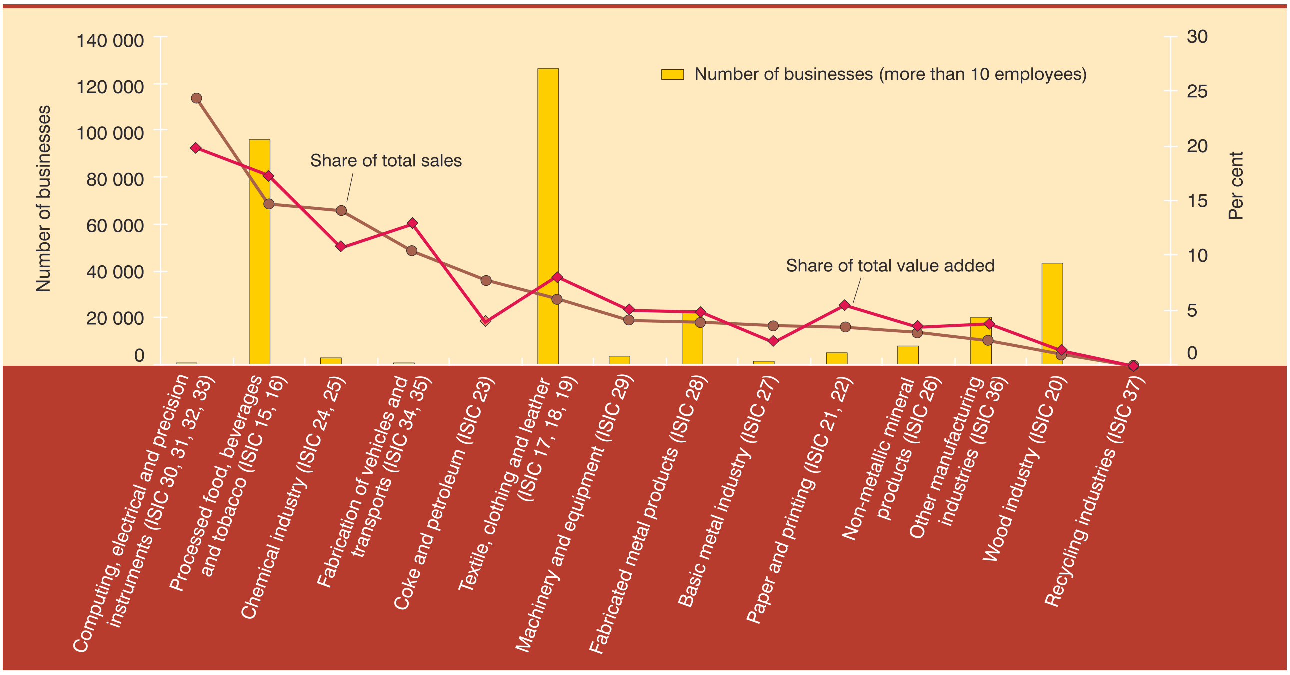
Chart 3.9 shows the contribution of the different industry branches to revenue and value added in manufacturing Thailand. The computing, electrical and precision instruments industry is the most important contributor to sales and value added in the Thai manufacturing sector. This industry is part of the Thai ICT-producing sector and has some of the highest Internet and web coverage. Estimation results indicate that in this sector the presence of computers and Internet access leads to as much as 30 per cent higher labour productivity on average.

The processed food, beverages and tobacco sector is the second highest contributor to value added in Thai manufacturing. This light industry sector is characterized by considerably low use of computers, the Internet and the web as compared to other sectors. However, estimation results show that productivity differentials within this industry were strongly correlated with the use of the Internet (4.9 per cent) and websites (7.5 per cent). If demand for food, beverages and tobacco remains favourable, there is scope for producers to increase productivity as they start using ICTs more frequently.

Last but not least, estimates showed that for the machinery equipment and the basic metal industries web presence seems to make the most difference.

Chart 3.9

Share of manufacturing industry sectors in total sales and value added in Thailand



Note: The 23 ISIC Rev.3 sectors were grouped into 14 broader manufacturing industry categories.
Source: Thai Manufacturing Survey 2003, businesses with more than 10 employees.

Firms in those industries with web presence have on average 16 per cent higher sales per employee than firms with just computers and Internet access. A more detailed study of how websites are used in the machinery equipment and basic metal industries in Thailand would help further understand why these firms have higher labour productivity.

E. Concluding remarks and policy issues

Measuring the economic impact of ICT allows a thorough assessment of the extent to which ICTs contribute to development. This chapter focused on the productivity impact of ICT from a macroeconomic and a microeconomic perspective.

