The Impacts of Information Technology on Total Factor Productivity: A Look at Externalities and Innovations

Yen-Chun Chou[a], Howard Hao-Chun Chuang[a], and Benjamin B. M. Shao[b,*]

[a]Department of Management Information Systems
College of Commerce
National Chengchi University
Taipei 11605, Taiwan, ROC

[b]Department of Information Systems
W. P. Carey School of Business
Arizona State University
Tempe, AZ 85287-4606, USA

Abstract

The impacts of information technology (IT) on total factor productivity (TFP) are assessed through an integrative framework of IT-induced externalities and IT-leveraged innovations. Based on network externalities and endogenous growth theory, our study aims to reconcile the seeming discrepancy between the recent observed evidence and the prediction by neoclassical growth theory. We argue that computerization has reshaped the competitive landscape into a network economy with IT-induced externalities that benefit not only IT purchasers but also other stakeholders. Moreover, IT is a platform technology that can leverage innovations to enhance the technological level of production process. Consequently, these two factors of IT-induced externalities and IT-leveraged innovations exert positive impacts on TFP, suggesting IT plays a more pivotal role than input consumption and accumulation that neoclassical growth theory assumes for IT. We use panel data from 30 Organization of Economic Cooperation and Development (OECD) countries over the period of 2000 to 2009 to empirically test hypotheses on this IT-TFP link. Implications are drawn from our findings for future research to measure IT's contributions at the macro level more accurately, and policymakers are urged to cultivate IT's positive impacts on TFP to help sustain long-term economic growth.

Keywords: impacts of information technology; total factor productivity; network externalities; endogenous growth theory; innovations; production economics.

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[*]Corresponding author. Tel.: + 1 480 727 6790; fax: +1 480 727 0881.
E-mail address: ben.shao@asu.edu (B.B.M. Shao).

1. Introduction

Information technology (IT) has recently been identified as a key driver for economic growth (Jorgenson, 2001; Stiroh, 2002). To explain the contributions made by IT to output production, researchers have leveraged neoclassical growth theory and treated IT as one type of input similar to capital and labor used in the production process that contributes to value added at the firm level (Brynjolfsson and Hitt, 1995, 1996) and gross domestic product (GDP) at the country level (Dewan and Kraemer, 2000). Moreover, since IT capital goods have become much less expensive over the years, its cost advantage has led to factor substitution for other inputs (Dewan and Min, 1997; Lin and Shao, 2006a; Chwelos et al., 2010), IT capital deepening (Oliner and Sichel, 2000; Jorgenson et al., 2008), and better performance of the IT industry to meet increasing demands (Chou et al., 2012). From the perspective of neoclassical growth theory, IT increases economic outputs through input consumption and accumulation.

Distinct from single factor productivity like labor productivity (Demeter et al., 2011), total factor productivity (TFP) is a performance metric that measures the "residual" portion of output produced beyond mere input usage (Hulten, 2001; Comin, 2008). TFP is driven by non-input factors such as technological progress that are not tied to explicit input usage (Stiroh, 2002). For example, when a producer combines resources in an innovative way to produce more output or create new features of value, this technological progress is reflected in TFP. Given the law of diminishing returns of inputs, TFP must continuously improve in order to sustain an economy's long-term growth through means like technological progress that can offset diminishing returns of input usage. However, since neoclassical growth theory conjectures that IT's contribution to output only occurs through input usage, IT has been regarded as unrelated to TFP by the related studies based on this framework (Brynjolfsson and Hitt, 2003).

The recent TFP acceleration of the U.S. economy, however, was found to be dominated by the industries that use IT creatively and innovatively (Jorgenson et al., 2006). This observation leads to the proposition that IT's effects on output may extend beyond input usage (Bosworth and Triplett, 2007). IT, for instance, may exert a direct influence on TFP through IT-induced externalities based on network effect as computerization has reshaped the competitive landscape into a network economy that provides value not only to IT purchasers but also to other stakeholders. An example is the IT investments made by buyers and suppliers of business-to-business (B2B) e-commerce systems that can be beneficial to all parties involved. Cheng and Nault (2007) and Han et al. (2011) examine the impact of inter-industry IT spillover on technology level of production processes and find that IT intensity and competitiveness moderate the effects of internal IT investments. Potential network effects resulting from communication systems and software use are other instances of IT-induced externalities (Brynjolfson and Kemerer, 1996; Oren and Smith, 1981; Shy, 2001).

In addition to IT-induced externalities, IT-leveraged innovations may also improve TFP in such forms as IT-facilitated new business processes and integrated supply chains (Kim and Narasimhan, 2002; Kim et al., 2011; Brynjolfsson and Hitt, 2000, 2003). IT services and IT-based product innovations may have a similar effect (Chou and Shao, 2014; Davenport et al., 2008). Park et al. (2007) have extended the idea of IT-leveraged innovations to knowledge transfer across countries through international trade of IT goods. In this light, IT as a platform technology can complement innovations to generate synergies and enhance the technological level of production process (Shapiro and Varian, 1999).

Our study probes two central research questions. First, does IT have impacts on TFP? Second, in what forms or through what channels do such impacts of IT manifest themselves? Based on network externalities (Katz and Shapiro 1985, 1986) and endogenous growth theory (Romer, 1986, 1990), our study reconciles the seeming discrepancy between the recent observed evidence of TFP and the prediction by the conventional neoclassical growth theory. We empirically explore the relationship between IT and TFP to show that IT enhances TFP through IT-induced externalities and IT-leveraged innovations, thus extending beyond the traditional role of IT as input consumption and accumulation that is deemed orthogonal to TFP by neoclassical growth theory. To answer the specific research questions, we analyze a panel dataset collected for 30 Organization of Economic Cooperation and Development (OECD) countries over the period of 2000 to 2009 and report our empirical findings.

