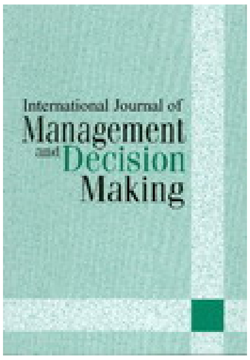

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A hierarchical structure model for blockchain technology adoption

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Abstract: Although blockchain technology (BT), with the characteristics of decentralisation, autonomy, and anonymity, shows significant promise in increasing operational efficiency and transparency, the diffusion of BT remains slow. To address this dilemma, we investigate the hierarchical structure among various determinants of BT adoption based on the technology-organisation-environment (TOE) model and the diffusion of innovation theory (DOI). We employ an integrated approach, sequentially including the decision-making trial and evaluation laboratory (DEMATEL) technique, the maximum mean de-entropy (MMDE) technique, and the interpretive structural modelling (ISM) approach. The empirical results from 17 BT practitioners and scholars reveal that complexity, compatibility, competitive pressure, and government support are four basic factors to constitute a hierarchical structure. In contrast, the relative advantage is the only factor in the second layer, followed by organisational readiness and top management support in the first layer. We contribute to BT adoption literature by presenting a new hierarchical structure of different determinants.

Keywords: blockchain; technology-organisation-environment model; diffusion of innovation theory; interpretive structural modelling; ISM.

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1 Introduction

Blockchain technology (BT), one of the representative technologies of Industry 4.0, has enormous potential to disrupt traditional sectors and create new business models (Morande and Vacchio, 2022). Many well-known companies, such as Google, IBM, and Taobao.com are actively investing in and developing BT to enhance the transparency of the supply chain and improve the efficiency of transactions (Sarker and Datta, 2022). The outbreak of the COVID-19 pandemic has also forced many sectors to re-evaluate the development and application of BT because of its potential to improve supply chain resilience (Philsoophian et al., 2021; Li et al., 2022). Although BT may provide many significant benefits for business operations (Leo and Hales, 2021), the diffusion of BT remains slow. A recent report reveals that notwithstanding the fact that the majority of the companies surveyed agree on the importance of BT, only 39% of those surveyed have truly launched a BT project (Pawczuk et al., 2020). Moreover, some practitioners believe that the value of BT is exaggerated (Pawczuk et al., 2020), and thus, they resist adopting BT. To address the above dilemma, developing a better understanding of which factors may influence a company's BT adoption decision is critical for both scholars and practitioners.

The extant studies primarily use the technology adoption model (TAM) (Zhu et al., 2022), the unified theory of acceptance and use of technology (UTAUT) (Jain et al., 2022), and the theory of planned behaviour (TPB) (Sadeghi et al., 2022) to explore the antecedents of BT adoption from the perspective of technology-related factors. However, BT adoption is not just a simple technical decision but a commercial decision (Toufaily et al., 2021), and thus, it requires leadership support at both the macro and micro levels, as well as consideration of the organisation's environment (Agi and Jha, 2022). Although several studies have employed the technology-organisation-environment (TOE) framework to explore the factors related to BT adoption, on the one hand, most studies are conceptual in nature (Toufaily et al., 2021; Kumar et al., 2022); on the other hand, they are primarily concerned with the simple linear relationships between various driving factors and BT adoption (Orji et al., 2020; Dehghani et al., 2022). Because there may be potential linkages among various driving factors (Yousefi and Mohamadpour Tosarkani, 2022; Farooque et al., 2020), to obtain a better understanding of the antecedents of BT adoption, scholars should go beyond the linear relationship and explore the possible structure from a holistic perspective. Given that the diffusion of innovation (DOI) theory reveals the major innovation characteristics of BT from the perspective of technology-related factors (Agi and Jha, 2022), we combine the DOI theory with the TOE framework. In this paper, our major research question is: *from an integrated DOI and TOE perspective, what is the hierarchical structure that promotes the companies to adopt BT?*

