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An exploratory study of Internet of Things (IoT) adoption intention in logistics and supply chain management - a mixed research approach

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An exploratory study of Internet of Things (IoT) adoption intention in logistics and supply chain management - a mixed research approach

Purpose – The Internet of Things (IoT) envisions a global infrastructure of networked physical objects that render radical transparency to supply chain management. Despite the perceived advantages of IoT, industry has still not widely adopted IoT-enabled logistics and supply chain management. To understand the incentives and concerns behind firms' decisions to adopt IoT, the primary purpose of this paper is to explore the determinant factors affecting IoT adoption in logistics and supply chain management.

Design/methodology/approach – This study uses mixed methods research to explore the determinants of IoT adoption intention in logistics and supply chain management. Qualitative analysis using the grounded theory methodology reveals the underlying perceptions regarding logistic innovation with IoT. Quantitative hypotheses are then developed based on qualitative investigation and adoption literature. Survey data were collected from the managerial staff of Taiwanese firms across various industries. Structural equation modeling with partial least square is used for data analysis.

Findings – The results of the qualitative study identify uncertainties and issues regarding firms' intention to accept or reject IoT technology in logistics and supply chain management, including the benefit and cost aspects of adopting IoT, uncertainties about the trustworthiness of IoT technology, and the external motivating force to embrace IoT. The resulting quantitative model shows that perceived benefits, perceived costs, and external pressure are significant determinants of IoT adoption intention, while technology trust is not. However, technology trust does indirectly influence IoT adoption intention through perceived benefits.

Practical implications – The empirical findings of this study provide some guidelines for logistics and supply chain managers to evaluate IoT adoption in their firms. Likewise, IoT solution providers can also benefit from this study by improving their solutions to mitigate the IoT adoption concerns addressed herein.

Originality/value – This paper is among the first known to examine IoT adoption intention in logistics and supply chain management using mixed methods research. The mixed methods approach offers a better insight in understanding incentives behind firms' decisions to adopt IoT versus the use of either a qualitative or quantitative method alone.

Keywords: Internet of Things (IoT), RFID, Logistics and supply chain management, Mixed research approach, IoT adoption intention

1. Introduction

The Internet of Things (IoT) has inspired many innovative applications of logistics and supply chains in recent years and will have far-reaching influences on future supply chain management. The ideal IoT vision is that each object has its own Digital Object Identifier (DOI) (Gershenfeld *et al*., 2004), and it is now achievable to create a global network with objects as the infrastructure through IoT (Kortuem *et al*., 2010). The goal of IoT is to create a global network infrastructure to facilitate the easy exchange of commodities, services, and information (Liu and Sun, 2011). The application of IoT technology in the industry, such as manufacturing and supply chains, is also known as Industrial IoT (IIoT) (Hairong *et al*., 2014; Li *et al*., 2014). IoT or IIoT has been applied by some enterprises to assist in the collection of on-site real-time information, which has successfully improved and promoted operating efficiency. The innovation of IoT benefits companies in fields related to logistics and affects the operations of enterprises (Grawe, 2009). Although the overall expenditures of IoT hardware, such as RFID tags and readers, have dropped significantly in recent years, many firms still hold hesitant and conservative attitudes toward the application of IoT in supply chain management. The aim of this paper is thus to explore what factors affect an enterprise's adoption intention of IoT in logistics and supply chain management.

Studying logistics innovation adoption across a supply chain, such as for IoT, is a relatively new and complex issue. Most studies on IoT or logistics innovation adoption use only a single research method. In contrast, the mixed research method employs quantitative and qualitative research methods, either concurrently or sequentially, to understand a research topic of interest. (Venkatesh *et al*., 2013). Even as the single-method (qualitative or quantitative alone) approach might be insufficient to describe the complex decision behavior of IoT technology adoption across multiple supply chain organizations, there are few mixed research studies in the literature. Although information system (IS) research communities encourage methodological diversity, there is a scarcity of IS research using mixed research methods (Venkatesh *et al.*, 2013). Similarly, mixed methods research is rarely used in supply chain management-related disciplines (Golicic and Davis, 2012). Thus, there is an excellent opportunity to advance the research discipline by using mixed research methods, which offer a good avenue to understand and explain how a supply chain strategy is implemented across organizations interconnected in the supply chain (Golicic and Davis, 2012). Detailed guidelines for mixed research methods in supply chain management and IS can be referenced in Golicic and Davis (2012) and Venkatesh et al. (2013), respectively. The following sections will address this research gap and further explicate the merits for the use of mixed research methods in studying IoT adoption. This article explores the key factors that influence the adoption of IoT in logistics and supply chain management from the perspective of empirical research using the mixed research method, which combines qualitative research and quantitative research. Thus, this study is divided into two parts. The first part is qualitative research, which looks at the perception of Taiwanese enterprises regarding IoT technology from multiple perspectives through in-depth interviews of Taiwanese executives. The second part uses questionnaire survey and quantitative analysis to explore the key factors affecting the adoption of IoT by enterprises in logistics and supply chain management.

The remainder of this paper is organized as follows. Section 2 reviews related works about IoT-enabled supply chain and previous literature concerning research methods for IoT adoption. Section 3 describes the mixed research methodology for this study. Section 4 discusses the qualitative research process and presents the research findings. Section 5 sets up the quantitative research model and hypotheses and then shows data analysis and research findings. The last section offers discussions and conclusions.

2. Related studies for IoT-enabled supply chain and IoT adoption

2.1 IoT-enabled supply chain

Massachusetts Institute of Technology (MIT) established the Auto-ID Center in 1999 and proposed the infrastructure of the EPC encoding scheme and EPCglobal Network to ensure the interconnectedness of Radio Frequency Identification (RFID) in the supply chain (Thiesse *et al.*, 2009). The design of the EPC Code applies to all products across the globe, where all codes are unique, and each object (product) has its own EPC Code; IoT has many choices in product tagging, such as Barcode or RFID technology, and RFID tagging is often used with EPC encoding scheme. RFID readers retrieve the information from a RFID tag through radio waves, with no line of sight operation, which allows for batch scanning of products. Compared with barcode technology, RFID technology can repeatedly write data into the memory blocks of a tag, which can carry more information than barcode does. Moreover, RFID tag can survive harsh environments, and not be easily contaminated or damaged.

The overall operations of the EPCglobal network rely on the integration of the IoT system. If RFID readers are widely placed in a supply chain, then each member along the supply chain can inquire, update, or exchange information promptly (Bo and Guangwen, 2009). The reason why IoT is taken seriously and seen as the solution for many industries is that it can interconnect the information in the virtual world with products and supply chain members in the physical world (Chen *et al.*, 2010; Kawsar *et al.*, 2010). IoT has been applied in the fields of logistics, manufacturing, and supply chains for some time and was initially applied in Closed Loop Supply Chains to improve automation and efficiency of enterprises. However, to realize an IoT-enabled supply chain, item-level tagging should be considered as opposed to only carton or pallet-level tagging. Since RFID can be tagged on items, cases, and pallets, the IoT tagging level must be considered in IoT adoption for supply chain operation. Therefore, item-level tagging is assumed to be the de facto tagging standard for supply chain herein.