Our paper contributes to the literature in four ways. First, on the theoretical front, we assess the economic value of IT beyond what neoclassical growth theory implies and explore the relationship between IT and TFP through the lens of IT-induced externalities and IT-leveraged innovations. Second, on the empirical front, our more recent data enables an assessment of IT-induced externalities that might not be prominent in the pre- or early Internet eras for which prior studies had produced mixed or inconclusive results (OECD, 2000; Stiroh, 2002). Third, while most existing studies on the topic focus on the U.S. (Stiroh, 2002; Han et al., 2011), our investigation into 30 OECD countries (including the U.S.) provides a broader perspective and addresses the shortage of cross-county studies on the association between macro characteristics and the economic value of IT (Lin, 2009). Finally, our measure of IT capital includes not only computer hardware but also software and telecommunication equipment. This operationalization of IT capital provides a more comprehensive measurement for examining IT-induced externalities and IT-leveraged innovations whereas prior studies mostly focus on computer hardware (Cheng and Nault, 2007; Han et al., 2011).

Dedrick et al. (2003) note that the impacts of IT on outputs in terms of marginal product and labor productivity enhancement through capital deepening have been extensively studied and well understood; however, IT's spillover effects and interplays with other complementary assets are still unsubstantiated and this represents an opportunity for more inquiry. In particular, it is "difficult to precisely interpret the allocation of productivity improvements to capital deepening and to MFP" (Dedrick et al., 2003, p.16). Our study endeavors to answer this call for more research on these issues by assessing IT's impacts on TFP and providing empirical evidences that so far have been elusive in the literature.

Our study relates to the productivity paradox coined by Solow (1987) that questioned the real contributions of IT to output production at the country level. Since it was raised, researchers had long debated about whether IT improves output production and renders its process more productive, and they examined the issue from different perspectives and analyzed data from a variety of sources. Reviews of this paradox can be found in Berndt and Hulten (2007), Brynjolfsson (1993), Diewert and Fox (2001), Lucas (1999), and Triplett (1999), among others. After positive and significant evidences were reported at the firm level (Brynjolfsson and Hitt, 1996; Hitt and Brynjolfsson, 1996) and the country level (Dewan and Kraemer, 2000; Jorgenson, 2001; Oliner and Sichel, 2000), the productivity paradox as originally formulated is now considered resolved (Dedrick et al., 2003). It is noted that the productivity paradox is cast in the framework of neoclassical growth theory and hence performance metrics being used by prior studies include marginal product, output elasticity, and substitution elasticity of IT, not TFP. Therefore, our IT-TFP study builds upon the prior literature and aims to shed new light on the issue.

The rest of the paper is organized as follows. Section 2 articulates the theoretical arguments for the IT-TFP link and formulates two hypotheses for IT-induced externalities and IT-leveraged innovations. Section 3 presents our research model that makes the IT-TFP link explicit and empirically testable. Section 4 describes the data collection and variable definitions. Section 5 presents estimation results, and Section 6 discusses the findings and implications. Finally, Section 7 concludes the paper with limitations and topics for future research.

2. Theoretical Framework and Hypothesis Development

2.1. IT-induced Externalities

In economics, *externality* is a benefit or cost experienced by one party due to another party's actions, without compensating payment between the parties. A *network* is a system made up of interconnected users who wish to communicate with one another. *Network effect* exits when a network's value to any user depends on the number of other users on the network, and positive network effect means the value of joining a network increases with more users. *Network externalities* are externalities due to network effects (Katz and Shapiro, 1985). In other words, network externalities occur when the value of owning and using a network product is directly linked to the installed base of the product (Hajji et al., 2012). Products that exhibit network effects are called *network goods*. Network effects are a powerful source of value and oftentimes called the "demand-side economies of scale" as they influence the revenue side of a provider's profit equation by increasing users' willingness-to-pay for its products or services. They are in contrast to the more traditional "supply-side economies of scale" that improve profit margins of a provider by reducing unit costs through means like fixed cost leverage, division of labor, and experience effect (Shapiro and Varian, 1999).

Many IT products and services are network goods that enjoy network effects and hence create not only direct value for their purchasers but also network externalities for other stakeholders involved. Examples of IT-induced network externalities include emails, mobile phones, video games, social networks, enterprise resource planning (ERP) systems, and proprietary software, to name a few. In other words, network externalities can be observed in the domains using these IT products and services (Katz and Shapiro, 1986; Rohlfs, 2001). For instance, Sena (2004) finds evidence for knowledge spillover from high-tech firms to non-high-tech firms in manufacturing by enhancing their total factor productivity. Hajji et al. (2012) note that network externalities of ERP systems lead to continuous updating of marketing and pricing strategies in the launching and early phases of market penetration for new ERP systems.

In our study, we argue IT contributes to TFP through such IT-induced externalities derived from the use of IT goods that have network effects. This channel of IT-induced externalities is elucidated by the new economy paradigm that envisages the outcomes of "more creates even more" and "co-creation of value in a network" as the IT investment made by one party improves the productivity of another party (Kelly, 1999). The new economy paradigm regards IT as the means to engender network externalities that constitute a different channel – other than input consumption and accumulation – for IT to contribute to economic growth (Stiroh, 1999). In this light, IT-induced externalities go beyond factor contributions and impact TFP directly.