Studies reviewed confirm that developing countries can gain as much as developed countries from ICTs in terms of productivity. In recent years developing countries have received a significant positive contribution to GDP growth from investment in ICTs. Those gains correspond to a period of sustained demand for ICT goods and services coming from developed OECD countries, but also from fast-growing developing economies such as China and India. Additionally, there are several developing countries where exports of ICT goods and ICT-enabled services have only recently started to grow (as shown in chapter 2).

At the macroeconomic level, growth accounting estimates reviewed in this chapter identify two principal sources of productivity gains from ICT: capital deepening through investment in ICT and technological progress in the ICT-producing industry. A comparison of the estimated impact of ICT on GDP growth shows that larger gains accrued to developing countries specialized in producing and exporting ICT goods and services. Developing countries have also benefited from ICT investment. However, in countries with a reduced level of ICT use the effects of ICT investment at a macroeconomic level remained low.

Since the mid-1990s, there has been an increase in global ICT investment. While this resulted in significantly higher gains from ICT to GDP in developed countries, in developing countries benefits had only started to become significant. Estimates show that over time technological progress in the ICT-producing sector has become an important factor contributing to GDP growth in developing countries. Furthermore, other estimates indicate that in a group of Asian developing economies total factor productivity growth is more strongly correlated with ICT investment in OECD countries rather than with ICT investment in the domestic market. This indicates that the demand for ICT goods and services coming from developed countries has had a positive effect on the productivity of developing economies. On the other hand, results from developed countries show that they gained relatively less from producing ICTs themselves, but rather from using ICTs as capital inputs in many sectors of economic activity.

Several studies reviewed point out that an innovative ICT use can lead to superior production efficiency. One of the ways to improve the efficiency of ICT use is to combine it with complementary skills such as a qualified labour force or superior management skills. An important study of the effects of computer capital investment on total factor productivity in the United States showed that significant gains occur with the time lag that is needed to effectively incorporate ICT solutions into production systems. This time lag can be reduced when "soft skills" such as superior management and marketing know-how are available.

At the firm level, this chapter reviews a number of studies using developed country statistical data to measure the contribution of specific ICTs to labour productivity in the business sector. Results show that the productivity effect of a specific information and communication technology can have different magnitudes, depending on the characteristics of the micro-environment analysed. For example, a 10 per cent increase in the share of employees using computers leads to 1.8 per cent higher labour productivity in manufacturing firms in Finland, 2.8 per cent in services firms in Finland and 1.3 per cent in a mixed sample of Swedish enterprises. Additionally, there are a series of complementary factors that come into play in determining the magnitude of the impact of ICT on labour productivity. These include firm age, foreign ownership and industry affiliation. These findings suggest that the profile of firms that gain most from the use of ICTs differs slightly from country to country, depending on the characteristics of the business environment. It is therefore necessary to further research and analyse the characteristics of firms from developing countries in which the impact of ICT use is greatest.

This chapter also presents the results of a joint research project of the Thai National Statistical Office and UNCTAD to assess the link between ICT use and labour productivity in Thai manufacturing firms. This study is one of the first using official data from a developing country to analyse the economic impact of ICT in the business sector. The empirical analysis is based on the theoretical framework applied in similar studies in developed countries. The project is part of a broader initiative of UNCTAD to improve ICT measurement and to enable the analysis of ICT impact in the business sector in developing and transition economies. It is promoted by several international organizations and statistical offices through the Partnership on Measuring ICT for Development.

The results of the firm-level study in Thailand show that computer use, Internet access and web presence are associated with significantly higher sales per employee. In comparison with similar analyses carried out in developed countries, this project finds that the use of computers is a key ICT factor for explaining higher productivity in firms. In developed countries the penetration rates of basic ICTs such as computers are already close to saturation levels and therefore computers are present in nearly all businesses (with more than 10 employees). However, in developing countries (see chapter 1) there is a lower share of businesses that use at least one computer. Variation in the intensity of computer use in Thailand was also reflected in greater productivity gains. Estimates show that a 10 per cent increase in the share of employees using computers was correlated with 3.5 per cent higher labour productivity, more than the 1.8 per cent estimated impact in a sample of Finnish manufacturing firms. In the theoretical setting considered, computers bring value to businesses both through their intrinsic characteristics such as processing and storage capacity and as necessary means for acquiring a greater complexity of ICT use such as Internet access and web presence. Internet access and website presence are also found to be correlated with higher sales per employee in Thailand, with a coefficient similar to that estimated in other studies. For example, Atrostic and Nguyen (2005) estimated that computer networks brought a 5 per cent positive net effect to firm labour productivity in the United States after accounting for the contribution of computer capital. Similarly, results derived here suggest that Thai firms with access to the Internet had on average 4 to 6 per cent higher sales per employee, additional to the effect of computers.