The EPCglobal network is also assumed to be the de facto underlying IoT information infrastructure, which is designed for item-level product tracking and tracing as each product is serialized by a 96-bit electronic product code (EPC). Some firms have adopted item-level RFID tagging for high priced clothing and accessories; however, enterprises still hold hesitant and conservative attitudes toward the application of IoT for supply chain management even though the overall cost of RFID tags and IoT devices have dropped significantly in recent years. Wu *et al.* (2006) pointed out that IoT adoption must consider several facets, including technology, standards, cost, patents, the infrastructure of the supply chain, and return on investment (ROI). IoT is a new and disruptive technology, and enterprises must consider many factors in its adoption decision, such as compatibility, technology, and technology transfer, especially in the applicability of the ultra-high frequency (UHF) technology. Its adoption also affects enterprise organizations and supply chains. For example, RFID technology and the EPC network can synchronize existing information and product flows in a supply chain and integrate the data of supply chain members, which can be passed to each supply chain participant to provide complete and transparent supply chain information (Fosso and Boeck, 2008).

Figure 1 illustrates the information technology (IT) infrastructure of an IoT-enabled supply chain based on the EPCglobal network architecture (EPCglobal, 2007; EPCglobal, 2010). As shown in Figure 1, item-level tagging can be applied in components tagging for part suppliers and product tagging for manufacturers, and both products and parts are serialized with a 96-bit electronic product code. IoT-based applications can track and trace each item through the EPCglobal network. Moreover, at the retail store, retailer and consumers can perform item-level tracking of goods through any user interface with a RFID reading device such as a kiosk or smartphone equipped with miniaturized RFID readers. These devices allow retailers and consumers at a retail store to connect to IoT systems built on the EPCglobal network and to retrieve a product's pedigree information from the IoT cloud, as illustrated in Figure 1. The IoT cloud platform can be accessed with permission from interested parties across the supply chain, including government agencies. As indicated by Panizza and Lindmark (2010), a lack of a global standard for IoT often proves to be a barrier for private companies to consider IoT technology for their supply chain. No global IoT standard, such as EPC, makes interoperability difficult among supply chain partners. Thus, the standardization of RFID technology is also a consideration regarding RFID adoption (Shin, S. and Eksioglu, B., 2015).

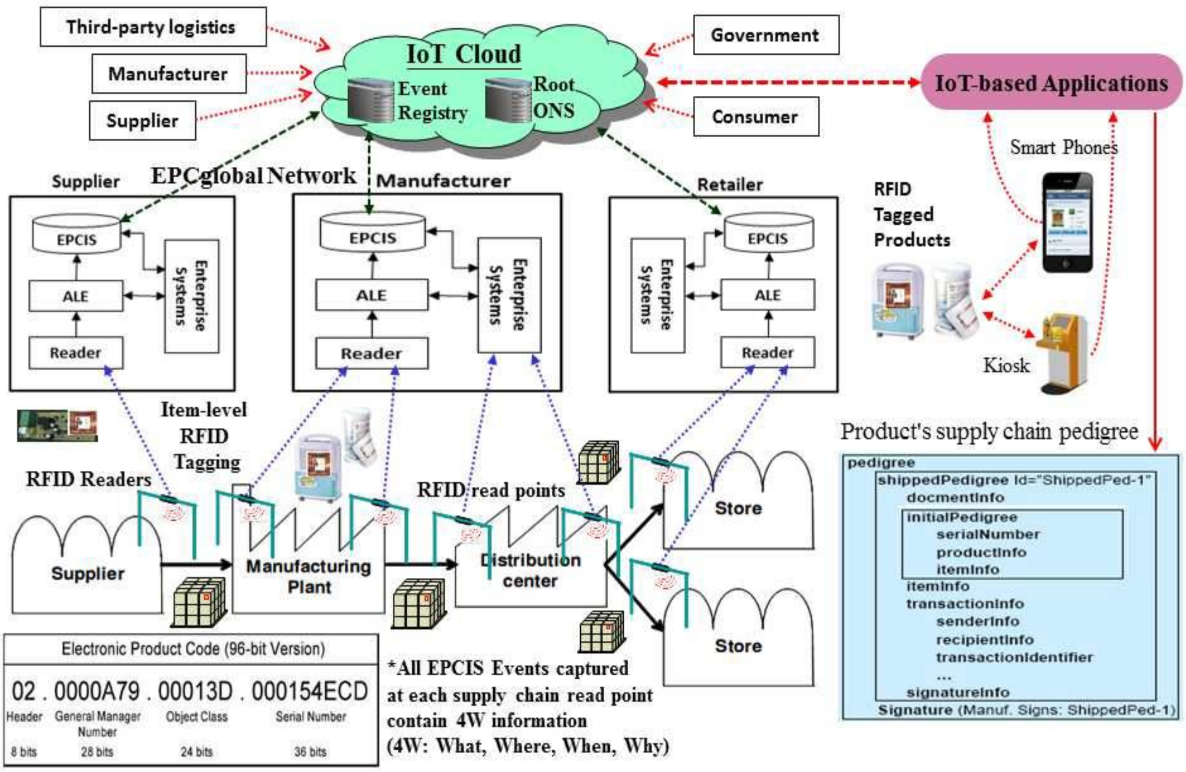

Figure 1. IT Infrastructure of an IoT-enabled Supply Chain

2.2 Review of IoT adoption studies

Adopting IoT technology in a supply chain is a complicated process, and different companies along a supply chain might have different expectations and attitudes toward accepting the new technologies. Most empirical research about IoT adoption has either adopted a qualitative or quantitate approach, with many previous research works having studied the adoption process of IoT through the qualitative research method to uncover motivations driving the IoT adoption (Boeck and Wamba, 2008; Fisher and Monahan, 2008; Hellström, 2008). As stated above, adopting IoT technologies, such as RFID and EPCglobal network, in supply chain management is not a trivial task, because different entities in the supply chain may have different expectations and requirements regarding the new and disruptive technology. Thus, clarifying key technology concerns facing supply chain participants through the qualitative research method contributes to the understanding of IoT adoption for supply chain management.