One representative example of IT-induced externalities is the connectivity observed in an integrated supply chain wherein returns to IT investments made by one party are rendered more valuable by IT investments of other trading partners (Kim and Narasimhan, 2002; Melville and Ramirez, 2008). In this setting, a supplier's capability to accurately forecast demand for raw materials through the supply chain relies on the demand data provided by its buyer's IT systems. Similarly, a buyer utilizes fulfillment data from its supplier's IT systems to make speedy and accurate order replenishment. Such connectivity makes IT investments beneficial not only to the owner of investments but also to its trading partners in the integrated supply chain. Accordingly, IT capabilities and information sharing are both found to have positive effects on logistics integration (Prajogo and Olhager, 2012), and IT use along with customer and supplier integration is considered an important organizational competency (Jitpaiboon et al, 2013).

Another manifestation of IT-induced externalities is the network effects observed in many IT goods and services. Gandal (1994) and Brynjofsson and Kemerer (1996) find that the value of a software to a user increases due to network externalities from the community of users. Also, the benefits of a party joining an electronic market derive not only from its IT equipment purchase and sign-up fee but also from others' participation (Bakos, 1991). We argue that these "non-pecuniary externalities" from IT usage are not reflected in factor productivity of IT capital goods but in their aggregated contributions to TFP (Schreyer, 2000).

The Internet is another prominent IT system that generates significant network externalities. In the late 1990s, the Internet started being used as a legitimate and efficient platform to conduct business transactions. Since then, externalities from the Internet usage have become even more pronounced over time. Compared with its predecessor Electronic Data Interchange (EDI), the Internet incurs much lower coordination costs. Before the Internet, early forms of B2B e-commerce were mainly conducted through EDI. Due to its prohibitively high set-up costs and lock-in effects, EDI was limited to supply chain coordination between large businesses and their first-tier suppliers (OECD, 2000). The Internet, however, has greatly facilitated B2B e-commerce by lowering development costs and switching costs. B2B e-commerce thus became feasible for firms of all sizes once the Internet was accepted as a legitimate platform for performing various business functions such as procurements, distributions, and customer relationship management. Moreover, the Internet also significantly reduces transaction costs for firms to participate in electronic markets. As a consequence, IT-induced externalities are expected to be more prevalent at the present than in the pre- and early Internet eras for which studies could only find inconclusive or mixed results (Stiroh, 2002).

Overall, IT-induced externalities are based on the idea that social returns to IT usage exceed private returns of ownership (Delong and Summers, 1991), thus leading to spillover benefits of network effects for other stakeholders and to an aggregated enhancement of TFP at the country level. Based on the above arguments, we formulate our first hypothesis on IT-induced externalities:

H1: Countries with a high level of IT capital have high TFP.

2.2. IT-leveraged Innovations

According to neoclassical growth theory, IT is considered unrelated to TFP, the part of output beyond input utilization (Stiroh, 2002). In this view, TFP is driven by technological progress fueled by innovations that are spontaneous, unpredictable, and independent of firms' decisions and government's policies. The argument for this seeming disconnect is that the trajectory of technological advance is difficult to predict as it does not follow straightforward evolutionary path. Although neoclassical growth theory recognizes the importance of technological progress to economic growth, it considers innovative advancement to be unrelated to firms' and government's actions (Grossman and Helpman, 1994). Thus, one limitation of the theory is that it places technological progress of innovations, a deciding factor of economic development and competitiveness, on the periphery (Miozzo and Walsh, 2006).

This neoclassical view applied to IT as a factor of production has been predominant in the productivity literature. Using this paradigm, most previous studies treat IT as a capital input unrelated to TFP and they assess the value of IT by analyzing its marginal product contribution to outputs (e.g., Barua et al, 1995; Brynjolfsson and Hitt, 1996; Dewan and Kraemer, 2000). Grounded in neoclassical growth theory, these studies also note that rapid decline in quality-adjusted prices of IT capital goods leads to substitution for other input factors and hence to IT capital deepening (Stiroh, 2002). In sum, IT contributes to output production and factor productivity through input consumption, substitution, and capital deepening.

In reality, however, firms purposively invest in technologies to adopt new innovations when they see opportunities to profit. Contrary to neoclassical growth theory, endogenous growth theory contends that technological development reflects firms' and government's conscientious and diligent efforts (Romer, 1986, 1990). Technological level thus is influenced by these decision makers' collective endeavors to continually introduce innovations to production systems that can result in either new products and services, new rules of doing business like mass customization and devolved manufacturing, or new capabilities to collaborate with other parties (Albadvi et al., 2007; Miozzo and Walsh, 2006; Jorgensen, 2009).

In endogenous growth theory, innovations are a crucial driver for technological development of production process. Since IT is a general-purpose platform technology for leveraging innovations (Bresnahan and Trajtenberg, 1995; Helpman, 1998; Varian et al., 2004), it can enhance technological development of production process and lead to an increase in TFP. Therefore, in addition to its impact on TFP through IT-induced externalities, IT can also play a facilitator role in helping leverage innovations for synergies. Like steam engines and electricity in the past, IT is considered by many to be the latest platform technology because it satisfies the criteria of rapidly falling costs, plentiful supply, and numerous applications to products and processes (Miozzo and Walsh, 2006).

This leverage of innovations by IT has been alluded to and suggested by the literature. Responding to the claim made by McKinsey (2002) about the missing correlation between productivity and IT investments, Martinsons and Martinsons (2002) urge researchers to explore IT value beyond efficiency (Lin and Shao, 2000, 2006b; Lin and Chiang, 2011) and factor contributions (Brynjolfsson and Hitt, 1995) and to focus on the effects of IT on innovations. McAfee and Brynjolffson (2008) also promote this innovation channel of IT value by arguing that "IT serves two distinct roles—as a catalyst for innovative ideas and as an engine for delivering them." They further note that it is the innovation role of IT that affects performance differentials among competitors. Varian et al. (2004) find that as more transactions become computer mediated, the costs of activity monitoring and coordination become much lower, and this IT-based capability complements innovative products and processes, reshaping the competitive landscape for industries like retailing, entertainment, and transportation. IT-leveraged innovations can lead to flexibility, quick response, variety, custom fit, high performance, and speedy delivery, all of which are reflected in TFP.

