# The changing returns on IT investment



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## Abstract

**Purpose** – Prior IT productivity research usually assumes constant returns on IT investment. This study suggests that the impact of IT investment on productivity may not be constant but may change with the IT investment scale and over time. Specifically, we divide IT investment into commercial IT and in-house IT and investigate their changing impacts on industry labor productivity.

**Design/methodology/approach** – A model of the productivity impacts of commercial IT and in-house IT with changing effects of scale and over time is developed and empirically tested based on industry-level panel data from the US. Bureau of Economic Analysis (BEA).

**Findings** – The returns on commercial IT investment increase with scale but decrease over time, while the returns on in-house IT increase over time.

**Originality/value** – This study provides a new perspective for IT productivity research by investigating the changing productivity impacts of IT investment. It also suggests that commercial IT and in-house IT should be distinguished, as they have different impacts on productivity.

**Keywords** Commercial IT, In-house IT, Labor productivity, Changing impacts

**Paper type** Research paper

## 1. Introduction

Since the middle of the twentieth century, with the progress of hardware and software technology, IT has been entering various fields of the national economy, becoming an important tool or factor of production for many industries. With the increasing importance of IT, an increasing number of scholars are investigating the economic value of IT investment from different perspectives (Cardona *et al.*, 2013; Dedrick *et al.*, 2003). For instance, Robert Solow, a Nobel laureate in economics, proposed the well-known "IT productivity paradox", questioning the contribution of IT investment to productivity (Brynjolfsson, 1993). However, by the mid-1990s, the debate on the productivity paradox cooled down, as an increasing number of studies found that under the framework of the production function, IT investment is positively related to productivity (Brynjolfsson and Hitt, 1998). Currently, the productivity paradox has been mostly solved, and most studies show that the impact of IT investment on productivity is positive (Cardona *et al.*, 2013; Sabherwal and Jeyaraj, 2015). Not only is IT a tool for achieving process automation and improving efficiency, but it is also a tool for achieving change and improving business effectiveness (Melville *et al.*, 2004; Mithas *et al.*, 2012).

However, prior research on IT productivity usually assumes constant returns on IT investment (Cardona *et al.*, 2013; Dedrick *et al.*, 2003). In fact, the economic returns on IT investment may not be constant due to the learning effect and the synergy effect of IT investment (Tanriverdi, 2006; Wang *et al.*, 2012). When the level of IT investment is low, firms may not have accumulated enough capabilities to use IT effectively. However, with an increase in IT investment, firms can learn from IT practices and accumulate more IT capabilities. Strong internal IT capabilities will help firms meet their business needs in an efficient and effective manner (Bharadwaj, 2000; Wang *et al.*, 2012). Therefore, the relationship between IT and productivity can change, as the contribution of IT to productivity can increase with the IT investment scale or over time. On the other hand, some research shows that the positive

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relationship between IT investment and average labor productivity (ALP) in the United States has been weakening since 2000 (Stiroh and Botsch, 2007). This result implies that the economic value of IT investment may change over time. Research has also suggested that IT investment opportunities that can be commercialized change over time (Dos Santos *et al.*, 2012). As a result, the impact of IT investment on productivity may also change over time.

Furthermore, prior research has often regarded IT as a collective and unified asset, even though different types of IT can have completely different impacts on productivity (Aral and Weill, 2007; Schryen, 2013). Following the classical "make vs buy" framework (Williamson, 1985) and prior IS research (Daneshgar *et al.*, 2013b; Hung and Low, 2008), we divide IT into commercial IT (software is bought from software vendors in the market) and in-house IT (software is developed by the internal IT department of the user firm). The "make vs buy" decision is one decision that firms have to make when they adopt IT application and it has an important influence on firm practices and outcomes (Hung and Low, 2008; Williamson, 1985). Accordingly, we suggest that the two types of IT affect productivity differently because they contain different characteristics and involve specific advantages/disadvantages. For instance, commercial IT is developed by external software vendors and is usually highly reliable, and its adoption does not require the user firm to have strong IT capabilities and resources (Xu and Brinkkemper, 2007). On the other hand, in-house IT is developed by the user firm, which requires the firm to have strong internal IT capabilities and resources. It is generally believed that in-house IT has a high initial cost, as the required internal IT capabilities and resources require considerable investment (Light and Sawyer, 2007).

In this study, we follow the "make vs buy" framework to divide IT into commercial IT and in-house IT (Daneshgar *et al.*, 2013b; Hung and Low, 2008) and investigate their impacts on labor productivity. We suggest that the economic returns of commercial and in-house IT change with scale and over time. The model is tested based on panel data on 18 US non-IT manufacturing industries from 1998 to 2017. To improve the robustness of the results, this study adopts a fixed effects model with robust errors, a random effects model with robust errors (Greene, 2011), and an ordinary least squares with panel-corrected standard errors (OLS-PCSE) analysis using both common autocorrelation and panel-specific autocorrelation techniques (Beck and Katz, 1995) for hypothesis testing. The results support most of our hypotheses.

