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Jungsoo Park, Seung Kyoon Shin, G. Lawrence Sanders,

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Impact of International Information Technology Transfer on National Productivity

Jungsoo Park
School of Economics, Sogang University, 1 Shinsu-dong, Mapo-gu, Seoul, Korea 121-742,
jspark@sogang.ac.kr

Seung Kyoon Shin
College of Business Administration, University of Rhode Island, 7 Lippitt Road,
Kingston, Rhode Island 02881-0802, shin@uri.edu

G. Lawrence Sanders
Department of Management Science and Systems, School of Management, State University of New York at Buffalo,
Buffalo, New York 14260-4000, mgtsand@buffalo.edu

Researchers have widely postulated that the adoption of information technology (IT) products enhances global competitiveness and production efficiency as successful technological innovation replaces and improves traditional inputs and modes of production. This study suggests that when IT products are traded across borders, IT investment in an economy has a positive influence on the productivity of its import partner country. We provide empirical evidence for the positive effect of global IT diffusion on productivity through international trading of IT products. The results show a positive effect of foreign IT transfer on the recipient country's productivity. In addition, we find that the effect of transferred IT is only significant when the source country is an IT-intensive or hi-tech export country. The results and implications are robust, even controlling for other important factors such as openness, innovative capacity, and IT infrastructure in addition to the transferred IT. Finally, a panel cointegration test—a recently developed advanced econometric method—is used to address the common problems of spurious relations that arise in regressions with nonstationary time-series data.

Key words: information technology; knowledge transfer; openness; innovative capacity; IT infrastructure; national productivity; international IT diffusion
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1. Introduction

After years of information technology (IT) productivity paradox debates, a stream of studies has found significant and positive returns from IT investment (Brynjolfsson and Hitt 1996, Hitt 1999, Lichtenberg 1993). Although these studies have generated encouraging evidence of IT payoffs, the interpretation of the results is limited. This is because most of these information systems studies have addressed the productivity question at the organizational level, while the IT productivity paradox was originally recognized at the national and industry level (Chan 2000).

Recent empirical studies using country-level data sets have identified a positive correlation between increased IT capital and productivity growth (Dewan and Kraemer 2000; Park et al., forthcoming). According to these studies, adoption of IT products as inputs of production enhances production efficiency and global competitiveness when IT products successfully transfer technological innovations, replacing the traditional inputs and modes of production. In this study, we suggest that when IT products are traded across borders, transferred IT stocks may have a positive influence on the productivity of its import partner country. According to World Trade Organization (1999), the share of IT products in world merchandise exports increased from 8.8% to 13.1% during the 1990s. Taking into account IT imports alone, the sum of 39 developed and developing countries' IT imports increased dramatically during a short period—approximately 2.5 times between 1992 and 2000 (see Figure 1). Given this rapidly increasing trend of globalization in trades

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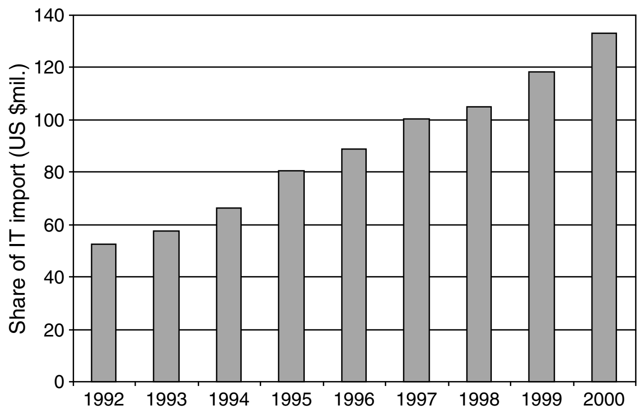
Figure 1 Trend of Increasing IT Imports, 1992–2000



Note. Data source: United Nations trade data 2000 (Feenstra and Lipsey 2005).

of IT-related products, a study investigating the productivity effects of international IT transfer is urgently needed.

Theoretical and empirical researchers of international technology transfers and diffusion have long argued that technological advances in general benefit other countries as well as the country in which they are developed (Eaton and Kortum 1999, Keller and Chinta 1990). Nevertheless, IT has been characterized as an idiosyncratic technology for numerous reasons (as outlined in the following discussion) and, thus international IT transfer should be classified separately from general technology transfer.

Information technologies have a number of unique characteristics that differentiate IT from general technologies. First, the marginal cost of reproduction of IT when it is transferred (primarily electronically) is generally a tiny fraction of the original cost of producing the technology and, thus, the momentum of IT transfer is substantially different from a general technology transfer (Shapiro and Varian 1999). Second, considering that IT is involved with a high level of customization before it is utilized, IT may require a relatively higher-level *intellectual* skill set (Curley and Pyburn 1982).[1] Industrial technologies, such as a drill press or a refrigerator, typically have a fixed set of functionalities. In contrast, IT functionalities are not fixed at the outset but can be innovated endlessly, depending on the technology's interaction with the intellect of the human beings who adopt and utilize it. Indeed, IT can be used to capture or formalize existing technologies and facilitate the development of new technologies. In the process of its instantiation into an individual information system, a given set of information technologies becomes subject to the various capacities of its implementers and users, who may ultimately create an information system that the inventors of the IT never intended.

The third characteristic of IT is that it evolves. Consider that once instantiated, IT may evolve with the intellects of its implementers and users, who can turn their transformed intellect toward innovating additional functionalities for the IT, which can extend the capacity of recipients.

Despite these distinct characteristics inherent in information technologies, little theoretical or empirical work has been devoted to unraveling the determinants of cross-country IT transfer or the productivity impact of IT investment across national boundaries. As a first step toward the development of scientific research on this issue, we examine the productivity effect of IT transfer using a country-level annual panel data set for 39 developing and developed economies from 1992 to 2000. In identifying the channel of IT transfer, we show empirically whether international trade of IT products plays a significant role in increasing national productivity in the recipient countries. We use a country-level total productivity measure because foreign IT products are entered as inputs in various sectors of the economy that benefit from their usage.

In this study, we offer a new perspective on an understanding of IT-productivity dynamics. Recent works on IT productivity effects based on aggregate country-level data have shown positive IT effects on national productivity (Dewan and Kraemer 2000; Park et al., forthcoming). This study is the first to provide robust empirical evidence illustrating a strong positive effect of imported IT on domestic productivity at a country level, where international trade serves as a transfer channel of information technologies. The results are robust even controlling for additional important factors such as openness, innovative capacity, and IT infrastructure, in addition to the transferred IT.

[1] The second and third characteristics of IT are also shared by general-purpose technology (Bresnahan and Trajtenberg 1995).

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Furthermore, this study shows that IT transferred from IT-intensive countries has significant positive effects on the productivity of the recipient countries, whereas IT from less IT-intensive countries does not. IT products from IT-intensive economies are relatively more effective than those from less IT-intensive economies because of the advantages and competitiveness of the technological contents in those IT imports. Thus, this study provides a set of strategic guidelines for importing information technologies from foreign countries.