Aggregated at the macro level, Freeman and Perez (1988) suggest that IT is a general-purpose platform technology that can leverage new innovations in products, services and processes, and bring about significant impacts on the economy. As a consequence, IT facilitates the use of creative ideas embedded in knowledge-based assets and promotes innovative development of other products and processes (Calestous and Lee, 2005; Joshi et al., 2010). That is, IT can be a complement to innovations due to its capabilities and applications to product development and process improvement. Accordingly, we present our second hypothesis on IT-leveraged innovations:

H2: Countries with a high level of IT-innovation complementarity have high TFP.

3. Research Model

To empirically test the IT‑TFP link, we propose a production function model based on the growth accounting framework in economics (Oliner and Sichel, 2000). We assume a general production function *f* that relates an economy's output (Q) to inputs of labor (L), IT capital (K_C), non-IT capital (K_N), and technology parameter (A):

$$Q = f(L, K_C, K_N, A) \tag{1}$$

Under the assumptions of competitive markets, full input utilization, and constant returns to scale, the contribution of each input to output is equal to the share of input cost to total costs (Schreyer, 2000). By assuming a Cobb-Douglas functional form, we express the production function *f* in logarithms for estimation as follows (lowercase letters for inputs denote logarithms and, for brevity but without loss of clarity, country and time subscripts are suppressed):

$$q = s_l l + s_c k_c + s_n k_n + a \tag{2}$$

where parameter s represents each input's factor share as indicated above.

In the presence of IT-induced externalities, there exists a discrepancy between a private investor's rate of return and the rate of return for society as a whole. In other words, IT generates benefits above and beyond those reflected in its measured factor share. We modify Equation (2) to include IT-induced externalities by a term θ (Romer, 1986; Lucas, 1988; Schreyer, 2000):

$$q = s_l l + (s_c + \theta) k_c + s_n k_n + a \tag{3}$$

IT-induced externalities θ is similar in spirit to knowledge spillovers studied by Romer (1986) and spillovers from human capital looked at by Lucas (1988). In practice, it is difficult to observe θ directly. What is normally observed is the factor share s_c. By definition, TFP is the difference between output and input utilization. Hence, from Equation (3), we can derive TFP as follows:

$$tfp = q - s_l l - s_c k_c - s_n k_n = \theta k_c + a \tag{4}$$

In Equation (4), technology parameter a captures a country's technological advancement. According to endogenous growth theory, we model the technology parameter a as a linear function of a country's innovation efforts in the form of patents and other related factors:

$$a = D_i + \beta_1 Patent + \beta_2 (k_c \times Patent) + \beta_3 HDI + \beta_4 FDI + \varepsilon \tag{5}$$

In Equation (5), D_i is a dummy for country-specific fixed effect that captures unobserved heterogeneity. The variable *Patent* is the number of patents that reflects a country's innovation efforts since the patent is generally considered an intermediate outcome of innovations for the commercialization of new products and services (Nerkar and Shane, 2007). The interaction term $k_c \times Patent$ represents the synergy that results from the complementary leverage of patents by IT (i.e., IT-leveraged innovations). *HDI* stands for human development index that indicates a country's level of human capital, which is critical to technological innovation capabilities (Furman et al., 2002). *FDI* denotes foreign direct investment that reflects openness of a country for receiving external investments in building new production facilities. Openness benefits a country's technological development because it allows a country, through foreign investments in facility establishment and production means introduction, to have access to new knowledge and competence from other countries, especially from those that are technologically more advanced (Glass and Saggi, 1998). Finally, ε is the error term that captures both random error and technical inefficiency (Lin and Shao, 2000).

By incorporating Equation (5) into Equation (4), we reach the complete IT-TFP model:

$$tfp = D_i + \theta k_c + \beta_1 Patent + \beta_2 (k_c \times Patent) + \beta_3 HDI + \beta_4 FDI + \varepsilon \tag{6}$$

Equation (6) indicates that TFP is influenced by IT-induced externalities θk_c (i.e., Hypothesis H1) and IT-leveraged innovations $k_c \times Patent$ (i.e., Hypthesis H2) along with other relevant factors (i.e., *Patent*, *HDI*, and *FDI*). To provide a visual overview, Figure 1 presents our IT-TFP research framework with the two hypotheses specified.

