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A model of adoption determinants of IoT within the T-O-E framework in the Malaysian agriculture sector

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Abstract
Purpose: The adoption of digital technologies in the agricultural sector has produced paradoxical outcomes in terms of enhancing productivity and managing food supply chains for economies. With a growing population, there is a pressing need to improve agricultural productivity and sustainability and reduce the waste of resources. In spite of having access to the digitalisation of IR4.0, Malaysian agricultural sector has yet to effectively harness the potential of the Internet of Things (IoT). IoT has revolutionized processes across various industries and is poised to play a transformative role in agriculture by enabling automation and remote monitoring, thereby reducing the need for human intervention. This paper aims to develop the framework for adopting IoT in the agriculture sector by agroprenuers. It integrates the theoretical perspectives of the Technology-Organization-Environment (T0E) Model and Diffusion Innovation Theory (DIT) in the conceptualisation of the IoT–A (IoT Agriculture) adoption framework.
Methodology: The adaptation of IoT in the agriculture sector is a complex process and requires many technical and non-technical aspects. The study began by identifying the problem, reviewing the literature, and examining previous research gaps on the subject of this study. Findings from the literature are analyzed and synthesized.
Findings: The findings for this study are the extraction of important internal (technology, organisational) and external (environment) determinants and their linkages with IoT-A diffusion for the agriculture sector.
Research limitations/implications: The limitation of this study is perhaps the empirical assessment of the proposed IoT-A diffusion framework.
Practical implications: The outcome of this paper will contribute to practices by suggesting the IoT–A diffusion framework that practitioners, policymakers, and government institutions

then use to draft policies and actions to increase the implementation initiative of IoT in the agriculture sector.
Originality/value: The originality of this research is the interplay between the model and DIT theory for the diffusion of IoT-A in the agriculture sector.

Keywords: Internet of Things, Agriculture, Malaysia, TOE model, Diffusion Innovation Theory

Introduction

Technology has changed every industry in Malaysia, including agriculture. IoT is an increasingly prominent technology in the contemporary agricultural sector (Muangprathub et al., 2019). Ashton (2009) first introduced the concept of IoT, which Gubbi et al. (2013) later expanded upon. IoT refers to "an open and complete network of intelligent things capable of self-organizing, exchanging information, data, and resources, and responding to environmental changes and events" (Madakam et al., 2015, p. 165). The global expansion of internet-based IoT technology is growing rapidly, utilizing standard communication protocols, self-configuring physical and virtual identities, and integrating seamlessly into broader information networks (Sundmaeker et al., 2010). Food productivity must improve to feed the world's expanding population and limited resources, and we probably need 70% more food than we have now (Digital News Asia, 2019). IoT can solve this developing challenge. IoT-A (IoT in Agriculture) replaces people to automate and monitor agriculture worldwide. IoT-A would help farmers to monitor soil, weather, water systems, and crop quality (Verma & Usman, 2016). In detail, the benefits of IoT-A include:

a) Monitoring water and soil quality – choosing the proper plants for the soil, and diagnosing water-relatedillnesses in ponds in time to administer pesticides and fertilisers (Ojha et al., 2015).
b) Irrigation management maximises farm material and water use (Gutierrez et al., 2014).
c) Farm monitoring – automated monitoring of remote farms and farm machinery to reduce delays and damage (Lerdsuwan and Phunchongharn, 2017).
d) Fertiliser usage control – maintaining soil nutrition and crop quality (Ojha et al., 2015).
e) Cattle movement surveillance to prevent agricultural damage (Baranwal et al., 2016).
f) Pest management and disease control – using pesticides and fertilisers to boost crop quality and yield (Cambra et al., 2014).

In the limited availability of arable land, water, and fuel, IoT applications—such as self-driving tractors, GPS field mapping, sensor-equipped farm machinery, localized weather forecasting, machine optimization tools, and productivity measurement systems—are enhancing crop production (Jayashankar et al., 2018; Ray, 2017; Talavera, 2017). The global market of IoT-A expected to rise at 14.5 per cent annually from 2018 to 2023, reaching USD 28.65 billion by 2023. (BIS Research, 2018). IoT-A has tendency to reduce waste and increases productivity. It also changed farm management drastically (Muangprathub et al., 2019). According to researchers' prediction that, global need for food would see a substantial growth of 50-60 percent from 2019 to 2050, making feeding humans difficult (Falcon et al., 2022). To boost production, the agriculture business must use IoT technologies (Ashford, 2015).

