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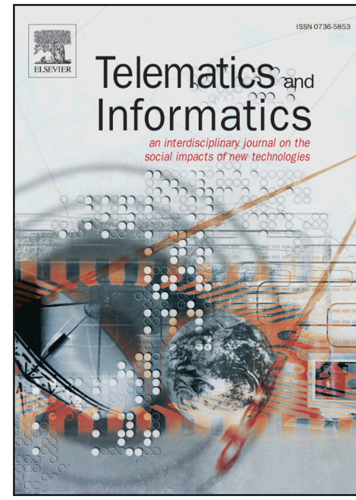

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Abstract

Recently, the Internet of things (IoT) has become most popular topic in various industries. For enterprises, IoT is not just the biggest buzz word but a developing trend, a proven strategy, and an innovative technology. Enterprises conducting IoT reach a turning point, but might also face diverse challenges related to technical or managerial aspects. Various challenges will be encountered, depending on different perspectives, i.e. the industry's first movers or second movers. Therefore, the impact of implementing conducting IoT will also vary. Previous studies have only focused on background technologies of IoT and applications. Meanwhile, no studies have discussed the impact of IoT implementation on firm performance. This study attempts to fill this gap. From the internal perspective, we want to comprehend the view of managers or shareholders to explore performance after enterprises have adopted IoT. In order to measure such practices have positive impacts on enterprises' financial performance, this study adopts three approaches to estimate the performance of IoT implementation vis-à-vis financial performance, productivity, and market value. We collected secondary data to perform a quantitative analysis with three dummy variables, including IoT adopters, first movers, and better performers. We hope to provide a complete reference to enterprises through different indicators, which will facilitate assessment of enterprises' implementation of IoT and also provide a more in-depth understanding of the impact of IoT.

Keywords: Business value of information technology; IoT implementation; Firm performance; Market value; Accounting-based measurement

1. Introduction

With the advance of information technology (IT), it has been able to transform the capability of organizations and industries into competitive advantages. The issue of firms investing in IT has received increasing attention in recent years (Carr, 2003; Rettig, 2007). Managers and operators have long evaluated the value of IT and hoped that their investments in IT would generate paybacks; we call this idea the business value of IT (BVIT). The term BVIT is commonly used to refer to the impacts of the organizational performance of IT, including productivity enhancement, profitability improvement, cost reduction, competitive advantage, inventory reduction, and other measures for performance (Kauffman and Kriebel, 1988; Hitt and Brynjolfsson, 1996; Devaraj and Kohli, 2003).

Many scholars have investigated BVIT related issues in order to figure out their benefits. For example, Dos Santos et al. (1993) focused on the announcements of IT investments and innovative IT investments. Hitt and Brynjolfsson (1996) used three measures to investigate the relationship between IT stock and profitability ratios. Bharadwaj (2000) used a resource-based perspective to study IT capability and firm performance. Hitt et al. (2002) studied the business impact of enterprise resource planning and productivity measures. Overall, the ultimate goal of these studies has been to understand whether IT can help companies to increase productivity. The research methods usually use a famous production function, Cobb-Douglas, to estimate the profitability of enterprises through some indicators, and adopt Tobin's q (Brainard and Tobin, 1968) to calculate the market value.

In recent years, Internet of Things (IoT) has become the most popular topic in several industries. IoT is not just the biggest buzz words in enterprises but is also a developing trend, a proven strategy, and an innovative technology. Ashton (2009) firstly proposed the concept of IoT and described IoT as uniquely identifiable interconnected objects with radio-frequency identification (RFID) technology, which have potential for changing the world. Pretz (2013) has indicated that IoT is a things-connected network, where things are wirelessly connected via smart sensors, which interact without human intervention. Some preliminary IoT applications have already been developed in healthcare, transportation, home appliances, and automotive industries (He et al., 2014; Joshi and Kim, 2008; Pretz, 2013).

There are five essential technologies of IoT: RFID, wireless sensor networks (WSN), middleware, cloud computing, and IoT application software. IoT technologies have also been widely used in several industries; for example, IoT can improve logistics and supply chain efficiency by providing information that is more detailed and up-to-date (Flügel and Gehrmann, 2009).

Gartner (2013) forecasted that IoT will reach 26 billion units by 2020, up from 0.9 billion in 2009. Accordingly, we can realize the intensity of the influencing power that IoT technologies are going to bring about. Currently, studies of IoT focus on the development of IoT technologies and applications, while no research addresses the impact of IoT implementation on firm performance; thus, this study attempts to fill this gap. After reading the related literature, we found that the study of Huang (2015) observed the effectiveness from an exterior view; on the contrary, another study, Huang (2016), investigated the performance from an inside view. Referring to both studies, we employ the latter approach because its methodology provides more concrete, actual information about IoT for managers, not just investors. This is of importance for managers because the abnormal return of IoT is just a short shock, but the accounting-based data of IoT has a long-term impact on enterprises.

To investigate the impact on IoT implementation, this study adopted a quantitative analysis with secondary data, and used three dummy variables, IoT adopters, first movers, and better (IoT) performers, to understand the performance of

IoT. The arguments presented here are based on the work of Hitt et al. (2002), Lieberman and Montgomery (1988), and Huang (2016).

We organize this paper as follows: in Section 2, we introduce the related works in this area; in Section 3, we present our analytical method; in Section 4, we discuss our research hypotheses; in Section 5, we present the research results; finally, in Section 6, we provide our conclusion and discuss the limitations of this study.

2. Related works

In this section, we discuss two research topics. First, we discuss the business value of information technology in Section 2.1; secondly, Section 2.2 addresses the issue of IoT.

2.1. Business value of information technology

Past literature did reveal any connection between information technology (IT) investment and productivity in the U.S. economy in the 1980s. However, subsequent studies have revealed that the impact of information technology investment on firm performance is significant and positive (Devaraj and Kohli, 2003; Melville et al., 2007; Melville et al., 2004). Although there are some different viewpoints, such as "IT doesn't matter" (Carr, 2003), research testimony suggests that IT is not just a tool for automating current business processes but also for enabling organizational changes and providing productivity gains (Melville et al., 2004; Mithas et al., 2012).

Before leaping to prior research, we must have a clear definition of this key term business value of IT (BVIT). BVIT is commonly used to refer to the organizational performance impacts of IT, including productivity enhancement, profitability improvement, cost reduction, competitive advantage, inventory reduction, and other measures of performance (Kauffman and Kriebel, 1988; Hitt and Brynjolfsson, 1996; Devaraj and Kohli, 2003). Melville et al. (2004) define BVIT as "the organizational performance impacts of IT at both the intermediate process level and the organizational-wide level, and comprising both efficiency impacts and competitive impacts." Kohli and Grover (2008) point out that IT value manifests itself in many ways, including productivity gains, process improvements, profitability enhancement, increased consumer surplus, and improvements in supply chains or innovation at the inter-organizational level. Schryen (2013) defines business value of information systems (IS) as "the impact of investments in particular IS assets on the multidimensional performance and capabilities of economic entities at various levels, complemented by the ultimate meaning of performance in the economic environment." Sabherwal and Jeyaraj (2015) consider empirical BVIT by focusing on "studies that are at the organizational level and include one or more IT-related independent variables and one or more dependent variables related to IT's organizational impact." The definition of Sabherwal and Jeyaraj (2015) addresses how to operate this kind of research and also includes the spirit of the two former definitions, i.e. Melville et al., 2004 and Schryen (2013). As a result, we adopt the definition of Sabherwal and Jeyaraj (2015) in this study.

