Asia Pacific Journal of Information Systems
Vol. 32 No. 4 (December 2022), 728-749

ISSN 2288-5404 (Print) / ISSN 2288-6818 (Online)
https://doi.org/10.14329/apjis.2022.32.4.728

Does R&D Mediate the Impact of ICT on Productivity through Knowledge Transfer?

Christina Y. Jeong[a], Sang-Yong Tom Lee[b,*]

[a] *Ph.D. candidate, Carlson School of Management, University of Minnesota, USA*
[b] *Professor, School of Business, Hanyang University, Korea*

A B S T R A C T

The information and communication technology (ICT) value creation process is inherently unobservable. In addition to the direct effect of ICT on productivity, some information or knowledge can create value through other knowledge activities. In this paper, we study the impact of ICT on productivity through R&D. We tested the mediating effect of R&D between ICT and productivity using panel data from 47 US industries from 1987 to 2013 from the Bureau of Labor Statistics. The results show that R&D partially mediates ICT and productivity. That is, ICT directly increases productivity, and some of its effects can be realized through R&D. Recipients who acquire knowledge through ICT have to interpret codified ideas and apply them to practice. The increased absorptive capacity that can be developed through R&D improves interpretation ability, allowing employees to share more complex ideas. Thus, ICT helps people to effectively communicate, but some information and knowledge can be realized and applied through R&D knowledge activities. This is the first study empirically examining the process of ICT value creation through R&D. It also provides practical guidelines for knowledge management, such as making decisions about ICT and R&D investments that are better done concurrently rather than individually to maximize their impact on productivity.

Keywords: Information and Communication Technology (ICT), Research and Development (R&D), Knowledge Transfer, Knowledge Management, Mediation Effect

Ⅰ. Introduction

Information and Communication Technology (ICT) plays an increasingly important role in the transfer of information and knowledge. Regardless of geographic boundaries, cultures, and time lags, companies use voice, video, and web conferencing to unify their employee networks. Especially in the last few years, the coronavirus has forced many workers to work from home, and online communication has become the only way to share information with colleagues (Perks, 2021). They shared and discussed

*Corresponding Author. E-mail: tomlee@hanyang.ac.kr

ideas and knowledge, and trained new hires through enterprise communication tools such as email, social media, and video conferencing software. Some companies have also encouraged their employees to meet colleagues and engage in team-building activities through metaverse video games (Gandolfi and Gandolfi, 2021). People transferred information and knowledge through ICT, even tacit knowledge, which is knowledge obtained from personal experiences and contexts (Bolisani and Scarso, 1999; Roberts, 2000).

Nevertheless, ICT cannot transfer all kinds of knowledge since it has a limitation to completely substitute face-to-face communication. Some researchers argued that the tacit knowledge can be conveyed only through face-to-face communication due to the stickiness of ideas, perceptions and experience (Antonelli, 1997; Johannessen et al., 2001). They also argued that the tacit knowledge is difficult to translate into code. However, difficulties of transferring tacit knowledge can been overcome by other knowledge-related work, such as R&D.

R&D generally serves two roles that can support the transfer of knowledge fluently: increasing absorptive capacity and implementing innovative outcomes (Cohen and Levinthal, 1989; Griffith et al., 2004). Absorptive capacity is a firm's ability to apply new knowledge to improve organizational learning (Cohen and Levinthal, 1990). Improved organizational learning means sharing more complex ideas and knowledge based on accumulated experience and knowledge. Therefore, R&D and ICT can be related in terms of transfer of knowledge, and their interrelationship will affect the value creation of companies.

In this study, we study the impact of ICT on productivity through R&D. Human intervention, the interpretation and actual use of knowledge, is unavoidable because the sender can only transfer their tacit knowledge by codifying it (Bolisani and Scarso, 1999). The role of ICT partly supports the exchange of knowledge in the form of pictures, drafts, and so on. Then, the decoding of data and information into fresh tacit knowledge has to be done by the receiver, which can be vary by receivers interpretation. The ability to interpret the knowledge can be improved by knowledge work such as R&D. Bardhan et al. (2013) found that R&D can interact with ICT and create business value. In addition to their work, this study examines whether people can create value by innovating and introducing new products and services based on knowledge transferred through ICT. Thus, we also test the direction of the effect of ICT on productivity through R&D.

We examine our hypothesis that R&D mediates the impact of ICT on productivity. To test this, we used panel data from Bureau of Labor Statistics. Our data includes 47 US industries including both manufacturing and non-manufacturing industries from 1987 to 2013. We did regression analysis to test mediation effect of R&D. To confirm if it is partial or full mediation effect, we did Sobel test. As a result, we found that R&D increases the business value of ICT, linking received knowledge to actual use by helping receivers who obtain knowledge through ICT to execute interpretation and use knowledge in their works. Even though there have been many studies proving the positive impact of ICT and R&D on business value and knowledge capital, our study would provide a greater understanding of the ICT, R&D and productivity. Moreover, this study would identify ICT and the unobservable process of creating business value.

This study contributes to the study of ICT value creation process. Numerous researchers have shown that the productivity paradox has diminished considerably (Brynjolfsson and Hitt, 1996). However, the method by which ICT positively affects productivity is still a black box and inherently unobservable. We add to this literature by examining the relationship between ICT, R&D, and productivity, and direction between them.

Ⅱ. Literature Review

For the last couple of decades, a growing number of researchers have shown that ICT plays a significant role in improving firm and industry productivity and rebutted the so called productivity paradox (Brynjolfsson and Hitt, 2000; Devaraj and Kohli, 2003). According to Brynjolfsson and Hitt (1996), the reasons why earlier research could not derive the exact relationship between ICT and productivity were mismeasurement, lags, redistribution, and mismanagement. Although the paradox was almost resolved, we believed that the value creation of ICT has not been not fully studied yet.[1]

In this paper, we study the effect of ICT on productivity indirectly, through R&D. Both ICT and R&D are related in terms of knowledge creation and transfer, and they affect productivity. Therefore, the mediation effect of ICT through R&D needs to be investigated more thoroughly. We review the previous studies of three topics: a) ICT and knowledge transfer, b) the role of R&D, and c) ICT and mediation. Using the literature, we are going to set up our research questions as follows: What are the relationships between ICT and R&D on productivity? Does R&D mediate the relationship between ICT and productivity through knowledge transfer?

1) For a comprehensive literature survey of the papers that examine the link between ICT and economic growth, please refer to Vu et al. (2020).

2.1. ICT and Knowledge Transfer

It is obvious that ICT contributed to managing and sharing knowledge (Bolisani and Scarso, 1999). ICT became an important capability for firms to manage knowledge capital which is widely recognized as a unique, inimitable, and valuable resource (Matusik and Hill, 1998). Even though ICT enabled employees to share knowledge within and between organizations, there have been discussions regarding which kinds of knowledge are transferred through ICT. Park et al. (2007) argue that in terms of knowledge, ICT payoffs not only result from the implementation of hardware and software, but also from the ICT knowledge base. Firm-level studies show that the use of ICT is only part of a much broader range of changes that help firms to enhance performance (Taştan and Gönel, 2020). Dabić et al. (2019) showed that absorptive capacity is mediated through knowledge management capacity on innovation output and performance in technology-oriented firms. Manesh et al. (2020) investigated the intellectual structure and trends of knowledge management in the 4^{th} industry revolution related technologies.