In the context of Malaysia, according to The World Bank (2020), the majority of B40 (bottom 40%) households are engaged in agriculture. During the pandemic, the decline in household income and responses to uncertainties have generated a high amount of volatility in food markets in Malaysia. The report further stated that MCO (movement control orders) restrictions had caused many lags in supply of food items in the society. For example, the pandemic results in a rise in food prices because of panic-buying, supply disruptions and MCO (EDP, 2020).

Inappropriately, Malaysia's agriculture industry is exceptionally at an early level of modernisation and transformation (The World Bank, 2020). Research published by MARDI (Malaysian Agricultural Research and Development Institute) in FFTC- AP (Food and Fertilizer Technology for the Asian and Pacific Region) indicates that the agricultural sector faced production, distribution and marketing hurdles during MCO and CMCO (conditional movement control order) in Malaysia (MARDI, 2021). Particularly in agriculture production due to heavy reliance on human-based activities (Rashidi et al., 2021). While IoT-A would reduce the dependency on humans in agriculture production related activities. Hence. the technological advancements of IoT become an opportunity to level up modernisation to enrich the resilience of the agriculture sector. According to Datuk Seri Mustapa Mohamed (Economic Administrator at the Prime Minister's Office), Malaysia must recover from this crisis to emerge as a robust and inclusive post-pandemic economy in a structurally changed environment (The World Bank, 2021).
Therefore, the study aims to achieve three objectives:

- RO1: To identify the technological, organizational, and environmental factors influencing the diffusion of IoT-A in Malaysia's agricultural sector.
- RO2: To conceptualize and propose a framework to accelerate the adoption of IoT-A in Malaysia's agriculture sector.

Literature Review

This study proposes an integrated research model that combines the Technology-Organization-Environment (TOE) framework with the three contexts of technology, organization, and environment to investigate the stages of IoT adoption—evaluation, adoption, and routinization—using the Diffusion of Innovation Theory (DIT). The rationale for incorporating these adoption stages is twofold, as outlined in the technology adoption literature (Cruz-Jesus et al., 2019). First, a factor influencing adoption may serve as an antecedent for IoT adoption at one stage but may not be relevant across all stages or could exhibit varying effects. Second, there is a notable gap in the literature concerning the inclusion of adoption stages in the analysis (Cruz-Jesus et al., 2019; Junior et al., 2019; Puklavec et al., 2018). In other words, it is reasonable to propose that certain factors or attributes may specifically predict the likelihood of adoption at a particular stage of IoT implementation.

TOE Model

The Technology Organization and Environment (TOE) model emerges from the book "The Process of Technological Innovation: Reviewing the Literature" by the National Science Foundation (NSF) United States (1983). This book is outcome of four years of rigorous literature review on technology innovation and processes for organisations. The NSF inducted a team of various prominence researchers to conduct the literature review, dissemination and publishing the book. In this book the authors had intent to research on organisational context of technology adoption for the reasons; first, to use innovations effectively, organisations must invest time and money in the innovation, and as a result these ideas are intrinsically linked to the dynamics of organisational behavior. Another drawback of previous innovation research was that it either looks at macro indicators like tax or social policies or micro indicators like attributes of innovation adopters, and rarely includes the influence of organisational context. Later in (1990), Tornatkzy wrote another book on technological innovation with two other researchers Fleischer and Chakrabarti. After words, this book "The Processes of Technological Innovation" become primary reference point for TOE Model. The book gives a full description of the innovation process, from the time an engineer or entrepreneur contemplates of an innovation, to the time when a user adopts and implements it within a company or organisation.

The TOE model describes three distinct components of a firm's contexts to impact adoption decisions. The elaboration of contexts is i) the technological context, which refers to both existing technologies and those with potential relevance to the organization; ii) the organizational context, which includes factors such as the organization's size, scope, and available resources; and iii) the environmental context, encompassing external influences such as competition and government regulation (Tornatzky, L. G., Fleischer, M. & Chakrabarti, 1990). A number of theories include all three as having a direct influence on technology adoption decisions (Baker, 2012).

Technology Diffusion Process

Innovation diffusion is described as a stage-based process of technology adoption. This process occurs over a sequence of steps which first starts with an awareness of the technology itself including the benefits and barriers to implementing it in the organisation. This step is followed by a formal decision to adopt the technology and then implementation as the beginning of integrating the technology (Ngah,2017). Most of the studies in the literature divided the process of IT innovation adoption into three different stages: Initiation is the first stage, where perceived advantages of IoT are assessed across all related processes at the firm level to complete the attitude towards the IoT adoption. IoT adoption is the following stage: formalising the adoption decision by evaluating the IoT technology infrastructure. The last stage is routinisation, which includes the implementation of IoT solutions and the preparation for use by setting up trial versions for the technology approval of agriculture players.

