Information and Communications Technology (ICT) and Spillover: A Panel Analysis

Sang-Yong Tom Lee*
Xiao Jia Guo

Department of Information Systems, National University of Singapore

Abstract

The pervasive role of information and communications technology (ICT) in the new economy is well documented. There is now considerable agreement among scholars regarding the ICT contribution to national productivity growth. On the other hand, the production spillover and network externality associated with ICT capital draws its contribution beyond the neoclassical baseline. Many researchers have provided empirical evidence for the correlation between ICT spillover and national productivity. Nevertheless, the ICT spillover in international context is still an unexplored area. Inspired by the belief that ICT bears the features of knowledge capital, we conjecture that ICT-related knowledge spillover could happen in today's open world economy. We conduct empirical tests on a balance panel of annual data series from a sample of 29 countries over period 1993-2001. The empirical results confirm the existence of international ICT spillover and the pattern of such spillover for two distinguished economic groups. With reference to these findings, policies in regard to promoting knowledge flow and trade openness are discussed for economies to fully reap the benefits of the international ICT spillover effect.

* Corresponding author, Tel.: +65–68744866; Fax: +65-67794580; E-mail address: tlee@comp.nus.edu.sg

1. Introduction

1.1 Background

Information and communications technology and economic performance has become a key area of research in the information systems field with contributions being made by information systems researchers, management scientists, and economists. The area has grown from less than a dozen studies in the 1980s to more than 50 studies in the 1990s. The surge of this research area is attributed to the important and mysterious role ICT has played in firms, industries as well economies as a whole. Figures on internet use, the number of web servers, the density of cellular mobile telephones, etc, all show a rapid increase in the use of ICT technologies The popular media has interpreted the rise of ICT as a possible third industrial revolution, of similar magnitude and significance as the first (steam) and the second (electricity) revolutions. Various scholars predicted the era of a ‘new economy’.

Information and communications technology, defined as a set of generic technologies, such as semiconductors, computer systems and software, has the broad power to reduce the costs of coordination, communications, and information processing. The majority of modern industries are being significantly affected by computerization. The rapid progress in ICT of the past decades has fundamentally changed the production process of many goods and services. Manufacturing operations in advanced countries are now largely carried out with computer controlled machinery, and many services are also increasingly delivered and customized with the help of ICT equipment. Unlike a new technology for steel or chemical production, ICT can be applied in virtually every economic sector, from automobiles to insurance to aerospace. Its application can make production more efficient, enhance existing products and create new products and services. ICT can reduce the cost to business by obtaining and processing information on markets, suppliers and competition, thus improving organizational efficiency and responsiveness. In addition, the ICT industry itself can be a source of economic growth and jobs. For these reasons, investment in ICT is believed to enhance national productivity and competitiveness, spurring economic growth.

It is not surprising that the massive reduction in computing and communications costs has endangered a substantial restructuring of the economy. The rapid decline in quality-adjusted ICT prices leads to traditional effects of investment, input substitution, and capital deepening. This "pecuniary externality" contributes directly to output and ALP (Average Labor Productivity) growth, but not TFP (Total Factor Productivity) growth. ICT-related production spillovers or network effects, however, could also yield a "non-pecuniary externality" that pushes the growth contribution of ICT beyond the neoclassical baseline.[1] In this case, ICT investment could also lead to TFP growth. Some observers have raised the possibility that production spillovers and network effects associated with ICT are an important part of the "New Economy".

1.2 Research Motivation

Dedrick, Gurbaxani and Kraemer [2003] points to ICT spillover effects as opportunity for future research. It argues that an understanding of whether these spillovers exist and how they occur is central to developing a comprehensive framework for understanding the returns to ICT investment and for developing guidelines for the successful deployment of these technologies. So far the most widely used approach to estimate ICT spillover effects has been using industry or firm level data which suggest that innovations in information technology have significant impacts on domestic TFP growth [Brynjolfsson and Hitt 1996, Black and Lynch 2000, OECD 2000a, 2000b]. As such, it would be interesting for us to look beyond country borders and investigate the ICT spillover from an international perspective. Our research question is mainly concerning the existence of international ICT spillovers and certain patterns associated with such spillovers.

A critical feature of the debate over the existence of ICT spillover is whether ICT is like traditional forms of capital, or whether it is more like knowledge capital, which is significantly different. In the case of traditional capital investment, returns accrue primarily to the firm, industry or country making the investment and receive diminishing returns from continuing investment. On the other hand, some economists hold that knowledge capital can be owned and used by many parties simultaneously, leading to potential spillovers, and that the returns may be difficult for a single entity

[1] OECD [2000a, 2000b], Schreyer [2000], and van Ark [2000] raise the possibility of this channel. See Griliches [1992] for a discussion of pecuniary and non-pecuniary externalities.

to capture in the presence of spillovers to others. Clearly, ICT capital has aspects of both forms of capital. As a production technology, it is similar to traditional forms of capital. In its informational and transformational roles, it is similar to knowledge capital, which associates ICT with knowledge spillovers.

A casual reading of recent economic history suggests two important trends in the world economy. First, technological innovations are becoming an ever more important contributor to economic well-being. Second, the nations in the world economy are becoming increasingly open and increasingly interdependent. Rapid communication and dose contacts among innovators in different countries facilitate the process of invention and the spread of new ideas. In this respect, the international ICT-related knowledge spillover is largely enabled by such open system. Specifically, international trade, foreign direct investment and international labor migration are all important carriers of knowledge flow and hence sources of the spillover effects. Meanwhile, we cannot overstate the role of Internet-facilitated international knowledge pool in transferring ICT-related knowledge in an efficient and effective manner. The ICT spillover is supposed to boost productivity growth in foreign countries other than the owner of ICT investment. Therefore, we put forward the first main hypothesis for current study:

Hypothesis 1. There is spillover effect of ICT investment in international context. In econometric sense, it implies that there is a significant and positive relationship between domestic TFP growth and foreign ICT investment.

In current study, we will empirically test this hypothesis by analyzing a panel sample. We use annual data of twenty-nine countries, which includes both highly developed countries (HDC) and less developed countries (LDC), temporally spanning from Year 1993 to Year 2001. As the initially raised research question suggests, besides studying the overall existence of ICT spillover, we are also motivated to investigate certain group pattern of such spillover. Theory suggests that LDC is supposed to reap more benefits from the international spillover than HDC due to different level of economic development. As such, our second main hypothesis is proposed:

Hypothesis 2. Less developed country group receives high spillover than the highly developed group. In econometric sense, it implies that the positive correlation of TFP with foreign ICT investment for LDC should be more significant than HDC.

The empirical test results of the two hypotheses will have important theoretical and practical implications. In theoretical sense, our findings are supposed to fill the gap of ICT spillover at aggregate (country) level. In practical sense, the empirical findings are supposed to shed some lights on related policy making. If there is indeed ICT spillover across country borders, an open-door policy should be recommended for an economy, moreover, measures to facilitate ICT-related knowledge flow should be in place to induce such spillover. Such policy implications are extremely crucial for the less developed countries to take advantage of ICT spillover in catching up with highly developed group if the second hypothesis in our study is supported.

1.3 Terminology

To make the rest of the discussion clear and to save duplicating explanations, a clarification of the important terms which will be used frequently throughout the paper is presented as follows.

TFP Growth

Total Factor Productivity (TFP) measures the synergy and efficiency of the utilization of both capital and human resources. It is also regarded as a measure of the degree of technological advancement associated with economic growth. Higher TFP growth indicates efficient utilization and management of resources, materials and inputs necessary for the production of goods and services.

TFP also refers to the additional output generated through enhancements in efficiency arising from advancements in worker education, skills and expertise, acquisition of efficient management techniques, and know-how, improvements in an organization, gains from specialization, introduction of new technology and innovation or upgrading of existing technology and enhancement in Information Technology (IT) as well as the shift towards higher added value processes and industries. Thus, productivity yield better returns if such quantitative increase in capital intensity is simultaneously complemented by growth in TFP. TFP growth, by definition is the output growth that is not explained by input growth. [NPC 2000]

A similar concept is multifactor productivity (MFP). MFP is a phenomenon that technical progress in the production process or in the quality of output can increase the level of output without additional investment in input. An increase in MFP means that for a fixed level and quality of inputs, a firm, industry or economy is achieving higher levels of output. This form of productivity improvement is of great importance because it reflects structural gains that are permanent. [Dedrick et al. 2003]

ICT Investment

ICT investment, according to the literature, has narrow and broad definitions. Dedrick et al. [2003] states that IT investment, broadly defined, includes investments in both computers and telecommunications, and in related hardware, software, and services. However, as operationally defined in nearly all of the research included in the review of Dedrick et al. [2003], IT investment is limited mainly to computer hardware. In most studies, investment is defined as an annualized value of the stock of computer investments including the depreciated value of previous investments that are still in service, or as annual spending.