To answer the above research question, we interview 17 practitioners and scholars who have specific knowledge and experience with BT. By integrating the decision-making trial and evaluation laboratory (DEMATEL) technique, the maximum mean de-entropy (MMDE) technique, and the interpretive structural modelling (ISM) approach, we exhibit how various factors derived from the DOI and TOE perspectives constitute a hierarchical structure to promote the adoption of BT. We contribute to the BT adoption literature in the following two aspects. First, we empirically confirm that the influence of different driving factors on BT adoption is not isolated, and they interact with each other. In particular, the factors of organisational level are influenced by the factors of technology level and environment level. At the same time, the organisational factors such as top management support and organisational readiness are not only influenced by other factors, but they may also influence each other to boost BT adoption. Hence, our study enriches the existing understanding of the antecedents of BT adoption. Second, we extend the existing understanding of the simple linear relationship between different driving factors and BT adoption to an overall structural perspective. To be specific, we articulate that the hierarchical structure for BT adoption consists of three layers: complexity, compatibility, competitive pressure, and government support make up the base layer; the middle layer is mainly connected to relative advantages, and the top layer includes organisational readiness and top management support. Accordingly, these findings provide a new theoretical explanation of how different factors jointly influence the company to adopt BT. Managerially, our study can help practitioners and policymakers better allocate scarce resources and take effective measures to promote the adoption of BT.

2 Literature review

2.1 Prior work related to BT adoption

From the perspective of technology-related factors, many studies have applied various theoretical frameworks, including TAM (Zhu et al., 2022; Davis, 1989), UTAUT (Jain et al., 2022; Venkatesh et al., 2012), and TPB (Sadeghi et al., 2022; Ajzen, 1987), to explore the antecedents of BT adoption. For example, Jain et al. (2022) use the UTAUT framework to identify and analyse the antecedents to Blockchain-Enabled E-commerce Platform adoption in secondhand apparel retailing. For example, Jain et al. (2022) use the UTAUT framework to identify and explore the driving factors adopting blockchain-enabled e-commerce platform in secondhand apparel retailing. Moreover, by constructing an integrated framework that includes TAM, TRI, and TPB, Kamble et al. (2019) investigate how perceived usefulness, perceived ease of use, and insecurity may generate impacts on a company's intention to adopt BT. Although the existing research has provided certain understandings of the antecedents of BT adoption, Zhu et al. (2022) further argue that BT adoption should be explored more thoroughly from the perspective of organisational strategy. The major reason is that adopting BT is a decision that involves both technology and business, so the organisational and environmental factors involved in BT adoption at the firm level must be studied (Agi and Jha, 2022).

To this end, some scholars have used the TOE framework involving the dimensions of technology, organisation, and environment to identifies the antecedents related to BT adoption (Kumar et al., 2022). For example, Dehghani et al. (2022) find that the seven antecedents affecting blockchain adoption intention based on the 146 survey samples collected from 71 North American organisations, such as perceived interoperability, lack of technological knowledge and regulatory uncertainty. By summarising the literature associated with BT adoption, Kumar et al. (2022) categorise the enablers into the SC view-related enablers and external view-related enablers. Although the existing work has made significant contributions, there are still some areas that can be strengthened. First, most studies are conceptual (Toufaily et al., 2021), and thus, the effectiveness of these factors needs to be further empirically tested. Second, most studies mainly focus on the simple linear relationships between various factors and BT adoption (Kamble et al., 2021), while ignoring the possible interaction between various factors.

Indeed, investigating the interactions between various factors is crucial because such interactions may result in unanticipated outcomes and promote the company to adopt BT (Yousefi and Mohamadpour Tosarkani, 2022). For example, Kamble et al. (2021) suggest that a low level of complexity and a high degree of compatibility may enhance the perceived ease of using BT, thus encouraging companies to adopt it. Agi and Jha (2022) argue that consumer and company managers' perception of BT usefulness and BT interoperability influence the cooperation of supply chain members towards BT adoption. Clohessy et al. (2020) argue that the potential link between organisational readiness and top management support results in inadequate resources for the BT innovation projects, pushing BT adoption forward. Yadav et al. (2020) believe that the lack of regulatory standards for BT may lead to a lack of trust among companies, increasing the complexity of designing BT-based systems and hindering the adoption of BT. Overall, given the complex interaction of different factors, merely focusing on the simple linear relationships between various factors and BT adoption is not sufficient, and scholars need to investigate from a holistic perspective.