This study contributes to research in three ways. First, unlike prior IT productivity research, which usually assumes constant returns on IT investment, this study considers the changing effect of IT investment on productivity with the change in scale and over time. Although the initial performance of IT investment can be low, the returns on IT investment may increase with more investment due to the learning effect and the accumulation of IT capabilities (Bharadwaj, 2000; Liang *et al.*, 2010; Wang *et al.*, 2012). In addition, IT investment opportunities (Dos Santos *et al.*, 2012) and the demand for IT (Adner, 2004) may change over time. The changing returns on IT investment provide fresh insights for IT productivity research. Second, unlike prior research, which usually treats IT investment in an aggregated manner, we follow the "make vs buy" framework to divide IT investment into commercial IT and in-house IT and investigate their impacts on labor productivity. This disaggregation of IT investment is important because different types of IT can have completely different impacts on productivity (Schryen, 2013). Finally, our study is able to provide an explanation for the inconsistent findings in recent IT productivity research (Acemoglu *et al.*, 2014).

## 2. Commercial IT and in-house IT

The division of IT into commercial IT and in-house IT is widely used in IS research (Daneshgar *et al.*, 2013a; Hung and Low, 2008). Commercial IT investment is IT investment in commercial software and related facilities, with commercial software being defined as "software for non-professional purposes, sold, or licensed in standard form" (Parker and Grimm, 2000). According to this definition, commercial IT has two essential characteristics. First, commercial IT software is developed by external software vendors, such as Microsoft, SAP or Oracle. Second, commercial IT software is a standardized product designed to meet the general needs of the market. To meet the changing market demand over time, software vendors often adopt incremental methods for iterative development. Each iteration includes the stages of collecting requirements, designing, coding, testing and deploying for one or more parts of the software product (Xu and Brinkkemper, 2007).

In-house IT investment is an IT investment in in-house software and related facilities, with in-house software being defined as "the software developed internally by enterprises or government units for their own needs or the software developed again with significantly enhanced functions" (Parker and Grimm, 2000). This definition suggests that in-house IT has two characteristics. First, in-house IT software is developed by the internal IT department of the user firm. Second, in-house IT software is a product designed for the specific needs of that firm. To save time and reduce the cost of development, firms often adopt sequential methods for in-house software development, and thus, each stage of the software development life cycle (i.e. requirements, design, development, testing and deployment) takes place only once (Xu and Brinkkemper, 2007). We list the differences between commercial IT and in-house IT that are most relevant to this study as follows.

### *2.1 Cost*

It is generally believed that there is a low-cost advantage to commercial IT (Daneshgar *et al.*, 2013b; Hung and Low, 2008). As a commercial IT vendor usually has a competitive source of labor and expertise and its standard product can be sold to multiple firms to distribute the development cost, the purchase price of commercial IT is generally lower than the development cost of in-house IT with similar functions (Fowler, 2004). In-house IT requires the firm to allocate the resources and knowledge needed in each stage of development, including hardware and relevant professionals. Thus, developing in-house IT is usually costly. Although the internal IT department of a firm can become cost-effective by improving its IT capabilities through an increase in IT investment, in-house IT still requires a high level of knowledge and resources to address increasingly complex system problems (Fowler, 2004; Schwager *et al.*, 2000). Therefore, compared to in-house IT, commercial IT usually has a cost advantage.

### *2.2 IT capabilities*

IT capabilities refer to a firm's abilities to acquire, deploy and utilize IT resources to gain a competitive advantage and improve performance (Bharadwaj, 2000; Santhanam and Hartono, 2003). As each stage of in-house software development is completed by the IT department of a firm (Xu and Brinkkemper, 2007), the department is able to learn from its IT development activities, transform widely available IT resources into unique IT capabilities embedded in firm processes, gain experience and gradually develop its own IT capabilities (Liang *et al.*, 2010; Wang *et al.*, 2012). On the other hand, commercial IT uses packaged software that is purchased directly from the external market. Thus, a firm using commercial IT relies on the technological capabilities of the external software vendor to develop and upgrade a commercial IT system (Daneshgar *et al.*, 2013b). However, firms may accumulate other types of IT capabilities, such as capabilities related to IT planning, IT implementation and IT use, if they can learn from their IT practices.