Knowledge could be classified into two types, explicit and tacit knowledge, which differed based on transferability (Gholami et al., 2013; Nonaka and Takeuchi, 1996). Explicit knowledge is what can be transferred through e-mail, electronic discussions or forums. This systematic knowledge has been readily communicated and shared through printing, electronic methods, or other formal means. People can reuse or create explicit knowledge based on an assumption that the future is predictable. On the other hand, tacit knowledge contains how to do something, which is based on practice or personal experience. Other people can access this type of knowledge through chatting, face-to-face contact, storytelling, or video conference. In the past, researchers thought ICT could only deliver explicit knowledge which could be described in formal language, as in manuals (Antonelli, 1997; Johannessen et al., 2001). Tacit knowledge, which was difficult to codify, often required considerable time and effort to transfer into the minds of people or society (Haldin-Herrgard, 2000).

The process of knowledge transformation can distort or miss precise meanings. In order to prevent those problems and reduce misinterpretations, the sender and the receiver should have proximity or a common background (Bolisani and Scarso, 1999). For example, when two individuals on different sides of the world read the same document containing codified knowledge simultaneously through e-mail, their interpretation will be different. Even if they have the assistance of video conferencing, it would not be easy to share tacit knowledge effectively. According to Bolisani and Scarso (1999), "a computer application can be used to partly support this knowledge exchange, for instance in the form of graphic files … It is not possible to pre-define the interpretation rules for each picture. All the process of de-coding data into information and knowledge has to be executed by the human operators." Therefore, learning and creating are necessary after obtaining shared knowledge to understand the background and create proximity. Moreover, learning can be supported by precise technology such as voicemail, teleconferencing, videoconferences, computer-aided design (CAD) and computer aided manufacturing (CAM), and groupware. Fernández-Portillo et al. (2020) empirically showed that ICT can drive the economic growth within the high knowledge society in Europe.

2.2. The Role of R&D

There have been many papers showing the positive impact of R&D on firm output or productivity (Brynjolfsson and Hitt, 1996). After Solow (1957) developed the aggregate production function based on Total Factor Productivity (TFP), the perception of the sources of economic growth dramatically changed and technology became one of the factors spurring economic growth. Arrow (1971) proposed that capital investment be attributed to increasing returns to scale (IRS) due to formation of knowledge on how to use new information and technology, etc. In addition, Romer (1986) discussed how an investment in R&D improves the efficiency of inputs and produces new intermediates such that it improves the overall economy directly.

There were two ways in which R&D improved productivity. Conventionally, most researchers only looked at R&D as an innovation factor, generating new information. However, according to Cohen and Levinthal (1989), R&D not only spawned innovation but it also improved the 'absorptive capacity', which is learning ability. When a firm improves absorptive capacity, the firm can imitate the innovation of a process or product, and can also exploit outside knowledge. Knowledge from the industrial environment, which is highly related to new industry changes, can be applied to R&D. Moreover, an absorptive capacity was also necessary for learning tacit knowledge, which was difficult to transfer to other people through written language or voice. Two roles of R&D, innovation and learning, were actually closely linked since new outside knowledge could create new internal knowledge. This is why we chose R&D as a mediator between ICT and productivity; R&D can learn and create new ideas from shared knowledge and ultimately improve productivity.

There have been few studies on the relationship between ICT and R&D. Most literature argued that ICT positively influenced R&D or other knowledge-related activities. However, the opposite relationship was scarcely dealt with, that is, the main influences were from ICT to R&D. There are three ways in which ICT accelerated R&D (Kleis et al., 2012). First of all, ICT improved the management of knowledge through communication and database applications (Thomke, 2006). This played an important role in activating R&D and improving productivity. Based on a better infrastructure for capturing and sharing knowledge across the enterprise, firms could combine and reuse knowledge in order to create new goods and services. Second, innovation production has been improved through ICT-based digital methods for design, prototyping, and testing (Thomke, 2006). For example, technology such as computer-based design applications (e.g., CAD/CAM systems) helped to digitize the design of a new product and make it available for innovation production. Third, ICT-based networks and real-time data flows enabled external innovation collaboration (Thomke, 2006). Thus, ICT made it possible to cooperate between different organizations for R&D projects, regardless of geographical distance. Recently, Nair et al. (2020) studied relationships among R&D, ICT and economic growth, and showed that both R&D and ICT infrastructure development contribute to long-term economic growth in the OECD countries. Coluccia et al. (2020) also showed that R&D elasticity is positively related to market appreciation by stakeholder-investor relationships. However, the mediating role of R&D was not fully investigated.

Our idea is also based on the thought that ICT and R&D do not work separately. Bardhan et al. (2013) did the first empirical test which focused on not only the relationship between ICT and R&D, but also on their impact on firm performance. They found that R&D positively affected a firm's productivity by moderating the effect of ICT via control of firm and industry-specific effects. It indicated that ICT enabled R&D intensive innovation. ICT, as simply hardware and software tools, did not create value in isolation, but was a part of a process that created business value with other factors operating in a synergistic manner. This research unlocked the possibility of exploring the relationship between ICT and R&D. In this paper, we consider all possible relationships in which ICT serves as a magnifier or accelerator of desired business capabilities (Kohli and Grover, 2008).

It is not difficult to find evidence showing that those variables work together. In late 1990, for instance, in order to minimize wasting time, Amway decided to build a portal site (EIP) which could give information intelligently to the R&D department staff.[2] Before the existence of the site, staff spent most of their time finding necessary information which was scattered throughout the entire company; however, the creation of the EIP allowed 60% of existing users to reduce the time searching for information by about 30 minutes per week. They did not have to be disturbed by repetitively logging in to multiple systems when they made regular reports and updated information. Additionally, all staff were provided with consistent information through the portal site. This example represents how ICT positively affects productivity or quality by improving R&D such that the real connection between these variables needs to be recognized.

2.3. R&D and Mediation

There have been some studies that treated R&D and ICT parallelly as inputs for the productivity. For example, Hall et al. (2013) showed that both R&D and ICT are strongly associated with innovation and

2) Nick Wreden, "Enterprise Portals: Integrating Information to Drive Productivity". Beyond Computing, March 2000, beyondcomputing.com, May 1, 2000.

productivity, with R&D being more important for innovation, and ICT investment being more important for productivity. Edquist and Henrekson (2017) found that R&D's impact on TFP is more contemporaneous, while ICT is positively associated with TFP with a lag of 7 to 8 years. These papers, however, did not see the complementary or mediation between R&D and ICT on production.

The purpose of this paper is to test the mediating effect of linking R&D and ICT on productivity. R&D might transform the common knowledge received from ICT into internal knowledge which is a key resource for improving productivity. The mediation test accounts for an invisible process embedded in the business value of ICT. However, people are sometimes confused by the use of moderation and the mediation effect. Therefore, we are going to distinguish between the properties of moderator and mediator variables, review literature on ICT and mediation, and explain why we use a mediator variable.

Both moderation and mediation include a third variable; however, the role of the third variable is different in each model (Baron and Kenny, 1986). The moderator variable interacts with an independent variable, influencing the direction and/or strength of the relation. That is, there are three variables affecting the outcome: independent variable, moderator, and interaction between independent and moderator variables. On the other hand, the central idea of the mediation model is a path diagram where each variable is connected by cause and effect. There are two causal paths for improving output: the direct impact of an independent variable and the indirect impact via a mediator.