The reason why managers long to evaluate the business or economic value of IT can be attributed to the productivity paradox. Reasonably, managers expect that the investment in IT should result in deserved payoff for their companies. Unfortunately, when it comes to the relationship between productivity and IT, past research did not find a positive relation between productivity (or profitability) and expenditures. The circumstance is referred as the productivity paradox (Brynjolfsson, 1993).

Research on the subject of BVIT can be divided into two facets: industry (or economic) and corporate levels. The first facet is related to a wide observed level. By the late 1980s, the conventional wisdom was that computers could not contribute significantly to productivity. "We see the computer age everywhere except in the productivity statistics" stated Robert Solow, the Nobel Prize laureate and economist, in the *New York Times Book Review* (July 12, 1987). The second facet is observed at narrow company level, where "there is no correlation whatsoever between expenditures for IT and any known measure of profitability" (Strassmann, 1997). The early studies established a result that either no relationship or a slightly negative relationship exists between firm-level spending on IT and firm performance (Dehning and Richardson, 2002). By the late 1990s, however, several studies found that there are positive payoffs from investment in IT (Dehning and Richardson, 2002). Therefore, the research issue changed from the productivity paradox, "is there a payoff?" to economic measurement, "when and why is there a payoff?"

Mostly, researchers investigating the two facets, the industry and company levels, invariably suffered from the obtainment of observed or second datasets (Masli et al., 2011). The measurement of dependent and independent variables is required not just from the general accounting data of a company but from the IT-related statistical data of a company. For example, we may need to understand the data from computer capital, IT labor expense, and IT stock. Since it is relatively easy to collect the latter data than the former, most researchers conducted research of a variety of IT-related systems or technology and business. Another reason why researchers did not explore the industry level is that the focused goals are broader and more complex, and therefore, do not easily capture the impact on IT investments.

In order to investigate the impact of IT investments (business performance), researchers often exploit two methods. The first one is to employ an event study method for understanding the short-term market reaction of investors. The efficient market theory proffers a theoretical cornerstone for this basic event study methodology (Malkiel & Fama, 1970). With this method, managers can understand whether an abnormal return is related to an unexpected event. Numerous investigations have adopted this method in diverse fields, for instance, in management (McWilliams and Siegel, 1997) and economics and finance (MacKinlay, 1997). In addition, the second approach is to adopt an accounting-based (financial) method to measure accounting performance, such as cash flow, sales growth rate, gross margins, inventory turnover, and market share. This method is a way to reveal the past performance of an enterprise, observing the long-term performance. Researchers have to determine when to measure the outcome and the time frame of the measurement related to IT investments (Masli et al., 2011).

As mentioned above, a large number of researchers have contributed research results at the enterprise level, involving the relationship between different types of IT investment and BVIT. Since the past research results are fruitful, we only provide some typical references in Table 1. They are all classified into two methods, the accounting-based method and event study method, as previously mentioned. Studies employing the event study methodology aim to investigate the external effects of IT investments. Otherwise, the use of the accounting-based method indicates that its goal is to investigate the interior efficiency of IT investments. Readers interested in a full review of research results can refer to the studies of Dehning and Richardson (2002), Masli et al. (2011), and Sabherwal and Jeyaraj (2015).

Table 1. The past studies on BVIT.

Topics	**Analytical methodology**	**Author(s) and Year**
Impact of information technology investment announcements on the market value of the firm.	Event study	Dos Santos et al. (1993)
Information Technology Effects on Firm Performance as Measured by Tobin's q.	Regression analysis	Bharadwaj et al. (1999)

Productivity, business profitability, and consumer surplus: Three different measures of information technology value.	Regression analysis	Hitt and Brynjolfsson (1996)
A resource-based perspective on information technology capability and firm performance: an empirical investigation.	Regression analysis	Bharadwaj (2000)
Information technology payoff in the health-care industry.	Time series models	Devaraj and Kohli (2000)
Effect of IT investments on firm value by the case of Y2K-compliance costs.	Ohlson's residual income model	Krishnan and Sriram (2000)
Impact of E-commerce announcements on the market value of firms.	Event study	Subramani and Walden (2001)
Business impact of enterprise resource planning and productivity measures.	Regression analysis	Hitt et al. (2002)
Performance Impacts of Information Technology: Is Actual Usage the Missing Link?	Regression analysis	Devaraj and Kohli (2003)
Market reactions to E-business outsourcing announcements.	Event study	Agrawal et al. (2006)
The business value of information technology and inputs substitution: The productivity paradox revisited.	Regression analysis	Lin and Shao (2006)
Financial performance effects of IT-based supply chain management system.	General linear model	Dehning et al. (2007)
Impact of information technology investments and diversification strategies on firm performance.	Regression analysis	Chari et al. (2008)
Effects of information technology failures on the market value of firms.	Event study	Bharadwaj et al. (2009)
How does data-driven decision making affect firm performance.	Regression analysis	Brynjolfsson et al. (2011)
Returns to IT excellence: Evidence from financial performance around information technology excellence awards.	Regression analysis	Masli et al. (2011)
The impact of business intelligence systems on stock return volatility.	Event study	Rubin and Rubin (2013)
Information technology impacts on firm performance.	Regression analysis	Sabherwal and Jeyaraj (2015)

2.2. The Internet of things (IoT)

The Internet of things (IoT) is not just the biggest buzz word for enterprises, but a developing trend, a proven strategy, and an innovative technology. The concept of

IoT was firstly proposed by Kevin Ashton, executive director of MIT's Auto-ID Center, in 1999. Kevin Ashton defined IoT as uniquely identifiable interconnected objects with radio-frequency identification (RFID) technology, which have the potential to change the world. IoT is considered as a part of the Internet of the future and will comprise billions of intelligent communicating things (Li et al., 2014). This key term has aroused significant research attention in recent year. However, the exact definition of IoT is still in the forming process, subject to a variety of perspectives (Hepp et al., 2007; Joshi and Kim, 2008; Pretz, 2013).

Pretz (2013) has indicated that IoT is a things-connected network, where things are wirelessly connected via smart sensors, which interact without human intervention. Some preliminary IoT applications have already been developed in healthcare, transportation, home appliances, and automotive industries (He et al., 2014; Joshi & Kim, 2008; Pretz, 2013). The words "Internet" and "things" mean an interconnected world-wide network based on sensory, communication, networking, and information processing technologies, which might be the new version of information and communications technology (ICT) (Kranenburg, 2013; Marry, 2013). Lee and Lee (2015) defined IoT as a new technology paradigm envisioned as a global network of machines and devices capable of interacting with each other. Currently, many new developments have occurred in the integration of objects with sensors in the cloud-based Internet (Hepp et al., 2007; Joshi and Kim, 2008; Pretz, 2013).