## 3. The changing returns on IT investment

Although previous studies on IT productivity have often assumed constant returns on IT investment, some studies suggest that IT investment may involve changing returns with scale or over time. In fact, the "productivity paradox" phenomenon can be considered an example of the changing returns on IT investment due to the learning effect (Brynjolfsson, 1993). That is, at the early stage, although firms had some IT investment, productivity was not improved; only after firms learned how to use IT effectively did they start to gain benefits from IT. With an increase in IT investment, firms may learn from IT practices and accumulate a high level of IT capabilities embedded in their IT management processes (Liang *et al.*, 2010; Wang *et al.*, 2012). IT capabilities can be embedded in the IT value creation process of the firm, enabling it to effectively select, integrate, deploy and utilize IT resources or cooperate with other firm resources and capabilities to bring high value added to the firm (Ong and Chen, 2013; Wade and Hulland, 2004). For example, firms that have built IT infrastructure platforms based on other IT investments can reconfigure their IT assets to develop new applications in a cost-effective way (Schwager *et al.*, 2000). In addition, IT capabilities are not restricted to one department, they can be applied by all departments of a firm. For example, to meet the demand of real-time data acquisition for offline sales stores, the sales department may invest in IT and develop big data acquisition and processing capabilities, which can be reused in other departments, such as the supply chain department or manufacturing department. Therefore, firms should obtain increasing returns on IT if they learn from the practices of other IT investments and develop strong IT capabilities to support their business operations.

The increasing returns on IT investment can also be due to its synergy effect, i.e. the value from the joint use of multiple IT assets is often greater than the sum of the value of each IT asset (Schryen, 2013). Different IT assets in a firm serve their own goals and create value by meeting these goals. However, one IT asset can also connect other IT assets so that they can jointly serve business objectives (e.g. supporting business processes and collaboration within and between firms) and create additional value through synergy. There are two types of IT synergies: super-additive value synergies and sub-additive cost synergies (Tanriverdi, 2006). Two IT assets enjoy super-additive value synergies if their joint value is greater than the sum of their individual values, and two IT assets enjoy sub-additive cost synergies if they use common physical or intellectual resources and can reduce joint costs, which is similar to an economy of scope. For example, a quality management system and a knowledge management system simultaneously serve the business objective of improving product performance and bring a value increment to the firm through their super-additive value synergies (Schryen, 2013). If the two systems share some common components of IT infrastructure, they can enjoy sub-additive cost synergies as well. Due to the synergy effect, IT investment can involve increasing returns because more IT provides more opportunities for super-additive value synergies and sub-additive cost synergies. As an industry is an aggregation of firms, increasing returns on IT investment for firms should also indicate increasing returns for industries. The approach of viewing an industry as an aggregation of firms and using firm-level reasonings to argue for industry-level outcomes has been used by many studies (e.g. Qu *et al.*, 2011; Ren and Dewan, 2015; Schilling and Steensma, 2001). Therefore, we propose that the economic returns on industry IT investment should increase with scale for both commercial IT and in-house IT.

*H1*. The productivity of industry commercial IT investment increases with scale.

*H2*. The productivity of industry in-house IT investment increases with scale.

On the other hand, some studies suggest that the productivity of IT investment may decrease over time (Lin and Shao, 2006). IT investment may experience decreasing returns due to the maturation of some IT applications (Adner, 2004). Studies show that the software industry has entered a mature stage, as the industry has become increasingly concentrated since the late 1990s (Suarez *et al.*, 2013). Dos Santos *et al.* (2012) showed that for the most important enterprise-wide systems, enterprise resource planning (ERP) systems have become commodities for firms, and the commoditization of supply chain management (SCM) systems and customer relationship management (CRM) systems is also rapidly approaching. As software is key for economic returns on IT investment (Poon and Davis, 2004), the maturation of a software product will influence the economic returns on IT. For example, while people gain high value when they update the Microsoft DOS operating system to Windows, they gain much less value when updating Windows 7 to Windows 8 or Windows 10 due to the maturation of Windows.

IT investment may also experience decreasing returns because of the maturing demand for IT over time (Adner, 2004). From a demand-based perspective, Adner and Levinthal (2001) suggested that as the technological performance of many IT applications exceeds the demand of firms, additional investment in more advanced IT may provide only limited additional value. Specifically, Adner (2004) argued that the value of a new (or new version of) IT application depends not on the advancements in its technological performance but on the additional benefits that the firm can gain from it. Although the technological performance of IT continues to improve, the law of diminishing marginal utility means that the additional value of such technological improvement to firms is not guaranteed. If current IT applications provide adequate performance for a firm, further technological advancements may not provide much additional value to that firm (Adner, 2004; Adner and Levinthal, 2001). For instance, for a small firm that finds Microsoft Excel sufficient to support its accounting tasks, adopting a complex ERP system may have limited additional value, even though the technological performance of an ERP system is much better than that of Microsoft Excel.