The reason why we see R&D as a mediator rather than a moderator is that R&D transforms the knowledge received from ICT in some way. Without learning and creating from R&D, the shared knowledge would work as common knowledge or just information. In order to understand tacit knowledge appropriately and adapt knowledge to strengthen competency, it is necessary to learn after knowledge transformation. That is, we are more interested in the mechanism for how ICT raises productivity in an indirect way. Moreover, when there is an unexpectedly weak or inconsistent relation between predictor and dependent variables, people typically use moderator variables. On the other hand, the mediation model is used when there is a strong relationship between predictor and outcome variables (Baron and Kenny, 1986). Since nowadays ICT has a strong positive correlation with productivity (besides, our data also supports this relationship), the mediation relationship is more appropriate for this model. Švarc et al. (2020) showed that social capital and working skills, a dimension of human capital, are the predictors of digital transformation and growth at a national level.

Many researchers have already developed mediation models in ICT literature, including additional third factors. This signifies that there are several ways ICT can impact productivity both directly and indirectly. Barua et al. (1995) argued that the association between ICT investment and performance is attenuated as the distance between cause and effect widens. This method allowed us to discover interrelated activities to achieve a result. ICT has been increasingly embedded deeply in processes, rather than driving capabilities (Kohli and Grover, 2008). That is, we should include other driving capabilities in ICT research and examine whether ICT investment creates the required capabilities, and the required capabilities alternatively create business value. To understand ICT as a part of processes, we see a mediating effect which identifies better combinations to maximize productivity.

Researchers have found many mediators that connect ICT and performance, especially organizational performance (Weill, 1992) or managerial strategies

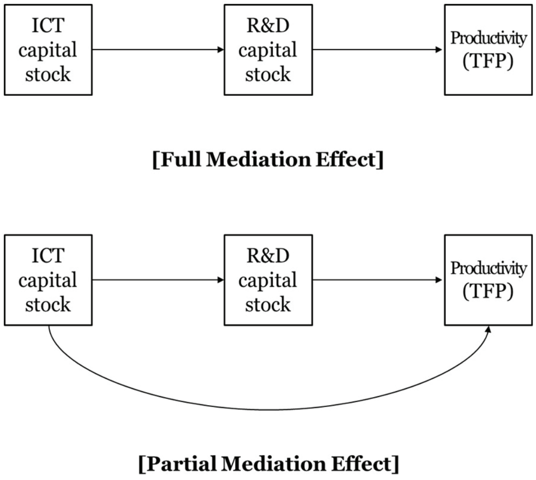
(Francalanci and Galal, 1998). Most of the mediators were determinable factors rather than the external environment of trading partners, industry characteristics and so on (Chatfield and Yetton, 2000). Process-based models showed a cause and effect linkage, and this could be widened through mediators. However, it is possible that, as the distance between cause and effect widens, the relationship between ICT and performance could be attenuated (Barua et al., 1995). The authors developed a model of ICT business value in which the impact of ICT on a firm's performance was mediated by intermediate processes. These measures do not exclude the possibility of ICT creating its own capabilities. However, the point was that ICT could indirectly work as a magnifier or an accelerator of business capabilities. Rather than separating ICT from the process, we are going to identify the causal relationship between ICT and productivity via R&D to understand appropriate processes.

2.4. Hypothesis Development

Although ICT can increase productivity in many ways, this paper examines the literature focusing on the knowledge management aspects of ICT to discuss the link between ICT and R&D. In terms of knowledge management, ICT benefits in three ways. First, ICT enables employees to communicate across boundaries such as geographical boundaries (Malhotra and Majchrzak, 2014), departmental boundaries (Pauleen and Yoong, 2001), and hierarchical differences (Jeong et al., 2022). Ideas and discussion points from colleagues outside of their groups or departments that bring innovative and fresh talking points (Rhee and Leonardi, 2018). Second, ICT helps employees store and easily retrieve all the communications they had (Majchrzak et al., 2006). ICT helps employees save time searching for information, effectively filter relevant information, and build communication and knowledge over time. Finally, ICT can increase digital visibility (Leonardi, 2014). Digital visibility leads to enhanced awareness of who knows what and whom. This is possible because people can read messages, posts, and videos uploaded by colleagues transparently. In addition, some corporate online communication tools allow employees to see people's connections and check internal networks. Digital visibility helps people find the knowledge they need and reduces the redundancy of information in organizations.

However, it is not in and of itself that people impart and receive knowledge that creates value. This is because, although knowledge is well transferred, not all knowledge can be understood or applied. People may not be able to codify their knowledge. Even though people can use a variety of ways to express their knowledge, it can be difficult to codify them (Shachaf, 2008). Also, people may not be able to interpret other people's knowledge. Interpreting codified knowledge and figuring out actual intentions requires experience, expertise, and an understanding of organizational communication styles (Lelic, 2001). Therefore, even if ICT transfers knowledge to people, ICT may not realize its value.

R&D that enhances absorptive capacity can help employees interpret and apply information shared through ICT. First, R&D is the process of collaborating and combining many ideas. People need to listen to other people's ideas, market analysis, and technological knowledge. Experience in interpreting and combining ideas can increase ability to interpret more complex ideas (Dana et al., 1991). Second, R&D is the process of making ideas and information feasible (Schepers et al., 1999). Communication of vague thoughts is difficult compared to communication of numbers, analysis, and specialized technical knowledge.



<Figure 1> Full and Partial Mediation Effects

The experience of turning a vague idea into a viable and applicable one can help people understand how to interpret vague new ideas. R&D thus enables ICT value and increases productivity.

In this paper, we're interested in mediation effect of R&D between ICT and firm's productivity. There are two types of mediation: full and partial mediation. <Figure 1> illustrates how full and partial mediation looks like in our study. If ICT can influence productivity only through R&D, it is called a full mediation. However, when ICT affects productivity through R&D in addition to its direct effect, it is called a partial mediation. Although ICT can have a direct impact on productivity, we argue that some of ICT can be realized as value through other knowledge activities. In this paper, it is R&D.

Ⅲ. Methodology

3.1. Mediation Test

In order to test the mediation effect, we use panel regression analysis because our data involves measurements than span over time. It requires four regressions. After checking for the existence of a basic relationship in each of the first three equations, the last equation reveals the existence of the mediation effect. If one or more of these relationships are non-significant, it is hard to continue the mediation test.

Step 1. $TFP = \alpha_0 + \alpha_1 ICT + \varepsilon$ (1)

Step 2. $RD = \beta_0 + \beta_1 ICT + \varepsilon$ (2)

Step 3. $TFP = \gamma_0 + \gamma_1 RD + \varepsilon$ (3)

The equation in Step 4 tests the existence of the mediation effect. In addition to mediation effect, we can also check if it is partial or full mediation effect. If both δ_1 and δ_2 are significant, it represents full mediation. That is, ICT affects productivity through R&D (δ_2), but even after controlling for mediation effects, ICT directly affects productivity (δ_1). If δ_2 is significant but δ_1 is insignificant, it represents partial mediation. That is, ICT affects productivity, but only when R&D mediates the effect. It does not directly affect productivity. In this paper, we argue that there is a partial mediating effect for the R&D variable, which means that the coefficients of both ICT and R&D are significant. If the coefficient of ICT is not significant but the coefficient of R&D is significant, the result would support the full mediation effect. This is because ICT still remains significant even after controlling for the mediation variable.

Step 4. $TFP = \delta_0 + \delta_1 ICT + \delta_2 RD + \varepsilon$ (4)

First, we performed basic analytical work for the data by doing a correlation analysis, unit root test, and cointegration test. The correlation test indicates a predictive relationship, but does not imply causation. It broadly involves a dependence relationship. The unit root test confirms the presence of a unit root which makes a time series variable non-stationary. Moreover, the cointegration test examines more than one cointegrating relationship by using residuals from an estimated cointegrating relationship. These tests reduce the possibility of testing spurious regression and increase reliability. Since the raw panel data has a high possibility of being unstable and has a high autocorrelation, we should take the logarithm or difference to make it stable.