2.2 Framework development from an integrated DOI and TOE perspective

BT adoption is not only a technical decision but also a business decision that requires macro and micro-level leadership support and considers whether the extant environment can favour relevant decisions (Toufaily et al., 2021). TOE framework focuses on factors that explain the adoption of technology innovation at the organisational level. BT is an innovative technology, and the factors influencing its adoption can follow the TOE framework which identifies the factors under three dimensions: technology, organisation, and environment (Kouhizadeh et al., 2021). Furthermore, BT adoption also requires the organisation to have innovative thinking. The DOI theory points out that five factors affect the innovation adoption decision (Erol et al., 2022). Various studies suggest that integrating the TOE framework with the DOI theory can provide comprehensive factors for businesses to adopt innovative technologies (Maroufkhani et al., 2020). Therefore, according to the existing literature, we summarise the factors derived from an integrated DOI and TOE perspective in Table 1. Next, we will discuss the factors of three dimensions in more detail and the potential influence of each factor on companies' adoption of BT.

Regarding the technological dimension, the DOI theory suggests that relative advantages, complexity, and compatibility, are the main factors associated with BT adoption (Agi and Jha, 2022). First, compared with traditional information systems, BT has many relative advantages, including decentralisation, stability, and non-tampering (Zhan et al., 2022), all of which have the potential to bring huge value to companies and encourage them to embrace it (Chen et al., 2022a). Second, BT adoption necessitates a high level of competence for effective system design (Nodehi et al., 2022), and technical immaturity complicates the application of BT in several sectors (Saberi et al., 2019). Hence, companies may be hesitant to invest in BT. Third, compatibility reflects to the degree to which an innovation fits with the existing values, previous practices, and current needs of adopters (Rogers, 1995). If BT is incompatible with existing information systems and business requirements, it may be difficult to achieve the value of BT (Nodehi et al., 2022). Similar to the prior studies, in this paper, we primarily treat relative advantages, complexity, and compatibility as the representatives of the technological dimension.

With respect to the organisational dimension, the prior work has identified various antecedents related to innovative technology adoption, such as training and education (Kamble et al., 2021), top management support (Huang et al., 2022), firm size (Rey et al., 2021), absorptive capacity (Queiroz and Fosso Wamba, 2019), organisational culture (Orji et al., 2020), and organisational readiness (Agi and Jha, 2022). Of the above factors, Clohessy et al. (2020) highlight that organisational readiness and top management support are particularly important for BT adoption. This is because, on the one hand, organisational readiness, which refers to the commitment of an organisation to allocate the resources (e.g., human resources, finance, and IT infrastructure) needed for innovative technology adoption (Agi and Jha, 2022), is the core for BT adoption. On the other hand, top management support, which reflects the determination of the executives, may influence resource allocations and the company's budgetary, as well as guaranteeing long-term commitment to BT deployment by cultivating a positive company culture that assists in overcoming obstacles and limitations (Huang et al., 2022). Therefore, in this paper, we use organisational readiness and top management support as the primary representatives of organisational factors.

Table 1 An integrated DOI and TOE framework

Dimensions	*Factors*	*Description*	*References*
Technological	Relative advantage	The degree to which an innovation is perceived as being able to provide greater organisational benefit	Zhan et al. (2022), Rogers (1995), Chen et al. (2022a)
	Complexity	The degree to which an innovation is perceived as being difficult to understand or use	Toufaily et al. (2021), Nodehi et al. (2022), Rogers (1995)
	Compatibility	The degree to which an innovation fits with the existing values, previous practices, and current needs of adopters	Toufaily et al. (2021), Kamble et al. (2021), Nodehi et al. (2022)
Organisational	Top management support	Managers have long-term commitment and support of adopting innovation to improve business capabilities	Kouhizadeh et al. (2021), Huang et al. (2022), Guo et al. (2020)
	Organisational readiness	The commitment of an organisation to allocate the resources needed for innovation adoption, mainly including human resources, financial, and IT infrastructure facets	Toufaily et al. (2021), Agi and Jha (2022), Zhou et al. (2020)
Environmental	Competitive pressure	The desire and internal motivation for enterprises to adopt innovation to gain competition when facing pressure from the competitors, the new business models, and industry standards	Agi and Jha (2022), Ahl et al. (2022), Wong et al. (2020a, 2020b)
	Government support	A series of policies and legal systems that have an impact on the survival and development of enterprises, such as regulatory standards, government incentive policy, and government guidance	Kumar et al. (2022), Yadav et al. (2020), Zhao et al. (2019)