The above arguments on decreasing returns over time are highly applicable to commercial IT because many commercial IT applications have become mature or the demand for them has become mature. For instance, the increased concentration of the software industry indicates that many packaged software products are maturing (Suarez *et al.*, 2013). As a result, commercial IT applications, which use packaged software, are also maturing. In addition, the demand for commercial IT has become mature. Research shows that most firms have adopted enterprise systems such as ERP, SCM and CRM systems (Dos Santos *et al.*, 2012). After most firms in an industry adopt such enterprise systems and related systems, the demand for new commercial IT in that industry may decrease because such enterprise systems and related systems have computerized most parts of a firm. Furthermore, firms may become unwilling to adopt new commercial IT because the integration of new and old systems requires changes, but currently, it is very difficult to change large IT systems (Rettig, 2007). As a result, once most firms in an industry have adopted most of the IT systems they need, new investment in commercial IT in the industry will be mainly for maintenance or upgrading purposes, and the contribution of such IT investment to productivity will decrease over time.

*H3*. The productivity of industry commercial IT investment decreases over time.

However, the returns on in-house IT over time should be different from those of commercial IT. First, while commercial IT addresses the common needs of many firms, in-house IT addresses the specific needs of individual firms (Hung and Low, 2008). As the common needs of many firms are usually stable and can be gradually addressed in a satisfactory manner, commercial IT may reach a mature stage, and the demand for commercial IT may become mature over time (Adner, 2004; Daneshgar *et al.*, 2013b). However, individual firms have various types of specific needs, and such needs may change over time due to changes in the environment. As a result, new specific needs of individual firms are always emerging, and new types of in-house IT are needed to address such specific needs. Accordingly, unlike commercial IT, in-house IT may not reach a mature stage, and the demand for in-house IT may not become mature over time.

Second, recent developments in digital innovation suggest that there are many investment opportunities for in-house IT. Currently, firms use IT to innovate not only their business processes but also their core products/services (Nambisan *et al.*, 2017; Porter and Heppelmann, 2014). Unlike the IT for business process innovation (e.g. packaged ERP and CRM systems) that can be bought from the market, IT for products/services usually needs to be developed in-house because IT is a core part of such smart products or services (Branstetter *et al.*, 2019; Svahn *et al.*, 2017). With the increasing importance of digital innovation in the economy (Bharadwaj *et al.*, 2013; Porter and Heppelmann, 2014), the demand for in-house IT is growing. This is also consistent with the observations of industry reports. For instance, IBM reported that more than half of the firms in a survey recognize that effective in-house software development is crucial for achieving competitive advantage (Albrecht *et al.*, 2013). A report by the Boston Consulting Group shows that attracting and retaining software talent have become critical tasks for firms (Gilliland *et al.*, 2014).

Finally, in-house IT investment experiences increasing returns over time possibly due to the accumulation of in-house IT development capabilities and other related capabilities as well as the advancement of technology. IT development capabilities and related capabilities are strategic capabilities that require firms to spend considerable resources on in-house IT practices, and they need to be accumulated over time (Qu *et al.*, 2010; Wang *et al.*, 2012). After a firm has developed such capabilities, however, they can be used to develop various IT applications to support different business functions. As a result, the returns on in-house IT investment may be small at the early stage, but they increase over time. The advancement of technology may also increase the returns on in-house IT investment. Currently, many IT firms and third parties provide platform-as-a-service (PaaS) to support the development of IT applications, which makes the development of in-house IT applications much easier for user firms (Beimborn *et al.*, 2011). These platforms provide not only infrastructure and tools for application development but also many application programming interfaces (APIs) with different functions that developers can directly use. Additionally, these platforms can provide firms with on-going operation services for IT applications. As a result, such platforms reduce the costs of in-house IT development and enhance the quality of in-house IT applications. In summary, based on the discussion above, the economic returns on in-house IT investment should increase over time. This conclusion should also be applicable at the industry level, as an industry is an aggregation of firms.

*H4*. The productivity of industry in-house IT investment increases over time.