In the current study, we employ the definition from van Ark et al. [2002], which is relatively broad. Three ICT assets types are distinguished: "computers", which comprises the whole category of office, accounting and computer equipment, "communication equipment" which includes radio, TV and communication equipment and "software", including pre-packaged, own account and customized software. This is in line with Triplett and Bosworth [2002] who argue in favor of a broad ICT concept, as the electronic-driven technological change that is most characteristic of computer and communication equipment is also evident in, for example, photocopiers and related equipment.

1.4 Organization of the Paper

The rest of the paper will be organized as follows. Section 2 will present a comprehensive review of the literature regarding ICT, productivity, and the spillover effects associated with ICT investment; the six sub-sections are supposed to represent a holistic view of ICT capital and its interplay with economic performance. Section 3 will introduce the econometric method we adopt to test for the spillover effect with a brief discussion of the common practice of linking ICT with productivity in a neoclassical model. Section 4 clarifies the data sources, variables we define and measures we use. Section 5 will be presenting the empirical results for alternative model specifications and Section 6 follows up with a discussion of the estimation results to provide more insights into the phenomenon of ICT spillover. We will cover theoretical and practical implications, limitation of current study and some suggestions for future research. Last but not least, concluding remarks of the study are included in Section 7.

2. Literature Review

2.1 ICT as General Purpose Technology

Information technology is best described not as a traditional capital investment, but as a "general purpose technology" [Bresnahan and Trajtenberg 1995]. General purpose technologies (GPT) are characterized by pervasiveness, inherent potential for technical improvements, and 'innovational complementarities', giving rise to increasing returns-to-scale. In most cases, the economic contributions of general purpose technologies are substantially larger than would be predicted by simply multiplying the quantity of capital investment devoted to them by a normal rate of return. Instead, such technologies are economically beneficial mostly because they facilitate complementary innovations. Bresnahan and Trajtenberg [1995] claim that ICT are essentially enabling technologies that facilitate innovations in the application sectors. For example, computers have been extensively used to automate back office operation, and network applications help to coordinate processes between organizations.

The central arguments of Brynjolfsson and Hitt [2000] support the notion of ICT being general purpose technology: first, a significant component of the value of information technology is its ability to enable complementary organizational investments such as business process and work practices; second, these investments, in turn, lead to productivity increase by reducing costs and, most importantly, by enabling firms to increase output quality in the form of new products or in improvements in intangible aspects of existing products like convenience, timeliness, quality, and variety.

Other research also suggests that IT has its greatest impact in its role as a technology for coordination [Brenahan 1997, Gurbaxani and Whang 1991, Malone, Yates and Benjamin 1989]. In Dedrick et al. [2003], IT is viewed as an especially potent technology that has a significant impact on the costs of coordinating economic activity both within and between organizations. Research in this arena suggests that the unique value of IT is that it enables fundamental changes in business processes and organizational structures that enhance MFP.

David [1990] argues that information technologies must be seen as pervasive, general-purpose technologies bound to spread in the economy and boost productivity growth, but with a lag. The bigger the costs of adjusting to a new technology, such as organizational changes, the longer the interval will be between its introduction and the visibility of the productivity-enhancing effects. Brynjolfsson and Hitt [1998] and Licht and Moch [1999] stress the importance of organizational innovations to reap the full benefits from IT investment at firm level. The argument comes close to the viewpoint that, being a typical general purpose technology, ICT will only be reflected in productivity growth with a certain time lag. Such characteristic has been used by researchers as counter-arguments to the notion of 'productivity paradox'.

2.2 Traditional Effect of ICT

As a production technology, ICT capital is similar to traditional forms of capital [Dedrick et al. 2003]. Jorgenson [2001] pointed out that the ICT investment boom was induced by the rapid decline in prices of IT goods driven by rapid and accelerating progress in semi-conductor manufacturing technology. Stiroh [2001] supports the point by stating that rapid decline in quality-adjusted ICT prices leads to traditional effects of investment, input substitution and capital deepening, meaning that rapid technological progress in ICT-production gives rise to a "pecuniary externality" in the form of rapidly falling ICT prices. This provides strong incentives for firms to invest in ICT, which in turn leads to input substitution. Capital deepening is a phenomenon that labor productivity increase when workers are provided with more capital. In addition, ICT rental prices are dominated by rapid depreciation and capital losses, which raise the rental cost of ICT relative to other assets and raises the

ICT input share. Thus, ICT capital must have large marginal products to cover the high rental prices.

Following a rigorous debate there is little doubt now that investment in information and communications technology equipment has had a significant impact on US labor productivity growth in the 1990s through the capital deepening channel [Jorgenson and Stiroh 2000, Oliner and Sichel 2000, 2002]. Evidence is also emerging of high contributions from ICT capital in European and other OECD countries [see Colecchia and Schreyer 2001 for a multi-country study and both Oulton 2001 and Cette et al. 2002 for single country studies], but at rates lower than in the US.

2.3 Non-traditional Effect of ICT

Van Ark [2000] argues that there are at least two reasons why ICT products are different from ‘normal’ products (non-ICT products): firstly, ICT products may be creating spillovers which are not appropriated by the investor or the consumer. Hence, ICT products may increase overall output and income beyond what is indicated by the actual prices paid for it; secondly, ICT typically represents a general purpose technology, which implies it is a broad technology with wide applications and much scope for incremental improvements [Bresnahan and Trajtenberg 1995 and Helpman 1998].

At a macro level, Delong and Summers [1991, 1992, 1993] concludes the social return to equipment exceeds the private return, implying productivity externalities, perhaps through production process efficiency gains, reverse engineering, or organization learning accompanying investment in new equipment. Wolff [1991] reports a statistical link between growth in the capital/labor ratio and TFP growth for seven countries from 1870 to 1979, which he attributes to embodied technical progress, investment-led organizational changes, learning-by-doing, technology-induced capital accumulation, and positive feedback effects.

OECD [2000a, 2000b] discuss potential production spillovers and network effects in specific context of ICT. For instance, OECD [2000a] argues that the emergence of the Internet in the mid-1990s greatly improved the effectiveness of ICT and may lead to

TFP growth. OECD [2000b] reports that improved B2B communications, facilitated by ICT, reflect new organizations of production and sales. These studies yield empirical evidence for complementarities between innovations and ICT use [Brynjolfsson and Hitt 2000, Bresnahan et al. 2002]. More recently, Vecchi and O'Mahony [2002] using industry data for the US and the UK non-agricultural market economy provide new evidence on the impact of ICT on TFP. Results of this line of research suggest a positive and significant long-run impact of ICT on TFP.

At a micro level, Gandal [1994] found evidence that computer spreadsheet users benefit from network externalities as firms gain from the ability to transfer information between users. Similarly, Brynjolfsson and Kemerer [1996] reported potential network effects in software, where the value to a user may rise due to network externalities from a community of users. Thus, one firm's ICT investment could increase the productivity of others, a classical spillover effect that would raise measured TFP growth.

Alternatively, the marginal product of capital could exceed the marginal cost as firms receive benefits beyond what the market forces to pay. Van Ark [2000] raises this possibility in the context of ICT. In an early example, Bresnahan [1986] report evidence of "downstream spillovers," which he interprets as a productivity spillover from the firm's computer investment. He argues that computer services provided a downstream spillover since the prices did not reflect the true value.

These types of "non-pecuniary externalities" in the form of production spillovers and network effects could lead the elasticity of ICT to exceed its measured input share and thus generate a correlation between ICT and measured TFP growth. Evidence, however, has been mixed. Griliches and Siegel [1991] find a correlation between computer investment and TFP growth for 4-digit U.S. manufacturing industries, while Stiroh [1998] reports no evidence of a correlation between growth in computer hardware and TFP in US industries. In a cross-section of US firms, Brynjolfsson and Hitt [2000a] finds that the computers' contribution equals its share in short differences, but greatly exceeds it in longer differences. Schreyer [2000] reports little obvious evidence for a link between ICT capital and TFP growth for the G7 countries, although his data end in 1996 and he does not present a rigorous statistical analysis. OECD [2000b] concludes that the available data do not allow clear tests for spillover effects in ICT-using sectors.