Boeck and Wamba (2008) conducted research on RFID adoption in a retail industry supply chain consisting of 10 companies for three years using several qualitative methods, including participant observation, the grounded theory, and action research. Several important findings emerged from their qualitative study. For example, they found that the benefit of RFID can be extended to downstream consumers and upstream suppliers through an EPC network; the RFID tagging level of products can affect the efficiency of the supply chain, and industry has a strong tendency to tag products in the upstream/source (RFID tagging). The above insights acquired through the qualitative research process help identify core perceptions regarding IoT adoption in supply chain among supply chain members.

The quantitative approach is still the main research method for studying the issue of technology adoption. IoT is an emerging and disruptive technology for supply chain management. Firms are typically required to evaluate and investigate new technology before adoption. In the quantitative research method, the theoretical foundation plays a major role in hypothesis development. For instance, the diffusion of innovations (DOI) (Rogers, 1995) and the technology-organization-environment (TOE) framework (Tornatzky and Fleischer, 1990) are the two main theories widely used by researchers to investigate organizational adoption and use of new technology. Many quantitative empirical studies in this field have explored and examined the intention to adopt IoT or logistics innovation from the organizational perspective (Brown and Russell, 2007; Lee and Shim, 2007; Chang *et al.*, 2008; Lee, 2009; Schmitt and Michahelles, 2009; Kim and Garrison, 2010; Fazel, *et al.*, 2011; Cheng and Yeh, 2011; Matta *et al.*, 2012; Chong and Chen, 2012; Pan *et al.*, 2013; Lin *et al.*, 2016).

The mixed method uses two or more kinds of research techniques during one research, such as quantitative and qualitative methods. Each research method has its potential weakness, and the mixed research method can complement the shortcomings of each one and synchronize the merits of each method. To understand the complex research problem about IoT adoption from different perspectives, this study adopts the mixed research method to examine important factors affecting the adoption of IoT in logistics and supply chain management.

3. Research methodology

In conducting the mixed method research, a sequential approach suggested by Venkatesh *et al*. (2013) is adopted, and data analysis is performed in two phases: the qualitative approach in the first phase and the quantitative approach in the second. The primary goal of this study is to explore factors affecting firms' intention toward adopting IoT technology in their supply chain management. Following the sequential mixed methods design strategy proposed by Venkatesh *et al*. (2013), a core set of factors about the research goal is first developed from interviews in the first qualitative study phase, and then a theory is subsequently developed to explain these factors. In the second phase, the quantitative study is conducted on a larger sample to obtain further empirical support for the theoretical framework developed in Phase 1. Research processes in each step are further elaborated in the following explanation.

In the first phase of qualitative research, the Grounded Theory is used to analyze the conceptual framework of the adoption intention concerning IoT technology in a supply chain. Focus group interviews and in-depth personal interviews are carried out with the top-level managers of different firms across various industries in Taiwan. The study analyzes the interview transcripts to obtain the views of the high levels of enterprises regarding their preference toward IoT technology, adoption intention, the influence of IoT on their organizations and supply chain partners, and their relevant technical and cost considerations. The inductive method in the Grounded Theory is used to discover and classify the concepts from those interview transcripts. Conceptualized views regarding the decision-making processes of IoT adoption are derived and organized in a hierarchical structure, with the top-level concepts forming a core set of factors (constructs) related to our research goal. Finally, a theoretical framework explaining these high-level conceptual factors is presented in the theoretical narrative.

In the second phase of quantitative studies, the research model and hypotheses are constructed based on prior qualitative research findings and literature review. Data are then collected through questionnaire surveys, and Partial Least Squares (PLS) is used to analyze the survey data and test the research hypotheses. Venkatesh *et al.* (2013) addressed the importance of meta-inferences after acquiring research findings from the mixed research study, where a meta-inference is defined as theoretical statements or narratives that offer a holistic explanation of the phenomenon of interest by combining findings from both qualitative and quantitative studies. Hence, after examining qualitative and quantitative studies separately in sequence and obtaining the results of research from each study, a meta-inference analysis is provided to synchronize findings from these two studies in the last part of the mixed methods research.

4. Qualitative design and data analysis (phase I)

Focus group interviews and in-depth interviews are the main methods for data collection in this investigation. Interviews are important information sources for qualitative research, because researchers can obtain the personal cognition and feelings of respondents regarding social phenomena and issues through the dialogue process. The main purpose of qualitative research is to gather an in-depth understanding of issues. Thus, most qualitative research has adopted non-random sampling (Auerbach and Silverstein, 2003).

This paper employs the Grounded Theory (GT) of the qualitative research method to investigate the perception of enterprises regarding IoT technology. GT was first proposed by two sociologists, Glaser and Strauss (1967). It helps and guides researchers to keep an open mind to discover unbiased new conceptual models from the emerging patterns in the qualitative data (Glaser and Strauss, 1967), which is an important tool to help this research to explore the prevalent perception of enterprises about IoT technology. Essentially, GT attempts to develop a theory from a model, theme, or category, as found in the observed data (Earl Babbie, 2010). In other words, GT is a theory construction method that is famous and popular in qualitative research and uses the method of induction to analyze phenomena to discover insights. As researchers provide no theoretical hypothesis before the start of the qualitative research, they derive the concepts and propositions directly from the original data through systematic data collection and analysis and then develop a theory. The theory developed through the analysis of GT also serves as a bridge linking qualitative inquiry and quantitative examination, making it possible to generalize the qualitative theoretical framework of IoT adoption. Thus, this study considers GT as the best alternative to other qualitative methods for our qualitative investigation.

In our mixed research design, the literature review of the theory development of GT plays a major role in bridging qualitative and quantitative studies. However, utilizing a literature review of GT is a debatable issue among many scholars (Van Rensburg and Ukpere, 2014). For those arguing for the use of a literature review in GT, there is also no agreement on where to place the literature review during the GT research process. Van Rensburg and Ukpere (2014) discussed different views about this issue. In choosing the research process of GT to support our use of mixed research method when relating the qualitative research results to the quantitative study, this paper adopts the guidelines suggested by Pandit (1996). Pandit (1996) devised the research process of GT into five phases, including research design, data collection, data ordering, data analysis, and literature comparison, and suggested using the literature comparison in the final step to discern similarities and differences to one's research (Van Rensburg and Ukpere, 2014). This study places the literature review as the last step of GT to pave the way for theory development in later quantitative studies and also to serve as a bridge between two research methods in a mixed research project. Thus, by following the research process of GT proposed by Pandit (1996), a literature comparison is placed at the beginning of the quantitative design, right after the data analysis of GT.

4.1 Qualitative data collection

The number of research participants interviewed in this research is 15, including 10 men and 5 women, with ages ranging from 27 to 56. All 15 research participants have a managerial position, including 2 assistant managers, 8 managers, 2 directors, 2 chief information officers (CIO), and 1 chief executive officer (CEO). The industrial distribution is electronics manufacturing, which accounts for 70% of participants, and the retail and logistics industry, which accounts for 30%. The data collection time for this research is from November 2013 to September 2014.