## 4. Empirical analysis

### *4.1 Research model*

This study measures productivity using labor productivity. Following previous research (Acemoglu *et al.*, 2014), we set up the following regression model:

$$\ln y_{it} = \beta_0 + \beta_1 \mathrm{Com}_{it} + \beta_2 \mathrm{In}_{it} + \beta_3 \mathrm{Com}_{it}^2 + \beta_4 \mathrm{In}_{it}^2 + \beta_5 \mathrm{Com}_{it} \times \mathrm{Time} + \beta_6 \mathrm{In}_{it} \times \mathrm{Time} + \beta_7 \mathrm{Cap}_{it} + \beta_8 \mathrm{Size}_{it} + \beta_9 \mathrm{Conc}_{it} + \beta_{10} \mathrm{R\&D}_{it} + \mathrm{Ind}_i + \mathrm{Year}_t + \varepsilon_{it}$$

where $y_{it}$ is labor productivity, $\mathrm{Com}_{it}$ is commercial IT investment and $\mathrm{In}_{it}$ is in-house IT investment. $\mathrm{Com}_{it}^2$ and $\mathrm{In}_{it}^2$ are corresponding quadratic terms for testing the increasing return effect of scale (Haans *et al.*, 2016). The interaction terms of the time variable Time with commercial IT and in-house IT are included to examine the changing returns of commercial IT and in-house IT over time, respectively. We add capital intensity $\mathrm{Cap}_{it}$ as a control variable because capital and labor are key inputs for output according to the production function. We also controlled for the effects of industry size ($\mathrm{Size}_{it}$), industry concentration ($\mathrm{Conc}_{it}$) and industry R&D intensity (R&$D_{it}$) on productivity, as prior studies suggest that these factors may influence productivity (Dedrick *et al.*, 2003; Melville *et al.*, 2007; Sabherwal and Jeyaraj, 2015). In addition, we include industry dummies $\mathrm{Ind}_{it}$ to control for industry fixed effects and year dummies $\mathrm{Year}_{it}$ to control for the time fixed effects in the analysis.



*4.2 Data and variables*

The data used in this study are from the annual industry economic accounts of the US Bureau of Economic Analysis (BEA) for the 1998–2017 period. The industry classification refers to the three-digit level of the North American Industry Classification System (NAICS), which includes 19 manufacturing industries. However, because research has shown that the impacts of IT investment are different between IT industries and non-IT industries (Dedrick *et al.*, 2003) and this research focuses on non-IT industries, we exclude the IT hardware industry. Therefore, the data used in this study are panel data on 18 non-IT industries in the private sector of the US economy. In addition, this study uses real values instead of nominal values, which are obtained by multiplying the chain type quantity indexes by the nominal value of the base year in 2012 (Han *et al.*, 2011).

The measurements of the key variables are shown in Table 1. Industry labor productivity is measured as the ratio of industry value added to labor (Han *et al.*, 2011). The data on industry *value added* come from the annual industry economic accounts of the BEA, and industry *labor* is measured by the number of full-time equivalent employees in the industry, which comes from the BEA Full-Time Equivalent Employees by Industry Table. Industry in-house (commercial) IT is measured as the ratio of in-house (commercial) IT investment to the capital stock (Acemoglu *et al.*, 2014). The data on industry *commercial IT investment*, *in-house IT investment* and the *capital stock* come from the Fixed Asset Tables of the BEA, which include stock data for 96 different types of nonresidential capital (categorized into three groups: equipment, structures and intellectual property products) for all industries. An industry's *capital stock* is measured as the sum of its total nonresidential capital. Among capital in intellectual property products, the BEA distinguishes between investment in own-account software and investment in packaged software (Parker and Grimm, 2000). In this study, we use an industry's stock in packaged software to approximate its *commercial IT investment* and its stock in own-account software to approximate its *in-house IT investment*. These two types of software stock can be used to approximate commercial and in-house IT investments because the hardware parts of commercial IT and in-house IT are both bought from the market and are similar to each other. Finally, regarding the control variables, *industry capital intensity* is measured as the ratio of the industry capital stock (minus commercial IT and in-house IT) to labor in logarithmic form (Bharadwaj *et al.*, 1999). *Industry size* is measured as the logarithm of an industry's gross output, which is from the industry

| Variables | Measurements (real value in 2012 USD) |
|---|---|
| Labor productivity | The ratio of industry value added to labor Han *et al.* (2011) |
| Commercial IT | The ratio of industry commercial IT investment to the capital stock Acemoglu *et al.* (2014) |
| In-house IT | The ratio of industry in-house IT investment to the capital stock Acemoglu *et al.* (2014) |
| Capital intensity | The ratio of the industry capital stock (minus commercial IT and in-house IT) to labor in logarithmic form Bharadwaj *et al.* (1999) |
| Industry size | The log of industry gross output |
| Industry concentration | The Herfindahl-Hirschman index (HHI) of all firms' sales in an industry |
| R&D intensity | An industry's R&D quantity index |

**Table 1.**
Key variables and their measurements (all data from the US BEA)

account of the BEA. *Industry concentration* is measured as the Herfindahl–Hirschman index (HHI) of all firms' sales in an industry, and the data are from the Compustat database (Kobelsky *et al.*, 2008; Qu *et al.*, 2011). *Industry R&D intensity* is measured as the capital R&D quantity index, which is from the BEA/Bureau of Labor Statistics (BLS) integrated industry-level production account. The mean values and correlations of the key variables are shown in Table 2.