IoT and Agriculture

The Internet of Things (IoT) refers to integrating many devices engaged in communication, sensing, and interacting with internal and external environments. This is made possible by using embedded technology inside IoT devices (Lee & Lee, 2015). The technological components of IoT include identifiers, sensors and actuators, communication devices and systems, computational devices, cloud-enabled data and information storage, and analytics (Al-Fuqaha et al., 2015). These components collectively offer an extensive suite of tools for process automation, reducing human involvement and making data-driven decisions that can bring forth breakthroughs in the agricultural sector (Brewster et al., 2017; Farooq et al., 2019). For example, Muangprathub et al. (2019) implemented and tested an IoT-A system for the automatic watering to vegetable crops based on the seasonal effect of temperature and crop production. The study further assessed the financial impact of IoT-A technology investments, finding that agricultural productivity gains led to a return on investment (ROI) within just two months.

Proposition development of IoT-A Adoption Framework

This study examines the diffusion phases—evaluation, adoption, and routinization—as dependent variables to explore the specific requirements of the agricultural sector (Chan & Chong, 2013). The determinants of IoT diffusion in the study model (Figure 1) are derived from the Technology-Organization-Environment (TOE) framework and the Diffusion of Innovation Theory (DIT), as identified in prior research on technology adoption (Lai et al., 2016; Oliveira et al., 2014; Picoto et al., 2014; Ruivo et al., 2012, 2014). Additionally, the Theory of Planned Behavior has aided in identifying the various stages of dissemination and the key factors most relevant to each stage. Meanwhile, the DIT framework has helped identify critical factors influencing the technological and organizational aspects of agricultural enterprises.

Technology Context

The technology context is considered to include compatibility, relative advantage, complexity and perceived cost. The relevance and linkages with IoT diffusion are discussed as follows

Linkages between compatibility and IoT diffusion:

The concept of compatibility, as proposed by Bradford and Florin (2003) and further developed by Picoto et al. (2014), is a latent variable that may be justified by the alignment between information systems and many aspects of the selling process, buying process, organisational culture, and information infrastructure inside a farm. This implies understanding how well a new technology fits with the norms, experiences, and requirements of the target audience who could embrace it in the future (Zitan & Khalid, 2021). In this regard, organisations tend to find it more practical to adopt a certain technology when it exhibits greater technological compatibility (Shi & Yan, 2016). Thus, the following propositions were formulated for the study:

P1a(+): Compatibility has a positive influence on IoT Evaluation.
P1b(+): Compatibility has a positive influence on IoT Adoption.
P1c(+): Compatibility has a positive influence on IoT Routinization.

Linkages between relative advantage and IoT diffusion:

The concept of relative advantage pertains to the extent to which a new technology is seen as superior to its predecessors by offering organisational benefits (E. Rogers, 1995). It has constantly emerged as an essential indicator of individuals' intention to adopt innovations, as shown by several studies in the field of innovation diffusion. According to (E. M. Rogers, 2003) more assumptions are included under this characteristic, including image, enhanced efficiency, convenience, and economic advantages. For instance, it is anticipated that implementing IoT technology would lead to enhanced capabilities and higher efficiency levels for individuals and business organisations. Consequently, we establish the subsequent. Propositions for the study:

P2a(+): Relative advantage has a positive influence on IoT Evaluation.
P2b(+): Relative advantage has a positive influence on IoT Adoption.
P2c(+): Relative advantage has a positive influence on IoT Routinization.

Linkages between complexity and IoT diffusion:

Complexity refers to the level of complexity involved in understanding and effectively using an innovation (E. M. Rogers, 2003). The adoption and routinisation are less likely to occur when users and organisations perceive an innovation to be difficult to use and complex. The extent of perceiving complexity for IoT is different for small- and large-scale producers, however the level of complexity negatively affects intention of both group in the process of evaluation, adoption and routinisation. For instance, according to Scur et al. (2023) small producers, who frequently experience less interaction with new technologies, complexity is a significant obstacle that must be overcome. The most important factor is the absence of access to technology providers and experts, pushing a potential adopters to seek to technology implementations at their own. As a result, the capability for small-scale producers to use IoT technologies might hindered, that ultimately limiting their willingness to fully embrace the roll out of IoT in agriculture. Based on that, we set the following propositions for the study:

P3a(−): Complexity has a negative influence on IoT Evaluation.
P3b(−): Complexity has a negative influence on IoT Adoption.
P3c(−): Complexity has a negative influence on IoT Routinization

Linkages between perceived cost and IoT diffusion:

Perceived cost is a critical factor influencing technology adoption decisions (Alam et al., 2011). According to Ha yes (2012), the implementation of new technologies often incurs significant costs. However, while high costs are involved, businesses that fail to adopt the latest technologies risk falling behind their competitors in the digital age. The perception of cost differs between large-scale and small-scale producers. For large-scale producers, the focus is on the potential cost savings and the long-term benefits that outweigh the initial investment. In contrast, for small-scale producers, cost remains a significant barrier to adoption, largely due to limited access to financing and the prevalence of high interest rates (Scur et al., 2023). As a result, the perceived costs associated with implementing IoT-A are likely to influence producers' decision-making processes regarding the adoption of this technology. Based on this, the following propositions are proposed for the study:

P4a(−): Perceived Cost negatively influences IoT Evaluation.
P4b(−): Perceived Cost negatively influences IoT Adoption.
P4c(−): Perceived Cost negatively influence on IoT Routinization

Organisational Context

Organisational context includes particular aspects of an organisation that affect the decisions made about the technology's evaluation, adoption and routinisation. The organisational determinants that have been discovered in research on the diffusion of IoT-A include top management support, technology competence, and readiness of resources.

Linkages between top management support and IoT diffusion:

The concept of top management support has been derived from the work of Jia and Barnes (2017), who built upon the research conducted by Chan and Chong (2013). The top management support plays a crucial role in strategic planning for the utilisation of IoT, particularly when informed by insights derived from analytical platforms. The choice to uphold an existing corporate system substantially influences the organisation's performance and long-term viability. The ultimate determination made by the management team is influenced by individual cognitive beliefs and the prevailing consensus stated through a collective perspective. Prior studies indicated that the effect of Top Management on the decision-making process of technology dissemination is significant (Junior et al., 2019; Martins et al., 2016; Shi & Yan, 2016). Thus, the propositions might be stated as follows:

P5a(+): Top management support positively influences IoT Evaluation.
P5b(+): Top management support positively influences IoT Adoption.
P5c(+): Top management support positively influences IoT Routinisation.

Linkages between technology competence and IoT diffusion:

Technology competence considers the technical attributes inherent in a company, which involves the IT infrastructure, expertise of IT employees and experts. In this research, technology competence (Kim et al., 2016), adapted from Chan and Chong (2013), is a latent variable justified by infrastructure, ability, knowledge, support to operation, wireless communication with tractors and combination and use of precision agriculture. There, it is postulated that there exists a positive relationship between an organisation's degree of technological competency and its readiness for the proliferation of IoT-A. The following are the proposed propositions:

P6a(+): Technology Competence positively influences IoT Evaluation.
P6b(+): Technology Competence positively influences IoT Adoption.
P6c(+): Technology Competence positively influences IoT Routinisation.

Linkages between the readiness of resources and IoT diffusion:

The measurement of organisational factors often includes the assessment of organisational resource readiness and organisation-technology compatibility. Resource readiness pertains to organisations' preparedness regarding the many resources required to adopt novel technologies, encompassing human, material, and financial resources (Nohria & Gulati, 1997). The presence of sufficient resources has been found to have a notable and favourable influence on the adoption behaviour of firms, as evidenced by the study conducted by Shalini and Nanda in 2018. The more surplus resources possessed by organisations, the enhanced their capacity to manage hazards and the increased their capability to embrace novel technology.

The level of readiness of resources has been found to have a notable and favourable influence on the adoption behaviour exhibited by firms. Excess organisational resources enhance the organisation's capacity to manage risks and bear the financial burden of unsuccessful innovation endeavours while fostering the organisation's inclination to embrace new technologies. This study employed the methodologies proposed by Nohria and Gulati (1997) to assess the readiness of resources in constructing cooperatives. This approach has shown to be efficacious in elucidating the preparedness of firms' resources in subsequent demonstration tests. Consequently, the propositions that have been formulated are as follows:

P7a(+): Readiness of resource positively influences IoT Evaluation.

P7b(+): Readiness of resource positively influences IoT Adoption.

P7c(+): Readiness of resource positively influences IoT Routinisation.