For the environmental dimension, past studies have shown that the uncertainty of the regulatory environment is the biggest obstacle associated with BT adoption (Kumar et al., 2022). More specifically, the existence of regulatory gaps, which is caused by the government's regulatory framework lagging behind technological progress, greatly hinders the enthusiasm of companies to participate in BT (Maden and Alptekin, 2021). Because government support not only completes the regulatory system but also provide various policy instruments, such as regulatory standards, incentive policies, and government guidance, to remove barriers related to BT adoption, most scholars claim that government support should be a key external driver for the companies to adopt BT (Toufaily et al., 2021). Moreover, because most companies are in a fiercely competitive environment, many scholars have claimed that competitive pressure should be another key environmental factor that affects a company's BT adoption decision (Agi and Jha, 2022). In particular, competitive pressure refers to the desire and internal motivation for companies to adopt innovative technology to gain a competitive advantage when facing pressure from the upstream and downstream competitors, the development of business models, and the new industry standards (Ahl et al., 2022). Currently, many well-known companies, such as Wal-Mart, Alibaba, and JD.com (Guo et al., 2020), have adopted BT in their supply chains to enhance their competitiveness. Given the above arguments, in this paper, we consider government support and competitive pressure as the major representatives of environmental factors.

2.3 Review of ISM approach

To identify the complex interactions between different factors and obtain an overall hierarchical structure, an effective way is to use the ISM approach (Trivedi et al., 2021). In particular, the ISM approach is based on experts' opinions on the direct interaction of system parts to examine the interrelationship and dependence structure between the different elements (Warfield, 1974), thereby ultimately constructing a multi-level structural model to decompose complicated issues into smaller subsystems and identify key issues (Kumar et al., 2022). Many studies have applied the ISM approach to address different problems in operation management (see Table 2), such as BT adoption in the tourism industry (Erol et al., 2022), building-integrated photovoltaics implementation (Chen et al., 2022a), and Assessment of circular economy enablers (Patel et al., 2021). However, the ISM approach also has some limitations. For example, the ISM approach primarily analyses the relationships at the level of whether variables affect each other (0 for no relationship, 1 if a relationship exists), but it does not explain the problem of 'how' (Farooque et al., 2020). Besides, the connection between elements is in the ISM approach not necessarily comparable in real-world circumstances because they might be weak, medium, or strong, and the ISM approach cannot effectively characterise them (Liang et al., 2022).

To compensate for the limitations of the ISM approach, past studies have integrated the DEMATEL technique into the ISM approach (Kumar et al., 2022; Trivedi et al., 2021). The DEMATEL technique is a structural modelling method that employs graph theory to analyse the cause and effect of variables and use a cause-result diagram to illustrate the connections (Altuntas and Gok, 2021). Moreover, the DEMATEL technique measures the strength of interaction between variables on a suitable scale, which assisting the ISM approach in determining interrelationships and building hierarchical structures (Singh and Bhanot, 2020). Currently, an integrated DEMATEL-ISM approach has been widely used in the innovative technology adoption field to identify the key obstacles, challenges, and drivers. For example, Raut et al. (2021) combine the ISM approach with the DEMATEL technique to identify the most significant barriers related to big data implementation. Sharma et al. (2021) propose a mixed methodology based on the analytic hierarchy process (AHP) and an integrated DEMATEL-ISM approach to rank critical enablers and barriers of BT adoption. Some studies using an integrated DEMATEL-ISM approach are summarised in Table 3.

Overall, the DEMATEL technique is a micro-oriented approach to determine the intensity of indirect and direct interactions between the factors and present the visualisation of the causal structure (Qazvini and Maleki, 2022), whereas the ISM approach is macro-oriented and aims to decompose a complicated structure into simpler subsystems (Gardas et al., 2019). Furthermore, past research is mainly based on the results of expert discussions to integrate the DEMATEL technique and the ISM approach, which is extremely subjective (Singh and Bhanot, 2020). In contrast, the MMDE algorithm is regarded as an objective method that determines the unique threshold to combine the DEMATEL technique with the ISM approach (Singh and Bhanot, 2020). Accordingly, in the following, we primarily use an integrated

DEMATEL–MMDE-ISM approach to explore deeper relationships and the possible structure between the factors of BT adoption.