The interview method is Semi-Structured Interviews, carried out by the researchers first preparing a syllabus for the interviews, asking the research participants about their opinions, and then flexibly adjusting the interview direction and contents according to the interview situations. The contents of the questionnaires are divided into three areas for discussion: (1)

enterprise/organization's understanding of IoT; (2) enterprise/organization's expectations for the adoption of an IoT system; and (3) the impact of adopting an IoT system on the enterprise/organization. This study conducted a total of 12 interviews and focus group interviews, including 7 personalized in-depth interviews and 5 focus group interviews, where each personalized in-depth interview covered 1 person, and each focus group interviewed 2 to 4 persons. The research participants (interviewee) reviewed the questionnaire glossary of terms regarding IoT and the descriptions of an IoT-enabled supply chain example before the formal interview in order to understand the background information. Each interview required 45 minutes to 85 minutes for completion.

4.2 Qualitative data analysis

Each recorded interview was first transcribed verbatim into words in a Microsoft Word document by a transcriber. Interviewers then read these verbatim transcripts and revised verbal expressions to improve the readability of the transcripts. After the interview recording materials are edited into transcripts, they can then be analyzed and encoded during the qualitative data coding process. Based on the GT coding scheme proposed by Auerbach and Silverstein (2003), this research conducted word coding of all transcript data using Nvivo(10) software. In the coding process, concept nodes are developed in Nvivo to denote concepts found in the transcripts. A concept node is designated to represent a sentence or a paragraph. Multiple concept nodes can be coded for a sentence or a paragraph in a transcript, indicating that a sentence or a paragraph can contain multiple concepts.

The goal of the qualitative research in phase 1 is to explore the firm's perception regarding the use of IoT technology in supply chain management. This study did not impose any pre-existing coding framework or theoretical constructs before the content analysis, as it shall explore the underlying conceptual structure of transcripts and reveal latent constructs related to IoT adoption in the supply chain. After the qualitative coding process, concept nodes are created and classified into categories to reveal an underlying structure of the qualitative data. Since this research adopts the coding scheme proposed by Auerbach and Silverstein (2003), the concept nodes are created and organized into a three-level concept hierarchy. The bottom level of a concept hierarchy encompasses text-based categories, which represent repeated ideas and also low-level concept nodes. The middle level of the concept hierarchy is sensitizing concepts; each sensitizing concept organizes repeating ideas into a higher-level category, which is also regarded as a theme or a middle-level concept node. The highest level of a concept hierarchy is the theoretical constructs; each theoretical construct consists of a group of themes describing a common theoretical concept. The coding process of this research is described and summarized in the following steps.

(1) Edit the interview recording materials into transcripts.
(2) Code the relevant text related to the concerns of this research from the interview transcripts.
(3) Read and interpret the contents of the relevant text to identify repeated ideas among related passages of relevant text and code them as text-based categories. The repeating ideas denote the same or similar words and sentences used by research participants to express the same concept (Auerbach and Silverstein, 2003).

(4) Select related text-based categories (repeated ideas) and group them into corresponding higher-level themes as sensitizing concepts.
(5) Develop theoretical constructs by organizing the themes (sensitizing concepts) into higher and more abstract concepts or ideas, which denote the highest-level concept nodes in the concept hierarchy.

The issues of reliability and validity regarding qualitative research can be addressed by triangulation of multiple data sources (Jick, 1979; Shluzas and Leifer, 2014). Auerbach and Silverstein (2003) incorporated multiple raters at different stages of the research process to enhance the reliability and validity of qualitative research. To ensure the reliability and validity of data analysis and strengthen GT building of this study, triangulation of multiple data sources and investigators is incorporated into the qualitative data analysis. Interview participants (mainly managerial staff) were selected from a variety of companies in different industries, and valid transcribed interview data were acquired from them through focus group interviews and in-depth personal interviews. For data analysis, this study included three researchers taking part in the coding process to examine the interview transcripts and independently design concept nodes thoroughly. For qualitative data analysis, single or multiple concept nodes can be coded to represent a sentence, a paragraph, or a whole document. A concept node can be associated with other nodes in many ways, such as in a hierarchical or parallel relationship. This study organizes emerging concept nodes in a hierarchical structure. After coding and classification of nodes, three separate lists of concept nodes were developed by the different researchers. The concept nodes in the three lists were compared and discussed by three researchers and then merged into an agreed-upon single list of concept nodes, as presented in Table 1.

The coding results were finally examined with interviewed participants and verified among researchers and research participants to assure the objectivity of our data analysis. Table 1 lists the analytical results of the qualitative research in this phase, dividing the results into three levels. The bottom level identifies the concept nodes, representing repeated ideas after transcript coding and analysis (listed in digits). The middle level classifies and concludes the concept nodes of these repeated ideas into themes (listed in the English alphabet). The highest level is the theoretical constructs, revealing the theoretical framework of this research (I~IV). The analysis results show that the concern of enterprises regarding the adoption of IoT technology for logistics and supply chain management can be understood from four dimensions: Technology Benefits, Cost Concerns, Uncertainties about Technology, and External Motivating Force. As the highest level of conceptual nodes, the theoretical constructs emerged from the coding procedure; the theoretical narrative can be conducted by summarizing the implications regarding our research concerns and bridging the concerns of researchers and the subjective experience of research participants (Auerbach and Silverstein, 2003). The theoretical narrative is considered as part of qualitative data analysis and is described in the following section.

Table 1. Repeating ideas, themes, and theoretical constructs for the IoT adoption study

I. Technology Benefits	*III. Uncertainties about the Trustworthiness of*

	Technology
A. Visibility of supply chain 1. Reducing complexity of supply chain integration 2. Easy access to product or part pedigree information 3. Detailed product lifecycle information 4. RFID tag has larger data storage than that of barcode 5. Improving track and trace capabilities 6. Part suppliers can provide complete component pedigree with IoT 7. Upstream suppliers can attach or embed RFID tags on the parts B. Supply chain efficiency 8. Scan without line of sight 9. Read multiple RFID tagged items at once 10. Simplify RMA operations * 11. Process automation C. Product tagging benefits 12. Integration of RFID with products 13. Data can be over-written repeatedly on RFID tags.	G. Reliability of IoT system 14. Operational difficulty of IoT system 15. Stability of IoT system 16. Reading rate of RFID H. Concerns for system integration 17. Compatibility with existing processes 18. Integration with existing IS infrastructure I. Concerns for integration of supply chain information 19. Concerns for information security 20. Concerns about the lack of a data format standard (for product pedigree across supply chain)
II. Cost Concerns	*IV. External Motivating Force*
D. Organization adjustment 21. Process re-engineering 22. Increase IT staff E. RFID equipment 23. Cost of RFID Tags 24. Cost of IoT system hardware F. Cost of ownership model for IoT system (software) 25. Lease of IoT system 26. Buyout purchase of IoT system 27. Self development	J. Customer expectations 28. Unwilling to take the initiative in adopting IoT (unless required) 29. Requirements of clients 30. Fear of losing customers K. Social expectations 31. Willing to adopt IoT system by governmental rules

* RMA: Return material authorization.