Finally, in the econometric analysis we show that cross-sectional time-series country-level data exhibit nonstationarity, which has not been previously discussed in IT investment research. A widely recognized problem in time-series analysis is that nonstationary dependent and independent variables with no true relation may exhibit statistical significance under classical regression analysis, which makes the classical inference on the estimates invalid (Greene 2000). Consequently, regressions involving nonstationary variables in level series often lead to spurious results. To verify that regressions are indeed showing true econometric relations, we test whether the variables are cointegrated using a panel cointegration test (Pedroni 1999). The key findings provide robust model specifications that are viable under various scenarios.

The remainder of the paper is structured as follows. Section 2 briefly discusses the theoretical foundation of the empirical model. Section 3 develops economic model specifications. Section 4 provides the data description and methodology. Section 5 describes the empirical model of the productivity effect of international IT transfer and the econometric method. Section 6 presents the main estimation results, and §7 discusses the implications of the empirical results. Finally, §8 provides the caveats as well as suggestions on directions for future work.

2. Trade in IT Products as an International IT Transfer Mechanism

Trade theory (Mahajan and Peterson 1985, Pugel 1982) suggests that foreign technologies can be transferred by the purchase or physical acquisition of foreign technology products, and thus, trade can be a vehicle of technology transfer among nations. In a similar vein, trade has been considered as a channel of international research and development (R&D) spillover (Coe and Helpman 1995, Engelbrecht 1997, Park 2004). According to trade theory, international IT transfer can be viewed as a process by which information systems "know-how" (i.e., IT) is transferred across a country boundary in the form of technology embodied in the traded products. In this study, we define IT transfer as international diffusion of information technologies by means of IT products traded from source countries to recipient countries.

There are two primary mechanisms for international IT transfer: (1) direct learning about foreign IT (Gong and Keller 2003) and (2) employing specialized and advanced intermediate products that have been invented abroad. Although technology can be transferred in a purely informational form, it can also be transferred through the trade of products and processes in which the technology is embodied (Connolly 2003, Kedia and Bhagat 1988, Romer 1993). The current study focuses on the second mechanism of IT transfer. In fact, the dominating form of IT transfer is clearly by means of technologies embodied in IT products, because information technologies can hardly be transferred without physically installing computer software and hardware in the recipient countries. A measure of the computing capacity traded, therefore, can be a direct measure of IT transfer (Caselli and Coleman 2001).

It is logical to use imported IT as a proxy for IT transfer. IT hardware and software embody the IT knowledge or know-how in a way that enables IT to be transferred and diffused in the countries where they are to be utilized. Studies suggest that the flow of information and communication technologies may be facilitated by direct international commercial exposure on the part of producing agents (Teece 1977). The advantage of an embodied form of IT transfer is that the material, informational, and managerial components are transmitted along with actual IT products. The embodied IT knowledge may be more efficiently and effectively assimilated within the recipient countries (Glass and Saggi 1998, Keller and Chinta 1990). This phenomenon is very evident when viewed in

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the context of transferring a business software package, such as a supply chain management system. In particular, many countries in the world do not have a computer manufacturing industry, which was especially true at the beginning of the IT era. For those countries, the installed computing capacity was from IT imports, and IT import is the primary channel of IT transfer (Caselli and Coleman 2001).

3. Model

3.1. Total Factor Productivity

We assume that the production technology is a Cobb-Douglas function with constant returns to scale

$$Y = A\lambda^N K^\beta L^{1-\beta}, \tag{3.1}$$

where Y denotes value added, A is a country-specific constant, K is physical capital stock, and L is total labor hours. We assume that with each innovation the technological level of production rises by λ. Thus, N represents the average number of quality upgrades with respect to a technology (Grossman and Helpman 1991a).

In selecting an appropriate measure for national productivity, the commonly used measure of labor productivity Y/L is inappropriate because it is influenced by capital contribution and does not accurately reflect the true technological environment of an economy. High labor productivity in a country may result from technological superiority, but it may also be simply due to greater levels of capital equipment per labor with no technological advantage. Total factor productivity (TFP) measures the productivity net of the contributions of measured inputs and therefore isolates the portion of output due purely to technological efficiency. Based on the production technology in Equation (3.1), TFP is defined as

$$\text{TFP} \equiv \frac{Y}{K^\beta L^{1-\beta}}. \tag{3.2}$$

Substituting Equation (3.1) into Equation (3.2) and taking logs of both sides, the log of TFP is derived as

$$\log \text{TFP} = \log A + N \log(\lambda). \tag{3.3}$$

Economywide quality upgrades result either from using higher-quality IT-related intermediate goods embodying superior technology or from directly adopting newly developed technology. Intermediate goods are produced by inputs in which the quality and efficiency are improved by innovations and accumulated investments in IT. Adopting these advanced inputs in the production of intermediate goods increases productivity, which may not be captured by the increased rents from the innovation. Equation (3.3) illustrates that this technological gain may be realized as a gain in TFP of the economy.

As inputs are internationally traded across countries, a country may benefit from foreign technical advances through imports of technologically advanced IT products. If a share of imported inputs includes IT products resulting from the accumulated IT investments in foreign countries, foreign IT investments will have an impact on the average quality of inputs used in the production of domestic intermediate goods. However, because not all inputs are available to all economies because of trade limitations and barriers, domestic and foreign IT will differ in the magnitude of influence on domestic productivity. To summarize, the average improvement in the quality of inputs existing in the economy is a function of accumulated investments in domestic IT (S^d) and foreign IT (S^f), as well as control variables (z)—which also may have substantial influence on domestic TFP—expressed as

$$N = F(S^d, S^f, z). \tag{3.4}$$

In the context of international IT transfer and recipient country's domestic TFP, recipient's openness (Glass and Saggi 1998, Rivera-Batiz and Romer 1991), innovative capacity (Furman et al. 2002, Kogut and Zander 1992, Suarez-Villa 1990), and IT infrastructures (i.e., personal computers [PCs] and telecommunication technology) are tested as the control variables (z) along with the IT stock. Incorporating Equation (3.4) into Equation (3.3), we find

$$\log \text{TFP} = \alpha_0 + \gamma F(S^d, S^f, z), \tag{3.5}$$

where α_0 and γ are constants. In the subsequent sections of this inquiry, we measure the influence of the accumulated investment in foreign IT (S^f) on domestic TFP as the productivity effect of the international IT transfer.

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Based on Equation (3.5) and its modified versions, we address the following three questions: (1) Can we find evidence of international IT transfer? (2) Is international trade a meaningful channel of IT transfer? (3) Does IT effectiveness depend on the characteristics of the source country?

4. Data Description

The annual time-series data were collected for 39 developing and developed economies from 1992 to 2000.[2] The periods and countries included in the data set were primarily determined by the availability of IT investment data.