Nowadays, researchers are studying techniques for the interactions between humans and the environment, humans and machines, as well as ubiquitous computing (Li et al., 2015). In the long term, the trend of IoT is the fusion of sensing and the Internet; all networked things should be flexible, smart, and autonomous enough to provide required services. IoT can provide our daily lives with desired connectivity and intelligence (Pretz, 2013).

Referring to the related research from Lee and Lee (2015), five essential technologies of IoT are widely used in IoT-based services and products: Radio frequency identification (RFID), wireless sensor networks (WSN), middleware, cloud computing, and IoT application software. The first technology is RFID, through which electromagnetic fields automatically identify and data capture using radio waves. The tags can store more data than traditional barcodes, and can be attached to cash, clothing, and possessions, or implanted in animals and people. IoT is initiated by the use of RFID technology, which is increasingly utilized in logistics, pharmaceutical production, re-tail, and diverse industries (Fielding and Taylor, 2002; Guinard et al., 2010; Guinard et al., 2009; Xu, 2011). The second technology is WSN, which consists of spatially distributed autonomous sensor-equipped devices to monitor physical or environmental conditions, and can cooperate with RFID systems to better track the status of things, such as their location, temperature, and movements (Atzori et al., 2010). The third technology is Middleware, which is a software layer interposed between the application and technological levels, making it easier for software developers to implement communication and input/output. Therefore, they can focus on the specific purpose of their applications. The fourth technology is cloud computing, which is a model for enabling ubiquitous, on-demand access to a shared pool of configurable computing resources (e.g., computers, networks, servers, storage, applications, services, and software). One of the most important outcomes of IoT is an enormous amount of data generated from devices connected to the Internet (Gubbi et al., 2013). The last technology is IoT application. The usage of IoT facilitates the development of myriad industry-oriented and user-specific IoT applications. Whereas devices and networks provide physical connectivity, IoT applications enable device-to-device and human-to-device interactions in a reliable and robust manner (Lee and Lee, 2015).

Gartner (2014) forecasts that IoT will reach 26 billion units by 2020, up from 0.9 billion in 2009, and will impact the information available to supply chain partners and how the supply chain operates. So far, IoT has been widely used in several industrials, such as manufacturing, health care, financial and insurance, retail, energy and materials. IoT can improve logistics and supply chain efficiency by providing information that is more detailed and up-to-date (Flügel and Gehrmann, 2009). When it comes to the health care industry, sensors can be placed on health monitoring equipment used by patients. The information collected by these sensors is made available on the Internet to doctors, family members, and other interested parties to improve treatment and responsiveness (Dohr et al., 2010). There are many ways IoT helps in optimizing manufacturing: inventory control and supply chain management help companies to become more efficient. One of the greatest advancements made possible by IoT is in energy management (Vardi, 2015). IoT in manufacturing can generate considerable business value that will eventually lead to a fourth industrial revolution, the so-called Industry 4.0 (Lee and Lee, 2015).

In the business aspect, startups have been actively joining the IoT industry to create new services or products. Therefore, Lim et al. (2018) conducted a network analysis on the IoT startup ecosystem to see how the ecosystem is built and also figure out how and what technologies are transferred among startups. In addition, smart city is an application of IoT notion. Silva et al. (2018) presented the IoT fundamentals of a smart city in terms of definitions, standards, and implications. In the technology aspect, Li et al. (2018) provided a report to review the state-of-the-art 5G (fifth generation) IoT, key enabling technologies, and main research trends and challenges in 5G IoT.

IoT is currently going through a phase of rapid growth. The number of connected ‘things’ has increased threefold over the past five years (Digitimes, 2013). For IoT to be fully adopted by businesses, financial returns are the key; organizations expect that IoT will become an important source of revenue. From the perspective of managers, IoT can generate data for automated analyses, leading to greater and faster decision making. Thanks to IoT, General Electric anticipates $19 trillion in profits and cost savings projected over the next decade (Vardi, 2015). Gartner (2013) predicts that the total global economic added value for the IoT market will be $1.9 trillion dollars in 2020.

In this study, we systematically investigate the business value of IoT from another perspective and examine the internal effectiveness of IoT. We use financial methods to evaluate the financial performance, productivity, and market value of IoT.

3. Research hypotheses

As mentioned above (Section 2), we realize that BVIT has shown better performance in response to the IT investment of companies. Since IoT is also an IT investment, including software, hardware, and cloud computing, by companies, we believe that a greater benefit would be achieved with various metrics. Accordingly, our basic hypotheses are as follows:

Hypothesis 1a (H1a): Companies that implement IoT will show greater efficiency as measured by financial performance measurements.

Hypothesis 1b (H1b): Companies that implement IoT will show greater efficiency as measured by productivity.

Hypothesis 1c (H1c): Companies that implement IoT will show greater efficiency as measured by stock market value.

In 1988, Lieberman and Montgomery (1988) proffered the issue of the first-mover advantage in the field of strategic management and defined the first-mover advantage in terms of the ability of pioneering firms to gain positive economic profits (i.e. profits in excess of the cost of capital). In general, the sequence of entry into a market becomes a crucial factor in the competition with rivals. The pioneering advantage is not usually a single advantage but rather a set of advantages that a company could obtain by developing and selling a product first. The first company which proposes a specific service or product believes that this will lead to long-term competitive advantages. On average, the first mover owns higher market shares or profits than do later entrants.

Hence, in order to gain first-mover status, firms often insist on pursuing preemptive strategies. A company that is eager to attain first-mover status can employ three primary approaches: (1) technological leadership, (2) preemption of assets, and (3) buyer switching costs (Lieberman and Montgomery, 1990). First movers can obtain advantages through continual leadership in technology. Two basic mechanisms are considered in the literature: (1) advantages derived from the ‘‘learning’’ or ‘‘experience’’ curve and (2) success in patent or R&D races. In short, a company can launch a new product or service. Second, a company can adopt a new process. Finally, the company enters a new market that can claim this distinction. Considering one of the three ways achieve the above goal, most enterprises utilize IT to design a new business model in their markets or to improve process performance in their organizations. As in the argument above, we believe that the investment in IoT may also generate the same advantage for first movers in the IoT. This suggests the following hypotheses:

Hypothesis 2a (H2a): Companies that gain the first-mover advantage in IoT will show greater efficiency as measured by financial performance ratios.

Hypothesis 2b (H2b): Companies that gain the first-mover advantage in IoT will show greater efficiency as measured by productivity regressions.

Hypothesis 2c (H2c): Companies that gain the first-mover advantage in IoT will show greater efficiency as measured by stock market value.