Table 2 Prior work related to the ISM approach

Application area	*Types of experts*	*Number of experts*	*Reference*
Barriers to IoT adoption in food retail supply chains	Professors and industry managers	10	Singh and Bhanot (2020)
Characteristics of BT	BT experts	11	Yadav and Singh (2020)
BT adoption in the tourism industry	Professors and industry managers	25	Erol et al. (2022)
Building-integrated photovoltaics implementation	Senior specialists	9	Chen et al. (2022b)
Factors influencing entrepreneurial inclination	Industrial experts	18	Kapse et al. (2018)
Enablers of sustainable manufacturing	Industrial experts	20	Thirupathi and Vinodh (2016)
Circular economy enablers	Academia and industry managers	9	Patel et al. (2021)

Table 3 Prior work related to the integrated DEMATEL-ISM approach

Application area	*Types of experts*	*Number of experts*	*Reference*
Barriers of IoT implementation in the manufacturing industry	Senior production managers, supply chain managers, operation research scholars, mechatronics scholars, and computer integrated manufacturing scholars	10	Singh and Bhanot (2020)
Enablers for BT adoption in the agricultural supply chain	Academicians, system integrators, senior-level managers, and bank managers	12	Kamble et al. (2020)
Factors influencing omnichannel retailing adoption	Industrial professors, senior-level industry practitioners, academicians, and senior research scholars	12	Mishra (2020)
Barriers to inland waterways	Industrial experts and academics	22	Trivedi et al. (2021)
Enablers for BT adoption in hospitality and tourism sectors	Industrial experts	18	Sharma et al. (2021)

3 Methods

3.1 Data collection

To use an integrated DEMATEL-ISM approach to identify the possible structure for BT adoption, the suggested number of an expert group should be between 5 and 25 members (Trivedi et al., 2021; Mathivathanan et al., 2021). As BT is a novel technology, it is essential to select respondents with sufficient knowledge and expertise to respond to the survey. Interviewees should also be aware of the field of operational management (OM) in theory and practice. Considering these two factors, researchers and decision makers with significant knowledge and practical experience in BT and OM are considered experts in our study. We first searched the Internet for experts with BT and OM knowledge and experience. Then, leveraging the social relations of one of the co-authors, we obtained the contact information of 24 experts with BT experience or academics who had a thorough grasp of BT. Before formally paying these 24 experts a visit, we informed them by phone calls, text messages, and e-mails, along with a cover letter outlining the goals of this research and their remarkable contributions. Of the 24 experts contacted, 17 of them agreed to participate in our research. As described in Table 4, eight are senior managers of Chinese companies, most of them have more than ten years' work experience in information technology (IT). The other nine are professors who have research experience and have published multiple papers in the field of OM research, focusing on the application of disruptive technologies such as big data, AI and BT. Accordingly, they were thought to be appropriate interviewees. During the formal interview, we first present the complete list shown in Table 1 to the expert group and held a 30min virtual meeting to introduce each factor. Then, we invited experts to briefly talk about their views on the current development and future application prospects of BT. After the meeting, the experts were given a pre-prepared questionnaire with seven driving factors related to BT adoption, and they were asked to rate the relative influence of these seven driving factors on a scale ranging from 0 to 4: 0 = no influence, 1 = low influence, 2 = medium influence, 3 = high influence, and 4 = very high influence. Finally, we double-checked each expert's responses to ensure that all questions about the relative influence of each factor were addressed. The average interview time for each expert was around 40 minutes, and the overall interview process with 17 experts lasted for nearly two months.

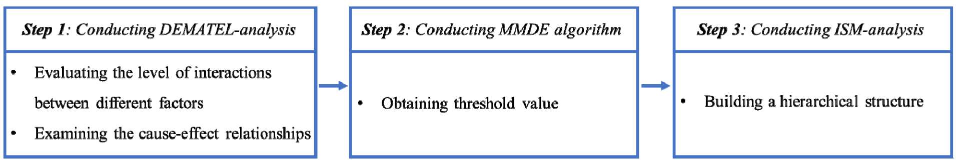
Table 4 Profiles of responding experts

Job titles	*Work/research domains*	*Years of experience*	*Number of experts*
Professor	Information system management	More than 10 years	6
CEOs	Digital technology application	More than 10 years	2
Top executives	Supply chain management	1–5 years	2
Top executives	Data security	More than 10 years	1
General managers	Information technology	More than 15 years	1
Professor	BT application	1–5 years	1
IT engineers	BT application	1–5 years	1
IT engineers	Digital technology application	More than 15 years	1
IT engineers	IT-related projects	More than 15 years	1
Professor	Information system management	More than 15 years	1

3.2 An integrated DEMATEL-MMDE-ISM approach

As we discussed before, the simple use of the ISM approach may incur some limitations (Farooque et al., 2020) and thus, in this paper, we adopt an integrated approach. We first utilise the DEMATEL to evaluate the level of interaction between different driving factors and analyse the potential causal-effect relationships (Altuntas and Gok, 2021). Then, we apply the MMDE algorithm to measure the threshold value of each factor (Singh and Bhanot, 2020). Finally, we employ the ISM approach to build the hierarchical structure and identify the key factors (Rajput and Singh, 2019). The methodology process of this study is summarised in Figure 2, and below, we focus on the details of each method.