### *4.3 Analytical procedure*

Before data analysis, we standardized all variables in this study. Because panel data are used, an fixed effects (FE) model or random effects (RE) model could be considered in this study (Greene, 2011). The Hausman test ($Chi^2 = 24.57, p > 0.1$) does not reject the assumption of the RE model. Therefore, this study used both a FE model with robust standard errors and a RE model with robust standard errors to estimate the model. In addition, to verify the robustness of the results, we also used the OLS-PCSE method (Beck and Katz, 1995) to analyze the data. As the OLS-PCSE method addresses the heteroscedasticity and synchronic correlation between groups, we only need to consider whether the panel data involved autocorrelation over time. Using the Wooldridge test for autocorrelation in the panel data, we found that first-order autocorrelation was present ($F = 41.1, p < 0.01$). Therefore, following prior research (Han *et al.*, 2011), we adjusted for first-order autocorrelation in the OLS-PCSE analysis using both panel-specific autocorrelation (PSAR) and common autocorrelation (AR) techniques.

### *4.4 Results*

The results are shown in Table 3. The coefficients of the quadratic term of commercial IT are positive in three of the four models (FE: $\beta_3 = 0.539, p < 0.05$; RE: $\beta_3 = 0.517, p < 0.05$; PSAR: $\beta_3 = 0.157, p > 0.1$; AR: $\beta_3 = 0.287, p < 0.01$), which partially supports Hypothesis 1, i.e. the productivity of commercial IT investment increases with scale. On the other hand, in all four models, we find that the coefficients of the quadratic term of in-house IT are not significant (FE: $\beta_4 = 0.194, p > 0.1$; RE: $\beta_4 = 0.111, p > 0.1$; PSAR: $\beta_4 = 0.047, p > 0.1$; AR: $\beta_4 = -0.032, p > 0.1$). Thus, Hypothesis 2, i.e. the productivity of in-house IT investment increases with scale, is not supported. Regarding the IT impacts over time, the results show that the coefficients of the interaction of commercial IT investment and the time variable are negative and significant in all four models (FE: $\beta_5 = -0.464, p < 0.05$; RE: $\beta_5 = -0.464, p < 0.05$; PSAR: $\beta_5 = -0.234, p < 0.01$; AR: $\beta_5 = -0.302$ $p < 0.01$). These results imply that the contribution of commercial IT investment to labor productivity weakens over time, which supports Hypothesis 3. We also find that the coefficients of the interaction of in-house IT investment and the time variable are positive and significant in all four models (FE: $\beta_6 = 0.384, p < 0.01$; RE: $\beta_6 = 0.397, p < 0.01$; PSAR: $\beta_6 = 0.305, p < 0.01$; AR: $\beta_6 = 0.279, p < 0.01$), which supports Hypothesis 4, i.e. the contribution of in-house IT investment to labor productivity becomes stronger over time.

We also check the endogeneity of our model. Following previous studies (Baum *et al.*, 2003; Han *et al.*, 2011), we used the one-year and two-year lagged variables of commercial IT investment, in-house IT investment, their quadratic terms and their interactions with time as instrumental variables to test the endogeneity of the model. The "xtivreg2" command in Stata was used, and the result suggests that endogeneity is not a problem in this study ($Chi^2(6) = 1.898, p > 0.1$).

## 5. Discussion

### *5.1 Findings*

The results show that the effect of commercial IT investment on industry productivity increases with scale. This finding is consistent with our argument that as investment in IT

**Table 2.** Means and correlations of the key variables

| Variable | Mean | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| 1. Labor productivity | 4.810 | 1 | | | | | | |
| 2. Commercial IT | 0.004 | 0.003 | 1 | | | | | |
| 3. Inhouse IT | 0.003 | −0.161** | 0.385** | 1 | | | | |
| 4. Capital intensity | 5.217 | 0.908** | −0.168** | −0.264** | 1 | | | |
| 5. Industry size | 12.249 | 0.672** | −0.156** | −0.141** | 0.643** | 1 | | |
| 6. Ind. concentration | 0.105 | −0.244** | 0.037 | −0.066 | −0.169** | −0.518** | 1 | |
| 7. R&D intensity | 0.938 | 0.01 | 0.417** | −0.034 | 0.068 | −0.012 | 0.166** | 1 |