In past studies, surveys of IoT performance are almost blank. Even if though there is a lack of the relevant work with respect to the issue, we still found a survey report from the American Society for Quality (ASQ), which studied how manufacturers are benefitting from IoT (Vardi, 2015). This report states that manufacturing companies implement related IoT technologies through connecting manufacturing devices and aggregating the data created by enabling manufacturers to reduce overhead, conserve resources, increase profits, and optimize efficiencies. The ASQ surveyed manufacturing companies, which have digitized their processes and found 3 astounding results: firms have increased efficiency by 82% after implementing IoT technologies, have experienced 49% fewer product defects, and also have increased customer satisfaction by 45%.

If companies implement IoT in their industry, then they should have better performance than those who do not; we call the former a better (IoT) performer. We, therefore, hypothesize the following:

Hypothesis 3a (H3a): Companies that are better performers will show greater efficiency as measured by financial performance ratios.

Hypothesis 3b (H3b): Companies that are better performers will show greater efficiency as measured by productivity regressions.

Hypothesis 3c (H3c): Companies that are better performers will show greater efficiency as measured by stock market value.

For ease of understanding the idea of the proposed hypotheses, we proffer a separated hypotheses model diagram in Figure 1.

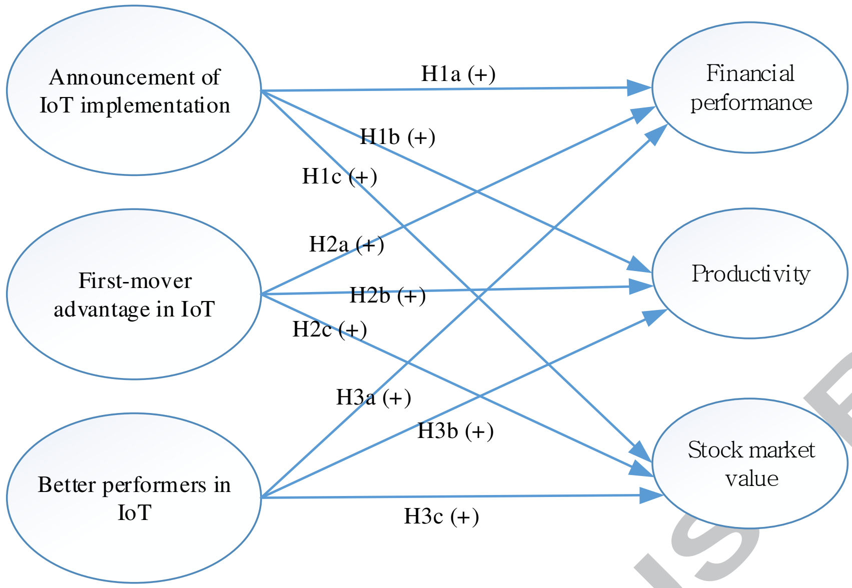

Figure 1. Separated hypotheses model diagram.

4. Analytical methodology

We now present our research methodology in three parts, data collection and selection, descriptive statistics, and research methods, as follows.

4.1. Data collection and selection

The concept of IoT was firstly proposed by Kevin Ashton in 1999, but the detailed definition and applications are not clear enough. With the extensive research in this area, IoT gained more attention in 2009. In 2010, enterprises attempted to acquire the knowledge of IoT, enabling them to be ready to invest relevant IoT resources (hardware and software) into firms. Thus, we tried our best to collect all the possible news, including which companies have invested in or implemented IoT from 2010 to 2015. The data collection process is introduced as follows. The period of the data we collected in this study is from 2010 to 2015; however, the baseline of the performance analysis is only available in 2015. The baseline shows that we only collected the performance data of the firms under study here for the fiscal year of 2015.

In this study, two procedures are conducted to collect the data. We confirmed the sample company list for collecting the data through Compustat, and then selected some ratios to evaluate their performance. First, the sample framework of this study is based on a Fortune 500 list. The Fortune 500 is an annual list compiled and published by *Fortune* magazine that ranks 500 of the largest United States corporations by total revenue for their respective fiscal years. Based on this list, we first excluded the corporations whose industry categories belong to information technology and then used Google to surf for related news with the keywords, Internet of Things, to see whether the corporations from Fortune 500 have announced news related IoT. Moreover, the keywords, Internet of Things, are also derived from the Google searching results, which can portray the idea of Internet of Things. We also used them in the news to collect all the stories about IoT. The only thing we worry about is the tremendous impact IT-type corporations have on IT, and we hope that we can measure the real influence on IoT without this kind of impact. Thus, in order to make sure that corporations with news mentioning IoT are certainly conducting IoT, we put great effort into reading the content of the news carefully. Finally, we tried our best to collect 887 news in total but screened 455 news out because they are IT-related corporations. The remainders (432 news) can be introduced into our experiment.

After confirming the corporations who have implemented IoT, we carried out a second procedure. The financial data of these IoT corporations were collected through a database, called Compustat. Compustat is a database, including financial, statistical, and market information on active and inactive global companies throughout the world, and contains a variety of financial ratios. We utilized financial data to assess the companies' performance. The ratios (or metrics) we selected are listed in Table 2.

Table 2. Financial performance measurements.

Ratio	Definition	Interpretation of high ratio
Asset turnover	Sales/assets	High level of sales arise by total assets.
Account receivable turnover	Sales/account receivable	Effectively manage customer payments.
Labor productivity	Sales/number of employees	Higher productivity per staff.
Inventory turnover	COGS/inventory	Higher efficiency in inventory management.
Return on assets (ROA)	Pretax income/assets	Higher efficiency in company operating, regardless of its financial structure.
Return on equity (ROE)	Pretax income/equity	Higher return with ordinary capital.
Profit margin	Pretax income/sales	High profit arise by sales.
Debit to equity	Debit/equity	Higher risk of the firm.
Tobin's q	Market value/book value	Higher performance with firm management.

4.2. Descriptive statistics

Since we only analyze the performance data in the fiscal year of 2015, those samples that did not have relevant IoT news from 2010 to 2015 were deleted. In addition, we did our best to find those companies which are on the Fortune 500 list but did not announce IoT news; we used them for the sake of comparison. In this study, we collected a total of 432 samples, with 168 corporations announcing IoT news, which 264 corporations did not announce any related news (see Table 3). Therefore, we can exploit two sample groups to verify Hypotheses 1a, 1b, and 1c.

In order to test Hypotheses 2a, 2b, and 2c, we divide the full sample into two groups. As we mentioned above, it is clear that there are 168 companies which have announced IoT news from 2010 to 2015; more than half of the news announcements were released in 2015. Hence, we consider the fiscal year of 2015 to be benchmark. Corporations which announced the IoT news before 2015 are defined as first movers; on the contrary, the remainders are viewed as second movers. Therefore, comparing first movers and second movers, the number of first movers is 61 and the number of second movers is 107.