4.3. Theoretical narrative

After performing coding and classifying procedures for qualitative data analysis based on a GT approach, the four highest level conceptual categories emerged as theoretical constructs (factors), as presented in Table 1. They include technology benefits, cost concerns, uncertainties about the trustworthiness of technology, and external motivation force. Under the overarching theme of IoT adoption intention in logistics and supply chain management, the four themes represent four critical dimensions of concern regarding those research participating firms. Benefits and costs are the most frequently addressed by our research participants in evaluating IoT adoption, who perceived technology benefits in three major themes: visibility of supply chain, supply chain efficiency, and product tagging benefits.

Participants are concerned about IoT adoption cost in three perspectives: organization adjustment, RFID equipment, and cost of ownership model for IoT systems. Many participants addressed uncertainties about the trustworthiness of technology. Uncertainties represent another source of IoT technology concern other than cost, and three major issues are found in this construct: reliability of IoT system, concerns for system integration, and concerns for integration of supply chain information. Most participants agreed that the external motivating force outside of their firms did affect their intention to adopt IoT technology in supply chain management. Finally, the construct of external motivating force is classified into two themes: customer expectations and social expectations.

Based on the investigation with research participants regarding the relationships and implications among the four identified theoretical constructs, most participants indicated that the four constructs could affect their decision toward IoT adoption. They feel that IoT adoption cost is a vital organizational issue and could strongly impact their firms' decision, while the external motivating force is more related to the pressure of their supply chain partners than to government regulations. Most participants considered the other two constructs as important technical issues in evaluating IoT technology. Nevertheless, an interesting link is found between the constructs of benefits and uncertainties. Some participants pointed out that reliability of IoT technology could affect their perceived benefit of IoT technology. For example, many participants expressed concerns about RFID reading rates. If the IoT/RFID system cannot guarantee a 100% reading rate for bulk reads in a harsh environment (such as in a metallic environment), then the perceived benefits of IoT will be severely comprised. On the contrary, if IoT technology is proven to be reliable in a harsh environment, then it will strengthen the perceived benefits of adopting and using IoT technology. However, many research participants still held a wait-and-see attitude toward adoption of IoT system under the assumption that all the potential IoT benefits could be realized. They often expressed their concerns from the organizational standpoints, such as whether their company has enough resources to support IoT adoption. Finally, external pressure is considered by the highest percentage of research participants as the most influential factor impacting their adoption decision. Specifically, requirements from clients are the most salient theme in the external motivating force construct.

5. Quantitative design and data analysis (phase II)

5.1 Development of research model based on literature and qualitative study results

In the second phase of this research, the construction of the quantitative research model is based on the literature review and a comparison with prior qualitative study results. DOI (Rogers, 1995) is a broadly used theory to explicate innovation diffusion and innovation or technology adoption over time. The perceived characteristics of DOI can be used to explain factors affecting new technology adoption. According to DOI, Rogers (2003) suggested that five characteristics of innovation (i.e., relative advantage, compatibility, complexity, trialability, and observability) affect technology adoption and explain significant variances in the adoption rate. Previous research revealed that relative advantage, compatibility, and complexity exhibit a consistent connection to innovation adoption (Agarwal and Prasad, 1998; Tornatzky and Klein, 1982). However, the results of this qualitative investigation show that many firms still hesitate or are unwilling to invest in IoT even though they are fully aware of the potential benefits of IoT-enabled logistics and supply chain management.

Concerns about IoT adoption in the prior qualitative study are illustrated under the theoretical concept of uncertainties about technology in Table 1. Most of the concerns about IoT listed in Table 1 imply that IoT adoption is not merely a technical issue or individual-level adoption behavior, but rather an organization level decision. Moreover, qualitative findings suggest that external driving force is also an important component affecting adoption intention. Tornatzky and Fleischer (1990) proposed the technology, organization, and environment (TOE) framework as a high-level theoretical model to explain a firm's decision behavior regarding new technology adoption and to help identify factors affecting innovation adoption. The TOE framework includes three dimensions: technological context, organizational context, and environmental context. Compared to DOI, TOE addresses more on firm-level evaluation, such as factors in organizational and environmental contexts. Thus, TOE is also considered as a better choice than DOI to evaluate an organization's decision-making behavior regarding IoT technology adoption (Kim and Garrison, 2010).

After the literature review and comparison with prior qualitative study findings, this study adopts the TOE theoretical framework as the basis for our quantitative research model. Kuan and Chau (2001) used perceived benefits in the technology context, perceived technical competence, the financial cost in the organizational context, and perceived industry and regulatory pressure in the environmental context to study EDI adoption. Hsu *et al.* (2014) employed perceived benefits and business concerns in the technology context, IT capability in the organizational context, and external pressure in the environmental context to investigate the intention to adopt cloud computing. Thus, the technology benefits in Table 1 fall into TOE's technology context. Cost concerns and uncertainties about the trustworthiness of technology correspond to TOE's organizational context; the perception of uncertainties about the trustworthiness of technology is conceptually related to the IoT technical competence or IoT capability in an organization. Finally, the external motivating force can be seen as a dimension in TOE's environmental context and is similar to the concept of external pressure. Based on qualitative findings and the TOE framework, this study proposes a research model in Figure 2 for the quantitative study in phase II.

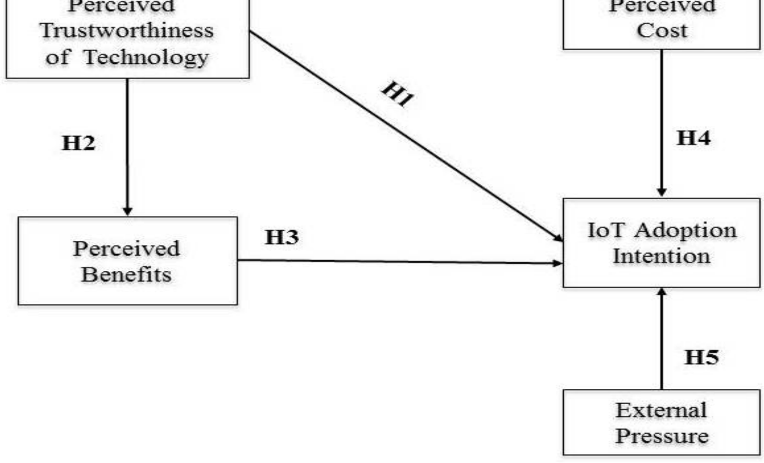

Figure 2. The research model

5.2 Hypotheses development

The research model of this study is developed by comparisons between the qualitative research results in Phase I and the relevant theories adopted by information technology in the literature reviews mentioned above. This study shows that the intention to adopt IoT for supply chain management could be affected by perceived benefits and costs, the trustworthiness of technology, and external motivations. In the above literature review, this study finds that the TOE framework can fully support the core conceptual model, as established by qualitative research. Tornatzky and Fleischer (1990) developed the TOE research model as a theoretical framework to explore whether or not an information system is adopted, including the three dimensions of technological context, organizational context, and environmental background. Research models adopted by many scholars use the TOE framework for developing unique research dimensions for specific patterns of innovation environments (Baker, 2012). Thus, this paper constructs a quantitative research framework on the basis of the TOE framework, as shown in Figure 1, and discusses the related research hypothesis below.