In calculating the TFP series, we rely on a constant-returns-to-scale technology assumption and a competitive factor market assumption that factors of production are assumed to be paid according to their marginal products. Thus, the output elasticity with respect to capital, β, in Equation (3.2) is equal to the average of actual capital shares. We use the actual capital shares data for 21 Organisation for Economic Co-operation and Development (OECD) countries from Coe and Helpman (1995), which lists the average shares for 1987–1989. The shares for the rest of the economies are assumed to be the average of the 21 OECD countries (0.335). The data sources for real gross domestic product (GDP), physical capital stock, and labor are described in the following discussion.[3]

Real GDP, Y, in 1996 purchasing power parity (PPP) U.S. dollars, real investments in 1996 PPP U.S. dollars, and number of workers, L, were obtained from the latest data set of *Penn World Tables* (PWT 6.1) (Heston et al. 2002).[4] Because capital stock series are not available in the new version of PWT 6.1, aggregate capital stock values are estimated from the real investment series for each country, based on the following formula:

$$K_{i0} = \mathrm{Inv}_{i0}/(\gamma_i + g_i), \tag{4.1}$$

where Inv_{i0} is the initial investment for country i. The investment growth rates (g_i) are calculated with the earliest 10 years of investment data available, and the retirement rates (γ_i) are assumed to be 5% (Sichel 1997). Given the estimated initial aggregate capital stock, the investments are then accumulated to form the subsequent aggregate stock series based on the perpetual inventory method ($K_{it} = (1-\gamma_i)K_{it-1} + \mathrm{Inv}_{it-1}$).

The shares of information and communication technology expenditures in GDP are available from the World Bank database (2002) for the 39 countries for the period of 1992 to 2000.[5] The shares are multiplied by the real GDP of the PWT 6.1 to estimate the real IT investment series in terms of 1996 PPP U.S. dollars. Based on these real IT investment series, we estimate the IT capital stock (S^d) using the analogous method previously described to construct aggregate physical capital stocks with an assumed depreciation rate of 20% to reflect the shorter service life of IT stock (Lau and Tokutsu 1992).[6] Non-IT physical capital stock (K) used in Equation (3.2) is derived by taking the difference of the aggregate physical capital stock and the estimated IT capital stock.

[2] The 39 countries are Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Colombia, Denmark, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Italy, Japan, Malaysia, Mexico, the Netherlands, New Zealand, Norway, the Philippines, Poland, Portugal, Romania, South Africa, Republic of Korea, Spain, Sweden, Switzerland, Thailand, Turkey, United Kingdom, United States, and Venezuela.

[3] Siegel asserts that quality improvements in inputs and output are not properly measured in the observed variables. This implies that the estimates of TFP using the measured inputs and output may be biased and imprecise. However, because most of our estimated models show cointegrating relationships, we conjecture a possible bias from the mismeasurement error is minor. A detailed explanation is provided in Part 1 of the online supplement, which is available on the *Information Systems Research* website (http://isr.pubs.informs.org/ecompanion.html).

[4] The PPP exchange rate is used in converting all variables denominated in domestic currency units into the common U.S. dollar currency unit. PPP exchange rate is the conversion rate between two currencies, which reflects the real purchasing power of each currency incorporating the price levels of each country. Ideally, the PPP exchange rate should be equal to the ratio of the two countries' price levels.

[5] Information and communications technology expenditures include external and internal spending on information technology and spending on telecommunications and other office equipment. External spending includes tangible spending on IT products purchased by businesses, households, governments, and education institutions from vendors or organizations outside the purchasing entity. Internal spending includes intangible spending on internally customized software, capital depreciation, and so on.

[6] The empirical results in this study are robust to alternative depreciation rates for IT investment such as 10% or 15%. The results are provided in Part 3 of the online supplement.

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4.1. Foreign IT Stock

Foreign IT capital stock represents the accumulated foreign IT investments that potentially influence the productivity of other countries. As discussed in the previous section, we consider international trade in IT products as one of the most significant channels of IT transfers. We consider two alternative definitions of foreign IT stocks: a simple sum of all other countries' IT stocks, Equation (4.2), and IT-import-weighted sum of foreign IT concentration, Equation (4.3):[7]

$$S_{it}^{\text{sum}} = \sum_{j \neq i} S_{jt}^{d} \tag{4.2}$$

$$S_{it}^{i} = \sum_{j \neq i} (v_{ij,t} \cdot S_{jt}^{d}) / y_{jt}, \tag{4.3}$$

where $v_{ij,t}$ denotes the IT imports of country i from country j, S_{jt}^{d} denotes the IT capital stock of country j, and y_{jt} is the GDP in country j in year t. To obtain bilateral IT import series, we use disaggregated ISIC four-digit level bilateral import flow data, which are available in *NBER-United Nations Trade* (Coe and Helpman 1995, Feenstra and Lipsey 2005). To proxy for the IT imports, we obtained imports of automatic data processing machines and units thereof (category 752), magnetic and optical readers, machines for transcribing data onto data media in coded form, and machines for processing such data, n.e.s.[8] Our data analysis follows a commonly used approach in the related area: Studies have shown that trade in general contributes to technology transfer (Grossman and Helpman 1991b, Saggi 2002), and numerous empirical studies on technology transfer through trade utilize a country's imports of all goods while attempting to measure technology spillovers through trade (Caselli and Coleman 2001, Okabe 2002, Xu and Wang 1999). As we discuss in §3, the quality of imported IT products and services are determined by the source country's IT capacity, so we define our measure for foreign IT stock in Equation (4.3) to capture the real IT concentration (S_{jt}^{d}/y_{jt}) of source countries embodied in the IT import flows.

The productivity effect of transferred IT may vary in terms of the source country's IT-related characteristics. IT intensity has been discussed as a meaningful variable of IT infrastructure metrics (Zhu and Kraemer 2002), influencing the performance and efficiency of IT (Harris and Katz 1991). We divide the foreign IT stock into two categories based on the IT intensity level of the source country: foreign IT stocks solely based on the IT-intensive countries and those based on the less IT-intensive countries. The IT intensity for each country is first estimated based on the ratio of IT stock to labor averaged over the sample period. In our study, IT-intensive countries are defined as those countries whose IT stock to labor ratio is higher than the median value of the ratio among the sample countries. Using Equation (4.3), we construct the foreign IT stock variable solely based on IT-intensive country IT stocks ($S^{i\text{-ITH}}$) and the variable solely based on the less IT-intensive country IT stocks ($S^{i\text{-ITL}}$).

As an alternative measure of the source countries' characteristics, we create IT stocks from high and low innovative countries. The innovativeness of the source country is proxied by the percentage of hi-tech exports.[9] Then, using Equation (4.3), we construct foreign IT stocks from hi-tech export countries ($S^{i\text{-TechH}}$) and from less hi-tech export countries ($S^{i\text{-TechL}}$). The hi-tech export countries are the countries that belong to the highest quartile group in terms of percentage of hi-tech goods in its manufacturing exports. Table 1 provides summary statistics for the variables used in this study.

[7] IT-import-weighted sum of foreign IT concentration is motivated by the definition for foreign R&D stocks in Lichtenberg and de la Potterie (1998), which improves on the simple import-weighted sum of R&D stocks by overcoming aggregation problem. See Lichtenberg and de la Potterie for a detailed discussion regarding the construction of foreign stock index.

[8] Category 752 in the United Nations data set includes the following subcategories (for which separate data are available): analogue and hybrid (analogue/digital) data processing machines (7521); complete digital data processing machines, comprising in the same housing the central processing unit and at least one input unit and one output unit (7522); complete digital central processing units; digital processors consisting of arithmetical, logical, and control elements (7523); digital central (main) storage units, separately consigned (7524); peripheral units, including control and adapting units (connected directly or indirectly to the central unit) (7525); and off-line data processing equipment, n.e.s. (7528).