Then, we performed the four regression analyses. However, when we performed the panel regression analysis, we had to understand the properties of error terms to apply ordinary least square (OLS), the fixed effect or the random effect. If the errors are homoscedastic and serially uncorrelated, the OLS estimator is consistent. However, if the errors are heteroscedastic, we have to additionally apply the fixed effect or random effect. When the explanatory variables are non-random and subject-specific, we use the fixed effect. However, when the independent variables are the population average but variations are heteroscedastic, the random effect is more appropriate. In order to choose the model and test validity, we did the Breusch-Pagan Lagrange multiplier (LM test) and Hausman tests.

Finally, we tested four regressions once again by using new TFP data for the robustness of the dependent variable. We used TFP data to estimate productivity, which has many different methods of measurement. The most basic TFP is measured by dividing the production value by capital and labor. However, the data provided by the Bureau of Labor Statistics considers not only capital and labor but also the cost of energy, materials, and purchased services. Therefore, we estimated a new TFP by considering capital and labor and compared the result with the previous one.

3.2. Significance Test

If the influence of an independent variable on a dependent variable is zero, when controlled by a mediator, the mediating effect exists perfectly. If not, we should do a significance test for the indirect effect of an independent variable and the effect of an indirect variable on a dependent variable without a mediator (Baron and Kenny, 1986). The significance test checks whether the calculated coefficient of an indirect effect is zero or not. The presence of an indirect effect indicates that a partial mediation effect exists. That is, the independent variable can impact the dependent variable as a result of both the mediator and itself. The significance test is needed because the presence of correlation between independent and dependent variables may cause multicollinearity (Kohli and Grover, 2008).

There are three ways to test the significance of the indirect effect of an independent variable: the Sobel test, bootstrapping, and simulation methods. In this paper, we used the Sobel test and Monte Carlo simulation method. Both tests have the same null hypothesis: the multiple of two coefficients ($\alpha_1 * \delta_2$) is zero. α_1 is a coefficient of the independent variable in Equation (1) and δ_2 is a coefficient of the mediator in Equation (4).

H0: $\alpha_1 * \delta_2 = 0$

The test methods are different. The Sobel test reports p-values under the assumption of a two-tailed z-test. However, the Monte Carlo simulation reports the distribution of a mediation effect via simulation. Sobel (1982) provided an approximate significance test for the indirect effect of the independent variable on the dependent variable via the mediator. Some other Sobel test equations omit the term ($S^2_{\alpha_1} * S^2_{\delta_2}$) because it is vanishingly small (Baron and Kenny, 1986). It is a specialized z-test that determines whether the effect of an independent variable is significantly reduced after including the mediator in the regression.

$$z - value = \frac{\alpha_1 * \delta_2}{\sqrt{\alpha_1^2 * s_{\delta_2}^2 + \delta_2^2 * s_{\alpha_1}^2 + s_{\alpha_1}^2 * s_{\delta_2}^2}} \tag{5}$$

Despite the advantages and importance of the Sobel test, it has low statistical power. Therefore, large sample sizes are required to have sufficient power to detect significant effects. This is because the main assumption of Sobel's test is the assumption of normality. To increase statistical power, we can use Preacher and Hayes (2004) bootstrap method. Bootstrapping can increase statistical power by involving repeatedly random sampling observations with replacements from the data set.

In addition, the Monte Carlo simulation method creates the distribution of the coefficient of the indirect effect. We followed the calculations in Monte Carlo Simulation provided by Selig and Preacher (2008). If the confidence interval does not include zero, the result could be interpreted as the existence of an indirect effect. According to MacKinnon et al. (2004), the Monte Carlo study had the lowest Type 1 and Type 2 errors, compared to 14 other significance tests. Additionally, Monte Carlo was also used in the research of Bauer et al. (2006) who examined mediation in multilevel models. The Monte Carlo method relies on the assumption that the parameters have normal sampling distributions. Two parameters, the coefficient of the independent variable in Equation 1 (α_1) and the coefficient of the mediator in Equation 4 (δ_2), are estimated by iterating a number of times. This gives the distribution of the multiple of two coefficients ($\alpha_1 * \delta_2$). The standard error of the indirect effect can be measured by using the variance and covariance of α_1 and δ_2.

3.3. Granger Causality Test

We performed the Granger causality test in order to confirm path order. Even though we argue that ICT impacts productivity through R&D, we are not able to completely rule out the possibility that R&D causes an increase in productivity via ICT. This is because regression does not represent causality, just correlation. The Granger causality test indicates that the past values of one variable cannot be used for the prediction of future values of the following variable when there are no Granger causes.

3.4. Data

We collected panel data from 47 US industries from 1987 to 2013. All of the data are provided on the Bureau of Labor Statistics.[3] It is full data with 1,269 observations. There are 47 industries in our data, including both 18 manufacturing industries and 29 non-manufacturing industries. The industries are defined based on the three-digit North American Classification System (NAICS). In previous studies of ICT productivity, many researchers have used industry-level data to examine ICT productivity (Roach, 1987; Stiroh, 2002b). The benefit of industry-level data is that it is easy to collect. It also reflects a broad-based phenomenon.

Each observation has TFP, R&D capital stock, and ICT capital stock. The value of the dependent variable, TFP, is an index. The TFP value is 100 for the year

3) http://www.bls.gov/home.htm

<Table 1> Description of Variables

TFP	The measures of sector output per combined unit of capital (K), labor (L), energy (E), materials (M), and purchased business services (S) input.
RD	Capital stock of R&D expenditure. Cumulated constant dollar measures of research and development expenditures net of depreciation. The rate of depreciation of R&D was estimated by the BLS.
ICT	Capital stock of ICT expenditure. Cumulated constant dollar measures of research and development expenditures net of depreciation. The rate of depreciation of R&D was estimated by the BLS.

2009 as a basis in this paper. The values of TFP for other years are calculated based on the value of that in 2009. The data of the independent variables, ICT and R&D, are capital stock data. Capital stock data are a good measurement of the TFP residual. Unlike investment data, capital stock data represent the 'level' of ICT or R&D. The logarithms of all the data sets were taken, except for TFP which is an index.

The descriptive statistics and correlation coefficients of variables are described in <Table 2>. It shows that R&D, ICT and TFP have relatively low correlations; therefore there is no concern about multicollinearity.

The unit root test reveals if variables are non-stationary and have a unit root. If the data are non-stationary, the difference or logarithm of the variables should be taken. Otherwise, the interpretation of the equation could be spurious. The TFP, R&D and ICT capital stock variables used in this paper, however, didn't need to be differenced because they are cointegrated. According to the result of the Johansen cointegration test, the equations are not false because the equations have cointegration, though they had a unit root

3.5. Measurement for Variables

In this paper, we used three variables, TFP, R&D, and ICT. Each variable has a different measurement and meaning. TFP, which is also called multifactor

<Table 2> Correlation Coefficient Matrix and Descriptive Statistics

	TFP	RD	ICT
TFP	1.000		
RD	-0.045	1.000	
ICT	-0.010	0.152	1.000
Mean	95.478	20,100,000,000	13,600,000,000
Std. dev.	16.016	59,000,000,000	37,100,000,000
Median	98.409	1,730,000,000	3,610,000,000

productivity, represents the productivity of an enterprise. It is the residual portion of the output produced beyond the input investment (Comin, 2010; Hulten, 2001), used in an innovative way such as technological progress (Stiroh, 2002a). The simple estimation of TFP is calculated by dividing the output by the weighted average of the labor and capital input; however, the equation differs depending on whether or not other input capital is included.