Based on the analytical results from the qualitative study in phase I, many research participants agreed that reliability of IoT technology is related to their organization's trust in new technology. Most participants also consented that the reduction of the uncertainty factors (outlined in Table 1) in the technology increases the trustworthiness of IoT technology and hence enhanced their firms' intention to adopt IoT technology. Many research studies also suggest that trust has a significant impact on the acceptance of science and technology, and if users increase their trust of technological products, then it will have a positive influence on users' acceptance intention (Lee, 2009; Tung *et al.*, 2008). Therefore, this study sets up the first hypothesis.

H1. Perceived trustworthiness of technology has a positive effect on a firm's intention to adopt IoT technology.

As unveiled by the qualitative study in the previous section, many participants are concerned about the reliability of IoT technology and acknowledged that uncertainties about the trustworthiness of technology could lower their perceived benefits of adopting IoT technology. The more technology uncertainties are removed, the more confident participants will become as they anticipate that the technology benefits could have a greater chance to be realized. For example, many participants considered the scan without line of sight and the bulk reads of tagged items as significant benefits of IoT technology under the assumption of 100% reading rates. If IoT technology cannot guarantee 100% reading rates, then most participants would think twice about adopting IoT and discount the aforementioned benefits of IoT. The impact of trustworthiness of technology on perceived benefits of technology has been addressed in the IT adoption literature (Gefen *et al.*, 2003; Farr-Wharton and Brunetto, 2007; Kim *et al.*, 2009; Lu *et al.*, 2011; Lai *et al.*, 2013; Siegrist *et al.*, 2000; Yang *et al.*, 2015). These studies found that firms with a higher trust in a certain technology are more likely to appreciate the advantage and benefits of that technology. Therefore, the arguments above lead to the second hypothesis.

H2. Perceived trustworthiness of technology has a positive effect on the perceived benefits of IoT technology.

The benefits make up the key factor that all organizations consider in evaluating the adoption of new technology. If an organization has higher perceived benefit towards new technology, then it will have higher intention to adopt it. IoT offers many advantages to companies in supply chain management, such as reducing inventory and labor cost, improving operational efficiency with the non-line-of-sight operation, and enhancing supply chain visibility. Thus, perceived benefit is one of the most touted reasons for adopting IoT technology (Lee, 2009; Chong and Chen, 2012; Pan *et al.,* 2013; Hsu *et al.,* 2014; Lin *et al.,* 2016). Therefore, the following hypothesis is proposed.

H3. Perceived benefits have positive effects on a firm's intention to adopt IoT technology.

Perceived cost refers to all types of expenses incurred by companies for the adoption of new technologies, such as hardware equipment, software, and system integration (Premkumar *et al.,* 1997). The perceived cost elements in the technology dimension have an adverse influence on the adoption of new technology for a firm (Tung *et al.*, 2008). Previous studies addressed cost concerns and found that cost is a major driver to affect an organization's intention to adopt IoT (Panizza *et al.,* 2010; Chong and Chen, 2012; Lin *et al.,* 2016, Chao and Chen, 2017). Thus, the following hypothesis is proposed.

H4. Perceived cost has a negative effect on a firm's intention to adopt IoT technology.

External pressure refers to the degree that the same industry or business partners influence the adoption of new technology in a firm (Premkumar *et al.,* 1997). In addition to the influence of supply chain partners, external social competition, government regulations, and other social environments are various sources of external pressure (Hsu *et al.,* 2014) that have a significant positive effect on a firm's adoption of new technology. The literature on the IoT adoption has found rich support for the impact of external pressure on organizational intention to adopt IoT technology (Matta *et al.,* 2012; Chong and Chen, 2012; Pan *et al.,* 2013; Lin *et al.,* 2016**)**. Therefore, the following hypothesis is proposed.

H5. External pressure has a positive effect on a firm's intention to adopt IoT technology.

5.3 Data collection

The survey subjects of this research questionnaire are top-level managers from manufacturers in the electronics industry, retail industry, transportation and logistics industry, general service industry, and others. The questionnaire of this research included six constructs, and they were measured on a five-point Likert scale ranging from "strongly disagree (1)" to "strongly agree (5)". After the initial questionnaire had been designed, pre-testing was conducted to avoid any vagueness or fuzziness in the questionnaire, which could affect both the reliability and validity of this study. IoT domain experts, professors, and EMBA graduate students carried out pre-testing. A formal survey was finalized after modification of the initial questionnaire based on the opinion of pre-testing participants. This study chose 317 Taiwanese firms and invited them to participate in our online or paper-based survey. In total, 146 questionnaires were collected. After discarding 16 incomplete questionnaires, we obtained 130 valid responses for a response rate of 41%. Table 2 lists the statistical information regarding the demographic characteristics of the respondents.

Table 2. Demographic information of samples

Demographic Categories	Frequency	Percentage (%)
Gender		
Male	102	78%
Female	28	22%
Current Position		
Chief executive officer	3	2.3%
Executive vice president	8	6.2%
Chief information officer	12	9.2%
Director of IT	34	26.2%
Manager	63	48.5%
Other	10	7.7%
Education Level		
Post-graduate	76	59.8%
University/College	42	40.2%
High school	0	0%
Industry		
Manufacturing	77	59.2%
Retailing	17	13.1%
Transportation and Logistics	7	5.4%
General Service	18	13.8%
Others	11	8.5%
Deployed enterprise information systems		
ERP (Enterprise Resource Planning)	115	88.5%
MES (Manufacturing Execution System)	63	48.5%
PLM (Product Lifecycle Management)	38	29.2%
SCM (Supply Chain Management)	56	43.1%
CRM (Customer Relationship Management)	57	43.8%