[9] Hi-tech exports are products with high R&D intensity. They include products such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.

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Table 1 Summary Statistics of Variables

Variable	Description	Mean	s.d.	Min.	Max.
Productivity					
TFP	Total factor productivity (index)	768	593	212	3,797
Domestic IT stocks					
S^d	Domestic IT capital stock (millions)	163	393	2.6	2,940
Foreign IT stocks					
S^{sum}	Simple sum of foreign country's IT stock (millions)	6,190	1,220	2,750	8,470
S^i	Import-weighted sum of foreign country's IT concentration (index)	565,715	1,232,638	1,703	12,289,912
$S^{i\text{-ITH}}$	Import-weighted sum of IT stocks from IT-intensive countries[a] (index)	419,467	652,311	2,577	4, 342,113
$S^{i\text{-ITL}}$	Import-weighted sum of IT stocks from less IT-intensive countries[a] (index)	152,379	668,464	42	7,947,808
$S^{i\text{-TechH}}$	Import-weighted sum of IT stocks from hi-tech export countries[b] (index)	468,752	891,969	1,177	7,591,718
$S^{i\text{-TechL}}$	Import-weighted sum of IT stocks from less hi-tech export countries[b] (index)	96,963	370,645	86	4,698,205
Openness					
imp	Ratio of total imports to GDP	0.3175	0.1710	0.0685	0.3175
ifdi	Ratio of FDI inflow to GDP	0.0281	0.0323	−0.0297	0.0281
Innovative capacity					
pat	Number of patent application in the United States per 1,000 persons	0.0639	0.0994	0.0000	0.0639
Physical IT Infrastructure					
pc	Number of PCs per 1,000 persons	0.1264	0.1265	0.0005	0.1264
dtel	Telecommunication dummy[c]				

Notes. FDI = foreign direct investment. Data sources are described in §3. Sample periods are from 1992 to 2000 for all economies. All foreign IT stocks are constructed based on IT stocks in 1996 PPP U.S. dollars using the relevant Equations (4.2) and (4.3) in §3. Except for S^{sum}, units of foreign IT stock definitions are all indices as they are import-weighted sum of real IT concentration index (S^d_{jt}/y_{jt}). TFP is an index derived from Equation (3.2).

[a]The IT-intensive (less IT-intensive) countries are countries whose ratios are higher (lower) than the median of the sample countries' IT stock-to-labor ratio.

[b]The hi-tech export countries are the countries that belong to the highest quartile group in terms of percentage of hi-tech goods in their manufacturing exports.

[c]The telecommunication dummy (*dtel*) variable equals one when the country's telephone-to-people ratio is above the median of the sample countries' ratios, and zero otherwise.

4.2. Openness

Openness is defined as the degree to which an economic environment is hospitable and open toward international trade (Gustavsson et al. 1999). Openness is believed to benefit from international technology transfer in several ways. Imports of improved capital equipment and intermediate goods and services enable the recipient country to capture the technology content of the good or service. This outward orientation benefits a country by giving it fast access to new information technologies and enables the country to reap the benefits of global technology spillover from more technologically advanced countries (Glass and Saggi 1998, Rivera-Batiz and Romer 1991).

Coe and Helpman (1995) provide empirical evidence on the importance of trade for international diffusion of knowledge. Keller (1998) extends the theory of import-based transfer in the context of international R&D spillover. The ratio of total imports to GDP (*imp*) is calculated to assess openness of each country (Caselli and Coleman 2001, Glass and Saggi 1998, Hu and Mathews 2005).

Researchers have often argued that foreign direct investment (FDI) involves the transfer of knowledge

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from one country to another, making it a potentially important vehicle for international technology diffusion (Carr et al. 2001, Glass and Saggi 1998). Therefore, we use the ratio of FDI inflow to GDP (*ifdi*) as an alternative measure of a country's openness.

4.3. National Innovative Capacity

National innovative capacity is defined as the intellectual capacity of a country to understand, produce, and commercialize a flow of innovative technology on the strength of its common innovation infrastructure and the environment for innovation in its industrial clusters (Furman et al. 2002). The dynamics of national innovative capacity have been investigated by numerous scholars since the definition and measures of the concept were formulated (Glass and Saggi 1998). Kogut and Zander (1992) argue that combinative capability is an ability to synthesize and apply current and acquired knowledge and that it is the intersection of the capability of the recipient country to exploit its pre-existing intellectual capacity and the unexplored potentials of the foreign IT. Returns on a newly imported IT will be decreasing without complementary knowledge capacity to be combined with the new technology. National innovative capacity of the recipient country serves as platforms on future and uncertain opportunities with the newly transferred IT.

We use patent statistics in this study because the data are widely available and cover all the sample countries (Griliches 1990, 1998; Lichtenberg 1993).[10] We reason that patents are the direct outcomes of the R&D efforts, and, thus, we expect a close relation to exist between the two variables (Stern et al. 2000). In addition, the patent rate has been shown to be a reliable proxy of innovative capacity (Suarez-Villa 1990). To concentrate only on the internationally competitive patents, we use the number of patent applications in the United States. International patenting has been used as a common indicator of innovative capacity in the literature (Furman et al. 2002, Mansfield 1985). For example, Furman et al. (2002) track the dynamics of innovative capacity using international patenting, taken as the number of patents granted from the U.S. Patent and Trade Office as a single measure of innovation. Mansfield (1985) emphasizes that the patent is the foundation of a nation's technological innovation. In our study, the innovative capacity is measured by the number of patent applications[11] in the United States per 1,000 persons (*pat*).

4.4. PCs and Network Telecommunication as Physical IT Infrastructure

Distribution of PCs and communication network technologies have been important components of tangible IT infrastructure (Dewan and Kraemer 1998, Lehr and Lichtenberg 1999, Zhu and Kraemer 2002). Existing in one form or another as a fundamental and affordable gestalt of computer systems, PCs not only have a direct and large impact on productivity (Landauer 1995); they also facilitate computer fluency and play a crucial role in knowledge creation and spillover (Nonaka and Nishiguchi 2001). In most countries, PC- and telephone-based communication networks are complimentary and together form the most common platform for Internet access and thus support the core of a virtual knowledge space. These two components of physical IT infrastructure offer a platform for the continuing transformation of the global economy from a physical basis to a knowledge- and information-based economy (Nonaka and Nishiguchi 2001).

Although IT trade is a new factor input via the import mechanism in a given period, IT infrastructure is a stock accumulated beforehand. It assists a

[10] Because numerous studies at various levels of aggregation show that a positive relation exists between R&D and TFP (cf. Griliches 1998, Lichtenberg 1993), we considered employing R&D as a control variable. However, the problem lies in the lack of availability of R&D data for our sample countries. Almost all existing R&D literature is based just on the OECD country sample, while approximately one-half of our sample countries are non-OECD countries. Therefore, we use patent statistics to proxy innovative capacity instead of the R&D stock. Note that the relationship between patents and R&D may not be consistent in various statistical settings (Griliches 1990).