2.4 ICT in Different Sectors

The impact of ICT on economic growth through productivity gains can be transmitted via three different channels, namely the increase in the ICT capital available per worker (capital deepening), technical progress in ICT producer sectors (TFP growth) and finally, technical progress in ICT user sectors through spillover effects (TFP growth) [Kegels, van Overbeke and Van Zandweghe 2002].

The IT-producing sectors are those which manufacture semiconductor semi-conductor, computer, or telecommunications hardware or provide software and services that enable these technologies to be used effectively in organizations. The IT-using sectors are all the other sectors of the economy that apply IT as part of their operations in order to achieve greater efficiency and effectiveness. They include sectors such as manufacturing (durable and nondurable), wholesale and retail trade, finance, insurance and real estate, business and professional services, and so on. [Dedrick et al. 2003]

There is considerable agreement among economists that TFP has increased in the IT-producing industries [Gordon 2000, Jorgenson and Stiroh 2000, Oliner and Sichel 2002, Council of Economic Advisors 2001]. This increase in productivity in the IT-producing sector has naturally contributed to TFP growth in the whole economy given its increasing share of the national economy. A critical question is whether there have been similar gains in productivity and TFP outside the IT-producing industry and if so whether those gains can be attributed to investment in IT capital. Put differently, are there spillovers from IT-producing industries to IT-using industries?

Stiroh [2002] searches for an empirical link between ICT capital accumulation and TFP growth across US manufacturing industries but he finds little evidence that ICT capital is associated with TFP growth. In a similar study Gordon [2000] suggested that the TFP acceleration in the US in the late 1990s was entirely concentrated in the

ICT producing sectors like manufacturing industries producing computing, electronic and communications equipment. However, a number of studies have disputed this extreme argument [Van Ark 2001, Fernald, Basu and Shapiro 2001]. For example, Council of Economic Advisers [2001] argues that the US TFP acceleration in the latter half of the 1990s is also explicit in industries, which are among the most intensive users of ICT equipment. Industry-level studies of US growth such as Jorgenson, Ho and Stiroh [2002] find that the main contributing sectors to acceleration of TFP, together with IT-producing sectors, are the retailing the finance sectors, which are both highly intensive users of IT. The most recent evidence suggests that TFP growth has increased in the IT-using industries, and most significantly, that TFP has increased in the services industries, which have historically posted difficult measurement problems [Dedrick et al. 2003].

2.5 ICT as Knowledge Capital

Mun and Nadiri [2002] argue that ICT capital has two major characteristics distinguishing itself from a traditional capital investment: one is its wide diffusion across industries and the broad range of its application, the other is that ICT capital may generate considerable economic externalities. The network effect of IT has been emphasized as one of the key factors for assessing the value of IT by many researchers [Bresnahan 2001, Brynjolfsson and Hitt 2000, Inoue 1998]. In addition to network externalities associated with IT, we may think of another type of externalities of IT, the so called knowledge spillovers (learning effect). The adoption of IT deeply involves innovations in the production process and organizational changes [Brynjolfsson and Hitt 2000]. The knowledge that enables a firm or an industry to adopt advanced technology successfully will naturally spill over to other firms or industries [Romer 1986]. For instance, the improved managerial practices – JIT (Just-In-Time), QA (Quality Assessment), QC (Quality Control), etc which are pre-requisites for effective and efficient use of the newer technology may spill over to the rest of the industry.

Dedrick et al. [2003] points out that IT clearly has aspects of both traditional capital and knowledge capital. In the case of traditional capital investment, returns accrue primarily to the firm making the investment and receive diminishing returns from continuing investment. On the other hand, some economists hold that knowledge capital can be owned and used by many parties simultaneously, leading to potential spillovers, and that the returns may be difficult for a single firm to capture in the presence of spillovers to other firms. Verspagen and Loo [1999] argues that since knowledge cannot be completely appropriated by the ones who developed the knowledge, spillovers emerge. It leads to the fact that while innovation occurs in one firm, other firms may use the knowledge embodied in that innovation in their activities. A discovery in one firm, sector or country can generate new opportunities of research, inspire new research projects or find new applications in other firms, sectors or countries [Mohnen 1990]. These spillovers can in turn lead to endogenous technical progress. In the specific context of IT, best practices information regarding the management of technology, complementary organizational practices, and techniques for better information use does lend itself to use by many firms. Such knowledge is often diffused by entities such as technology user groups, academic institution, management consulting firms, and, especially, labor mobility. It is often the case that competing firms rapidly copy IT investments made by innovative firms.

2.6 International ICT Spillover

As mentioned earlier on, so far the most widely used approach to estimate ICT spillover effects has been using industry or firm level data which suggest that innovations in information technology have significant impacts on TFP growth. As we discussed in Section 1, the nature of international ICT spillover is ICT-related knowledge spillover. There have been considerable studies investigating international knowledge spillovers, together with some important channels, for instance, international trade and foreign direct investment. The literature on such studies will facilitate understanding of international ICT spillover as we conclude from the preceding section that ICT capital bears the features of knowledge capital.

One influential study conducted in the area of knowledge spillover is Coe and Helpman [1995], which demonstrates a significant positive relationship between TFP and knowledge, approximated by R&D capital stock, exists. Coe et al. [1997] extends their sample to 77 developing economies, and estimates an equation that relates TFP to foreign R&D capital, imports of machinery and equipment relative to GDP, and educational attainment. Results imply that a developing country's TFP is larger the larger is its foreign R&D capital stock, the more open it is to machinery and equipment imports from the industrial countries and the more educated is its labor force. By trading with an industrial country that has a larger 'stock of knowledge' a developing country stands to gain more in terms of both the products it can import and the direct knowledge it can acquire than it would by trading with another developing country. Bernstein and Mohnen [1994] and Nadiri and Kim [1996] also present empirical evidence on international spillovers from R&D.

As discussed in Xu and Wang [1999], it is useful to draw the distinction between embodied knowledge flows and disembodied knowledge flows. Some R&D spillovers are embodied in trade flows and foreign direct investment (FDI); other R&D spillovers are transmitted in disembodied form through the scientific literature, international conferences, international patenting, and so on. These knowledge spillover channels all apply to ICT spillover through its innovation and knowledge-related characteristics. The disembodied knowledge flows get back to the point that knowledge is essentially public good, which is non-excludable and non-rivalry in nature. In the current study, since we are using trade openness of an economy to construct foreign ICT investment, we will mainly introduce the literature on knowledge flow through trade.

While the literature on spillovers from FDI is well developed, research on learning through trade is less extensive. Nevertheless, in the development literature, there is direct evidence from country studies on the transfer of technical knowledge through trade [Feenstra 1996]. The theoretical literature in international economics and economic growth over the last decade has given considerable attention to the potential role of technological externalities in generating endogenous growth and determining the pattern of trade. Krugman [1987] and Young [1991] examined learning-by-doing, and Grossman and Helpman [1990, 1991] have looked at knowledge externalities.

The FDI literature emphasizes three mechanisms for technology diffusion through FDI [Kumar 1996, Blomström and Kokko 1997 and Moran 2001]: demonstration effects, labor mobility, and linkages with buyers and suppliers. MacGarvie [2003] examines the three mechanisms in the context of international trade, concluding that demonstration effects and linkages with buyers and suppliers are likely to facilitate technology diffusion through exporting and importing. Demonstration effects operate when firms observe and imitate the products or practices of foreign firms — for example, when foreign firms copy or modify aspects of exporters' products, or when the exporter's study of the foreign market yields information about foreign innovations. Similarly, linkages with buyers and suppliers seem likely to be an important source of learning for exporters and importers. Westphal [2001], stressing "the importance of technology transfers from export buyers can hardly be overstated", explains that export buyers provide technology through blueprints and specifications, technical advice offered during plant visits, and consultations with the buyer's engineers.