The Cobb-Douglas production function is an economic production function with two or more inputs that describes the output of a firm. Production function f is assumed to have variables: economy's output (Y) to inputs of technology parameter (A), labor (L), and non-ICT capital (K).

$$Y = f(A, L, C, K) = A * L^{\alpha} * K^{\beta} \tag{6}$$

The production function can be converted to a linear model by taking the logarithm of both sides of the equation. This will allow for OLS regression methods, which is commonly used in economics to understand the association between inputs (L and K) on production (Y).

$$log(Y) = log(A) + \alpha log(L) + \beta log(K) \tag{7}$$

Then, we can derive TFP. TFP is the difference between output and input, as the following equation.

$$TFP = log(Y) - \alpha log(L) - \beta log(K) \tag{8}$$

For robustness, we also measured another TFP by subtracting labor and capital costs, energy costs, material costs, and purchased business services costs from the output.[4] We created another TFP measurement because productivity can be influenced by other external factors.

$$\begin{aligned} TFP = \log(Y) - \alpha \log(L) - \beta \log(K) - \delta_1 \log(energy) - \\ \delta_2 log(materials) - \delta_3 log(business\ services) \end{aligned} \tag{9}$$

Thus, we tested mediation regression using two TFP variables; one is from equation (8) and another is from equation (9). The first TFP is followed by the general Cobb-Douglas productivity function. The second TFP controls other external variables which can affect the US industrial productivity.

R&D and ICT variables are measured by capital stock which is the weighted sum of past investments. They are derived from National Income and Product Accounts (NIPAs) investments using the perpetual inventory method and by assuming that services decline as a function of age (Young and Musgrave, 1980). The perpetual inventory method derives the gross capital stock for a given year by cumulating past investments and deducting the cumulated amount of the investment that has been discarded. This follows the capital accumulation equation as follows:

$$K_{it} = (1-\delta)K_{i,t-1} + I_{i,n}, (t = 1987, \ldots, 2013) \tag{10}$$

The initial capital output ratio is defined as

$$(\frac{K}{Y})_{1987} = \frac{j}{(g+\delta+n)} \tag{11}$$

where j, g, and n are industry averages of the investment to output ratio, the growth rate of per capita income, and the population growth rate, respectively. The depreciation rate (δ) is measured by the cost of the asset allocated over its service life in proportion to how it is employed in the NIPAs in order to deflate the investment flows.

Ⅳ. Results

We now present the results of our econometric estimation results. The dependent variable of main test is TFP measured by the value of production over inputs such as labor costs, capital costs, energy costs, material costs, and purchased business services costs. It controls not only labor and capital costs, but also other external factors.

<Table 3> shows the results of equations regressed with a fixed effect. There is a positive relationship between ICT and TFP. The coefficient of ICT is 4.485 which can also be interpreted as a marginal effect of ICT on TFP. There is a positive relationship between ICT and R&D; the marginal effect is 0.024. R&D and TFP have a positive relationship with a coefficient of 3.627. These results show that ICT and TFP, ICT

4) http://www.bls.gov/mfp/mprtech.pdf

<Table 3> OLS Estimation with Fixed Effect

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)
Dependent variable	TFP	LOG(RD)	TFP	TFP
C	-3.401 (11.246)	4.886*** (0.523)	17.832 (9.828)	-11.714 (11.609)
LOG(RD)			3.627*** (0.459)	1.701*** (0.613)
LOG(ICT)	4.485*** (0.510)	0.749*** (0.024)		3.210*** (0.685)
Adjusted R-squared	0.512	0.952	0.506	0.515
F-statistic	29.296***	544.000***	28.662***	29.003***

Note: *, **,*** denote significance at the 10%, 5%, and 1% levels, respectively.

and R&D, and R&D and TFP are positively correlated. These relationships are already presented in the literature review, and we confirm them by actually testing with our US industry data.

Following that, what we are really interested in is the result of the mediation test which asked if ICT leads to TFP through R&D, presented in the results of Eq. (4). In this equation, the coefficient of the R&D controlled by the ICT variable determines whether the mediation effect exists. Controlling the ICT variable allows us to estimate the indirect effects. As shown on the right side of <Table 3>, the effect of R&D on TFP is 1.701. However, even though we put R&D and ICT simultaneously, ICT is still significant with $p < 0.001$. If ICT is not significant, R&D can be an absolute mediator; however, in this case, R&D partially works as mediator. That is, ICT can improve TFP both directly and indirectly.

The indirect effect is calculated by taking the difference between two regression coefficients, as suggested by Judd and Kenny (1981). The indirect effect is ICT's coefficient from Eq. 4 minus ICT's coefficient from Eq. 7. Consequently, the indirect effect of ICT on TFP is 1.275 (calculation: 4.485 - 3.210).

We tested the validity of the model, since we used the fixed effect panel regression model. First, we performed a Breusch-Pagan LM test to check whether a significant panel effect exists or not. The null hypothesis of the LM test is that there is no significant unobserved heterogeneity across observations. The result of the test can be criteria for choosing the OLS model or other effects models. Since the p-values of the LM test were lower than 0.001 for all four regressions, we could determine that the model has individual differences between observations. Therefore, we chose a different effects model than OLS in order to consider individual differences.

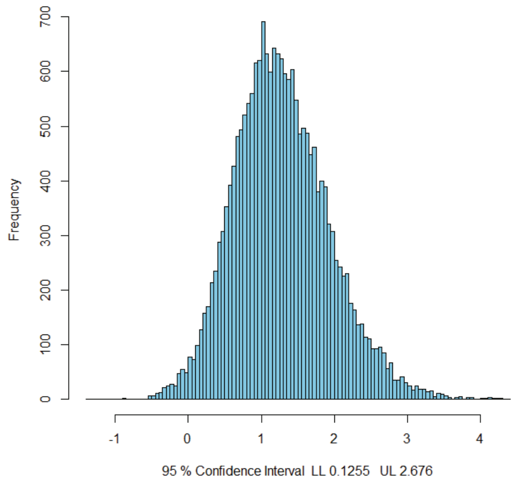
We did the Hausman test to check whether residuals were correlated with independent variables or not. This can be tested by comparing the results of fixed and random effects models. If there is no correlation between residuals and independent variables, the results of the estimation of the fixed effects and random effects will be similar. In this case, we can choose the random effects model because the difference between observations occurred by randomized errors. However, if the results of the estimation between the fixed and random effects are different, the result of the Hausman test will be rejected. Our result shows that the difference between observations does not arise from random causes but from the individual specific effects. The test result rejects the null hypothesis, meaning that it is hard to use a random effects model.

The results showed that ICT can raise productivity by going through R&D activities. This means that ICT would help to improve R&D work which would improve productivity. The usefulness of ICT assisting R&D was shown in a lot of literature; for example, ICT could increase communication among employees, improve access to a lot of information, and increase opportunities for collaboration. The pervasive availability of ICT improves the probability of communication between researchers over long distances (Boutellier et al., 1998).

In this paper we shed light on the process of knowledge exchange. It is highly unlikely that receivers incorrectly interpret the intention embedded in codified knowledge or graphics. The transformation of tacit knowledge is supported by an appropriate understanding of the embedded knowledge of the senders' message. The R&D activities might help receivers to understand a sender's embedded meaning because those activities allow firms to imitate the innovation of a process or product, and to exploit outside knowledge. Employees exchange explicit and tacit knowledge by using ICT, which is a direct effect of ICT on productivity. However, not all kinds of tacit knowledge can be transferred through ICT. This is because tacit knowledge requires appropriate interpretation by receivers. R&D can help those understandings because of its role sharing experience and imitating an internalized knowledge resource. That is why we derive the result that R&D capital stock partially mediates ICT and productivity.