[11] Patent granted is another potential proxy. However, because of the significant delays in processing patent applications, the patent granted may not reflect the correct innovative capacity for each period. For example, the approximate delay between the patent application and the grant in 2006 is about 31.1 months; in 2003 it was 26.7 months (http://www.uspto.gov/web/offices/com/annual/2006/2006annualreport.pdf). Furthermore, the patent granted variable showed signs of a multicollinearity problem with other control variables.

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country in the efficient utilization of the imported information technology by drawing and relying on the pre-existing infrastructure. We examine the effects of physical IT infrastructure of recipient countries using the number of PCs per 1,000 persons (*pc*) and a dummy variable (*dtel*), where the variable takes a value of 1 when the country's telephone-to-people ratio is above the median of the sample countries' ratios.

5. Econometric Method

5.1. Panel Unit Root Test

We use a cross-section time-series data set to estimate the magnitude of international IT transfer on the TFP of each economy. A widely known problem in time-series regressions is that they usually involve time-series variables that exhibit nonstationarity. Nonstationary processes are processes with a nonconstant mean that may involve a time trend or exhibit a random walk process. Seminal papers in time-series econometrics literature by Granger and Newbold (1974) and Phillips (1986) suggest that regressions involving nonstationary variables may lead to spurious results. Granger and Newbold find that if two unrelated nonstationary processes with strong time trends are regressed one on the other, the regressions almost always produce a significant relation because of the underlying trend, even for unrelated series. Similar findings apply to random walk processes.

Standard significance tests such as t and F tests in these regressions are usually misleading and have a tendency to support significant relations even when no true relations exist. Therefore, to avoid possible nonstationarity, we perform Pedroni's (1999) panel unit root tests on all variables. The panel unit root test determines whether a variable is nonstationary (or a unit-root process) under a panel data set context. Pedroni's test allows for heterogeneous autocorrelation in each individual time series in the panel for the alternative hypothesis. The standardized test statistic possesses an asymptotic standard normal distribution.

Table 2 presents the test results of the panel unit root test at log levels and log differences of TFP, domestic IT stock (S^d), alternative specifications of foreign IT stock (S^{sum}, S^i, $S^{i\text{-ITH}}$, $S^{i\text{-ITL}}$, $S^{i\text{-TechH}}$, $S^{i\text{-TechL}}$), and other control variables (imp, $ifdi$, pat, pc, $dtel$). I(1) and I(2) indicate first-order and second-order integrated processes, respectively, where integrated process of order d, $I(d)$, mean that the series is nonstationary and needs first-differencing of d times to attain stationarity. Decisions are statistically significant at the 5% significance level of a one-sided test. We note that all variables except for S^{sum} are first-order integrated but not second-order integrated, which implies that they are nonstationary in log levels but stationary when first differenced.

Table 2 Panel Unit Root Test

Variables (levels)	Statistic	Variables (differenced)	Statistic	Decision[a]
log(TFP)	7.396	d log(TFP)	−5.564	I(1)
log(S^d)	3.634	d log(S^d)	−6.349	I(1)
log(S^{sum})	13.931	d log(S^{sum})	−0.636	I(2)
log(S^i)	1.975	d log(S^i)	−8.298	I(1)
log($S^{i\text{-ITH}}$)	4.152	d log($S^{i\text{-ITH}}$)	−6.639	I(1)
log($S^{i\text{-ITL}}$)	−0.046	d log($S^{i\text{-ITL}}$)	−11.925	I(1)
log($S^{i\text{-TechH}}$)	2.554	d log($S^{i\text{-TechH}}$)	−2.576	I(1)
log($S^{i\text{-TechL}}$)	1.300	d log($S^{i\text{-TechL}}$)	−5.148	I(1)
imp	2.139	*dimp*	−8.268	I(1)
ifdi	0.067	*difdi*	−6.055	I(1)
pat	4.375	*dpat*	−10.893	I(1)
dtel	2.253	*ddtel*	−3.627	I(1)
pc	3.876	*dpc*	−5.563	I(1)

Notes. The panel unit root test statistic is from Pedroni (1999), which has asymptotic normal distribution. A strong negative statistic rejects the null hypothesis of panel unit root. log(X) is log of X, and dY is the first difference of Y.

[a]Decisions are based on a 5% significance level of a one-sided test.

[b]The statistic for dd log(S^{sum}) is −7.3442.

The results of the panel unit root test clearly indicate that all variables considered are nonstationary. Therefore, the regressions involving these variables in log-level terms are subject to spurious relations, thus requiring that we verify whether they actually represent true relations. In the next subsection, we adopt the cointegration test, which is an advanced econometric method that helps verify the true relation among nonstationary series.

5.2. Empirical Model

From Equation (3.5), we form the baseline empirical equation in a panel regression context:

$$\log \text{TFP}_{it} = \alpha_0 + \alpha_i + \beta_1 \log S^d_{it} + \beta_2 \log S^f_{it} + \beta' Z_{it} + \varepsilon_{it}, \tag{5.1}$$

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where α_i are respectively country-specific constants, S^d is domestic IT stock, S^f is foreign IT stock, and Z_{it} is a vector of control variables. As discussed in the previous subsection, for each model based on Equation (5.1), we must explore whether the model represents true long-run relations of nonstationary series. Greene (2000) provides a good overview of contemporary thought on how to deal with nonstationary data in the time-series and econometrics literature. The intuition is briefly summarized in the following discussion.

Assume a fully specified regression model such as $y_t = \beta x_t + \eta_t$. If y_t and x_t are two unrelated nonstationary series with strong time trends, we would normally expect $y_t - \beta x_t$ to be nonstationary as well, growing with another trend. However, if some relation exists between those trends of the two variables (y_t and x_t), β may exist such that $y_t - \beta x_t$ $(=\eta_t)$ is stationary. This result implies that the series are drifting together at roughly the same rate. Two series that satisfy this requirement are said to be *cointegrated*, and the vector $[1, -\beta]$ is a *cointegrating vector*, where its error term η_t is stationary.

The widely used cointegration tests for a single time-series equation are addressed in Engle and Granger (1987), and discussion related to vector autoregression models can be found in Johansen (1991) and Stock and Watson (1988). We adopt the powerful panel cointegration test to examine the null hypothesis of noncointegrating vectors in a panel data set context (Pedroni 1999).[12] As ordinary least squares (OLS) are super-consistent for cointegrating vectors (Davidson and MacKinnon 1993), we provide OLS estimates for our regression models. All models include country-specific constants to control for unobserved cross-country heterogeneity, which implies that our fixed effect panel regression results capture the within-country differences in IT stocks and other variables over time and their influences on TFP growth.

[12] An alternative to our method of cointegration may be a regression method using stationary first-difference variables, which may have the advantage of eliminating econometric issues involving nonstationarity. However, a concern regarding the first-difference method is that it increases noise in the data. A brief explanation of the test is provided in Part 2 of the online supplement.