In order to verify Hypotheses 3a, 3b, and 3c, the complete samples have to be divided into two groups based on performance, namely, better (IoT) performers and non-better (IoT) performers. According to the Standard Industrial Classification (SIC) Code of industries, all of our samples stem from six industries (see Table 4). We divided the samples to two groups, first companies in the manufacturing (SIC=15-33, 45, and 47) and healthcare (SIC=80) industries, and second, companies from four other industries, including financial and insurance (SIC=60-64), retail (SIC=52-59), energy and materials (SIC=10-14), and conglomerates (SIC=48, 65, and 99). In fact, we referred to a survey report from American Society for Quality (ASQ) to divide these samples into two groups (Vardi, 2015). The ASQ survey reported that manufacturing companies have digitized their processes and found astounding results in increasing efficiency, lessening product defects, and increasing customer satisfaction. In addition, IoT also brings benefits with IoT implementation in the healthcare industry (Veilumuthu, 2017). According to the two reports, we treated manufacturing and healthcare industries as better performers; other types of industries were treated as non-better performers. In brief, the total number of better performers is 64 and the total number of non-better performers is 104. Ultimately, all sample statistics with different classifications are shown Table 3.

Table 3. Sample statistics.

Observations of IoT Adopter	168	**Behavior**	First mover	61
			Second mover	107

		Performance	Better (IoT) performer	64
			Non-better(IoT) performer	104
Observations of IoT Non-Adopter	264			
Total Observations	432			

Table 4. Industry matching by SIC code.

Industry	N	SIC Code
Manufacture	69	15-33, 45, 47
Healthcare	59	80
Financial and Insurance	67	60-64
Retail	118	52-59
Energy and Materials	60	10-14
Conglomerates	59	48,65,99
Total	432	

4.3. Research methods

Ordinary least squares (OLS) regression is used to test our proposed hypotheses. We adopted three basic specifications to analyze the impact of IoT implementation on performance: performance ratios, productivity (production functions), and stock market valuation (Tobin's q). The methods of financial performance analysis are mainly based on the work of Hitt et al. (2002) and Huang (2016); however, in order to correspond to our proposed hypotheses, we made some changes to the research variables. The general form of the financial metrics with the logarithm function is:

$$Log(\text{ ratio}) = Log\left(\frac{ratio\ numerator}{ratio\ denominator}\right) \quad (1)$$

To present the original form of the estimating regression, we adopted the property of $Log\left(\frac{ratio\ numerator}{ratio\ denominator}\right) = Log\ (ratio\ numerator) - Log(ratio\ denominator)$ to model the above equation as follows.

$$Log(ratio\ numerator)$$
$$= intercept + Log\ (ratio\ denominator) \quad (2)$$
$$+ dummy\ variables\ + industry\ variables + \varepsilon.$$

In this study, we chose to model the numerator as the dependent variable at the left-hand side of the formula. At the right-hand side of the formula, we modeled the denominator as independent variables, i.e. ratio denominator, IoT adoption or dummy variables, industry variables, and error term. This formula has the advantage that it allows us to provide greater flexibility in the relationship between the numerator and denominator, thus maintaining the original ratio performance interpretation. Various financial performance ratios in Table 2 are compared as they capture distinct perspectives of IoT performance, terms of four dimensions, i.e. profitability, operation capability, capital structure, and market reward. Furthermore, we controlled the industry to avoid variation in financial performance ratios due to the specific characteristics of different industries (at the 2-digit SIC level).

According to the discussion of Hitt et al. (2002) in Formula (2), these types of analyses have the advantage that they can capture an extensive variety of distinct perspectives of BVIT. However, the primary disadvantage is that the model specification does not have a strong theoretical basis, and thus we can only discuss the result of correlations rather than the estimation of an econometric model. To conquer this concern, there are two other approaches, i.e. productivity function and stock market valuation (Tobin's q) (see the market reward dimension in Table 2), commonly employed to measure the performance of IoT enterprises. The descriptions of two ratios also refer to the study of Hitt et al. (2002). Introductions to these three approaches, financial performance analysis, productivity function, and stock market valuation (Tobin's q), are provided as follows.

4.3.1. Financial performance analysis

Financial performance metrics are a subjective measure of how well a firm can use assets, based on its primary mode of business, and generate revenues. These kinds of metrics can be used to reveal a company's performance. They also help in short-term and long-term forecasting and growth, which can be identified as financial performance analysis. Therefore, business managers, operators, and investors all pay attention to these metrics. They can help business managers and operators to comprehend the state of operation and provide valuable information to decision makers. They also support the risk assessment of investors. In this study, we capture different perspectives of companies' financial performance through three aspects, including the profitability dimension (i.e. ROA, ROE, and profit margin), operation capability dimension (i.e. inventory turnover, labor productivity, asset turnover, and account receivable turnover), and capital structure dimension (debit to equity). Derived from Formula (2), the three hypothesis groups are tested with three estimation regressions as follows.

(1) Hypotheses 1a, 2a, and 3a:

$$
\begin{aligned}
Log(ratio\ numerator) &= intercept + Log\ (ratio\ denominator) \\
&+ BDI\ adoption\ variables\ + industry\ variables + \varepsilon.
\end{aligned}
\qquad (3\text{-}1)
$$

$$
\begin{aligned}
Log(ratio\ numerator) &= intercept + Log\ (ratio\ denominator) \\
&+ first\ mover\ variables\ + industry\ variables + \varepsilon.
\end{aligned}
\qquad (3\text{-}2)
$$

$$
\begin{aligned}
Log(ratio\ numerator) &= intercept + Log\ (ratio\ denominator) \\
&+ first\ mover\ variables\ + industry\ variables + \varepsilon.
\end{aligned}
\qquad (3\text{-}3)
$$

It is worth noting that we used a control variable for the industry as the dummy variable; therefore, the control variable is absent from Formula (3-3). The same formula design is used to test Hypotheses 1b, 2b, and 3b, and will be shown below.

4.3.2. Productivity function

Productivity regressions fall in accordance with the economic concept of production function. The most commonly used functional form of the production function is the Cobb-Douglas function, which has the advantages of both simplicity and empirical robustness for the computation of performance differences (Hitt et al., 2002). In economics, the Cobb–Douglas production function is a particular functional form of the production function; the important idea is to investigate the relationship between inputs and outputs. In this function, the output proxy is sales and value added (*VA*) (*VA*=sales minus materials), and the input proxy is firm consumption, i.e. labor (*L*) and capital (*K*). In order to use the Cobb-Douglas function to examine our proposed hypotheses, we employed log-log regression to observe the differences in percentage of productivity as the change of the coefficients. The three hypothesis groups are examined with three different Cobb-Douglas regressions, as represented below.

(2) Hypotheses 1b, 2b, and 3b:

$$Log(VA) = intercept + a_1 logK + a_2 logNE + a_3 \log EE + BDI\ adoption\ variables + industry\ controls + \varepsilon. \quad (4\text{-}1)$$

$$Log(VA) = intercept + a_1 logK + a_2 logNE + a_3 \log EE + first\ mover\ variables + industry\ controls + \varepsilon. \quad (4\text{-}2)$$

$$Log(VA) = intercept + a_1 logK + a_2 logNE + a_3 \log EE + better\ performer\ variables + \varepsilon. \quad (4\text{-}3)$$

Table 5 presents the variables we used in the above formulas, and their sources are described.

Table 5. Introductions of Variables.