4.1. Results of Significance Test

We did significance test to check if partial mediation effect of R&D exist. We used Monte Crlo simulation

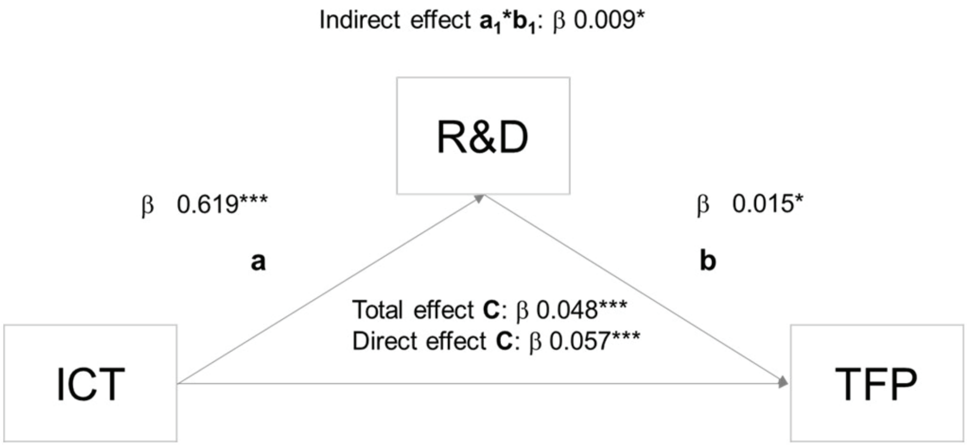


<Figure 2> Result of Monte Carlo Simulation Method

method, presented in <Figure 2>. This simulation test examines Type Ⅰ and Type Ⅱ error rates. As the distribution in <Figure 2> shows, the confidence interval of the distribution of the indirect coefficient is from 0.1255 to 2.676. Since the result does not include zero, the indirect mediation effect significantly exists. As the results of the two significance tests indicate, the indirect effect of ICT capital stock is significant.

Then, we did Sobel tests to confirm the existence of an indirect effect. Sobel test examines the relationship between the independent variable and the dependent variable by comparing the relationship between the independent variable and dependent variable including the mediator. According to the result of the Sobel test, the indirect effect significantly exists (coefficient is 0.009). That is, it is statistically significant that the R&D capital stock partially mediates the effect of ICT on productivity.

<Figure 3> describes the indirect, direct, and total effects based on the Sobel test. The total effect is the total effect of exposure on the outcome, which can be divided into two parts: direct and indirect



Note: *, **,*** denote significance at the 10%, 5%, and 1% levels.

<Figure 3> Indirect, Direct, and Total Effect

effect. The direct effect is the effect of exposure on the outcome without the mediator. The indirect pathway is the effect of exposure on the outcome that works through the mediator. <Figure 3> shows that the ICT significantly increase productivity (β is 0.048). The effect directly affects productivity (direct effect, β is 0.057), and also indirect effect productivity through R&D (indirect effect, β is 0.009). The result supports the partial mediating effect of R&D.

For robustness, we rechecked the total, direct, and indirect effect using Preacher and Hayes (2004) bootstrap method. Preacher and Hayes (2004) bootstrap method provides some advantages to Sobel's test, primarily increase of statistical power. <Table 4> shows that there is significant indirect, direct, total effect of ICT on TFP. Thus, it shows the existence of partial mediation effect of R&D.

4.2. Granger Causality Test

Since we used regression analysis to test the mediation effect, there can be a question about causality. The result of the regression only represents the correlation between the dependent and independent variables; however, it cannot solve the question as to whether the independent variable causes the change in the dependent variable. In order to verify the order of effects, the Granger causality test is used to determine whether one variable is useful in forecasting another one. Even though the test can't be used as proof of causation, it determines whether the past value of an independent variable can be used to predict the value of a dependent variable. The results of the test with two lags are presented in <Table 5>.

<Table 4> Reexamination of Indirect, Direct, and Total Effect by Bootstrap Method

	Coefficients
Indirect Effect	0.009* (0.005)
Direct Effect	0.048*** (0.008)
Total Effect	0.057*** (0.006)

Note: The numbers in parentheses are the bootstrap standard deviations. *, **,*** denote significance at the 10%, 5%, and 1% levels.

<Table 5> Results of Granger Causality Test

Null Hypothesis	W-Statistic	$\bar{Z}$-Statistic
RD $\nrightarrow$ TFP	3.387***	3.139***
TFP $\nrightarrow$ RD	2.946	1.937
ICT $\nrightarrow$ TFP	3.740***	4.099***
TFP $\nrightarrow$ ICT	2.540	0.831
ICT $\nrightarrow$ RD	4.709***	6.740***
RD $\nrightarrow$ ICT	2.683	1.220

Note: *, **,*** denote significance at the 10%, 5%, and 1% levels.

According to the Granger results, R&D causes TFP, ICT causes TFP and ICT causes R&D. However, significant relationships in the opposite direction do not exist.

4.3. Reexamination with TFP Controlling External Factors

In order to check the robustness of TFP data, we reexamined the regression test by using new TFP data which follows a very basic equation. The TFP is measured based on the Equation (8), where output data is controlled with only two variables: the log of labor and capital costs. The TFP variable used in <Table 6> controls fewer variables than the main test, but it is generally used variable in the Cobb-Douglas production function.

The result of the test using new measured TFP was similar to the main regression test. The directions and significances of variables are similar to <Table 3>. Thus, the test results reassure that R&D partially mediates ICT and TFP. There is a positive relationship between ICT and TFP, and the coefficient is 0.092. There is a positive relationship between ICT and R&D, and the coefficient is 0.749. R&D and TFP have a positive relationship with a coefficient of 0.065. The coefficients are smaller than the results described in <Table 3>, because the dependent variable is no longer indexed. In the result of Eq. 4, we see the partial mediation effect of R&D. The indirect effect of ICT on TFP is 0.013 (the difference between the coefficients of ICT in Eq. 1 and Eq. 4 = 0.092 - 0.079). Therefore, ICT can improve TFP both directly and indirectly through R&D.

<Table 6> Reexamination from a Macroeconomic Perspective

	Eq. (1)	Eq. (2)	Eq. (3)	Eq. (4)
Dependent variable	TFP	LOG(RD)	TFP	TFP
C	-2.032*** (0.134)	4.886*** (0.523)	-1.386*** (0.121)	-2.117*** (0.138)
LOG(RD)			0.065*** (0.006)	0.017** (0.007)
LOG(ICT)	0.092*** (0.006)	0.749*** (0.024)		0.079*** (0.008)
Adjusted R-squared	0.874	0.953	0.865	0.875
F-statistic	188.324***	544.000***	173.875***	185.221***

Note: *, **,*** denote significance at the 10%, 5%, and 1% levels.

Ⅴ. Discussion and Implication

This study investigates the mediating effect of R&D between ICT and productivity. Using multi-year US industry-level data, we found that R&D partially mediates the impact of ICT on productivity. The results show that some of the ICT values can be realized through other knowledge activities. In this paper, it is R&D that enhances absorptive capacity. We also calculated the indirect effect of ICT on TFP. All models are valid by the LM and Hausman tests. These results remain robust even after reexamining the effect through bootstrap and simulation. We also tested using two TFP measurements to confirm robustness after taking into account external factors that may affect productivity.