Equation (5.1) allows us to estimate the influence of domestic IT on TFP (β_1) and the foreign IT transfer effect (β_2). To alleviate potential endogeneity bias, all IT stocks are constructed to include only up to their one-year lagged value of IT investments. We first investigate the importance of international IT trade in the IT transfer process by examining two alternative baseline regressions in which the foreign IT stocks are constructed with and without import weights (S^i, S^{sum}). Selecting the import-weight version in Equation (4.3) as the baseline definition for foreign IT stock, we investigate the differential impact of alternative foreign IT stocks, each constructed based on the distinctive characteristics of the source country: foreign IT stocks distinguished by the degree of IT intensity ($S^{i\text{-ITH}}$ and $S^{i\text{-ITL}}$) and hi-tech export ($S^{i\text{-TechH}}$ and $S^{i\text{-TechL}}$) of the source countries. In so doing, we estimate the effects of imported IT from countries with different IT and hi-tech intensities.

Finally, we choose to use foreign IT stock as consisting solely of IT stocks from IT-intensive countries ($S^{i\text{-ITH}}$). We check the significance of our main result, controlling for factors proxying openness, innovative capacity, and physical IT infrastructure. The variables proxying for openness (*imp* and *ifdi*), innovative capacity (*pat*), and physical IT infrastructure effects (*pc* and *dtel*) are regarded as control variables. As a robustness check, we conduct alternative regressions for the same set of specifications but with foreign IT stock definition composed solely of IT stocks from hi-tech export countries.

6. Results

6.1. Imported IT Stocks and TFP

We first examine the productivity effects of domestic and foreign IT stocks in four alternative models in Table 3. To see the effects of domestic IT and imported IT stocks on recipient countries' TFP, Models (i) and (ii) include foreign IT stocks without and with import weights, respectively. Models (iii) and (iv) examine whether differential productivity effects exist with respect to foreign IT stocks differentiated by source country characteristics. In Model (iii), the import-weighted foreign IT stocks are divided into

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Table 3 Panel Total Factor Productivity Estimation: Dependent Variable: log(TFP)

	Model (i)	Model (ii)	Model (iii)	Model (iv)
log(S^d): Domestic IT capital stock	0.148* (0.036)	0.074* (0.018)	0.089* (0.021)	0.074* (0.018)
log(S^{sum}): Simple sum of imported IT	0.020 (0.029)			
log(S^i): Import-weighted sum of foreign country's IT concentration		0.066* (0.011)		
log($S^{i\text{-ITH}}$): Import-weighted sum of IT from IT-intensive countries			0.084* (0.013)	
log($S^{i\text{-ITL}}$): Import-weighted sum of IT from less IT-intensive countries			−0.003 (0.004)	
log($S^{i\text{-TechH}}$): Import-weighted sum of IT from hi-tech export countries				0.054* (0.013)
log($S^{i\text{-TechL}}$): Import-weighted sum of IT from less hi-tech export countries				0.011 (0.007)
Observations	351	341	337	341
Number of countries	39	38	38	38
Adjusted R^2	0.514	0.559	0.557	0.562
Cointegration test				
Panel ADF statistics[a]	−4.221	−4.942	−6.094	−5.914
Decision	CI[b]	CI	CI	CI

Notes. log(X) is log of X. Standard errors are in the parentheses. All estimations include unreported country-specific constants.

*Denotes significance at the 1% level.

[a]Panel ADF statistic is from Pedroni (1999), which has asymptotic normal distribution.

[b]CI represents panel cointegration.

two groups: IT-intensive countries and less IT-intensive countries. In Model (iv), the import-weighted foreign IT stocks are again split into two groups: foreign IT stock from hi-tech export countries and foreign stock from less hi-tech export countries.

To verify whether the empirical models considered in Table 3 represent statistically meaningful relations involving nonstationary variables (i.e., cointegrating vectors), we conduct Pedroni's (1999) panel cointegration tests on all regressions. The test has a null hypothesis of no cointegration for the vector specified in a given model. The panel-adjusted Dicky-Fuller statistic for the cointegration test has an asymptotic normal distribution. Table 3 indicates that the null hypothesis of no cointegration is rejected in favor of the alternative of cointegration in all four specifications of Models (i)–(iv). That is, the variables in each model's specification involve cointegrated relations, as indicated by CI in Table 3.

The coefficients of domestic IT stocks are consistently positive and significant in all model specifications of Models (i)–(iv), suggesting that domestic IT stocks (S^d) have a positive impact on national productivity. Our result confirms the findings on the productivity effect of IT in earlier studies (Dewan and Kraemer 2000; Park et al., forthcoming). In addition, our models find statistically significant positive effects of transferred IT. Note that foreign IT stock is not statistically significant in Model (i), in which foreign IT stock is calculated as a simple sum without import weights (S^{sum}). The foreign IT stocks, however, appear to exert significant positive influence when they are weighted by IT imports (S^i), as shown in Model (ii), implying that IT imports play a crucial role in the process of international IT transfer.

Model (iii) examines the productivity effects of the foreign IT stocks from two foreign country groups. The result is very strong and somewhat conclusive, indicating that the foreign IT stocks from the IT-intensive countries have a significant positive effect on TFP of the recipient countries, whereas those from the less IT-intensive countries do not. The reason may be that the IT stocks from the IT-intensive countries produce internationally competitive, cutting-edge technologies, which may enhance the productivities of other economies that adopt these technologies. This result is examined in the conclusion.

In a similar context, we divide foreign IT stocks into two groups in terms of the ratio of hi-tech export of the source countries and examine the effects of the two foreign IT stocks from the two country groups (Model iv). The results are analogous to Model (iii), showing that only the IT from technologically innovative countries is effective, whereas those from the remaining countries do not have a statistically significant effect on the domestic TFP. The adjusted R^2 of model specifications with domestic and foreign IT ranges from 0.514 to 0.562.

In essence, our results illustrate that trade serves as an effective mechanism in cross-country IT transfer and that foreign IT plays an important role in improving domestic TFP. Furthermore, our findings suggest that the productivity effect of international IT transfer exists only when the source country is an IT-intensive or hi-tech export country. In the subsequent analysis,

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Table 4 Panel TFP Estimation Based on IT-Intensive Foreign IT Stock ($S^{i\text{-ITH}}$): Dependent Variable: log(TFP)

	Model (i)	Model (ii)	Model (iii)	Model (iv)	Model (v)	Model (vi)	Model (vii)[b]
log(S^d)	0.083***	0.067***	0.084***	0.058***	0.056***	0.056***	0.066***
	(0.015)	(0.016)	(0.015)	(0.015)	(0.015)	(0.015)	(0.020)
log($S^{i\text{-ITH}}$)	0.078***	0.068***	0.062***	0.057***	0.051***	0.050***	0.048**
	(0.011)	(0.012)	(0.011)	(0.011)	(0.011)	(0.011)	(0.019)
imp		0.239***		0.216***	0.197***	0.197***	0.201**
		(0.073)		(0.069)	(0.069)	(0.069)	(0.093)
ifdi			0.543***				
			(0.099)				
pat				0.629***	0.392**	0.417***	0.386**
				(0.117)	(0.161)	(0.160)	(0.152)
pc					0.146**	0.131*	0.137*
					(0.069)	(0.068)	(0.072)
dtel						0.040**	0.037*
						(0.019)	(0.020)
Observations	341	331	338	329	329	329	293
Number of countries	38	38	38	38	38	38	38
Adjusted R^2	0.572	0.576	0.609	0.598	0.604	0.611	0.507
Cointegration test							
Panel ADF statistics[a]	−4.355	−2.259	−4.705	−4.047	−5.574	−4.768	
Decision	CI	CI	CI	CI	CI	CI	N/A