In the same vain, Grossman and Helpman [1991] justifies that the international trade in tangible commodities facilitates the exchange of intangible ideas in several ways. First, the larger the volume of international trade, the greater presumably will be the number of personal contacts between domestic and foreign individuals. These contacts may give rise to an exchange of information and may cause the agents from the small country to acquire novel (for them) perspectives on technical problems. Second, imports may embody differentiated intermediates that are not available in the local economy. The greater the quantity of such imports, the greater perhaps will be the number of insights that local researchers gain from inspecting and using these goods. Third, when local goods are exported, the foreign purchasing agents may suggest ways to improve the manufacturing process. The recommendations might take the form of ideas for new intermediate inputs. The number of such suggestions is likely to increase with the quantity of goods exported.

3. Methodology

3.1 ICT in a Neoclassical Model

The standard neoclassical model is well known and has been used extensively to evaluate and to examine the link between ICT and productivity. Bureau of Labor Statistics [2000], Council of Economic Advisors [2001], Jorgenson and Stiroh [1999, 2000], Oliner and Sichel [2000] employ it at the macro level; Berndt and Morrison [1995], Brynjolfsson and Hitt [1995], Gera et al. [1999], Lichtenberg [1995], Lehr and Lichtenberg [1999], McGuckin and Stiroh [2000a, 2000b], Steindel [1992], and Stiroh [1998, 2001] provide results from an industry or firm perspective. In a neoclassical model, which assumes a Cobb-Douglas production function, ICT is modeled as a special form of capital and distinguished from other form of capitals to study separately the impact of ICT capital on productivity. An important point about this framework is that there is no special role for ICT capital, for there is no direct impact on TFP growth from capital deepening. TFP growth, by definition, is the output growth that is not explained by input growth, so any output contribution associated with ICT investment is attributed to ICT capital deepening and not TFP. On the other hand, Stiroh [2001] argues that the special effects of ICT drive its growth contribution beyond the neoclassical baseline and standard measurement tools might be failing to capture a significant part of the economic impact from ICT use. In current study, we shall take an endogenous growth perspective to link up TFP with ICT investment to investigate the significant economic impact from ICT use.

3.2 Cobb-Douglas Production Function

We assume a Cobb-Douglas function for final production to estimate the Solow's Residual, which represents the total factor productivity of our interest.

The aggregate production function has the simple functional form:

$$Y = A\,f(K, L) = A\,K^{\alpha}L^{1-\alpha} \quad \text{……………….Equation (1)}$$

where

Y is GDP or output,

K is the aggregate capital stock,

L is the labor force,

$A > 0$ is the constant representing other factors for production, which measures mainly the productivity of the available technology,

$0<\alpha< 1$ is the share parameter, representing the elasticities of the production resources.

Using the production function from Equation (1):

Since $Y = A\,K^{\alpha}L^{1-\alpha}$

Solow's Residual, A, can be derived as

$$A = Y / (K^{\alpha}L^{1-\alpha}) \quad \text{………………………..Equation (2)}$$

Since data on output (or GDP), capital stock, and labor input can be acquired; and since α can be approximated by the share of profits in total output, the Solow's Residual can be determined by Equation (2). According to definition, TFP (Total Factor Productivity) is the contribution to Value Added net of contributions of the capital and labor inputs, and it measures the efficiency in which capital and labor are used. It is noted that because TFP is the difference between Value Added and the sum of the contributions of all the factor inputs, TFP is the residual of things we can observe. TFP is therefore popularly known as the Solow's Residual. As such, TFP values are derived. Economists tend to place the value of α between 0.3 and 0.4.

3.3 Modeling ICT Impact on TFP

As the preceding sections elaborated, ICT investment, may it be domestic or foreign, both incur spillover effects, which causes embodied technological progress and in turn boosts domestic productivity. With these considerations in mind, our empirical work is based on a linear specification that links total factor productivity to measures of domestic ICT investment, foreign ICT investment and the degree of openness to trade.

Following Coe and Helpman [1995], the basic TFP equation used to assess the importance of ICT spillover effect is:

$$\log TFP_{it} = \alpha_0 + \alpha_1 \log ITD_{it} + \alpha_2 \log ITF_{it} + \varepsilon_{it} \quad \text{..................Equation (3)}$$

where

i =1, …, n denote countries,

t = 1, …, t denote years, Σ

ITD is domestic ICT investment,

ITF is foreign ICT investment, which is measured as country i's bilateral import share weighted-average of the domestic ICT investment of its trading partner. Hence, we have incorporated the trade openness with each individual trade partner of country i in the construction of foreign ICT investment of country i:

$$ITF_i = \sum_j (IPT_{ij} / Y_i) ITD_j \quad \text{..................Equation (4)}$$

where j iterates through all the trade partners of country i; IPT_{ij} is the import volume of country i from country j, thus IPT_{ij}/Y_i is bilateral import share which in turns weights country j's domestic ICT investment. The rationale of constructing foreign ICT investment of one country is as discussed previously that trade is one of the major channels through with this spillover of ICT investment across country border happens. In other words, IPT_{ij}/Y_i is intended to model the influential portion of ICT investment of trading partner *j* which spills over to country *i*.

Back to Equation (3), the α's are the unknown parameters to be estimated, and ε is a white noise error term. The parameter α_1 and α_2 are the elasticity's of TFP with respect to domestic and foreign ICT investment, respectively. As our hypothesis is that the effect of domestic ICT investment could spill over to foreign countries, we expect the estimate of α_2 to be positive and statistically significant. As far as α_1 is concerned, the estimate is also expected to be significantly positive based on the conclusion drawn from the preceding literature review concluding that the non-traditional effects of ICT causes the positive correlation between ICT investment and domestic total factor productivity.

In order to gain more insights into the spillover phenomenon, categorizing the sample of 29 countries into some relevant groups is supposed to be helpful. We observe there are essentially two country groups in our sample, as presented in Table 1, highly developed countries and less developed countries, the cutting point being $19, 000 of GDP per capita in PPP $US for the year 2002. We expect to discover certain group pattern of benefiting from the international spillover effects by incorporating two so-called group dummies. Hence, our equation is further modified to the following:

$$\log TFP_{it} = \alpha_0 + \alpha_1 \log ITD_{it} + \alpha_2\, DH(\log ITF_{it}) + \alpha_3\, DL(\log ITF_{it}) + \varepsilon_{it} \text{ ....Equation (5)}$$

DH is the group dummy for highly developed countries; DH will be 1 for highly developed countries and 0 for the rest. Similarly, DL is for less developed country group; it will be 1 for less developed countries and 0 for highly developed countries. Equation (5) will be the major specification for regression estimation in our study. However, since the majority of the macro-economic series are non-stationary, the level regression might produce spurious result. Thus, respective series will be differenced to become stationary before the regression is conducted, which will in turn lead to our major findings.

As Wong [2002] argues, rapid advances in ICT present the late-industrializing nations opportunities for rapidly catching-up with the more advanced nations through rapid diffusion in the use of new ICT [Kagami and Tsuji 2001]. Late-comers may be able to exploit new ICT more efficiently than the advanced countries for two reasons. First, they may be able to learn from the experience of the advanced countries without having to pay the cost of initial learning and experimentation (the 'fast follower' advantage). Second, they may be able to 'leapfrog' into the latest generation of technologies, thus avoiding the 'legacy' problems of having too much asset-specific investments sunk into earlier generations of obsolete technologies (the 'leapfrogging' advantage). The more 'disruptive' the new technological advances, the greater the new 'attacker's advantage' can be in exploiting new technologies versus the incumbents [Foster 1986]. Therefore we expect a higher spillover effect from highly developed group to less developed group rather than the other way round. Translated to statistics, estimate of α_3 is expected to be more significantly positive than α_2.

3.4 Panel Causality Analysis

The standard neoclassical model assumes that TFP growth is an exogenous force that shifts the production function. Hulten [1979], however, has pointed out that much of observed capital accumulation is induced by TFP growth, while real business cycle models routinely allow productivity shocks to affect input accumulation. A similar point has been made in the econometrics literature where the endogeneity of input choices is well known. That is, firms respond to productivity to shocks by increasing inputs since marginal products have risen. This reverse causality story could lead to a correlation between input accumulation and TFP growth. In principle, one can correct for this endogeneity problem with instrumental variable techniques or be comparing TFP growth to lagged ICT intensity, which is essentially causality analysis.