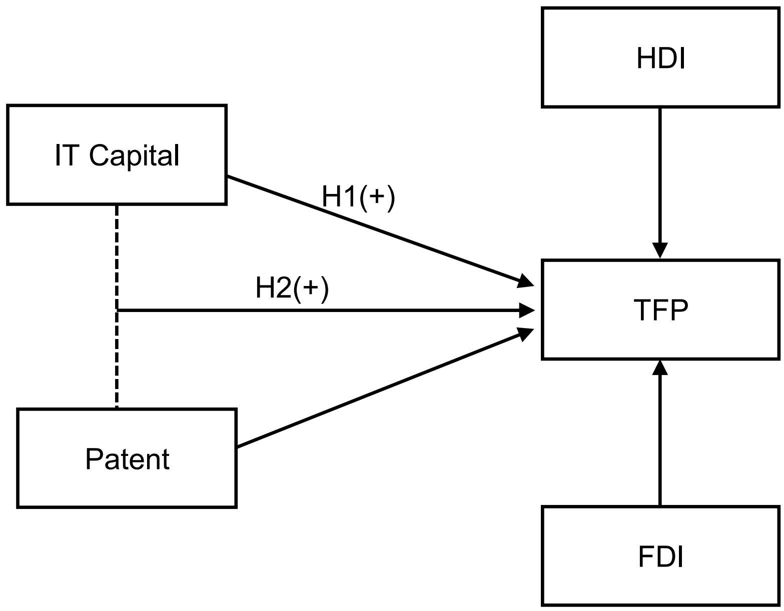

Figure 1. The IT-TFP Research Framework

4. Data Description

We collected a panel dataset for 30 OECD countries from 2000 to 2009, including Australia, Austria, Belgium, Canada, Czech Republic, Demark, Finland, France, Germany, Greece, Hungary, Ireland, Israel, Italy, Japan, Korea, Mexico, New Zealand, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. The period of the dataset is specifically chosen for the new millennium because by 2000, network effects of IT products and services were conceivably manifested when the Internet had matured as an e-commerce platform. The list of countries is selected based on data availability of their IT investments. We acquired archival data on TFP, IT capital, and other variables from several data sources. Variables measured in monetary terms are converted into 1995 international dollars by purchasing power parity (PPP).

The measure of TFP is derived from the EU Total Economy Database. The estimation of TFP growth in the database is carried out using the growth accounting framework. According to the EU Total Economy Database, TFP growth captures the changes in output not caused by changes in inputs. TFP thus reflects the effect of technological change, efficiency improvements, and the inability to measure the contribution of all other possible inputs. It is calculated as Solow residual by subtracting the sum of two-period average compensation share weighted input growth rates from the output growth rate. Log differences of level are used for growth rates, and hence TFP growth rates are essentially Tornqvist indexes. In calculating Solow residual, the Cobb-Douglas function is used most often because of its analytical tractability but in theory any production function with constant returns to scale that satisfies the Inada conditions will do (Romer, 2000).

Using 1995 as the base year, we construct TFP on the basis of growth data from the database in the following way: $TFP_{t+1} = TFP_t \times TFPGrowth_t$. Each country's TFP is further transformed to the level relative to the U.S. for cross-country comparisons. A scale multiplier is determined by a country's labor productivity relative to the U.S.'s from the OECD Productivity Database.

The data on IT capital stock at the country level are known to be difficult to collect because only a limited number of national statistical offices in OECD countries have published capital stock data on a regular basis. In addition, the comparison across countries is not straightforward due to the different aggregate measures used across volume indices, asset types, and industries (Schreyer and Webb, 2006). Under this constraint, we approximated IT capital stock values from a series of IT spending. We acquired IT investment data for each country from World Information and Technology and Service Alliance (WITSA, 2010). This data provides a consistent basis for comparison of IT capital, including computer hardware, software, and communication equipment across countries.

To estimate IT capital stock from IT investment data, we used the method suggested by the OECD's Productivity Measurement Manual (OECD, 2008). The method enables the estimation of an initial capital stock in a given year, working forward from the earliest investment flows that one is able to acquire, to derive the accumulated capital stocks in subsequent years. The initial capital stock at $t = 0$ for country i is defined as $TotalCapital_{i0} = InvFlow_{i0}/(g_i+\delta)$, where $InvFlow_{i0}$ is the initial capital investment flow in the benchmark year for country i; the growth rate g_i of investment capital flow is approximated by the average GDP growth rate over the period of 1990 to 1999; and the depreciation rate δ for IT goods is obtained from the EU KLEMS database. Once we obtained the initial capital stock $TotalCapital_{i0}$ for each country, we computed the subsequent IT capital stock series using the perpetual inventory method (OECD, 2008): $TotalCapital_{it} = TotalCapital_{i(t-1)} \times (1-\delta) + InvFlow_{i(t-1)}$. We adopted this perpetual inventory method to construct three sets of capitals for computer hardware, software, and communication equipment. IT capital is then aggregated from these three data series and used as one independent variable for our model estimation.

Regarding the other variables in Equation (5), *Patent* represents the number of patents granted from the U.S. Patent and Trade office (USPTO) and the European Patent Office (EPO). Patent is commonly used for measuring a country's innovation capacity (Mansfield, 1985) and it is highly correlated with a country's R&D investments (Furman et al., 2002; Park et al., 2007). We also collected data on *HDI* from the Human Development Report Office and obtained data on *FDI* from the Euromonitor database. Table 1 presents descriptive statistics of the variables.

Table 1. Descriptive Statistics of Variables

Variable	Obs.	Measurement Unit	Mean	Std Dev	Min	Max
TFP	293	Index	0.800	0.247	0.277	1.377
IT Capital	293	$ Million	147,000	325,000	2,840	1,790,000
Patent	293	Number of Patents	120,875	352,849	32	2,246,346
HDI	293	Index	0.843	0.057	0.629	0.937
FDI	293	$ Million	230,000	424,000	1,470	2,720,000

5. Estimation Results

To estimate Equation (6) using panel data, it is customary to specify the regression model as $y_{it} = \beta x_{it} + c_i + u_{it}$ where c_i captures the *individual heterogeneity* and u_{it} represents the *idiosyncratic error.* The difference between fixed effect (FE) modeling and random effect (RE) modeling lies in the correlation between explanatory variables x_{it} and heterogeneity c_i where FE allows $\text{corr}(x_{it}, c_i) \neq 0$ but RE assumes $\text{corr}(x_{it}, c_i) = 0$ (Wooldridge, 2001). Although RE modeling is more efficient, the Hausman test (Cameron and Trivedi, 2009) rejected the null hypothesis that no systematic difference exists in FE and RE coefficients. Hence, we chose the FE model over the RE model and allowed country-specific heterogeneity (c_i) to correlate with IT capital as well as other regressors. Following the approach of two-way FE modeling (Cameron and Trivedi, 2009), we also added year dummies to control for time effect.