**Note(s):** $^{**}p < 0.01$

| Variable | Fixed effects | Random effects | OLS-PCSE (PSAR) | OLS-PCSE (AR) |
|---|---|---|---|---|
| Commercial IT | 0.180 (0.141) | 0.188 (0.137) | 0.136 (0.098) | 0.122 (0.095) |
| In-house IT | 0.465** (0.126) | 0.527** (0.162) | 0.453* (0.178) | 0.498** (0.156) |
| Commercial IT$^2$ | 0.539* (0.237) | 0.517* (0.239) | 0.157 (0.108) | 0.287** (0.107) |
| In-house IT$^2$ | 0.194 (0.449) | 0.111 (0.393) | 0.047 (0.346) | −0.032 (0.353) |
| Commercial IT*Time | −0.464* (0.179) | −0.466* (0.190) | −0.234** (0.084) | −0.302** (0.081) |
| In-house IT*Time | 0.384** (0.111) | 0.397** (0.134) | 0.305** (0.064) | 0.279** (0.057) |
| Capital intensity | 0.510* (0.203) | 0.845** (0.151) | 0.670** (0.147) | 0.522* (0.208) |
| Industry size | 0.085 (0.100) | 0.199** (0.044) | 0.223** (0.067) | 0.206** (0.075) |
| Industry concentration | 0.046* (0.020) | 0.056* (0.023) | 0.047** (0.013) | 0.045** (0.017) |
| Industry R&D intensity | −0.154** (0.035) | −0.159** (0.033) | −0.129* (0.058) | −0.125 (0.076) |
| Cons | 4.885** (0.130) | 5.032** (0.181) | 4.675** (0.196) | 4.558** (0.196) |
| Industry dummies | / | / | Yes | Yes |
| Year dummies | Yes | Yes | Yes | Yes |
| $N$ | 360 | 360 | 360 | 360 |
| $R^2$ | 0.738 | 0.840 | 0.899[a] | 0.899[a] |

**Note(s)**: $^{*}p < 0.05$ (two-tailed); $^{**}p < 0.01$
[a]Excluding the variance explained by autocorrelation and industry fixed effects

**Table 3.** Results based on the fixed effects, random effects, and OLS-PCSE models

increases, firms may learn from IT practices and develop strong IT capabilities (Wang *et al.*, 2012; Xu and Brinkkemper, 2007). Such IT capabilities can be used in different departments and for different types of new IT applications, thus providing high value for firms (Ilmudeen and Bao, 2018; Liang *et al.*, 2010; Wang *et al.*, 2012). The increasing returns on commercial IT investment may also be due to the synergy effect between different IT applications (Schryen, 2013; Tanriverdi, 2006). As more commercial IT investment indicates more opportunities for IT synergies, we may observe increasing returns on commercial IT investment. However, the returns on in-house IT investment do not increase with scale, which is inconsistent with our hypothesis. One explanation for this result is that developing in-house IT costs firms many resources (Hung and Low, 2008). Therefore, the cost of developing in-house IT on a large scale may be too high for a firm, thus hurting its economic performance.

In addition, we find that the contribution of commercial IT to productivity gradually weakens over time. Prior studies have suggested that the commercial software market has become increasingly mature (Suarez *et al.*, 2013). Accordingly, investment opportunities through commercial IT decrease over time (Dos Santos *et al.*, 2012), and the marginal returns on commercial IT investment weaken as well (Adner, 2004; Adner and Levinthal, 2001). As a result, the contribution of commercial IT to industry productivity gradually weakens. The results of our analysis are consistent with the arguments and findings related to the maturation of commercial IT and the maturation of its demand in prior research mentioned above.

Finally, unlike commercial IT, the results show that in-house IT involves increasing returns over time. As discussed above, in-house IT addresses the specific needs of individual firms, and the demand for in-house IT may not reach a mature stage because firms often have new specific needs for IT when the environment changes. In addition, firms currently use IT to innovate both their business processes and core products/services (Nambisan *et al.*, 2017; Porter and Heppelmann, 2014). Unlike IT for business processes, IT for core products/services often needs to be developed in-house (Branstetter *et al.*, 2019). Therefore, in-house IT may become more valuable for firms over time because it also supports product/service innovation. Furthermore, firms may accumulate strong IT development capabilities over time with in-house IT practices (Qu *et al.*, 2010; Wang *et al.*, 2012), and currently, such capabilities are highly valuable to firms for digital innovation (Albrecht *et al.*, 2013). The finding of increasing returns on in-house IT investment is consistent with the arguments mentioned above.