The findings of the study have several interesting implications. First, this study contributes to the literature on the productivity paradox. Previous research has found that capturing the value of ICT is difficult due to mismeasurement, lags, redistribution, and mismanagement (Brynjolfsson and Hitt 1996). We found another reason why it was difficult to capture the business value of the ICT. Some business values of ICT can be realized or enhanced through other activities. In this paper, we found that knowledge activities enable employees to improve online communication between colleagues through experiences of interpreting and combining other people's ideas, market analysis, and technological knowledge.

Second, we expand the literature on the value of ICT. Although previous literature has revealed that ICT has a positive effect on productivity, the mechanisms by which ICT has a positive effect on productivity are still black boxes and inherently unobservable. Our research adds to this literature by showing that while communicating ideas and information in itself can create business value, some of that can be realized through other knowledge activities. Interpreting and applying information transferred and collected through ICT is important for realizing ICT values.

Third, this study contributes to the benefits of R&D literature, especially in terms of absorptive capacity. Previous literature found two benefits of R&D: increased innovation and improved absorptive capacity. Researchers have paid attention to absorptive capacity, which is a learning ability, only for innovation purposes. Our research expands this literature by showing that absorption ability learned through R&D is also helpful for online communication in addition to innovation. R&D can increase employees' absorptive capacity for online communication by increasing experience, expertise, and understanding of organizational communication styles.

The results of this study have practical implications for company managers and corporate online communication tools designers. First, managers can consider both ICT and R&D when making strategies for increasing knowledge capital and enhancing the knowledge competitiveness. The study results suggest that the decision making of ICT and R&D investments would better be done simultaneously rather than individually to maximize their impacts on productivity. Thus, ICT investments need to be embedded deeply in the R&D innovation processes. Second, communication software designers can consider how employees can share more complex ideas through corporate communication tools. Our research results show that communication can lead to the creation of feasible business value through knowledge activities, and designers can consider software features that can link communication content to knowledge activities such as R&D.

Our study is not without limitations; some of which may serve as research directions for future work to explore. First, we used data from 47 US industries from 1987 to 2013, which is rather outdated. The period of data is 27 years, which is a fairly long period of observation. However, it is possible that the recent trend may be different from the results because companies have implemented new and diverse enterprise communication tools. It will be interesting to compare or reexamine whether mechanisms exist in recent years that some of the effects of ICT on productivity can be realized through R&D knowledge activities. Second, endogeneity problems can exist between ICT and R&D equations. For example, ICT, R&D, and productivity can be jointly influenced by unmeasured third variables such as globalization. Companies that have merged with other companies in other countries are more likely to invest in ICT and thus gain more productivity. Discovering good instruments that are correlated with firm productivity but not with ICT and R&D capital stock will solve the endogeneity problem. Finally, in this paper, the mediating effect of R&D on ICT was extensively verified. However, the current model specifications allow for the evaluation of statistical significance between ICT, R&D, and TFP, rather than understanding the underlying mechanisms for associations between variables. In future research, it will be possible to specify the types of ICT and R&D and to reveal the way R&D mediates ICT in detail. Comparing the mediating effects by types of ICT and R&D can show possible mechanisms by which R&D mediates ICT. It is also possible to compare industries such as manufacturing and service industries (Roach, 1987) to provide several possible elaborations for the mechanisms by which R&D mediates ICT.

Acknowledgements

This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2020S1A3A2A 02093277).

<References>

[1] Antonelli, C. (1997). New information technology and the knowledge-based economy. The Italian evidence. *Review of Industrial Organization, 12*(4), 593–607.

[2] Arrow, K. J. (1971). The economic implications of learning by doing. In *Readings in the Theory of Growth* (pp. 131-149). Palgrave Macmillan.

[3] Bardhan, I., Krishnan, V., and Lin, S. (2013). Research note—business value of information technology: Testing the interaction effect of IT and R&D on Tobin's Q. *Information Systems Research, 24*(4), 1147-1161.

[4] Baron, R. M., and Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173.

[5] Barua, A., Kriebel, C. H., and Mukhopadhyay, T. (1995). Information technologies and business value: An analytic and empirical investigation. *Information Systems Research, 6*(1), 3-23.

[6] Bauer, D. J., Preacher, K. J., and Gil, K. M. (2006). Conceptualizing and testing random indirect effects and moderated mediation in multilevel models: New procedures and recommendations. *Psychological Methods, 11*(2), 142.

[7] Bolisani, E., and Scarso, E. (1999). Information technology management: A knowledge-based perspective. *Technovation, 19*(4), 209-217.

[8] Boutellier, R., Gassmann, O., Macho, H., and Roux, M. (1998). Management of dispersed product development teams: The role of information technologies. *R&D Management, 28*(1), 13-25.

[9] Brynjolfsson, E., and Hitt, L. (1996). Paradox lost? Firm-level evidence on the returns to information systems spending. *Management Science, 42*(4), 541-558.

[10] Brynjolfsson, E., and Hitt, L. M. (2000). Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives, 14*(4), 23-48.

[11] Chatfield, A. T., and Yetton, P. (2000). Strategic payoff from EDI as a function of EDI embeddedness. *Journal of Management Information Systems, 16*(4), 195-224.

[12] Cohen, W. M., and Levinthal, D. A. (1989).

Innovation and learning: The two faces of R & D. *The Economic Journal, 99*(397), 569-596.

[13] Cohen, W. M., and Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly,* 128-152.

[14] Coluccia, D., Dabić, M., Del Giudice, M., Fontana, S., and Solimene, S. (2020). R&D innovation indicator and its effects on the market. An empirical assessment from a financial perspective. *Journal of Business Research, 119,* 259-271.

[15] Comin, D. (2010). Total factor productivity. In *Economic growth* (pp. 260 – 263). Springer.

[16] Dabić, M., Vlačić, E., Ramanathan, U., and Egri, C. P. (2019). Evolving absorptive capacity: The mediating role of systematic knowledge management. *IEEE Transactions on Engineering Management, 67*(3), 783-793.

[17] Dana, M. E., Scheffler, A. J., Richmond, M. G., and Smith, S. (1991). Writing to read: Pen palling for a purpose. *Reading Improvement, 28*(2), 113.

[18] Devaraj, S., and Kohli, R. (2003). Performance impacts of information technology: Is actual usage the missing link? *Management Science, 49*(3), 273-289.

[19] Edquist, H., and Henrekson, M. (2017). Do R&D and ICT affect total factor productivity growth differently? *Telecommunications Policy, 41*(2), 106-119.

[20] Fernández-Portillo, A., Almodóvar-González, M., and Hernández-Mogollón, R. (2020). Impact of ICT development on economic growth. A study of OECD European union countries. *Technology in Society, 63,* 101420.

[21] Francalanci, C., and Galal, H. (1998). Information technology and worker composition: Determinants of productivity in the life insurance industry. *MIS Quarterly,* 227-241.

[22] Gandolfi, S., and Gandolfi, E. (2021). Playing across the social zone: Animal Crossing, gaming communities and connectedness in a time of crisis. *Academicus, 2021*(23), 41-51.

[23] Gholami, M. H., Asli, M. N., Nazari-Shirkouhi, S., and Noruzy, A. (2013). Investigating the influence of knowledge management practices on organizational performance: An empirical study. *Acta Polytechnica Hungarica, 10*(2), 205-216.

[24] Griffith, R., Redding, S., and Reenen, J. V. (2004). Mapping the two faces of R&D: Productivity growth in a panel of OECD industries. *Review of Economics and Statistics, 86*(4), 883-895.

[25] Haldin-Herrgard, T. (2000). Difficulties in diffusion of tacit knowledge in organizations. *Journal of Intellectual Capital, 1*(4), 357-365.