This study also quantified differences in the ICT–labour productivity relationship across employment size groups, firm age, regional location and industry affiliations. This type of estimates aimed at indicating the areas where the use of specific ICTs is more strongly correlated with superior economic performance. Among Thai manufacturing businesses the groups that seem to benefit from a stronger ICT–labour productivity relationship are the larger and medium-sized more experienced firms located in the central region and also in Bangkok and its vicinity. Younger firms, however, tended to use computers more effectively, while in smaller firms Internet access made a considerable difference. Further case study evidence is needed in order to establish how specific ICTs contribute to improved economic performance in specific fields and how their efficiency can be scaled up to other groups of enterprises.

The chapter concludes that in order to maximize productivity gains from ICT in a period of economic prosperity, developing countries need to encourage the efficient use of ICT in their economies. The impact of ICT on productivity in developed countries is well researched, but only few similar studies have been carried out in developing countries. Therefore, it is necessary to measure and monitor the use of ICT in a way that enables international comparisons and allows the economic impact of ICTs in developing countries to be assessed.

Estimates of the impact of ICT uptake in firms may give different results depending on the maturity level of ICTs in a specific market. These considerations make country, regional and sectoral studies more pertinent when analysing the impact of the use of specific ICTs on firm-level performance. More research is needed in developing countries to better assess how productivity gains from ICT can be scaled up.

Annex 3.1

Summary of Literature on ICTs and Productivity at the Firm Level

Author	Dataset	Dependent variable	ICT variables used	Type of regression	Impact of ICT variables on labour productivity
Atrostic & Nguyen (2002)	US manufacturing panel, 3 years (1992, 1997 and 1999) 38 000 firms	Sales per employee	Dummy variable for presence of computer networks (such as Internet, intranet, LAN, EDI, extranet or other).	Cobb–Douglas production function with 3 factors (labour, capital and materials). Control variables: size of establishment instead of number of employees, skill mix, multi-unit firm, industry.	5 per cent from presence of computer networks.
Atrostic & Nguyen (2005)	US manufacturing, 1999	Sales per employee	Computer capital and computer networks dummy (as above).	Cobb–Douglas production function with 4 factors (labour, ordinary capital, computer capital and materials). Control variables: size of establishment instead of number of employees, firm age, skill mix, multi-unit firm, industry.	5 per cent from presence of computer networks and 12 per cent for computer capital.
Maliranta & Rouvinen (2003)	Finland panel; 3 years (1998–2000) Manufacturing and services separately with 1 500 firms each. ICT-producing sector considered separately.	Output per employee	Share of computer-equipped labour, share of Internet-using labour, share of labour using LAN at work.	Cobb–Douglas production function with 2 factors (labour and capital). Control variables: skill mix and firm age.	A 10 per cent increase in computer-equipped labour results in 1.8 per cent higher labour productivity in manufacturing and 2.8 per cent in services. A 10 per cent increase in Internet-equipped labour results in 2.9 per cent higher labour productivity in services (negative estimated impact in manufacturing). A 10 per cent increase in the share of labour using LAN results in 2.1 per cent higher labour productivity in manufacturing (no significant impact in services).
Maliranta & Rouvinen (2006)	Finland, 2001, 2 358 services and manufacturing firms	Output per employee	Share of workforce using desktops, laptops, wireline access to Internet (LAN) and wireless access to Internet (WLAN).	Cobb–Douglas production function with 2 factors (labour and capital). Control variables: skill mix, firm age and gender participation in labour force.	9 per cent labour productivity gains from a higher share of labour force using computers (desktop). Additional 32 per cent from computer portability. Additional 14 per cent from wireline Internet connectivity. Additional 6 per cent from wireless connectivity.