	Variable	Code	Source
Input	Capital	*K*	Raw data from Compustat
	Numbers of employees	*NE*	Raw data from Compustat
	Employee expense	*EE*	Raw data from Compustat
Output	Value added	*VA*	Sales minus cost of goods sold

Compared with the financial indicators, productivity regression provides a more rigorous basis; the financial indicators can only capture the short-term measurement but cannot acquire the long-term benefits if enterprises implement IoT. Mangers should take interest in future gains, not just current gains. Therefore, we adopted another approach, stock market valuation, to capture the performance of IoT enterprises. The idea of stock market valuation is introduced as follows.

4.3.3. Stock market valuation

Tobin's q is the last approach we use for stock market valuation in this study. The Tobin's q ratio was first introduced in 1969 by James Tobin as a predictor of a firm's future investments. Tobin's q represents a forward-looking measure of firm value, taking into consideration the lag effects between investments in R&D and IT and their payoffs, and complements the retrospective firm performance captured in financial accounting measures (Kohli et al., 2012). Observing the future earnings relating to current book value is a better indicator of future growth options associated with R&D and IT spending (Bardhan et al., 2013). Accordingly, with the adoption of Tobin's q, we can capture the current value of IoT enterprises as well as the expectation of future benefits for investors. The approach can solve the problem of productivity regressions. The three hypothesis groups are examined with different Tobin's q regressions, as shown below.

(3) Hypotheses 1c, 2c, and 3c:

$$Log(market\ value) = intercept + a_1 Log(book\ value) + BDI\ adoption\ variables + industry\ controls + \varepsilon. \quad (5\text{-}1)$$

$$Log(market\ value) = intercept + a_1 Log(book\ value) + first\ mover\ variables + industry\ controls + \varepsilon. \quad (5\text{-}2)$$

$$Log(market\ value) = intercept + a_1 Log(book\ value) + better\ performer\ variables + \varepsilon. \quad (5\text{-}3)$$

5. Data analysis and results

We now describe the results of our analyses, which are divided into three parts, and compare three approaches. The first is IoT adopters versus non-IoT adopters, the second is first movers versus second movers, and the third is better (IoT) performers versus non-better (IoT) performers. The three approaches are financial performance analysis, productivity function, and stock market valuation (Tobin's q).

5.1. Comparison between IoT adopters and non-IoT adopters

Table 6 presents our basic regression results using the estimating regression formulation described in Formula (3-1). Different measurements of performance are regressed on an indicator variable of implementation (1 = IoT adopters), and a control variable for industry. Each column in Table 6 represents a different performance estimating regression. We present a similar format in the following tables.

Overall, we find that, controlling for industry, IoT adopters show greater performances in terms of labor productivity, return on assets, inventory turnover, return on equity, asset utilization, collection efficiency, and leverage, amounting to 0.065, 0.0126, 0.136, 0.182, 0.16, 0.159, and 0.122, respectively. Even though the profit margin is not significant, the positive effect (0.038) on the performance of IoT still partially supports our proposed hypothesis.

In particular, the inventory turnover (0.136) reveals a positive correlation between implementation and cost of goods sold. Three of our six targeted industries have inventories of actual products and face the issue of inventory turnover, including manufactures (SIC=15-33, 45, and 47), retail (SIC=52-59), and conglomerates (SIC=48, 65, and 99).

According to the result, we know that IoT implementation improves profitability and operation ability. This can be beneficial to operation budgets and all companies to obtain profits earlier. The significant statistical differences range from 4 to 18 percent, showing the positive effects of IoT on performance.

Table 7 shows the basic regression results of the regression formulations described in Formulas (4-1) and (5-1) to assess the performance of short-term productivity and long-term market value, respectively. Several factors affect gross profit, including cost of raw materials, competitive products, production levels, specialized techniques, innovation, and customers. According to the production function, the results show that the productivity performance is between 6.3% and 15.1%, indicating that conducting IoT could produce a positive impact on productivity performance in the short-term.

Owing to the constraint of data collection, we cannot verify if IoT adopters can continually improve performance in the long-term. Therefore, we measured with Tobin's q, and the result suggests that firms that conducted IoT are worth approximately 12% more than their non-IoT counterparts. Also, we found that conducting IoT could bring a strategic advantage in business management, produce higher business performance, and exert a powerful influence on market value.

Collectively, the results above lend support to the proposed hypotheses, i.e., H1a and H1c−firms that conduct IoT have better financial performance and increase in market value. When the result in productivity measurement did not show significant support, we still found positive impacts on output and valued added. This finding partially supports H1b.

Table 6. Performance ratio regressions (IoT adopters and non-IoT adopters).

Dependent Variable	*In(Sales)*	*In(Pretax Income)*	*In(Cost of Goods Sold)*	*In(Pretax Income)*	*In(Pretax Income)*	*In(Sales)*	*In(Sales)*	*In(Debt)*
Interpretation	Labor Productivity	Return on Assets(ROA)	Inventory Turnover	Return on Equity(ROE)	Profit Margin	Asset Utilization	Collection Efficiency	Leverage
Implementation (1=IoT Adopters)	0.065* (0.033)	0.126*** (0.036)	0.136*** (0.050)	0.182*** (0.038)	0.038 (0.033)	0.160*** (0.037)	0.159*** (0.041)	0.122*** (0.047)
In(Employees)	0.748*** (0.025)							
In(Assets)		0.675*** (0.031)				0.619*** (0.032)		
In(Inventory)			0.634*** (0.035)					
In(Equity)				0.641*** (0.035)				0.653*** (0.043)
In(Sales)					0.764*** (0.033)			
In(Account Receivable)							0.534*** (0.026)	
Control Variable					Industry			
R^2	0.589	0.5	0.436	0.468	0.6	0.441	0.342	0.432
Observations	432	398	336	386	398	432	423	352

Notes: *** p<0.001; ** p<0.01; * p<0.05.

Table 7. Productivity and market value regressions (IoT adopters and non-IoT adopters).

Dependent Variable	*In(Gross Profit)*	*In(Sales)*	*In(Market Value)*
Interpretation	Value Added	Output	Tobin's q
Implementation (1=IoT Adopters)	0.151* (0.073)	0.063 (0.043)	0.121** (0.032)
In(Ordinary Capital)	0.199** (0.033)	0.120* (0.021)	
In(Employees)	0.049 (0.129)	0.093 (0.075)	
In(Labor Expense)	0.679*** (0.137)	0.495*** (0.085)	
In(Cost of Goods Sold)		0.433*** (0.042)	
In(Total Assets)			0.625*** (0.028)
Control Variable		Industry	
R^2	0.671	0.878	0.429
Observations	66	66	431

Notes: *** p<0.001; ** p<0.01; * p<0.05.

5.2. Comparison between first movers and second movers

To check our second assumption of whether the order of implementing IoT turns into an advantage when competing with rivals, we estimated the performances of first movers and second movers with financial metrics. The results are reported in Table 8.