Since we have data over 10 years from 2000 to 2009, we conducted the Wooldridge's test for autocorrelation in pane data models (Wooldridge, 2001) and found a significant first-order autocorrelation in error terms ε_{it}. We also performed a likelihood ratio test for panel-level heteroskedasticity (Greene, 2000) and rejected the null hypothesis of homoskedasticity in error terms. Taken together, we adopted a procedure of robust clustered standard errors (Hoechle, 2007) to ensure estimation consistency in the presence of autocorrelation and heteroskedasticity. Furthermore, we were aware of the potential existence of contemporaneous correlations between countries. The Pesaran's CD test (2004) revealed no evidence of cross-sectional dependence in our data. We estimated Equation (6) using the XTREG command with the cluster option in Stata 13 (StataCorp, 2013).

Table 2. Coefficient Estimates of the Models

	Model I	**Model II**	**Model III**	**Model IV**	**Model V**
Intercept	-0.607 (0.608)	-0.639 (0.626)	-0.986* (0.569)	-1.040 (0.679)	-1.085 (0.684)
IT	0.056** (0.025)	0.057** (0.025)	0.065*** (0.020)	0.064*** (0.021)	0.064*** (0.020)
Patent		0.0001*** (0.000)	0.0001*** (0.000)	0.0001*** (0.000)	0.0001*** (0.000)
IT × Patent			0.002* (0.001)	0.002* (0.001)	0.002* (0.001)
HDI				0.092 (0.593)	0.130 (0.603)
FDI					0.000 (0.000)
F-statistic (df1, df2)	8.66 (10, 29)	12.46 (11, 29)	11.81 (12, 29)	10.95 (13, 29)	11.78 (13, 29)
p-value	0.00	0.00	0.00	0.00	0.00
R^2	0.34	0.36	0.41	0.41	0.42
Country	30	30	30	30	30
Observations	293	293	293	293	293

Note: Standard errors in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 2 presents the estimation results where all the five models are statistically significant according to the F-test. Including only IT capital and FE terms, Model I shows a significant positive association between IT and TFP, a finding that is contrary to the orthogonality assumed by neoclassical growth theory. Models II to V introduce four more variables (i.e., *Patent*, *IT*×*Patent*, *HDI*, and *FDI*) stepwise to reflect a country's innovation efforts as suggested by endogenous growth theory. As can be seen, the coefficient estimates for IT capital remain significantly positive throughout and we have acquired evidence for Hypothesis H1 that IT-induced externalities exist as IT capital has a direct positive impact on TFP.

Next we find the coefficient estimates for *IT*×*Patent* in Models III-V are all significantly positive, providing evidence for Hypothesis H2 that IT-leveraged innovations have a favorable impact on TFP. For the other variables, *Patent* not surprisingly also has a positive direct effect on TFP. On the other hand, neither *HDI* nor *FDI* is found to have any significant impact on TFP.

The presentation of Models I-V in Table 2 provides us with more results as consistent evidences to support our two hypotheses on IT-induced externalities and IT-leveraged innovations. In other words, instead of relying on one particular model, having these different models with each introducing an additional variable shows more evidences if the results on the two main variables of interest *IT* and *IT*×*Patent* are consistent across the models. Such use of different models to offer reliable results is often employed by researchers in reporting their findings (e.g., Chang and Gurbaxani, 2013; Chari et al., 2008; Ghose et al., 2006).

To ensure that the identified IT-TFP link is robust, we further assess the potential endogeneity between IT capital and TFP. That is, when externalities captured by TFP are high, countries may be more inclined to make investments in IT. The endogeneity may violate the assumption of corr(IT_{it}, u_{it}) = 0 and cause estimation bias. Using $ITCapital_{i,t-1}$ as an instrument for $ITCapital_{it}$ (Brynjolfsson and Hitt, 1996), we checked the endogeneity issue by performing the Davidson-MacKinnon test on the null hypothesis that FE estimates are consistent (Cameron and Trivedi, 2005) as well as the C-test that is robust to heteroskedasticity (Baum et al., 2007). Both tests revealed no significant endogeneity. Furthermore, consistent findings are derived from instrumental variable estimation with two-stage least square (Wooldridge, 2001) and two-step generalized method of moments that accommodates autocorrelation and heteroskedasiticty (Baum et al., 2007). These robustness checks on potential endogeneity issues further validate our findings in Table 2.

Table 3 summarizes our results in terms of hypotheses formulated, theories used, outcomes, and the main findings. Overall, our analysis shows that IT capital is positively associated with TFP. The estimated effects are fairly stable across all the regression models. Our country-level results provide empirical evidence for the hypothesis that IT-induced externalities contribute to TFP. In addition, we also find evidence that IT-leveraged innovations increase TFP as the interaction between IT capital and patents creates synergies and aids economic growth.

Table 3. Results Summary

Hypothesis	Theory	Outcome	Finding
H1: Countries with a high level of IT capital have high TFP.	Network Externalities	Supported	IT-induced externalities have a positive impact on TFP.
H2: Countries with a high level of IT-innovation complementarity have high TFP.	Endogenous Growth Theory	Supported	IT-leveraged innovations have a positive impact on TFP.

6. Discussions and Implications

In neoclassical growth theory, TFP is deemed unrelated to input usage. Accordingly, IT capital as a production input contributes to factor productivity by its factor share but is considered orthogonal to TFP. The new economy paradigm based on network effects, however, suggests that IT capital as a special production input may go beyond factor share and contribute to TFP through IT-induced externalities. Additionally, according to endogenous growth theory, IT may also play a role of complement to innovations and provide synergies that add to TFP.