3.3.1 Least Squares Dummy Variable (LSDV) Approach

Analysis of the causal relationship between the variables of TFP, domestic ICT investment and foreign ICT investment is studied using fixed effects and instrumental variable panel data approaches. Since Granger [1969] and Sims [1972], the most widely used operational definition of causality is the Granger definition of causality. It is defined as follows: x is a Granger cause of y (denoted as $x \rightarrow y$), if present y can be predicted with better accuracy by using past values of x rather than by not doing so. The introduction of a panel data dimension allows using both cross-sectional and time series information to test the causality relationships between y and x. In particular, it provides the researcher with a large number of observations, increasing the degree of freedom and reducing the multi-collinearity among explanatory variables.

Therefore, the availability of panel data noticeably improves the efficiency of Granger causality tests. Pooling cross-sectional units does have certain advantages; the assumption of time stationarity can be relaxed. The disadvantage is imposing the strong assumption of homogenous behavior across countries. We consider the following VAR model:

$$TFP_{it} = \alpha_1 + \sum_{m=1}^{M} a_m TFP_{i,t-m} + \sum_{n=1}^{N} b_n ITD_{i,t-n} + \sum_{k=1}^{K} c_k ITF_{i,t-k} + u_{it} \text{ ....Equation (6)}$$

The error term u_{it} follows a two-way error component structure [Baltagi 2001] and can be broken down into an unobservable country specific μ_i, a time specific λ_t, and a random error term v_{it} components as:

$$u_{it} = \mu_i + \lambda_t + v_{it}$$

The error term v_{it} represents measurement errors in the dependent variable and omitted explanatory variables. The error term is assumed to be independently and identically distributed with zero mean and constant variance, σ^2. The country and time specific effects μ_i and λ_t, are factors representing country heterogeneity and neutral shift in TFP over time respectively and assumed to be independent of each other and of the regressors.

In the literature, the time effects λ_t are often replaced with a time trend reducing the two-way error component model to a one-way error component model. In the specific context of panel literature the estimation of the model (6) has been developed in two directions, the fixed effect (FE) model where μ_i is assumed to be fixed and correlated with explanatory variables and the random effects (RE) model where μ_i is assumed to be random and not correlated with the explanatory variables. In this study we use the FE model since we have a relatively small open sample of countries not chosen randomly. Any inference is made only on the included sample of countries. Furthermore, the causality tests will be conducted using two lags of TFP, ITD and ITF variables.

3.3.2 Instrumental Variable Technique

To further correct for the endogeneity problem and control for measurement errors and omitted variable problems, we employ Two-Stage Least Square (2SLS) technique to conduct the causality test. The method of 2SLS can be used when standard regression estimates of the relation of interest are biased because of reverse causality, selection bias, measurement error, or the presence of unmeasured confounding effects. The central idea is to use a third, instrumental variable to extract variation in the variable of interest that is unrelated to these problems, and to use this variation to estimate its causal effect on an outcome measure.

The 2SLS estimator increases computational efficiency without significantly detracting from its effectiveness. A typical example of traditional panel data causality testing is Holtz-Eakin *et al*. [1988]. The Holtz-Eakin model is:

$$y_{it} = \alpha_1 + \sum_{j=1}^{m} \alpha_j y_{i,t-j} + \sum_{j=1}^{m} \delta_j x_{i,t-j} + \mu_i + v_{it} \text{ ....Equation (7)}$$

where i =1…N. In order to eliminate the fixed effects, μ_i the authors difference the data leading to the model:

$$y_{it} - y_{i,t-1} = \sum_{j=1}^{m} \alpha_j (y_{i,t-j} - y_{i,t-j-1}) + \sum_{j=1}^{m} \delta_j (x_{i,t-j} - x_{i,t-j-1}) + (v_{it} - v_{i,t-1}) \text{ ......Equation (8)}$$

This specification introduces a problem of simultaneity because the error term is correlated with the regressor $y_{i,t-j} - y_{i,t-j-1}$. Therefore, a 2SLS instrumental variables procedure with a time-varying set of instruments is used to estimate the model. There are two conditions for the instruments to be valid in such specification:

i) The instruments should be uncorrelated with the error term, or the orthogonality conditions should be satisfied by the data (exogeneity requirement);

ii) The instruments should have a strong correlation with the regressors of the model (relevance requirement).

Anderson and Hsiao [1982], suggest instrumental variables on the differenced model using y lagged twice, $y_{(-2)}$ and differenced x's as instruments (Δx). The authors then equate the question of whether or not x causes y with a test of the joint hypothesis: $\delta_1 = \delta_2 = ... = \delta_m = 0$. For estimation purposes, we will use the 2SLS estimation procedure available in Eviews.

4. Data and Measures

Annual data are collected for 29 countries for the period of 1993-2001, consisting of annual panel data of 6 main variables – GDP (Y), Capital (K), Labor (L), ICT investment (DIT), aggregate imports (Im) and education level (EDU). The grouping of the countries is based on GDP per capita in PPP $US as in year 2002; the criterion to be in highly developed group is the value greater than $19, 000. Data is a balanced panel and is chosen based on availability for the ICT variable:

Highly Developed Countries:

Australia, Austria, Canada, Denmark, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Singapore, Spain, Sweden, Switzerland, UK, and US

Less Developed Countries:

China, Greece, India, Indonesia, Korea, Mexico, Philippines, Poland, and Turkey

GDP (Constant Local Currency) and Labor data have been directly obtained from World Development Indicators (WDI), which in turn are derived from World Bank National Accounts Data and International Labor Organization (for data of GDP and Labor respectively). However, WDI only provides values for Gross Fixed Capital Formation (Constant Local Currency), which is usually gross domestic fixed investment, and not really capital stock that should be used to calculate Solow's

Residual. We construct the capital stock from Gross Fixed Capital Formation by three main steps: obtaining investment series, obtaining a price deflator to transform investment into constant-quality units valued at base-year prices (1995), and calculating the capital stock. Since the capital data for the initial year (1993) is not available, we calculate the benchmark stock from investment series. Assuming a constant growth rate in investment, the benchmark stock (K_{t-1}) is expressed as follows.

$$K_{t-1} = \frac{I_t}{g + \delta}$$

I_t is investment at period t, g is the growth rate of investment, and δ is the depreciation rate. We assume a depreciation rate of 10% as non high-tech capital stock is generally, on the average depreciated with a 10% rate [Capital Income Taxes and Economic Performance]. Starting with the benchmark stock, we construct capital stock series using the perpetual inventory method.

$$K_t = K_{t-1} + I_t - Depreciation_{t-1}$$

Collecting data for ICT investment has been challenging since data unavailability in this area is prevalent in all countries in the 1980s. By far, the most reliable data source is from World Information Technology and Service Alliance, WITSA [Digital Planet 2002] and the values are only available from 1993 to 2001. ICT investment as we collected refers to the annual spending on IT hardware for office machines, data processing equipment, data communications equipment, and of IT software and IT services, plus telecommunications equipment and services.

5. Findings

We can now return to the research question raised in Section 1 regarding the existence of international ICT spillover. We wish to determine whether an economy's TFP growth is boosted by the ICT investment of its trading partners. A positive correlation between foreign ICT investment and domestic TFP of the economy would support the assertion. A negative correlation indicates that an economy's total factor productivity growth is impeded by foreign countries' ICT investment, probably because the economy is disadvantaged when the competitiveness of foreign countries is raised due to higher investment in ICT. The regression results derived from alternative model specifications as discussed in Section 3 are summarized in Table 2 for easy comparison. With a glance at the results of level estimation, our results afterwards are all based on differenced-series estimation, which range from simple ordinary least squares (OLS), OLS with country fixed effects, fixed effects with year dummies or trend; to fixed effects estimation with grouping of the countries; and to the most comprehensive specification which control for education level (including the lags) as right-hand-side variables of TFP.

5.1 Level-series Estimation

The first section of Table 2 shows the results of simple OLS estimation using level series. The estimated coefficient of ITD is positive and very significant, which implies a positive correlation between domestic ICT investment and domestic TFP. This result is in line with the literature concluding that ICT investments have had a major impact on labor productivity and economic growth at the country level [Dedrick et al. 2003]. The coefficient of ITF is also positive and very significant, which is a preliminary supporting result of our first hypothesis that ICT investment has spillover effects across country borders.