5.4 Data analysis

This study employs the statistical technique of Partial Least Squares (PLS) to perform data analysis and uses SmartPLS software to analyze research data and empirically test the research model and hypothesis. PLS is a technique of the structural equation model (SEM) and is based on regression analysis. Unlike the covariance-based SEM that is designed for confirmatory model testing, PLS is a component-based SEM that aims for exploratory or predictive research. PLS thus has relatively less strict requirements for sample size and is distribution-free (employing non-parametric statistics); PLS is also insensitive to impurities in the real-world model and the real data (Kijsanayotin *et al.*, 2014). Only 130 valid samples were obtained in this study due to limitations of time and the limited number of firms participating in this survey. Given the above analysis, the PLS method is considered as a better alternative than covariance-based SEM for this research, because the nature of our study is more exploratory than confirmatory and due to the small sample size. PLS also has been wildly used in the field of information systems, in particular for researchers investigating technology adoption, which is another reason for using PLS in this study. PLS is a second-generation multivariate technique that can simultaneously test the measurement model and estimate the parameters of the structural model. Thus, SmartPLS is used to assess the measurement model and structure model. SmartPLS adopts a two-step approach and tests a model in two stages (Kim and Garrison, 2010). In the first stage, the measurement model is analyzed to verify the reliability and validity of the instrument; in stage 2, the structural model is evaluated to test the research hypotheses.

5.4.1 Measurement model assessment

As stated above, the first stage of PLS data analysis in this study evaluates the measurement model by examining the reliability and validity of the instrument. To assess the measurement model, this study tests item reliability, convergent validity, and discriminant validity. The measurement for item reliability uses factor loadings on the construct. According to Hair (1998), individual items with a factor loading above 0.5 are recommended to be included, whereas items with a factor loading lower than 0.5 are recommended to be removed. As shown in Table 3, all of the item loadings are greater than 0.55, indicating a satisfactory factor loading in the survey instrument.

The testing of convergent validity includes Cronbach's α, composite reliability (CR), and average variance extracted (AVE). As detailed in Table 3, the value of Cronbach's α for each construct ranges from 0.76 to 0.91, which is greater than the cut-off threshold of 0.7 suggested by Nunnally (1978). The composite reliabilities all exceed 0.8, which is above the 0.7 minimum thresholds recommended by Nunnally (1978). In the measurement model, the average variances extracted (AVE) score for each construct is above the 0.5 recommended level, as suggested by Fornell and Larcker (1981). These results indicate that our measurement model has good convergent validity.

The average variances extracted (AVE) must be tested to assess discriminant validity. Discriminant validity is the lack of a relationship among latent variables (factors) that should not be related in theory (Kim and Garrison, 2010). Therefore, to justify discriminant validity, the shared variance (squared correlation) between two constructs (latent variables) should be lower than the square root of AVE (Fornell and Larcker, 1981). The results in Table 4 are used to examine discriminant validity. Table 4 lists the correlations between the constructs, and the diagonals represent the square root of AVEs for each construct (latent variable), with other entries representing the shared variance among the latent variables. As shown in Table 4, for each latent variable, the square root of AVE is noticeably larger than its correlation coefficients with other latent variables. Thus, the results support discriminant validity of the measurement model.

Table 3. Results of descriptive statistics, convergent validity, and reliability

Constructs	Item	Mean	Std. Dev.	Loading	Composite Reliability	AVE	Cronbach's Alpha
Perceived Costs (PC)	PC1	4.28	0.58	0.86	0.86	0.62	0.79
	PC2	4.20	0.63	0.89			
	PC3	4.02	0.77	0.66			
	PC4	4.15	0.62	0.72			
Perceived Benefits (PB)	PB 1	4.39	0.61	0.68	0.89	0.57	0.85
	PB 2	4.08	0.74	0.79			
	PB 3	3.71	0.75	0.74			
	PB 4	3.52	0.92	0.71			
	PB 5	4.00	0.77	0.78			
	PB 6	4.07	0.72	0.84			
Perceived Trustworthiness of Technology (PT)	PT 1	4.39	0.61	0.82	0.85	0.59	0.76
	PT 2	4.08	0.74	0.87			
	PT 3	3.71	0.75	0.65			
	PT 4	3.52	0.92	0.71			
External Pressure (EP)	EP 1	4.25	0.57	0.73	0.87	0.57	0.81
	EP 2	4.13	0.72	0.75			
	EP 3	4.33	0.65	0.78			
	EP 4	4.14	0.66	0.74			
	EP 5	4.20	0.66	0.77			
Adoption Intention (AI)	AI 1	2.97	1.02	0.89	0.95	0.86	0.91
	AI 2	3.33	0.86	0.94			
	AI 3	3.25	0.90	0.95			

Table 4. The square root of AVEs and factor correlation coefficients

	PC	PB	PT	EP	AI
Perceived Costs (PC)	**0.787**				
Perceived Benefits (PB)	0.107	**0.755**			
Perceived Trustworthiness of Technology (PT)	0.326	0.547	**0.768**		
External Pressure (EP)	0.219	0.508	0.541	**0.755**	
Adoption Intention (AI)	-0.251	0.348	0.188	0.405	**0.927**

5.4.2 Structural model assessment

The second stage of PLS data analysis in this study assesses the structural model. This study uses SmartPLS to perform path analysis and to test the model hypotheses. The analytical results of PLS are shown in Figure 3. The squared multiple correlation (R^2) value refers to the amount of variance in the dependent variable explained by the independent variables and represents the predictive or explanatory power of the model; its value is between 0 and 1, and the greater the value is, the better the explanatory power of the model. The four independent constructs, excluding the perceived trustworthiness of technology, explain 31.5% of the variance in IoT adoption intention, and the perceived trustworthiness of technology explains 27.8% of the variance of perceived benefits. To achieve a satisfactory predictive power of the PLS model, the value of R^2 should be greater than 10% (Falk and Miller, 1992). As the R^2 value in this research ranges from 0.28 to 0.32, all R^2 values exceed the 10% recommended threshold, indicating satisfactory predicting power of our research model.

The path coefficients in Figure 3 indicate the strength of the causal relationship between two constructs. The results show that the path coefficients are significant for H2~H5 and not significant for H1. Specifically, perceived trustworthiness of technology has a positive effect on perceived benefits, thus supporting H2 ($\beta=0.528$, $p<0.001$). Perceived benefits have a positive influence on IoT adoption intention, thus supporting H3 ($\beta=0.199$, $p<0.05$). Perceived cost is found to be significantly related to IoT adoption intention, thus supporting H4 ($\beta=-0.351$, $p<0.001$). Finally, external pressure also displays a significant and positive effect on IoT adoption intention ($\beta=0.39$, $p<0.001$), thus H5 is supported. However, perceived trustworthiness of technology is not significantly related to IoT adoption. Thus, H1 is not supported. Common method bias, which might occur in survey data, is also examined using Harman's single-factor test. The result shows that no one general factor emerges to account for the majority of data variance, indicating no significant common method bias in this study (Podsakoff *et al.*, 2003).