In formulating and testing the two hypotheses on IT-induced externalities and IT-leveraged innovations, our study empirically confirms the IT-TFP link and demonstrates the economic value of IT beyond input consumption and accumulation. Although researchers have speculated about the possible presence of externalities from IT usage, few studies have explored this phenomenon empirically (McKinsey, 2002; Lin, 2009). Using archival data on 30 OECD countries from 2000 to 2009, our analysis presents new evidence for the under-studied association between IT investments and productivity at the macro level. This identified IT-TFP link is corroborated by our study as substantial and robust since our models also consider other possible innovation factors (i.e., patents, HDI, and FDI) that may influence TFP as suggested by endogenous growth theory.

Growth in economic outputs can be achieved either by increases in inputs or by improvements in TFP. Relying exclusively on input increases, an economy will experience output increases only in proportion to input consumptions in capital and labor. In the long run, the law of diminishing returns of inputs would cause economic growth to slow down or even stop eventually (Solow, 1956). In this regard, TFP is of paramount importance because it is the antidote to such adverse effects of diminishing returns of input usage in order to sustain long-term economic growth. Along the same line, Hall and Jones (1999) find major differences in income per capita between rich and poor countries to be associated with differences in TFP. Based on the concept of network externalities, our empirical findings indicate that IT enhances not only factor productivity but also TFP. Policymakers thus should adapt their decision-making and recognize the spillover value of IT in TFP as an important factor for sustaining long-term economic growth. In terms of measurement, conventional metrics focus on economic impacts of IT through IT capital deepening and mostly ignore the contributions of IT to TFP. Our results show that efforts should be made to measure, reflect and capture additional economic benefits of IT more accurately as in TFP and innovations.

In terms of practical implications, we can see from our confirmation of the IT-TFP link that it is imperative for a government to devote attention and resources to the generation, diffusion and use of IT goods and services in an economy. IT represents a new technological paradigm shift that belongs to the category of general-purpose technologies (Miozzo and Walsh, 2006). As such, IT has the potential to be adopted and adapted in a wide range of sectors in a country, in ways that can dramatically improve operations and products as well as the relationships between different sectors. In this regard, IT serves both roles of competence enabler and capability enhancer (Perunović et al., 2012). As a competence enabler, IT opens up new opportunities or markets, and as a capability enhancer, IT helps deliver better solutions that are cheaper and faster. A government thus should seek regulation reforms and allocate resources to develop IT competence and capability using various means, such as fostering skill development through the education and training in science, technology, engineering, and math (STEM).

The leverage of IT to support innovations also suggests innovational complementarities where the productivity of a downstream sector increases as a result of innovation in an upstream sector facilitated by IT capabilities. These innovational complementarities underscores the importance of establishing a national innovation system where IT can help connect and cluster institutions, policies, and practices that together determine a country's capacity to generate and apply innovations.

Moreover, since innovations can be either incremental or radical (Abernathy, 1978), IT should be used to leverage innovations in two different ways as well. For incremental innovations that refine, improve and exploit existing innovations to strengthen the dominance of incumbents, IT can be used to facilitate certain sequential improvements sought by these incremental innovations. One good example of using IT to introduce incremental innovations is Netflix, the company that has been dominating the industry of Internet video streaming and DVD rental over the last decade with its recommendation system Cinematch and dynamic queue, subscription and delivery methods. For radical innovations that offer dramatic improvement in performance or cost and that result in transformation of existing markets or creation of new ones, IT can play a pivotal role in enabling the fundamental changes in the design or platform of the innovative products and processes. One illustrative case of continuously introducing IT-enabled radical innovations is Google, the company that revolutionizes Internet search, online advertising, cloud computing, and other phenomena with its many new products, services, software, and offerings.

On the front of network externalities, IT products and services that exhibit network effects yield spillover benefits to all the parties involved in the transaction or connected in the system. Since many IT goods and services exhibit positive network effects and have direct impacts on TFP, a government ought to find ways to encourage their adoption and use and to facilitate their dissemination through the economy. It can design and offer the right incentives to help industries and sectors adopt and use more IT goods and services as well as best practices. It can also eliminate legislative and administrative hurdles that stymie

IT adoption and usage by, for example, assisting in establishing IT standards and protocols. Thus, IT investments should be encouraged and effective incentive mechanisms should be designed and put in place to induce network externalities from interconnection of IT equipment across firms and industries.

Our research framework hypothesize that IT exerts direct and interaction effects on TFP and our empirical results support these hypotheses. In this light, IT is inherently different from other traditional factors of production such as non-IT capital and labor that are considered unrelated to TFP by both neoclassic growth theory and previous studies. It is noted that IT can play both roles of traditional capital and knowledge capital (Dedrick et al., 2003). As a traditional capital, IT is used as a production technology and subject to the same law of diminishing returns as non-IT capital and labor are. On the other hand, as a knowledge capital, IT's payoff through capital deepening and TFP growth suggest increasing returns. It is in the second role of knowledge capital that IT functions differently from other traditional inputs like non-IT capital and labor. Our results on the IT-TFP link complement the previous findings that IT is a different as its use is associated with a technological shift that favors workers with higher skills (i.e., skill-biased technical change) (Autor et al., 1998).

7. Conclusion

IT is believed to have a favorable impact on value creation by establishing linkages with trading partners, customers, and suppliers (Soroor et al. 2009), resulting in better products, higher quality, enhanced equipment utilization, reduced resource needs, and increased flexibility (Kim and Narasimhan 2002). Aggregated at the macro level, IT should have a positive effect on the production output of an economy (Jorgenson, 2001). Our study examines the link between IT and TFP and corroborates the existence of IT economic value beyond factor productivity.