[26] Hall, B. H., Lotti, F., and Mairesse, J. (2013). Evidence on the impact of R&D and ICT investments on innovation and productivity in Italian firms. *Economics of Innovation and New Technology, 22*(3), 300-328.

[27] Hulten, C. R. (2001). Total factor productivity: A short biography. In *New developments in productivity analysis* (pp. 1 – 54). University of Chicago Press.

[28] Jeong, C. Y., Chan, J., and Guo, Y. (2022). Enhancing enterprise social media participation with social groups. *Academy of Management Proceedings, 2020*(1), 21525.

[29] Johannessen, J. A., Olaisen, J., and Olsen, B. (2001). Mismanagement of tacit knowledge: The importance of tacit knowledge, the danger of information technology, and what to do about it. *International Journal of Information Management, 21*(1), 3-20.

[30] Judd, C. M., and Kenny, D. A. (1981). Process analysis: Estimating mediation in treatment evaluations. *Evaluation Review, 5*(5), 602-619.

[31] Kleis, L., Chwelos, P., Ramirez, R. V., and Cockburn, I. (2012). Information technology and intangible output: The impact of IT investment on innovation productivity. *Information Systems Research, 23*(1), 42-59.

[32] Kohli, R., and Grover, V. (2008). Business value of IT: An essay on expanding research directions to keep up with the times. *Journal of the Association for Information Systems, 9*(1), 1.

[33] Lelic, S. (2001). Creating a knowledge-sharing

culture. *Knowledge Management, 4*(5), 6-9.

[34] Leonardi, P. M. (2014). Social media, knowledge sharing, and innovation: Toward a theory of communication visibility. *Information Systems Research, 25*(4), 796-816.

[35] MacKinnon, D. P., Lockwood, C. M., and Williams, J. (2004). Confidence limits for the indirect effect: Distribution of the product and resampling methods. *Multivariate Behavioral Research, 39*(1), 99-128.

[36] Majchrzak, A., Wagner, C., and Yates, D. (2006). Corporate wiki users: Results of a survey, 99-104, Retrieved from https://scholar.google.com/scholar_lookup?title=Corporate%20wiki%20users%3A%20Results%20of%20a%20survey&author=A.%20Majchrzak&author=C.%20Wagner&author=D%20Yates&publication_year=2006&journal=WikiSym%20%2706&volume=&pages=99-104

[37] Malhotra, A., and Majchrzak, A. (2014). Enhancing performance of geographically distributed teams through targeted use of information and communication technologies. *Human Relations, 67*(4), 389-411.

[38] Manesh, M. F., Pellegrini, M. M., Marzi, G., and Dabic, M. (2020). Knowledge management in the fourth industrial revolution: Mapping the literature and scoping future avenues. *IEEE Transactions on Engineering Management, 68*(1), 289-300.

[39] Matusik, S. F., and Hill, C. W. (1998). The utilization of contingent work, knowledge creation, and competitive advantage. *Academy of Management Review, 23*(4), 680-697.

[40] Nair, M., Pradhan, R. P., and Arvin, M. B. (2020). Endogenous dynamics between R&D, ICT and economic growth: Empirical evidence from the OECD countries. *Technology in Society, 62, 101315.*

[41] Nonaka, I., and Takeuchi, H. (1996). The knowledge-creating company: How Japanese companies create the dynamics of innovation. *Long Range Planning, 4*(29), 592.

[42] Park, J., Shin, S. K., and Shin, H. H. (2007). The intensity and externality effects of information technology investments on national productivity growth. *IEEE Transactions on Engineering Management, 54*(4), 716-728.

[43] Pauleen, D. J., and Yoong, P. (2001). Relationship building and the use of ICT in boundary-crossing virtual teams: A facilitator's perspective. *Journal of Information Technology, 16*(4), 205-220.

[44] Perks, M. E. (2021). Self-isolated but not alone: Community management work in the time of a pandemic. *Leisure Sciences, 43*(1-2), 177-183.

[45] Preacher, K. J., and Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers, 36*(4), 717-731.

[46] Rhee, L., and Leonardi, P. M. (2018). Which pathway to good ideas? An attention-based view of innovation in social networks. *Strategic Management Journal, 39*(4), 1188-1215.

[47] Roach, S. S. (1987). *America's technology dilemma: A profile of the information economy.* Morgan Stanley.

[48] Roberts, J. (2000). From know-how to show-how? Questioning the role of information and communication technologies in knowledge transfer. *Technology Analysis & Strategic Management, 12*(4), 429-443.

[49] Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94*(5), 1002-1037.

[50] Schepers, J., Schnell, R., and Vroom, P. (1999). From idea to business—How Siemens bridges the innovation gap. *Research-Technology Management, 42*(3), 26-31.

[51] Selig, J. P., and Preacher, K. J. (2008). Monte Carlo method for assessing mediation: An interactive tool for creating confidence intervals for indirect effects, Retrieved from http://quantpsy.org/

[52] Shachaf, P. (2008). Cultural diversity and information and communication technology impacts on global virtual teams: An exploratory study. *Information & Management, 45*(2), 131-142.

[53] Sobel, M. E. (1982). Asymptotic Confidence Intervals for Indirect Effects in Structural Equation Models. *Sociological Methodology*, 13, 290-312.

[54] Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics, 39*(3), 312-320. https://doi.org/10.2307/192604

[55] Stiroh, K. J. (2002a). Are ICT spillovers driving the new economy? *Review of Income and Wealth, 48*(1), 33-57.

[56] Stiroh, K. J. (2002b). Information technology and the US productivity revival: What do the industry data say? *American Economic Review, 92*(5), 1559-1576.

[57] Švarc, J., Lažnjak, J., and Dabić, M. (2020). The role of national intellectual capital in the digital transformation of EU countries. Another digital divide? *Journal of Intellectual Capital, 22(4),* 768-791. https://doi.org/10.1108/JIC-02-2020-0024

[58] Taştan, H., and Gönel, F. (2020). ICT labor, software usage, and productivity: Firm-level evidence from Turkey. *Journal of Productivity Analysis, 53*(2), 265-285.

[59] Thomke, S. H. (2006). Capturing the real value of innovation tools. *MIT Sloan Management Review, 47*(2), 24.

[60] Vu, K., Hanafizadeh, P., and Bohlin, E. (2020). ICT as a driver of economic growth: A survey of the literature and directions for future research. *Telecommunications Policy, 44*(2), 101922.

[61] Weill, P. (1992). The relationship between investment in information technology and firm performance: A study of the valve manufacturing sector. *Information Systems Research, 3*(4), 307-333.

[62] Young, A., and Musgrave, J. C. (1980). Estimation of capital stock in the United States. In *The measurement of capital* (pp. 23-82). University of Chicago Press.

◆ About the Authors ◆

Christina Y. Jeong

Christina Y. Jeong is a Ph.D. candidate in the Carlson School of Management at the University of Minnesota. She studied Business Administration for both her bachelor's and master's degrees in the School of Business at Hanyang University. Ms. Jeong is particularly interested in the area of economic value and the social impact of information technology. In particular, her specific research interests include gender inequality and the spread of fake news.

Sang-Yong Tom Lee

Sang-Yong Tom Lee is a professor in the School of Business at Hanyang University. He previously worked at the National University of Singapore. His research interests include economics of information systems, online information privacy, and value of IT. His publications have appeared in MIS Quarterly, Management Science, Journal of Management Information Systems, Information & Management, the IEEE Transactions on Engineering Management and others.

Submitted: January 31, 2022; 1st Revision: June 3, 2022; Accepted: July 19, 2022