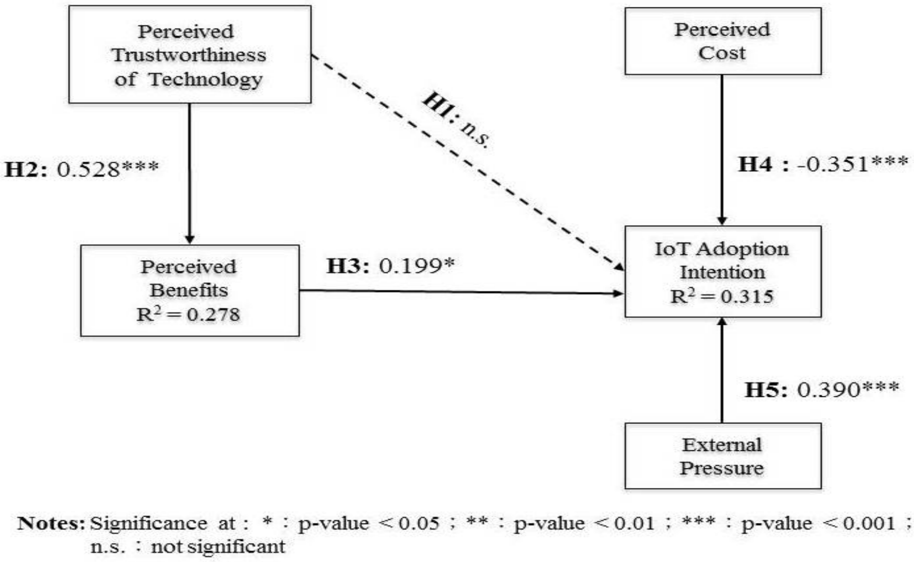

Figure 3. The PLS results of the structural model

6. Discussions and conclusions

The major contribution of this paper is that it is among the first to examine the issue of IoT adoption in logistics and supply chain management using mixed research methods. The mixed method strategy offers a better insight in understanding incentives behind firms' decisions to adopt IoT than just the use of either the qualitative or quantitative method alone. This section first employs meta-inference analysis to develop a consensus between the qualitative and quantitative findings and then presents managerial implications and concluding remarks.

6.1 Meta-inference

To evaluate the research findings obtained in the previous section, meta-inference analysis is applied with the bridging approach in the following discussions to develop a consensus between qualitative and quantitative findings (Venkatesh *et al.*, 2013). The qualitative data analysis in Phase I reveals that technology benefits have a positive effect on IoT adoption; however, the uncertainties about IoT technology could compromise the perceived benefits of IoT and might lower the adoption intention of an organization. The qualitative results also indicate that organizational level concerns (such as cost concerns) might become barriers to adoption, and the most influential factor affecting IoT adoption of an organization might be the external motivation force. The qualitative findings in phase I are mostly confirmed by quantitative data analysis whereby perceived benefits, perceived cost, and external pressure have a significant impact on the IoT adoption intention. The fact that perceived trustworthiness of technology has a positive influence on perceived benefits is also supported and echoes the qualitative finding that uncertainties (less trust) lead to lower perceived benefits of IoT, and vice versa. However, the relation between perceived trustworthiness of technology and IoT adoption intention is found to be insignificant, indicating a mediating effect that technology trust indirectly affects the adoption intention through perceived benefits. The results of the study show that the qualitative findings in Phase I can be generalized through quantitative research, indicating that the mixed research approach of this study successfully bridges the qualitative and quantitative research gap and synchronizes the merits of both research methods. The empirical findings in both research methods can also be cross-referenced to enhance the understanding of a research topic. Thus, the mixed research method of this study provides a more in-depth understanding of IoT adoption than a single method approach.

6.2 Managerial implications

The results of this research also have significant managerial and practical implications. The empirical results of this study offer some guidelines for logistics and supply chain managers to evaluate IoT adoption in their firms. Likewise, IoT solution providers can also benefit from the research findings of this work by improving their solutions to mitigate the IoT adoption concerns addressed herein, such as increasing the trustworthiness of IoT technology and overall reliability of IoT systems. This study demonstrates the importance of using a mixed research method when evaluating a firm's intention to adopt IoT for supply chain management within and across its organizational boundary. The above findings indicate that the reduction of technology uncertainties about IoT could enhance a firm's perception of benefits regarding IoT technology. Organizations that are evaluating IoT technology can take on some pilot IoT projects to assess the feasibility of applying and integrating IoT in their supply chain operations. Another perspective in the qualitative study expressed by many research participants is that the reliability of IoT technology often relates to the concept of trust in the IoT system. The quantitative study of this investigation further validates that the perceived trustworthiness of IoT has a strong impact on the perceived benefits of IoT, which significantly affect the intention to adopt IoT technology. Thus, for IoT service providers or in-house IoT system development teams, this study suggests they should focus more effort on reducing the risk and uncertainties of IoT systems addressed in the findings of qualitative research (Table 1), such as enhancing the RFID reading rate and system reliability in a manufacturing environment.

This study also finds that the external factor deeply affects the adoption intention in both qualitative and quantitative studies of this research, implying that large corporations or governments can play important roles in fostering IoT adoption by the proper use of regulations or mandates as incentives to encourage supply chain participants to take action in implementing IoT technologies. The high RFID adoption rate in the supply chains of Walmart and the U.S. Department of Defense (DoD) shows evidence for the above argument. Our mixed research results not only give a general guideline for IoT adoption as described in the quantitative findings but also articulates specific directions related to IoT adoption in the qualitative findings, which provide detailed and practical directions on how to enhance IoT adoption in the supply chain.

6.3 Concluding remarks

The qualitative research of this study gives researchers the opportunity to place themselves in the context of research participants' perspectives to gain fruitful insights for the theoretical development of IoT adoption intention. This study has tested the theoretical model about IoT adoption and synchronized the qualitative and quantitative findings. This research notes four key factors that affect firms' intention to adopt IoT when managing their logistics and supply chain: perceived benefits, perceived cost, trust of technology, and external pressure. Trust of technology indirectly affects the adoption intention through perceived benefits. The research finding indicates that many firms do not feel urgent to adopt IoT when there is no external pressure, such as regulations or strong requirements from customers.

A major limitation of this study is the small sample size, which affects the parameter estimates of the research model. Another limitation is that the research data are limited to Taiwan's domestic firms, indicating a potential culture or regional bias. Therefore, future research is encouraged to collect a larger sample for the quantitative study and also to acquire research data from other countries or different industry sectors. By testing the proposed model in other geographies or different industrial sectors, the findings herein can be further validated.

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