Grounded in network externalities and endogenous growth theory, we propose an integrative IT-TFP framework to explain the relationships between IT and TFP through IT-induced externalities and IT-leveraged innovations. Our study empirically tests this integrative framework that links IT with TFP to reconcile the seeming discrepancy between neoclassical theoretical arguments and recent TFP statistics.

We conclude that IT induces network externalities that benefit not just IT adopters but all stakeholders, and technological progress reflects not only uncertainties faced in technology development but also production agents' conscious efforts to leverage innovations for knowledge dissemination and idea applications (Malhotra et al., 2005).

Agarwal and Lucas (2005) suggest that demonstrating the value of IT investments is fundamental to advancing our understanding of the subject. Kohli and Grover (2008) also identify the need for theory and measurement development in IT value as one area for conducting research on the topic. Responding to these calls, our IT-TFP study proposes an integrative framework of IT economic value that extends beyond input consumption and accumulation. In essence, we empirically establish two unconventional channels with externalities and innovations for IT to contribute to TFP. Our study represents one of the first endeavors towards the direction for future research on IT economic value to go beyond factor shares and partial productivity.

A substantial amount of empirical literature exists on IT capital deepening and economic outputs. However, Dewan and Min (1997) point out that another interesting direction for future research is to analyze time series data and try to separate the effects of factor substitution and technical change. With the topic of IT factor contributions well studied, there is a need for more research on IT impacts at the macro level. Our study considers the role of IT in enhancing TFP through IT-induced externalities and IT-leveraged innovations. While a few prior studies have examined the impacts of IT on new products and processes (Joshi et al., 2010), we take one step further and evaluate the complementarity of IT and innovations for synergies in terms of TFP.

Moreover, we consider possible network externalities induced by IT in such forms as B2B e-commerce, communication networks, and software usage, among others. The non-pecuniary externalities from IT lead to direct contributions of IT to TFP. Our comprehensive measure of IT capital that includes computer hardware, software, and telecommunication equipment provides a better instrument for examining externalities from IT usage while most prior studies mainly focused on computer hardware. We also study IT-induced externalities based on more recent data to explore such effects that might not be observable or pronounced in the pre- or early Internet eras (Stiroh, 2002).

In conclusion, our research on IT value in TFP looks beyond neoclassical growth theory by proposing and empirically testing an integrative framework that explains the relationships between IT and TFP through the two channels of externalities and innovations. TFP represents the "residual" portion of outputs above input usage, and our study indicates that TFP can be a competitive advantage that benefits from IT-leveraged innovations. Therefore, our study offers a missing piece of the picture by linking IT's innovation effects to TFP. By answering the two research questions posed in the first section to fill the gap in the literature, our study shows that IT exerts impacts on TFP and it does so through the two channels of network externalities and innovation leverage.

In their critical review of the related literature on the topic of IT and economic performance, Dedrick et al. (2013) propose a conceptual framework that emphasizes different perspectives at the three levels of country, industry, and firm. While the inputs used are similar (e.g., IT capital, non-IT capital, and labor), each level employs production processes subject to unique influential factors (e.g., capital deepening, technical progress, and labor quality) that lead to different outcome measures (e.g., economic growth, labor productivity, profitability, and consumer welfare). It is noted that the phenomena at each level are interrelated and sometimes become the foundation for the phenomena at a higher level, but the findings may not be directly portable, suggesting the need for researchers to conduct specific studies at each level. For example, the finding that "IT investment improves aggregate productivity does not imply that individual firms enjoy similar benefits… there may be significant social benefits from IT investments that increase consumer welfare but are not captured by the firms making those investments" in the form of profitability (Dedrick et al., 2003, p.7). At the same time, relatively fewer industry-level studies raise the prevalence issue of IT payoff across industries (i.e., do IT investment payoffs occur across many industries or are they concentrated to just a few?). Therefore, while our study is at the country level and corroborates the impacts of IT on TFP, our findings need to be further substantiated for the industry, firm or even individual worker level. It is likely, for instance, that actual IT usage which is easier to measure at the firm and individual worker levels may be a key factor for TFP differences at those levels (Aral et al., 2012; Devaraj and Kohli, 2003).

Like any research, our study has its limitations. First, in following the literature, we assess the TFP impacts of IT-induced externalities and IT-leveraged innovations by controlling for other innovation-related factors such as HDI and FDI. This list of controls is by no means exhaustive. We try the best to econometrically alleviate this issue by incorporating year- and country-specific fixed effects into our analysis. We encourage future studies to expand data collection and further validate the IT-TFP link.

Second, we recognize that country-level data are highly aggregated and inevitably subject to measurement errors. For example, improvements in the quality of product may still be captured in the output measure, even with the aid of hedonic price index (Hulten, 2001). In cases where quality improvements of intermediate inputs are not perfectly measured, input contributions of downstream industries can be manifested beyond factor shares, while they in fact benefit from better quality of intermediate inputs and hence enjoy more output (Baily and Lawrence, 2001).

Finally, it is possible that the association between IT and TFP can be driven by other forces or country characteristics in addition to IT-induced externalities and IT-leveraged innovations. Since it is not feasible to include all potential variables in our models, this possible omission of relevant variables may lead to endogeneity and estimation bias. We address this potential issue by conducting appropriate statistical tests and by employing econometric techniques that can remedy potential biases in our model estimation. Still, future research is encouraged to consider other relevant variables (either IT-related or not) to identify other sources of TFP. One approach for doing so is suggested by Lin and Chiang (2011). It will be interesting to follow the same approach and adopt similar estimation models to investigate the interrelationships between IT and specific contextual factors of countries.

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