5.2 Differenced-series Estimation

Since the majority of the macro-economic series are non-stationary, our findings rely more on the regression by differenced series to avoid spurious results. The second section in Table 2 presents the regression result of simple OLS for differenced series. The coefficients of ITD and ITF remain positive and stick to a high significance level. The improving effect of the differenced series estimation can be seen from the adjusted R-square which rises from 0.18 in level estimation to 0.28 in differenced-series estimation. R-square is the value concerning the extent or degree to which the change in right-hand-side variables can explain the change in left-hand-side dependent variable.

Since our sample includes countries with a wide range of productivity levels, we add in country dummies to control for the productivity differences across. The results of including country fixed effects are shown in the third section of Table 2. Furthermore, to account for the productivity differences across the panel period of 9 years, we add in year dummies; alternatively to capture average technical changes we include a time trend variable. These two specifications are collectively known as fixed effects estimation. The results are shown in the fourth and fifth sections of Table 2 respectively. From the result table, we could see that the coefficients of concern remain similar, however, as country dummies and year dummies are added to the specification, R-square increases significantly, which indicate that country-specific effects and year specific effects do account for the growth in TFP. On the other hand, including trend variable incurs different result from adding in year dummies in the sense that the coefficient of trend variable is not significant and the resultant R-square does not increase in a significant manner. Such finding further affirms that the findings derived from our data are not spurious from time dimension.

Till this point, we have shown the results of alternative specifications regressing differenced series and controlling for fixed effects in terms of country dimension as well as time dimension. The significance level suggests that our result is robust, hence the positive correlation between ITD and TFP is affirmed; moreover the first major hypothesis of our study regarding the significantly positive correlation between ITF and TFP is supported: there is indeed spillover effect from ICT investment at aggregate (country) level inferred from the sample in current study.

5.3 Estimation with Grouping

To illuminate possible effects in groups of countries that are masked in the pooled regression, we have formed two categorizations of countries that are relevant to our research model and spillover theory. As mentioned in Section 3, the 29 countries in the sample are grouped according to their economic level of development as measured by GDP per capita. We re-estimate the fixed effects specification with year dummies and trend variable respectively taking into account the group dummies for highly developed and less developed countries. The results of the two regressions are shown in the sixth and seventh section of Table 2. As theory suggests, the coefficient of the cross product of ITF (foreign ICT investment) with DL (group dummy for less developed countries) is positive and significant, while for the cross product of ITF with DH (group dummy for the highly developed countries), the coefficient is still positive but lacks of significance. The result implies that the less developed country group is receiving significant spillover effects of foreign ICT investment from the whole sample group; while for the highly developed group, TFP is positively correlated with foreign ICT investment but such correlation is not significant. Since we are solely separating the impacts of ITF of the two groups by incorporating two group dummies, the explanatory power of right-hand-side variables remains similar as there is no much change in R-square. We will provide more insight into the grouping estimation result in the discussion section later on.

5.4 Control for Education Level

In the preceding model specifications we have only counted ITD (domestic ICT investment) and ITF (foreign ICT investment) which embeds openness to trade, as right-hand-side variables of TFP (total factor productivity). Nevertheless, we have to bear in mind that these are not the only sources and determinants for such productivity growth. To further control for the contribution of domestic and foreign ICT investment, we would include one more right-hand-side variable of TFP. We have chosen education level as the control variable, which is considered in literature to be one of the determinants of TFP. As argued in Coe et al. [1997], productivity, of course, also depends on the quality of a country's labor force, i.e. on its human capital. The current study uses secondary school enrolment as proxies for human capital.

As mentioned in Benhabib [1994], a standard approach is to treat human capital, or the average years of schooling of the labor force, as an ordinary input in the production function. The recent work of Mankiw, Romer and Weil [1992] is in this tradition. An alternative approach, associated with endogenous growth theory, is to model technological progress, or the growth of total factor productivity, as a function of the level of education or human capital. The presumption is that an educated labor force is better at creating, implementing, and adopting new technologies, thereby generating growth. This is in line with Nelson and Phelps [1966], who suggested that simply including an index of education or human capital as an additional input would represent a gross misspecification of the productive process. Instead, they argued that education facilitates the adoption and implementation of new technologies, which are continuously invented at an exogenous rate.

When Benhabib [1994] introduces the model in which human capital influences the growth of total factor productivity they obtain more positive results as compared the traditional approach. In this model, human capital affects growth through two mechanisms. First, human capital levels directly influence the rate of domestically produced technological innovation, as in Romer [1990]. Second, the human capital stock affects the speed of adoption of technology from abroad, in the spirit of Nelson and Phelps [1966].

In the literature, two sources of human capital accumulation have been emphasized. The first one is education [Uzawa 1965, Lucas 1988]. It is postulated that education improves the skill level and knowledge of students, and through intergenerational spillovers, human capital accumulates over time. The increase in human capital allows the economy to grow. Another source of human capital accumulation is learning by doing (LBD) [Arrow 1962, Lucas 1988]. It is argued that workers can gather experience and improve productivity through working. For an open economy, it is further argued that workers may get learning experience not only through its own work, but may also learn from workers in other countries through direct (through personal interactions, for example) and indirect (through the products and other media such as journals) contacts with them. Since measuring human capital accumulation through learning by doing is quite a complex issue, we will only account for human capital accumulation through education in current study; we use secondary school enrolment as proxy for education level.

The central idea of controlling for other determents of TFP is to counter the omitted variable problem. In the specific context of ICT, anything that raises productivity, is correlated with ICT-use, and is not measured by the specification would lead to a correlation between ICT and measured TFP growth. For instance, the ICT investment level is supposed to correlate with education level, thus it could be the education level that truly boosts productivity growth rather than ICT investment. If that is the case, by including education level in our specification a considerable reduction in the significance of ICT investment is expected. The eighth and ninth sections of Table 2 show the results of fixed effects estimation with year dummies and trend respectively including solely current education level (proxied by secondary school enrolment). The coefficients for domestic and foreign ICT investment remain similar which affirms the robustness of previous results before controlling for education level. Meanwhile we observe that in the fixed effects specification with year dummies, the coefficient for education level is positive and significant, while in the specification with trend variable, the coefficient becomes negative and insignificant. This may be attributed to the fact that when controlling for the average education level throughout the 9 years (as in trend model), the contribution to TFP growth is not salient, though this is not of central interest in our study. It is also interesting to note that R-square remains similar after controlling for education level. The result implies that either education level cannot explain productivity growth well or there is correlation between ICT investment and education level, but the causal direction is from ICT investment to education level.

On the other hand, we conjecture that the contribution to productivity growth of education level should be only manifested with a time lag. According to this consideration, we further add in three lagged education indicators to our specification. The result is shown in the last section of Table 2. Still, the coefficients of DH*ITF and DL*ITF remain similar, not being influenced by the lags. The coefficient for current education level is positive and significant, other than that, the coefficients for the three lagged education levels are all positive, with only the three-period-lagged value being significant. There might be significant correlation between current level of education and the three-period lagged value, hence the regression result; but still, it is not of central interest for our study.

With several alternative model estimations, the robustness of the grouping estimation result is confirmed. Our second hypothesis is supported: the less developed country group receives higher spillover effects of foreign ICT investment than the highly developed group. The important implications of such will be discussed in next section.

5.5 Panel Causality Analysis

As discussed in Section 3, we conduct causality test by LSDV approach as well as instrumental variable technique (2SLS) to correct for the endogeneity problem and control for measurement errors and omitted variable problems. The causality test results are shown in Table 3 and 4.

As shown in Table 3, in LSDV estimation, causal relationships are found both from ITD to TFP and from ITF to TFP, the former at 1% significance level whereas the latter at 5% significance level. However, while an instrumental variable technique (2SLS) is applied, the causal relationship from ITF to TFP, which implies that the causality from ITF to TFP is not very robust for in the context of our sample.

To illuminate possible effects in different country groups, we conduct the LSDV and 2SLS causality tests for the highly developed and less developed group respectively. Results in Table 4 indicate that no significant causal relationship is found except for one from ITD to TFP in highly developed group by LSDV approach which is lost again in applying 2SLS. The lack of significance might be due to the limited sample size while it does not contradict the robustness of positive correlation found in previous regression results.