*5.2 Research contributions*

This study has three key research implications. First, unlike prior IT productivity research, which usually assumes a constant relationship between IT investment and productivity (Cardona *et al.*, 2013; Dedrick *et al.*, 2003), our study shows that this relationship is not constant. Specifically, our study finds that the returns on commercial IT investment increase with scale but decrease over time, while the returns on in-house IT investment increase over time. Our study suggests that the increasing returns on IT investment may be due to the accumulation of IT capabilities (Liang *et al.*, 2010; Wang *et al.*, 2012) or the synergy effect of IT (Schryen, 2013; Tanriverdi, 2006), while the decreasing returns on IT investment may be due to the maturity of IT or the maturity of the demand for IT (Adner, 2004; Adner and Levinthal, 2001).

Second, prior research has argued for different types of impacts of IT on economic returns. For example, while some suggest that the returns on IT investment decrease over time due to the maturity of IT or the maturity of the demand for IT (Adner, 2004; Adner and Levinthal, 2001), others suggest that the returns on IT investment may increase if firms continue to invest in IT and develop strong IT capabilities (Bharadwaj, 2000; Wang *et al.*, 2012). However, most research uses overall IT investment, rather than disaggregated IT investment, to study the impact of IT on productivity. Our findings suggest that both arguments may be correct, depending on the type of IT investment. In this study, we follow the "make vs buy" framework and divide IT into commercial IT and in-house IT, and we highlight their different characteristics (Hung and Low, 2008). When an industry invests in commercial IT, the returns can continue to increase with more IT investment, even though they decrease over time. On the other hand, when an industry invests in in-house IT, its returns can increase over time. By showing the different effects of commercial IT and in-house IT, our study reminds IS researchers that different types of IT should be distinguished and that the relationship between IT investment and productivity goes beyond the assumption of constant returns in prior studies.

Finally, our study is able to provide an explanation for the mixed results in recent IT productivity research. Although most prior studies show that IT investment has a positive impact on productivity, there are still some inconsistent findings. For example, after controlling for fixed effects, the studies of Han *et al.* (2011) and Cheng and Nault (2012) showed that there is no significant association between IT investment and industry gross output. Additionally, Acemoglu *et al.* (2014) found that there is no significant difference in productivity growth between IT-intensive industries and other industries after 2001, which they referred to as the return of the Solow paradox. Our study provides an explanation for these recent mixed findings in IT productivity research. Specifically, our findings suggest that the contribution of commercial IT to productivity may decrease over time due to the law of diminishing marginal utility. As a result, it is possible to once again observe the Solow paradox (Acemoglu *et al.*, 2014).

*5.3 Policy implications*

Our findings are based on industry-level data, and the results have important implications for policy-makers who intend to use IT-related policies to improve the productivity of different industries. According to our results, the impact of IT investment on productivity is very complex, as different types of IT investment have different and changing impacts. Given that IT has been suggested to be the main driver of recent economic growth (Cardona *et al.*, 2013), policy-makers tend to use IT-related policies to boost the economy. When developing IT-related policies for economic growth, however, policy-makers should have a good understanding of the economic value of different IT investments and the different mechanisms through which IT investment affects productivity. In particular, when policy-makers plan to develop policies related to promoting in-house IT investment, they need to develop long-term policies, as firms need time to learn from their in-house IT practices, accumulate internal IT capabilities and gain economic value in the long run. If policy-makers plan to develop policies related to promoting investment in commercial IT, they need to monitor the evolution of the commercial IT market and understand the maturity level of commercial IT in different industries. If commercial IT has reached a stage of maturity and most firms in an industry are satisfied with their current commercial IT, policy-makers should be very careful about promoting such commercial IT because typically it will not provide high additional value to the economy. In addition to the implications for policy-makers, our findings may provide some guidance to managers when they make IT investment decisions because industry-level results represent the outcomes of an aggregation of firms.

### *5.4 Limitations*

This study considers the changing effects of different IT investments on productivity. Although our results of increasing returns on IT with scale and increasing/decreasing returns on IT over time provide new insights for research on the economic value of IT, our study has three limitations. First, due to data availability, this study focuses on the aggregation result at the industry level. Although similar approaches have been used in many studies (e.g. Qu *et al.*, 2011; Ren and Dewan, 2015; Schilling and Steensma, 2001), future research may retest our model at the firm level and augment our understanding of the details of firm behaviors and outcomes. Second, the decreasing returns on commercial IT investment are based on data from the current technology environment in the United States, where the computerization of firms started early and the commercial IT market is reaching maturity (Suarez *et al.*, 2013). For developing countries where IT is still in the early stages of the technology life cycle, there might be different conclusions. Future research can include samples from both developed and developing countries and consider the technology environment as a moderating variable. Finally, the findings of this study are based on manufacturing industry samples. As different industries have different characteristics, our findings may not be applicable to other industries, such as service industries. Future research may investigate similar research questions based on data from other industries and test the generalizability of our findings.

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