According to the specification in Formula (3-2), our results show that only labor productivity (0.061) has significantly positive effect on financial performance. However, there are negative correlations between dependent and independent (dummy) variables for inventory turnover (-0.1), return on equity (-0.017), asset utilization (-0.149), and collection efficiency (-0.151). In brief, half of the financial metrics demonstrate negative impacts on the performance of IoT for first movers. The results reveal a negative correlation between first movers and cost of goods sold. That is to say, first movers conducting IoT can reduce the cost of goods sold by a maximum of 10%. Although inventory turnover is not significant, the result meets our expectation. The result shows a positive effect on profit margin, with improved performance of about 8.4 percent. Even though the correlation is positive between first movers and debt, this is actually not a good result for first movers. This means that first movers that have invested early in IoT and have to pay more IT-related capital. In general, the cost of IT-related capital paid by first movers is higher than that of second movers. Hence, the higher debt ratio results the more the risk for first movers. In addition, negative asset utilization indicates that assets are not being used effectively, resulting in reduced waste of resources and reduced asset operating efficiency. The results of asset utilization are related to leverage, connoting that IoT adopters take on debt when investing in assets with a negative impact of 14.9%. That is to say, first movers that invest early have higher asset costs, leading to a decrease in asset utilization.

Table 9 shows the results of value added (0.103) and output (0.008). Formula (4-2) presents positive, yet insignificant, impacts on productivity. The difference between value added and output is that the latter returns the cost of goods sold to its regression. The performance ratio, cost of goods sold, includes depreciation of fixed assets; therefore, first movers who adopt IoT early encountered this kind of problem. Through Formula (5-2), we find that first movers enjoy the early entry advantage in terms of market value (-0.035). However, the negative coefficient of the dummy variable, first movers, is not significant.

In short, we summarize the above results as follows. First, the proposed assumption that H2a–first movers who implement IoT early have better financial performance is partially supported. Furthermore, there is a somewhat preemptive advantage for first movers, and the first IoT adopters have to compete with second movers in the short-term and long-term. The results of productivity function and market value partially support H2b but reject H2c.

Table 8. Performance ratio regressions (Samples limited to IoT adopters only).

Dependent Variable	*In(Sales)*	*In(Pretax Income)*	*In(Cost of Goods Sold)*	*In(Pretax Income)*	*In(Pretax Income)*	*In(Sales)*	*In(Sales)*	*In(Debt)*
Interpretation	Labor Productivity	Return on Assets(ROA)	Inventory Turnover	Return on Equity(ROE)	Profit Margin	Asset Utilization	Collection Efficiency	Leverage
First Movers	0.061* (0.051)	0.121 (0.065)	-0.100 (0.080)	-0.017* (0.057)	0.084 (0.049)	-0.149 (0.061)	-0.151* (0.071)	0.010 (0.069)
In(Employees)	0.815*** (0.040)	0.641*** (0.055)						
In(Assets)						0.678*** (0.051)		
In(Inventory)			0.699*** (0.051)					
In(Equity)				0.738*** (0.046)				0.698*** (0.056)
In(Sales)					0.811*** (0.046)			
In(Account Receivable)							0.530*** (0.046)	
Control Variable					Industry			
R^2	0.643	0.391	0.502	0.538	0.647	0.465	0.279	0.481
Observations	168	159	143	157	159	168	166	162

Notes: *** p<0.001; ** p<0.01; * p<0.05.

Table 9. Productivity and market value regressions (Samples limited to IoT adopters only).

Dependent Variable	*In(Gross Profit)*	*In(Sales)*	*In(Market Value)*
Interpretation	Value Added	Output	Tobin's q
First Movers	0.103 (0.096)	0.008 (0.064)	-0.035 (0.053)
In(Ordinary Capital)	0.061 (0.045)	0.029 (0.030)	
In(Employees)	-0.103 (0.150)	-0.068 (0.095)	
In(Labor Expense)	0.910*** (0.159)	0.644*** (0.117)	
In(Cost of Goods Sold)		0.447*** (0.057)	
In(Total Assets)			0.675*** (0.044)
Control Variable		Industry	
R^2	0.678	0.896	0.448
Observations	36	36	168

Notes: *** p<0.001; ** p<0.01; * p<0.05.

5.3. Comparison between better (IoT) performers and non-better (IoT) performers

As mentioned before, IoT technologies have been widely used in several industries, of which manufacturing and health care are defined as better performers. In Table 10, we check the relationship between organizational performance and the value of IoT implementation by using financial metrics to measure better (IoT) performers with the specification described in Formula (3-3).

The results show that there are two significantly positive results for better (IoT) performers, including return on assets (0.06) and asset utilization (0.091). It is worth noting that the negative correlation between better (IoT) performers and cost of goods sold is positive. That is to say, better (IoT) performers conducting IoT can reduce the cost of goods sold by maximum of 3.6%. In addition, the results show a significant effect on return on assets; this indicates that better (IoT) performers conducting IoT are able to enhance the performance by about 6 percent. There are negative correlations between dependent and independent (dummy) variables for labor productivity (-0.79), inventory turnover (-0.036), return on equity (-0.005), profit margin (-0.033), and leverage (-0.125). In brief, most of financial metrics demonstrate negative impacts on the performance of better (IoT) performers.

As seen in Table 11, for the dummy variable, better (IoT) performers are used to examining productivity efficiency (Formula (4-3)) and market value (Formula (5-3)). The results reveal that better (IoT) performers conducting IoT could not significantly improve productivity in the short-term (-0.117 and -0.067). However, the Tobin's q results show significantly positive results, i.e., firms that are better (IoT) performers in IoT are worth approximately 11.5% more than non-better (IoT) performers.

Overall, the discussion above demonstrates that most financial metrics reveal negative impacts on the performance of IoT for better (IoT) performers. There is no evidence to support that companies that are better (IoT) performers achieve better efficiency, according to financial performance measurements and productivity. Hence, H3a and H3b are rejected. The results in Table 11 show significantly positive effects on market value; as a result, H3c is supported.

Table 10. Performance ratio regressions (Samples limited to IoT adopters only).

Dependent Variable	*In(Sales)*	*In(Pretax Income)*	*In(Cost of Goods Sold)*	*In(Pretax Income)*	*In(Pretax Income)*	*In(Sales)*	*In(Sales)*	*In(Debt)*
Interpretation	Labor Productivity	Return on Assets(ROA)	Inventory Turnover	Return on Equity(ROE)	Profit Margin	Asset Utilization	Collection Efficiency	Leverage
Better performers	-0.79 (0.050)	0.060* (0.061)	-0.036* (0.079)	-0.005 (0.057)	-0.033 (0.049)	0.091* (0.062)	0.028 (0.071)	-0.125* (0.067)
In(Employees)	0.809*** (0.039)							
In(Assets)		0.780*** (0.044)				0.684*** (0.052)		
In(Inventory)			0.702*** (0.052)					
In(Equity)				0.737*** (0.047)				0.687*** (0.055)
In(Sales)					0.801*** (0.046)			
In(Account Receivable)							0.517*** (0.047)	
R^2	0.645	0.591	0.493	0.538	0.641	0.045	0.257	0.496
Observations	168	159	143	157	159	168	144	162

Notes: *** p <0.001; ** p<0.01; * p<0.05.