Annex 3.1 *(continued)*

Author	Dataset	Dependent variable	ICT variables used	Type of regression	Impact of ICT variables on labour productivity
Hagén & Zeed (2005)	Sweden, 2002 2 752 firms with 10 employees or more (manufacturing and services together)	Value added per employee	Share of employees using computers, dummy variable for access to broadband, a composite ICT index.	Cobb–Douglas production function with 2 factors (labour and capital). Control variables: size of establishment instead of number of employees, skill mix, ownership, perceived lack of IT competence and industry.	A 10 per cent increase in computer-equipped labour results in 1.3 per cent higher labour productivity. 3.6 per cent labour productivity gains from broadband. Positive but decreasing impact of adopting an increasing number of ICT solutions.
Criscuolo & Waldron (2003)	UK manufacturing panel, 2 years (2000, 2001) 5 500 firms	Gross output per employee and value added per employee	Dummy variables for e-commerce (either placing or receiving orders online)	Cobb–Douglas production function with 3 factors (labour, capital and materials). Control variables: region, ownership, firm age, industry and year fixed effects.	Between 7 and 9 per cent labour productivity gains from placing orders online. Receiving orders online has negative effects (-5 per cent).
Farooqui (2005)	UK panel, 4 years (2000–2003); 2 277 manufacturing firms and 3 490 services firms taken separately	Value added per employee	Hardware capital stock, software capital stock, share of employees using ICT (computer and Internet), spending on telecommunication services, e-commerce (placing and receiving orders online).	Cobb–Douglas production function with 2 factors (labour and capital). Control variables: firm age, ownership, region and industry.	A 10 per cent increase in the share of employees using computers results in 2.1 per cent higher labour productivity in manufacturing and 1.5 per cent in services. A 10 per cent increase in the share of employees using Internet results in 2.9 per cent higher labour productivity in manufacturing (no significant impact on services).
Brynjolfsson & Hitt (2002)	US manufacturing panel, 8 years (1987–1994); 527 large firms	Total factor productivity growth	Computer capital	Total factor productivity growth framework.	Gain in multifactor productivity over time from 1.9 per cent for 1 year differences to 5.3 per cent for 7 year differences in computer capital investments.

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Notes

1. Chapter 2 of the present report deals with the ICT producing sector in detail.

2. See, for example, Atkinson and McKay (2007) and Bayoumi and Haacker (2002).

3. Chapter 1 of IER 2006 (UNCTAD, 2006).

4. Initial studies focused on estimating the effect of IT on growth rather than that of ICT. As technology evolved, concepts also developed to better capture technology. Today the OECD definition of the ICT sector (see chapter 2) is the reference for measuring the impact of ICT on growth in a way that enables international comparisons.

5. For more detailed information see UNCTAD (2008, forthcoming).

6. For more information see http://measuring-ict.unctad.org.

7. A more comprehensive literature review of the theoretical concepts was carried out in Chapter 1 of IER 2006, and in Chapter 2 of ECDR 2003.

8. For example, Oliner and Sichel (1994) and Jorgenson and Stiroh (1995).

9. Quoted by Triplett (1999), who shows updated tables from the original authors.

10. Rather than capturing investment growth rates defined as changes in gross capital formation, this table shows the increase in the share of ICT capital inputs in total investment.

11. This time lag of one decade was considerably shorter than the time lag needed by developing countries during previous technological revolutions (Crafts, 2002).

12. For example, in the Republic of Korea venture capital investments in ICT represented 40 per cent of all venture capital investment (1999–2002) as compared with the 50 per cent OECD average for the same period (OECD, 2004).

13. More information on the ICT-producing sector can be found in chapter 2.

14. See also discussion in the introduction of this Report on the contribution of technology to growth in the newly industrialized countries in South-East Asia. Similar findings by various authors indicated that the major contribution to growth in those countries came from capital and labour accumulation, with technology playing a minor part. However, it has been counter-argued that technology enhanced labour productivity, thus indirectly contributing to growth in a significant way.

15. ECDR 2003, chapter 3.

16. For example Atkinson and McKay (2007).

17. For the purpose of that comparison they used both the demand and the production sides of the GDP national account.

18. Argentina, Brazil, Chile, China, Colombia, Egypt, India, Indonesia, Malaysia, Philippines, Singapore, South Africa, Taiwan Province of China, Turkey and Venezuela.

19. UNCTAD recommends that countries give priority to gathering data on the core ICT indicators (United Nations, 2005).

20. For example, Atrostic and Nguyen (2005), Bloom, Sadun and van Reenen (2005) and Farooqui (2005).

21. More information on the core ICT indicators can be found in chapter 1.

22. Measured as placing or receiving orders on line in Criscuolo and Waldron (2003).

23. For example, Brynjolfsson and Hitt (2002).

24. More information on this can also be found in UNCTAD (2008, forthcoming).

25. The Information for Development Programme (InfoDev) launched in 2006 a project for measuring the impact of ICT use in Poland, the Russian Federation and the Baltic States.

26. All descriptive statistics in this section were constructed with sampling weights.

27. The information presented here is not directly comparable with the data in chapter 1 on the use of ICT by businesses in Thailand since those businesses comprise only firms located in urban areas.

28. For example 93 per cent of all European enterprises have fewer than 10 employees and employ 34 per cent of the workforce (Eurostat, 2003).

29. A similar approach was used in Maliranta and Rouvinen (2006) with respect to certain complementary computer characteristics (processing and storage capacity, portability, wireless and wireline connectivity).

30. Total employment in this study refers to paid and unpaid persons engaged.

31. See for example, Atrostic and Nguyen (2002).