Notes. log(X) is log of X. Standard errors are in the parentheses. All estimations include unreported country-specific constants.
*, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.
[a]Panel ADF statistic is from Pedroni (1999), which has asymptotic normal distribution. CI represents panel cointegration, and N denotes no cointegration.
[b]Model (vii) is the result of instrumental variables method (iv) regression.

we take foreign IT stock solely based on IT stocks from IT-intensive countries and use it as our foreign IT stock definition.[13]

6.2. Technological Characteristics of Recipient Country

Having discussed the productivity effects of domestic and foreign IT stocks found in Table 3, we validate the robustness of our results by including additional control variables that describe the technical characteristics of recipient countries and are potential sources of TFP improvements. Model (i) in Table 4 is equivalent to Model (iii) of Table 3, except that only the foreign IT from IT-intensive countries is included ($S^{i\text{-ITH}}$). The foreign IT stock from the less IT-intensive countries ($S^{i\text{-ITL}}$) is excluded, as it is not statistical significance, compared with Model (iii) of Table 3.

We examine the effects of the following control variables characterizing the recipient countries: (a) openness toward foreign IT proxied by import to GDP ratio (*imp*) and by FDI to GDP ratio (*fdi*); (b) the innovative capacity proxied by the number of patent applications per 1,000 (*pat*); and (c) physical IT infrastructure proxied by the number of PCs per 1,000 people (*pc*) and by a network infrastructure dummy (*dtel*).

To verify whether the empirical models in Table 4 represent statistically meaningful relations with respect to nonstationary variables, a set of panel cointegration tests is performed on these models. The test results support that the null hypothesis of no cointegration is rejected in favor of the alternative of cointegration in Models (i)–(vi).

First, we observe that both domestic and foreign IT stocks are significant in Models (i)–(v), which represent cointegrating relations.[14] Models (ii), (iv), (v), (vi),

[13] Regressions with a more comprehensive definition for foreign IT stock produced results that were qualitatively similar. The results are provided in Part 4 of the online supplement.

[14] One concern is that our results may simply reflect the fact that countries that import a lot of IT inputs also produce a lot of IT, and those sectors have seen big increases in productivity over the

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and (vii) include an openness measure *imp*. They all show consistently positive and significant estimates, implying that the TFP is higher when the country is more open to the external economy. Model (iii) uses an FDI-to-GDP ratio (*fdi*) as an alternative measure of openness, and the results confirm that the degree of the recipient country's openness is a substantial determinant of TFP.

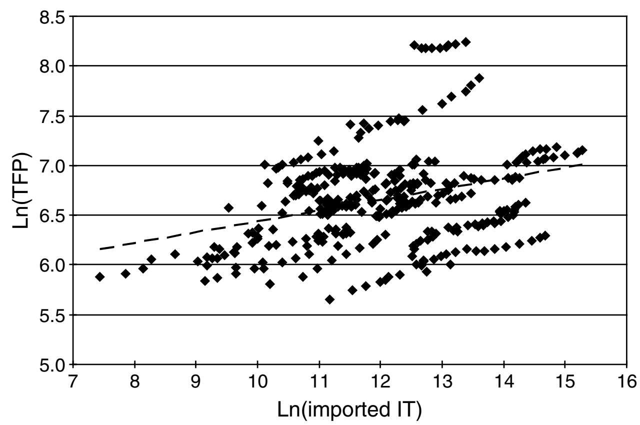
Models (iv)–(vii) expand Model (ii) by including innovative capacity measures as an additional variable. We find innovative capacity measured by *pat* statistically significant and important in raising TFP. We further expand Model (iv) with the distribution of PCs in Model (v) and with network infrastructure dummy in Model (vi). The distribution of the physical IT structure appears to be a meaningful factor in influencing TFP. To address the potential endogeneity problem regarding the IT stock variable, we run the instrumental variables method, where the one-year lagged IT stocks and all other included contemporaneous variables are used as instruments to the domestic IT stock variable in Model (vii). The results are qualitatively robust and very close to the OLS results. This result suggests that the endogeneity issue may not be serious in our econometric model.[15] The regression results in this section provide a strong case for domestic and foreign IT stocks being substantial factors influencing the diffusion of foreign IT even with the control variables of openness, innovative capacity, and physical IT infrastructure.[16]

authors' sample period. Assuming that countries with large hi-tech sectors are strongly correlated with the countries exporting lots of hi-tech goods, we have divided the sample countries into two groups according to the shares of hi-tech exports in GDP: high-share and low-share countries. The Model (i) in Table 4 is estimated for the two subsamples, separately, and the results show that the coefficients are strongly robust for both high- and low-share groups. This may be indirect evidence that the observed significance in the IT variables is not caused by our concerns. The results are provided in Table 6.

[15] The results, however, rely on the assumption that the used instruments (lagged IT stocks) are not correlated with the unobservables influencing the current TFP. We acknowledge that further research using more appropriate instruments could be pursued in the future.

[16] As a sensitivity analysis, we attempt the same set of regressions with foreign IT stock definition, which is solely composed of hi-tech export country IT stocks. The results closely resemble those in Table 4. The results are provided in Part 5 of the online supplement.

Figure 2 Imported IT and TFP



Note. Data source: NBER-United Nations Trade and Penn World Tables (PWT 6.1).

7. Discussion

The results provide substantial evidence that, in addition to the domestic IT stocks, trade in IT products serves as an effective mechanism in international IT transfer and that transferred IT plays an important role in leveraging the domestic productivity, assuming that IT products and services carry embedded knowledge.[17] The relationship between imported IT and recipient countries' TFP is illustrated in Figure 2.

We also find that the magnitude of impacts of transferred IT may depend on the technological characteristics of both the source and recipient countries. The results indicate that information technologies from IT-intensive (or high hi-tech exporting) economies have a strong and significant influence on the productivity of a recipient country, whereas IT stocks produced by the less IT-intensive (or less hi-tech exporting) countries do not. The results imply that IT stocks from technologically advanced countries are relatively more effective and that those IT products and services, by nature, are agents of advanced knowledge and know-how.

This finding further implies that the IT stocks produced by less IT-intensive countries may lag behind the IT technological frontier in general. They may have been devised to meet these countries' own needs and may be effective only in increasing their own productivity to approach the frontier; they may or may

[17] Keller (1996) and Saggi (2002) discuss embedded knowledge in traded goods.