6. Discussion

Having presented the estimation results of alternative model specifications in the previous section, we will further discuss the implications of such findings. In general, the implications can be theoretical and practical. Theoretical implications are mainly the contributions we have made to the research field in terms of theory. Our findings first fill the gap of ICT spillover at aggregate (country) level. The scope of our empirical study implies a contribution to the theories of technology diffusion interacted with trade and economic growth in international context. In the meantime, our findings add to the cumulative evidence of the multiplicity of the growth sources of TFP and provide insights into the determinants of TFP growth. Following the theoretical implications, we look beyond the theoretical arena and turn to consider some practical implications which might guide the policy makers to attune their policies to fully reap the benefits in the presence of such international ICT spillover. The two major issues concerning policy making in our context are international knowledge flow and trade openness. Last but not least, the limitation of our study and suggested future research are presented to wrap up the current section.

6.1 Theoretical Implications

6.1.1 Filling the Gap

As elaborated in the section of research motivation, we find that thus far most studies on ICT spillover have been at firm or industry level and the widely discussed effects are production spillover and network externality. As far as we know, there is no specific study approaching the issue from international perspective. To fill the gap, we study the characteristics of ICT capital and deduct that the knowledge-carrying capacity of ICT capital, or put differently, ICT bearing the feature of knowledge capital, induces spillover effects across country borders. These knowledge spillovers are made very much possible in nowadays world economy in which nations are increasingly open and interdependent.

To empirically test our hypotheses regarding the existence of international ICT spillover and the group pattern, we deploy a linear specification to link up total factor productivity with domestic and foreign ICT investment. This is essentially an endogenous growth approach in which TFP growth becomes endogenous variable. The two hypotheses in our study are both supported by empirical results. Access to panel data at the first place gives enough degrees of freedom to estimate more robust results. Meanwhile, our estimation results are robust to a number of alternative model specifications to control for variables usually considered as important determinants of productivity growth, education level and its lagged values. We also include country dummies and year dummies to capture country-specific effects and year-specific effects; alternatively time trend is included to capture average technical change over the sample period.

Therefore, we have provided empirical evidence for the existence of ICT spillover effects across country borders. Our study is a first step in search of such international effect and adds to the cumulative studies of ICT spillover in general. The empirical findings also suggest that the less developed country group reaps more benefit from the ICT spillover than the highly developed group. This is mainly because the highly developed country group possesses a larger stock of ICT-related knowledge to spill over to other countries and the highly developed group should be the one leading the technology edge of the world economy. Such result has further implications for technology diffusion theory, which will be elaborated in next section.

6.1.2 Technology Diffusion and Trade

What is the geographic scope of technical progress? One camp holds that by its very nature technology is freely available everywhere. A questionable implication is that countries enjoy no relative advantage from being innovative. At the other extreme, the new growth theory typically relates a country's technical advances to only its own innovations. A troubling implication here is that innovative countries leave everyone else behind. In contrast to either polar position, economic historians describe world growth in terms of the gradual diffusion of advances from a small set of innovators. Innovative countries are the most productive, but their innovations also drive growth elsewhere. The notion of concern is essentially externality; in our specific context, it concerns international ICT spillovers.

As highly-developed countries spearhead investment in state-of-the-art ICT capital, they understand the technologies through learning-by-doing and acquire insights into the successful implementation of such technologies. Such managerial insights are accumulated to managerial innovations to complement the adoption of technology; these innovations spill over naturally to other countries in form of embodied (trade flows and foreign direct investment) and disembodied knowledge flows (scientific literature, international conferences, international patenting, and so on) which are largely enabled by ubiquity of Internet; hence contribute to productivity growth in other countries, especially the less developed countries. Our empirical findings from the grouping estimation are strongly supportive of such notion; nevertheless the less developed group may have to keep breast of technological advance in a strategic manner to assimilate fully such spillover effects from highly-developed countries, meaning that the less developed countries should have the technology in place to apply the managerial innovations spilled over from highly developed countries.

In our empirical studies, we have accounted for trade openness to construct foreign ICT investment. The findings suggest that economies reap more benefits from ICT spillover effect; the more openness to trade the economy embraces. The rationale as we discussed is that the nature of international ICT spillover is ICT-related knowledge spillover. Recent theoretical models of economic growth highlight the importance of trade as a vehicle for technological spillovers that allow less developed countries to close the technological gap vis-à-vis the industrial countries. Our findings further affirm such role of foreign trade as knowledge carrier in facilitating technology diffusion particularly from highly developed country group to the less developed.

6.1.3 Determinants of TFP Growth

In our model specification, we have counted domestic ICT investment, foreign ICT investment (embedding trade openness) and education level as right-hand-side variables, i.e., determinants of TFP growth. However, our regression results suggest that there should be other determinants of TFP growth since the maximum value of adjusted R-square is less than 0.5. This is in line with the literature on total factor productivity. In particular, NPC [2000] suggests that there are five major determinants of TFP growth:

(a) **Demand intensity** which indicates the extent of productivity capacity of the economy. A slow-down in demand intensity would result in unused capacity, lowering the utilization of existing machinery and equipment. Demand intensity is reflected in sales performance.

(b) **Education and training** of the workforce which aims to upgrade skills, and knowledge. With higher level of skills, workers will be more efficient and produce better quality products and services. Investments in human resource development reflects the emphasis given to education and training.

(c) **Economic restructuring** which refers to the movement of resources from less productive to the more productive sectors of the economy. Experience of the developed countries indicates that resources in the more productive sectors of the economy were utilized at the more efficient level than resources in the less productive sectors.

(d) **Capital structure** which relates to the proportion of investments in machinery and equipment which are productive capital inputs yields immediate output as compared to infrastructure, plant and buildings which have longer lag time.

(e) **Technical progress** which relates to the effective and efficient utilization of technology, innovation, work attitudes and management and organizational effectiveness. With high technological capabilities, a motivated workforce and as effective management, higher value-added products and services will be produced at competitive costs.

Clearly, out of the five determinants, (a)demand intensity and (c)economic restructuring are extremely difficult to define and measure; on the other hand, the determinants concerning (b)education and training, (d)capital structure and (e)technical progress are clearly defined and the literature in search of growth sources of TFP have paid considerable attention in these factors. It is interesting to find that in the current study, we are measuring the impact of domestic and foreign ICT investment on TFP which goes to category (d) capital structure, however, the nature of ICT spillover goes back to category (e) technical progress in the sense that it is the utilization of technology, innovation, etc that have spill over across the country borders rather than the ICT investment itself.

To improve over the misspecification problem due to omitted variables, we control for the impact of education and training of category (b) on TFP, using secondary school enrolment as proxies. Significant and insignificant correlations have been found of TFP with current level of education and lagged values in different specifications. While the impact of education level is not our major concern in current study, the estimation result affirms the robustness of growth contribution of ICT investment and the existence of spillover effect. The control for education level also eliminates the possibility that it is in fact education level that has considerable impact on TFP while ICT is highly correlated with education level. A country with higher education level may very likely invest highly in ICT to improve work environment and production efficiency. Our estimation result does not reject the possibility of correlation between ICT investment and education level, however, the causal relationship is more likely from the former to the latter. Such result renders higher level of confidence for the one-directional causality from ICT investment to TFP growth in our study.

6.2 Practical Implications

6.2.1 Promoting Knowledge Flow

Teece [1977] argued that the economic growth of every nation is linked to the successful international transfer of knowledge. Such successful transfer of knowledge is also the foundation of the international ICT spillover which has been investigated in the current study. The findings of international ICT spillover have important implications for policy making because policy makers may be facing questions as in whether policy should facilitate the international transfer of knowledge. The findings of this paper show clearly that there are indeed ICT spillovers across country borders. Furthermore, this spillover takes place through knowledge flow. Therefore, to assimilate such positive externality, policy to promote knowledge flow should be favored.

In regard to promoting knowledge flow, ICT also plays the role of enabler through its communicational functions. Madden and Savage [2000] argue that information technology and telecommunications (ITT) is an important source of international knowledge transfer in an emerging global information economy. International trade in ITT equipment and services generates direct productivity benefits through lower transaction costs and improved marketing information, and indirect benefits due to accelerated information and knowledge diffusion across borders [Jussawalla and Lamberton 1982, Antonelli 1991]. As such, ITT and trade policy are becoming a priority for many governments and international agencies endeavoring to improve national productivity and economic growth [European Bank for Reconstruction and Development 1995, OECD 1996a, Spiller and Cardilli 1997]. Further, Antonelli [1991] suggests the diffusion of advanced ITT services provides a means by which developing countries can overcome information asymmetries and take advantage of opportunities for technology catch up. As such, policy makers may have to re-adjust the investment in ITT equipment, either through domestic manufacturing or foreign trade, to reap the benefits of ITT to economic growth.