Environment Context

Diverse organisations encounter varying degrees of external exposure to obstacles, resulting in differential impacts across industries. According to the research conducted by Wang, Brooks, and Sarker (2015), when pressures are more pronounced, the scope for divergence becomes limited. Within this particular setting, organisations are engaging in the replication of established practices while also adjusting to external demands. It is important to note that a change from these established practices is not readily accepted and necessitates the process of legitimisation. Frumkin and Galaskiewicz (2004) propose that adapting to one's surrounding environment may be seen as a strategy to prevent or reduce disputes. The subsequent section analyses the three distinct categories of external or institutional influences. The sequence in which they will manifest is as follows: coercive pressures, normative pressures, and mimetic pressures.

Linkages between coercive pressures and IoT diffusion

According to Grant and Marshburn (2014), coercive pressures can originate from governmental bodies in the form of regulations or policies. Governments hold the authority to impose regulations or mandates, such as laws concerning pollution control (Wang et al., 2015), which organizations are obligated to comply with. Coercive pressures manifest in the need to adhere to legal requirements and associated rules (Lei & Ngai, 2012). It has been suggested that these pressures are particularly pronounced when an organization's practices are perceived as misaligned with societal interests, prompting governmental intervention (Grant & Marshburn, 2014). These pressures typically come from entities with legitimacy and power to influence others. Grant and Marshburn (2014) further argue that pressures arise from the interactions and dependencies between organizations, and can be exerted through formal regulations or informal "directives," as the proposition describe.

P8a(+): Coercive pressure positively influences IoT Evaluation.

P8b(+): Coercive pressure positively influences IoT Adoption.

P8c(+): Coercive pressure positively influences IoT Routinisation.

Linkages between normative pressures and IoT diffusion

Normative pressures refer to an organization's need to conform to what is considered legitimate within its specific context. It is common for organizations to adopt practices that are regarded as the norm in a given environment. Grant and Marshburn (2014) suggest that normative pressures often arise from interactions with key stakeholders, such as partners, customers, and suppliers. Similarly, Lei and Ngai (2012) argue that stakeholders' expectations can serve as a form of normative pressure. These pressures help align an organization's internal practices with broader societal expectations and the well-being of its operations. Based on this understanding, the following propositions are proposed:

P9a(+): Normative pressure positively influences IoT Evaluation.
P9b(+): Normative pressure positively influences IoT Adoption.
P9c(+): Normative pressure positively influences IoT Routinisation.

Linkages between mimetic pressures and IoT diffusion

The likelihood of adopting a practice increases when other organizations have previously implemented it (Chen et al., 2011). Mimetic pressures arise when organizations feel compelled to emulate the practices of their peers within the same sector or industry (Fong Lei & Ngai, 2012). To effectively imitate others, organizations must remain attentive to the actions of their counterparts in the specific sector (Wang et al., 2015). Additionally, Grant and Marshburn (2014) suggest that the organizations that serve as models for imitation are those perceived to have achieved success by incorporating the practices being emulated. Mimicking can serve as a viable strategy for companies that lack certain resources or capabilities possessed by leading competitors.

H10a(+): Mimetic pressure positively influences IoT Evaluation.
H10b(+): Mimetic pressure positively influences IoT Adoption.
H10c(+): Mimetic pressure positively influences IoT Routinisation.

Discussion and Conclusion

The phenomena of technology diffusion are complex, and it is not achievable with one theory to take into account every aspect of technology diffusion. The main objective of this research is to broaden the perspective of research in finding out the critical determinants for the dissemination of IoT-A (Internet of Things in Agriculture). A theoretical framework has been developed to promote the proliferation of IoT-A, drawing upon the interplay between the Technology-Organization-Environment (TOE) model and the Diffusion of Innovation Theory (DIT). In literature, little attention has been given to the determinants within the TOE model for the diffusion of IoT-A, particularly within the Malaysian context. The current study explores the diffusion of IoT-A via a review and conceptualisation of the determinants influencing its diffusion throughout three distinct stages: evaluation, adoption, and routinisation. The theoretical framework was developed with an emphasis on the determinants within the technical context, organisational context, and environmental context. The present study is part of a larger research project focused on the diffusion of IoT and blockchain technologies across Malaysia's agricultural and food sectors.

Theoretical Implications

The current research has two theoretical implications for the agricultural sector of Malaysia. First, it offers a fresh theoretical perspective for the diffusion of IoT-A in the agriculture sector by considering internal and external factors for organisations using the TOE model. Second, the conceptualisation of the theoretical framework IoT-A extended the scope in the previous literature from adoption to diffusion, which encompasses three phases: technology evaluation, adoption and routinisation.