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Table 5 Bilateral IT Trading Among Four Country Groups Classified by IT Intensity: Average Size and Percentile, 1992–2000 (Values in U.S.$ millions)

	IT exports (from)									
	Group 1		Group 2		Group 3		Group 4		Total	
	$	%	$	%	$	%	$	%	$	%
IT imports (to)										
Group 1[a]	281	0.3	228	0.3	922	1.1	2,196	2.6	3,627	4.3
Group 2[b]	309	0.4	159	0.2	851	1.0	2,772	3.3	4,091	4.8
Group 3[c]	2,245	2.6	1,491	1.8	6,412	7.6	12,593	14.8	22,741	26.8
Group 4[d]	6,536	7.7	6,713	7.9	21,990	25.9	19,230	22.6	54,469	64.1
Total	9,370	11.0	8,591	10.1	30,175	35.5	36,792	43.3	84,928	100.0

[a]Group 1 includes Brazil, China, Colombia, Egypt, India, Indonesia, the Philippines, Poland, Romania, Thailand, and Turkey.
[b]Group 2 includes Argentina, Chile, Greece, Hungary, Malaysia, Mexico, Portugal, the Slovak Republic, Slovenia, South Africa, and Venezuela.
[c]Group 3 includes Austria, Finland, France, Germany, Hong Kong, Ireland, Italy, Japan, Norway, Republic of Korea, and Spain.
[d]Group 4 includes Australia, Belgium, Canada, Denmark, the Netherlands, New Zealand, Sweden, Switzerland, United Kingdom, and United States.

not have a productivity-enhancing effect on the recipient countries. They may actually have an insignificant productivity effect for the IT-mature economies that are closer to the technological frontier.

Bilateral IT trading volumes between the technologically discriminated country groups provide further supporting evidence. All sample countries are first classified into four groups by IT intensity. The volume and share of the average IT trading between groups during the period from 1992 to 2000 are summarized in Table 5. The summary shows that approximately 78.8% of IT imports for all countries are from IT-intensive countries (Groups 3 and 4) in which information technologies are relatively mature. We conjecture that this result is because the importing countries have realized that the IT from IT-intensive countries is more beneficial than IT from less IT-intensive countries.

We posit that differential impacts of foreign IT from the two groups arise because the IT products embody diverse levels of knowledge, depending on the source country IT capacity. This may suggest—and reify—that IT is a knowledge-intensive good. This characteristic of IT distinguishes IT products from other non-knowledge-intensive commodity goods that might be outsourced to countries having a comparative advantage with a more labor-abundant domain.

The diffusion process of foreign IT is, in general, a costly proposition to recipient countries, and its cost and effectiveness can be greatly influenced by the domestic capacity of the country. The costs and consequences of obtaining and using IT are not fixed or predetermined but depend on a wide variety of conditions. For example, the effects of imported IT may depend on recipient countries' hi-tech capacity. Based on a pair of simple regressions, Table 6 presents a comparison of the positive impact of domestic and foreign IT in two technologically different domains. The sample countries are divided into two groups

Table 6 The Effects of Foreign IT in Subsamples: Hi-Tech vs. Less Hi-Tech Export Countries

	Hi-tech export countries	Less hi-tech export countries
$\log(S^d)$	0.100*	0.093*
	(0.025)	(0.020)
$\log(S^{i\text{-ITH}})$	0.107*	0.045*
	(0.016)	(0.016)
Observations	171	170
Number of countries	19	19
Adjusted R^2	0.688	0.516
Cointegration test		
Panel ADF statistics[a]	−2.094	−3.761
Decision	CI	CI

Notes. $\log(X)$ is log of X. Standard errors are in the parentheses. All estimations include unreported country-specific constants.
*Denotes significance at the 1% level.
[a]Panel ADF statistic is from Pedroni (1999), which has asymptotic normal distribution. CI represents panel cointegration, while N denotes no cointegration.

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in terms of the shares of hi-tech exports in GDP: hi-tech and less hi-tech export countries. Assuming that the hi-tech export economies have more hi-tech capacity, Model (i) in Table 4 is estimated for the two subsamples separately. Interestingly, imported IT appears to exert considerably greater positive effects in hi-tech export countries than the other. That is, both groups have a similar degree of benefits from accumulated IT stock, but hi-tech abundant economies digest imported IT more efficiently.

8. Concluding Remarks

8.1. Findings and Contributions to the Literature

A burgeoning amount of empirical literature exists on the relationship between IT and productivity. Although researchers have conducted studies at various levels of aggregation, most previous studies have addressed this issue at the micro level. Our macro-level analysis provides empirical evidence and supports the critical role of the international IT trading network for facilitating technology transfer and generating positive returns on investment. The results and implications are timely and relevant as a means to elucidate the impact of cross-country IT adoption on economic growth and productivity. This study contributes to the growing literature on the productivity effect of IT by providing a broader perspective on the effect of international IT transfer.

The results suggest that the development of local information technologies is by no means confined to the local economy but is influencing productivity of the world economy. Indisputably, international trade is an important mechanism of IT transfer. How to deploy international IT transfer, however, should be carefully considered. In addition, the subsidies on both human and physical IT capital that induce domestic innovativeness and technical progress may affect productivity of foreign countries (Glass and Saggi 1998). Our results offer important implications for IT policies on international IT transfer.

Our study extends the previous macro-level studies on the growth effect of IT investments by exploring a set of variables relating to adoption of foreign IT through international IT trade. Although information systems researchers have hypothesized the existence of international IT transfers, few studies have empirically explored this phenomenon. We believe that this study is the first study investigating the effect of cross-country IT transfer on the national productivity, using cross-section time-series data at the macroeconomic level of analysis. The econometric method was carefully devised to address the common problem of spurious relations that arise in regressions with non-stationary time-series data. To confirm the result of each regression, appropriate tests (i.e., Pedroni's 1999 panel cointegration test) were performed.

8.2. Limitations and Future Research

International IT transfer may take place through many different channels and mechanisms, such as codified knowledge transfer through digital means enabled through various forms of information technologies, transfer of software and other technologies over the Internet, and tacit knowledge that is somehow transferred across nations to adapt general-purpose IT to the needs of local businesses. This study focuses on an embodied form of IT transfer that, we believe, is a primary transfer channel. However, to capture the total IT transfer effect across countries and to measure the full social returns to IT investments, it may be necessary to examine various forms of IT transfers, including both embodied and disembodied forms, in future research.

Researchers view technology transfer as analogous to the transplantation of a living organ from one person to another (Robinson 1988). In a similar context, transferred IT contains informational and managerial components that ought to be understood and absorbed in appropriate forms so that the technologies can be fully digested and utilized in the recipient countries. Mere access to foreign information technologies and products, therefore, may not increase productivity. In fact, Keller (1996) and Furman et al. (2002) theorize that if a country's innovative capacity remains unchanged, adopting foreign technologies may not lead to a higher growth rate in productivity. If trade is the basic engine driving IT transfer, innovative capacity of a recipient country may be a complementary driver that reinforces transmitted IT to enhance productivity effectively in the long term. Further investigation should examine the relation between the effectiveness of transferred IT and complementary determinants.

Finally, there are some limitations related to data availability and measurement. For example, future

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studies could employ quality-adjusted input and output variables in TFP calculation; they could use a better measure to capture the innovative capacity; a broader and more comprehensive set of control variables could be used, and, finally, better instruments could be developed to deal with endogeneity issues.

In this study, we shed new light on the phenomenon of international IT transfer, illustrating the substantial role played by IT-specific factor inputs in international IT transfer. While broadening the area of macro-level IT investment to the new perspective of international IT transfer, we address a fundamental issue: quantifying an empirical model with rich and realistic diffusion patterns by identifying who is benefiting how much and from whom. Although this study provides a fundamental framework for understanding the dynamic effects of international IT transfer, researchers should further consider additional variables and other local factors in assessing the antecedents and consequences of the dynamics of international IT transfer.

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