Table 11. Productivity and market value regressions (Samples limited to IoT adopters only).

Dependent Variable	*ln(Gross Profit)*	*ln(Sales)*	*ln(Market Value)*
Interpretation	Value added	Output	Tobin's q
Better performers	-0.117 (0.090)	-0.067 (0.056)	0.115* (0.053)
ln(Ordinary Capital)	0.075 (0.043)	0.026 (0.029)	
ln(Employees)	-0.163 (0.142)	-0.076 (0.089)	
ln(Labor Expense)	0.974*** (0.158)	0.655*** (0.111)	
ln(Cost of Good Sold)		0.449*** (0.053)	
ln(Total Assets)			0.691*** (0.044)
R^2	0.682	0.901	0.46
Observations	36	36	168

Notes: *** p <0.001; ** p<0.01; * p<0.05.

6. Conclusion and Implication

According to the established framework of performance analysis, we investigate the impact of IoT implementation on firm performance. The findings, implications, and limitations of this study are offered below. We also provide suggestions for future research and conclusions.

6.1. Summary of results

Basically, the majority of results reveal the positive impacts IoT investments. First of all, our study confirms that IoT implementation has a positive impact on firms' Tobin's q and financial performance. In particular, it enhances return on assets (ROA). We discuss the details as follows.

(1) Consideration of IoT implementation

As expected, across a variety of measurements, the results indicate that IoT adopters have higher performance and market value than do non-IoT adopters. Although the results show that IoT implementation provides a positive impact on productivity performance, the intensity of support is not as strong as those of financial performance and market value. This means that the consistency of productivity should be considered as companies attempt to implement IoT technologies.

(2) Consideration of first movers

First movers have to take a higher risk and pay more attention to IoT-related investment, compared with second movers. On the other hand, first movers have pioneering advantages that go along with early implementation of IoT technologies, especially in profitability, productivity, and labor productivity. First movers also show great ability to allocate resources and labor.

(3) Consideration of better performers

When we compare better performers and non-better performers, the results do not support H3a and H3b, but significantly support H3c. This shows that better performers do not achieve better results for financial performance ratio and productivity, but gain a positive impact in market value. There could be several reasons for this; e.g., the industries we defined as better performers might be able to make some changes or may face limitations related data collection, such as staffs' IT ability, organization culture, etc. Therefore, while these factors may influence on our hypothesis, we were not able to measure them entirely.

In brief, our results confirm that enterprises implementing IoT technologies really can improve their financial performance. Although risks or charges related to

IoT-related capital might arise when enterprises implement IoT technologies, it will bring positive feedback to performance and payback in the long-term. Hence, the results of this study support our proposed hypotheses.

6.2. Implications

IoT has been one of the most popular issues in recent years; it can be used in various industries and brings many influences to enterprises, such as changing the organizational environment and having impacts on companies' financial performance. The impact of IoT for enterprises is different from other types of IT technologies in past studies. Some studies examining the impact of IT technology implementation on financial performance is existing, but no research has reported the impacts of IoT on financial performance. This study also helps audiences to comprehend the financial performance of IoT in the information management and economics fields.

These results can also serve as references for enterprises and managers. Our results demonstrate that the adoption of IoT is beneficial to companies and may have an impact on financial performance, productivity, and market value. In addition, companies in the manufacturing and health care industries should be more cautious when considering investing in IoT.

6.3. Limitations and future research

Like most studies on the value of IT business, our work is constrained by the concerns of data and empirical norms. First, the data structure of this study is from the S&P 500 list, and we collect data through the Compustat database. However, the S&P 500 list is unstable; it can be adjusted anytime. The data we adopted in this study is based on December 31, 2015; as a result, the lists other researchers use will be slightly different from ours. However, this is inevitable and does not affect our research results.

Furthermore, we have searched all kinds of information related with IoT implementation to the best of our ability. We collected the information, which includes company names and when each company began to adopt IoT technologies, from newspapers, journals, and companies' official websites. Some companies have implemented IoT but no news is shown in media. This might lead to a problem that the company is treated as a non-IoT adopter, influencing the precision of our study. Google searches also revealed that many companies have conducted IoT-related work, but we did not include companies that were not on the S&P 500 list. Thus, future work might extend the sample size from the S&P 500 to the S&P 1000 to ensure the external validity.

The study is also subject to certain limitations due to the data used for the analysis. As mentioned above, the period of the data we collected in this study is from 2010 to 2015; however, more than half of the news announcements were released in 2015. Moreover, the baseline of the performance analysis was set as 2015; hence, we made the fiscal year 2015 the benchmark. However, the data of some enterprises were collected from 2015; this might mean their paybacks were not immediately reflected on the financial statements in the end of 2015. If we set the benchmark as 2016, the results might be better.

Referring to the empirical norms, since the causal relationship cannot be explained by regression, we conducted a t test to analyze whether our dummy variables and independent variables have a linear relationship. Table 12 shows that our dummy variable, IoT adopters, has a significantly positive relation to five independent variables, including sales, pretax income, cost of goods sold, debt, and market value, yet only the relationship between IoT adopters and profit margin is negative. The second dummy variable, first movers, shows a positive and significant relationship only with cost of goods sold. The third dummy variable, better performers, only shows a positive relationship with market value and has a significantly negative relationship with debt. As companies begin to conduct IoT technologies, they must invest in IoT-related capital, and first movers must pay more related expenses, thus causing the negative impact on profit margins. The results in Table 12 also indicate that there may be suitable factors to predict our assumptions. Though the above limitations make it difficult for us to examine the real impact on better performers, we believe that the paradox will lead to new research issues.

Table 12. Linear relationship between independent variable and dummy variable.

	Sales	**Pretax Income**	**Cost of Goods Sold**	**Profit Margin**	**Debt**	**Market Value**
IoT adopters	5.6***	5***	4.6***	-0.9	3.8***	4.7***
First movers	1.5	-0.1	2.1*	-2.1*	-0.4	-0.002
Better(IoT) performers	-1.6	-0.8	-0.6	-0.5	-2.3*	0.14

6.4. Conclusion

In order to improve our understanding of impact of companies' implementation of IoT on performance, we analyzed our results based three perspectives: financial performance, productivity measurement, and market value (Tobin's q), and drew the following conclusions.

First, our results indicate significant support for H1a and H1c; IoT adoption has greater impacts on financial performance and market value. H1b is partially supported. Second, with respect to the topic of first movers, both H2a and H2b are partially supported but are not significant. As we test first movers and market value, the results do not support H2c and present a negative impact. Third, as we analyze better performers, the results show that only H3c is significantly supported; both H3a and H3b are rejected and show negative impacts on better performers. Ultimately, we hope that the results of this study provide some insights into the business value of IoT implementation and inspire further research in this field.

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The Impact of Internet of Things Implementation on Firm Performance

Research highlights

> Recently, the Internet of things (IoT) has become most popular topic in various industries.

> Previous studies have only focused on background technologies of IoT and applications.

> No studies have discussed the impact of IoT implementation on firm performance.

> This study adopts three approaches to estimate the performance of IoT implementation.

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