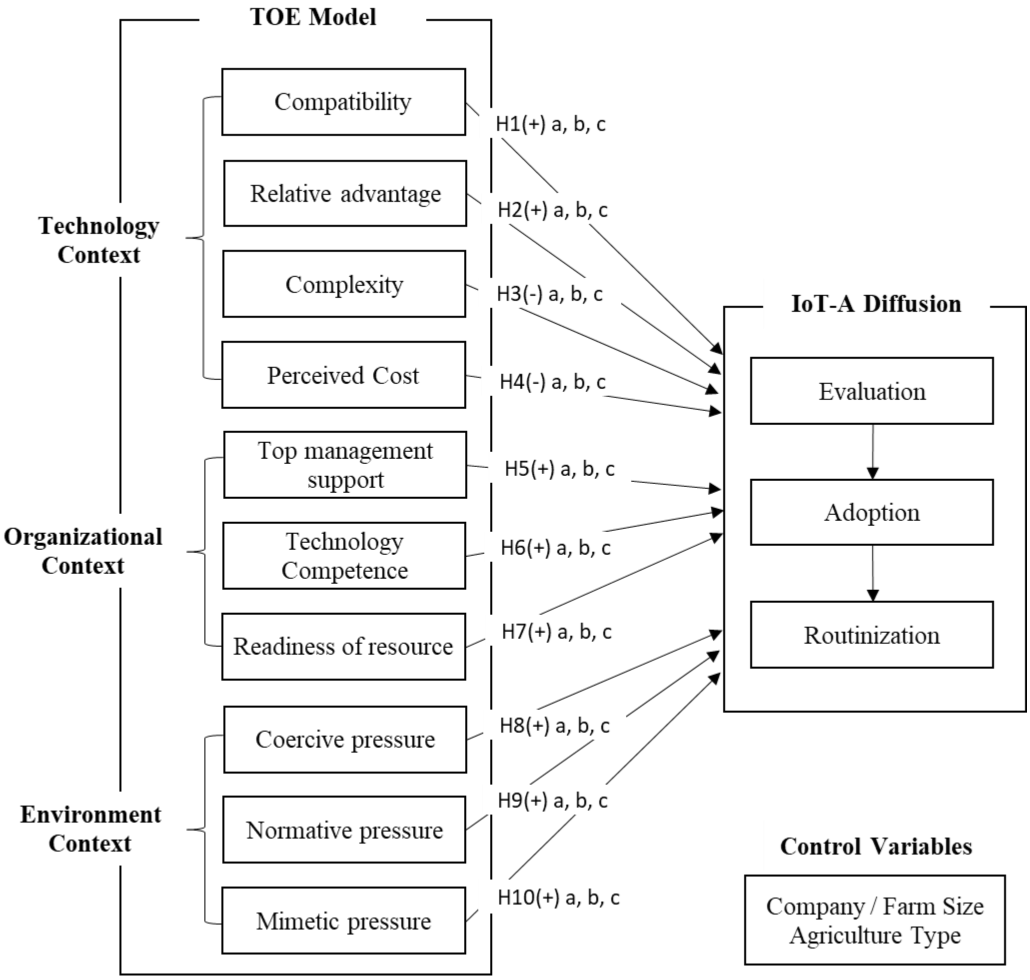

Figure 1: The Proposed IoT-A Diffusion Framework

Practical and Social Implications

The study would add value to the practices for the absorption of modernisation in the agriculture sector of Malaysia. The proposed framework will allow practitioners, policymakers, and governments to use it as a benchmark tool to devise policies and action plans for agroprenuers to utilise IoT-A in the agriculture sector. In the long run, the diffusion of IoT-A in agriculture via our proposed framework would increase productivity and performance, contributing to the availability of food for future generations and society.

Limitations and Suggestions for Future Research

The primary limitation is that the current study attempts to conceptualise and proposed IoT-A diffusion framework, which has yet to be empirically tested. So, the first suggestion for future researchers would be the empirical assessment of the relationships proposed using the PLS-SEM approach to determine the significance of each construct in the framework. Secondly, the empirical analysis would include group-level analysis for Malaysia's small, medium, and large-scale agroprenuers. For instance, the negative influence of perceived cost and complexity on

IoT-A diffusion stages would differ because large-scale agroprenuers have sufficient funds and expert IT teams to manage the IoT-A implementation initiative.

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