6.2.2 Promoting Trade Openness

As suggested by Grossman and Helpman [1991], not all international knowledge flows are independent of economic activities. The transmission of knowledge often takes place when business associates meet to engage in commerce. For example, foreign buyers of local products may provide information about manufacturing techniques, while foreign sellers may suggest ways that their products can be used more effectively. If these channels of communication are empirically important, countries that opt for economic isolation will forfeit many spillover benefits. In short, international commerce can spur innovation by facilitating the process of industrial learning. Kuthuria [1996] supports such view arguing that if spillovers are found significantly positive then an open-door industrial and trade policy similar to the one adopted by Singapore is worth practicing.

Our empirical findings reaffirms such notion by suggesting that the more open an economy, the more impact foreign ICT investment has on domestic TFP growth; in other words, the more spillover effects the economy assimilates. The implication for policy makers is straightforward. In presence of the international ICT spillover, to take full advantage of it, an economy should opt for open-door policy especially to those trading partners which have large knowledge stock. A subtle issue to note while making such policies is that for a country to benefit from foreign trade in these ways, it needs to have trade partners that are capable of providing it with products and information in which the country is in short supply. Both depend on the trade partners' accumulated knowledge that is embodies in products, technologies and organizations. Thus by trading with an industrial country that has a larger 'stock of knowledge' a developing country stands to gain more in terms of both the products it can import and the direct knowledge it can acquire than it would by trading with another developing country.

It is a widely held view that international trade leads to faster technological diffusion and to higher rates of productivity growth [e.g., Coe et al. 1997]. While this would be important for all countries, it has dramatic implications for less developed countries as they seek to catch up with the technological leaders in the OECD. Antonelli [1991], in a similar vain, suggests that the diffusion of advanced ICT services provides a means by which developing countries can take advantage of opportunities for technology catch up. International agencies such as World Bank routinely recommend policies that foster international trade, in part because it is presumed to benefit international technology diffusion [World Bank 1991, 1998].

6.3 Limitations

Our findings, though consistent with the notion of ICT spillover in general, do not provide conclusive evidence of a casual relationship, given the small proportion of ICT investment in the overall investment picture, the broad array of factors which affect economic growth and total factor productivity, and the lack of significance in causality test findings. Despite our intention to analyze a more comprehensive framework for endogenous TFP model, the data availability limits our findings. For instance, there is considerable agreement on the growth contribution of R&D to TFP. However, the R&D data for our specific sample in a unified definition turn out very challenging to collect. Since our econometric analysis is based on a panel of 29 countries through 9 years, the generalizability of the result is also constrained. As far as grouping of the sample is concerned, there are 20 highly developed countries whereas only 9 less developed countries. Such unbalanced group sizes might add to limitation of the empirical results of grouping estimation.

6.4 Future Research

To overcome the limitation as above-mentioned, future research may explore more of the broad array of factors which affect economic growth and investigate the relationship between ICT investments with such factors. To enable such studies, better operationalization of the right-hand-side variables of TFP is needed to make possible the data collection as well as to support hypotheses (in terms of construct validity). As far as we know, the current study is a first step in search of international ICT spillover. There has been considerable research work regarding ICT and its contribution to productivity gain and economic growth and the mechanisms of such contribution so that economic policy can be attuned to facilitate the contribution. Nevertheless, the existence of international ICT spillovers and the channels for such effects to take place have important policy implications as well, which goes back to the very basic issues of openness of an economy and world trading system. Therefore, further theoretical and empirical research are called for to add to accumulative evidence of international ICT spillover effects, which will in turn back up the policy making in related areas for economic well-being at aggregate level.

7. Concluding Remarks

ICT spillover is not a new area of research. The important role ICT has played in economic performance has drawn attention from scholars to study the non-traditional effect of ICT, which are in most cases spillover associated with ICT capital. However, there has been no study dedicated to approaching the ICT spillover at country level. In this paper, we provide empirical evidence of the existence of such spillover effects. We conduct our empirical tests using alternative model specifications on a sample of 29 countries with wide range of economic development from 1993 to 2001. A balanced panel of annual data series is collected for the estimation. Our empirical findings support the existence of ICT spillover across country borders and it means that an economy can benefit from ICT investment of other economies. Furthermore, while dividing the sample into two country groups according to their economic development level, we find the group pattern of ICT spillover. The less developed country group could reap more benefits from the ICT spillover than the highly developed group. Our empirical results have important implications for policy makers. As the nature of ICT spillover is ICT-related knowledge spillover, to reap full benefits of the spillover effect, policy to promote knowledge flow is recommended. Similarly, in the presence of international ICT spillover, an open-door policy should be put forward in a strategic manner to facilitate the assimilation of such spillover.

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Table 1. GDP per capita, 2002
at current prices, in US dollars

Highly Developed Country Group		Less Developed Country Group	
Country Name	Based on Current Purchasing Power Parities	Country Name	Based on Current Purchasing Power Parities
Australia	28, 100	China	4,400*
Austria	28, 900	Greece	18, 400
Canada	30, 300	India	2,540*
Denmark	29, 300	Indonesia	3, 100*
Finland	26, 500	Korea	17, 000
France	27, 200	Mexico	9, 200
Germany	25, 900	Poland	10, 700
Hong Kong	26, 000*	Philippines	4, 200*
Ireland	32, 600	Turkey	6, 400
Italy	25, 600		
Japan	27, 000		
New Zealand	21, 800		
Netherlands	29, 000		
Norway	35, 500		
Singapore	24, 000		
Spain	22, 400		
Sweden	27, 200		
Switzerland	29, 900		
United Kingdom	28, 000		
United States	36, 100		

Note: values appended by * are extracted from CIA-The World Factbook; the rest are from OECD.

Table 2. Summary of Regression Results

Variables	Simple Level Estimation	Simple Differenced Estimation	Differenced with Country Dummies	Fixed Effects with Year Dummies	Fixed Effects with Trend	Grouping Fixed Effects with Year	Grouping Fixed Effects with Trend	Control for Education with Year	Control for Education with Trend	Control for Education with 3 Lags
Constant	1.665177	0.025426								
ITD	0.294245***	0.108818***	0.110219***	0.112642***	0.109425***	0.115878***	0.112556***	0.108575***	0.112908***	0.118883***
ITF	0.211679***	0.049643***	0.054950***	0.036239**	0.050258***					
DH*ITF						0.004592	0.034881	0.000390	0.034634	0.021354
DL*ITF						0.048947***	0.059296***	0.054096***	0.058830***	0.054196***
EDU								0.026462*	-0.001273	0.019283*
EDU(-1)										0.004555
EDU(-2)										0.019287
EDU(-3)										0.039975***
Adj. R^2	0.186296	0.286995	0.349688	0.417508	0.348743	0.422471	0.348184	0.429462	0.344962	0.401166

Notes: The inclusion of country dummies, year dummies and trend in estimations are not demonstrated in the result table. * significant at the 10 percent level; ** significant at the 5 percent level; *** significant at the 1 percent level.

Table 3. Results of panel causality test for whole group

Hypothesis	F-Statistics (LSDV)	Causality	Chi-Square Statistics (2SLS)	Causality
H_1	5.16	ITD→TFP***	7.22	ITD→TFP**
H_2	3.37	ITF→TFP**	4.49	No

Table 4. Results of panel causality test for HDC and LDC

Group	Hypothesis	F-Statistics (LSDV)	Causality	Chi-Square Statistics (2SLS)	Causality
Highly Developed Countries	H_1	2.45	ITD→TFP*	0.34	No
	H_2	1.49	No	3.16	No
Less Developed Countries	H_1	0.64	No	2.64	No
	H_2	1.52	No	0.58	No

Notes: * significant at the 10 percent level; ** significant at the 5 percent level; *** significant at the 1 percent level. H_1 denotes the hypothesis that ITD does not Granger cause TFP, H_2 denotes the hypothesis that ITF does not Granger cause TFP.