Figure 1 The process of this research (see online version for colours)



3.2.1 DEMATEL method

According to prior studies (Trivedi et al., 2021; Sumrit, 2019), the DEMATEL method typically contains the following steps:

Step 1 Computing the average relation matrix. Assuming that the number of experts is h, and each expert's pairwise comparison between factor i and factor j is denoted as $X^k = \left[x_{ij}^k\right]$, where k refers to a certain expert. Among every X^k, the diagonal elements of each relation matrix are set to 0 because the elements do not need to be compared with themselves. Finally, the average relation matrix A is computed by combining all the h experts' matrices as follows:

$$A = a_{ij} = \frac{1}{h}\sum_{k}^{h} x_{ij}^k \tag{1}$$

Step 2 Normalising the direct relation matrix. The sums of each row and column in the relationship matrix are calculated and the max u is used as the standard to normalise the direct relation matrix. Finally, the normalised direct relation matrix N is gained as follow:

$$u = \max\left\{\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}\right\} \tag{2}$$

$$N = \frac{A}{u} \tag{3}$$

Step 3 Calculating the total relation matrix. The normalised direct relation matrix is continuously multiplied to obtain the increased indirect relationship between the elements, and all of the indirect relationships are added to get the total relation matrix T as follows:

$$T = \left(N + N^2 + N^3 + \cdots + N^k\right) = N(I - N)^{-1} \tag{4}$$

Step 4 Calculating R and C as well as drawing the cause-effect diagram. The sum of each row R_i represents the comprehensive influence an element t_i exerts on other elements. This set is recorded as R. Similarly, the sum of each column C_i represents the comprehensive effect received by an element t_i from other elements. This set is recorded as C. Adding R and C indicates the prominence of the factor and subtracting C from R denotes the cause degree of this factor. If the cause degree is greater than 0, it indicates that the factor has a large impact on other factors, which is called the cause factor. In contrast, it is referred to effect factor. Based on these two vectors, the cause-effect diagram is drawn with $(R + C)$ as the x axis and $(R – C)$ as the y axis.

$$R = \left(R_1, R_2, R_3, \cdots, R_n\right) \tag{5}$$

$$R_i = \sum_{j=1}^{n} t_{ij} \left(i = 1, 2, 3, \cdots, n\right) \tag{6}$$

$$C = \left(C_1, C_2, C_3, \cdots, C_n\right) \tag{7}$$

$$C_i = \sum_{j=1}^{n} t_{ji} (i = 1, 2, 3, \cdots, n) \tag{8}$$

3.2.2 MMDE algorithm

To acquire the hierarchical structure of the factors, the threshold is needed to convert the total relation matrix to a 0–1 relation matrix. We use the MMDE algorithm to measure the threshold. Specifically, the MMDE algorithm is developed from the information entropy method (Shannon, 1948), which uses information entropy to measure the uncertainty of random variables. The following is a description of utilising the MMDE algorithm to calculate the threshold according to the total relation matrix:

Step 1 Creating a data set $\{t_{11}, t_{12},\ldots, t_{21}, t_{22},\ldots, t_{nn}\}$ from the total relation matrix. Each element in the set T can be expressed as (t_{ij}, x_i, x_j), where x_i and y_j respectively represent the row and column position of t_{ij} in the total relation matrix, that is, the starting node and the receiving node. Then, the elements in T are arranged in order and transformed into a set T^* with ordered triples (t_{ij}, x_i, x_j).

Step 2 Calculating the Average de-entropy of the starting node-set. The second element x_i of each ordered triple in T^* is extracted to develop the starting node-set T^{Di}. Then, the first t elements of T^{Di} forms a new set T_t^{Di} and the probability $p_i = \frac{k}{m}$ to each different element in the set T_t^{Di} is calculated, where k refers to the frequency of element v_i in the set T_t^{Di}, and m refers to the sum of all elements in the set T_t^{Di} (e.g. For set{1, 2, 1}, m = 3, $p\_1 = \frac{2}{3}$). Finally, the entropy set H_t^{Di} of the set T_t^{Di} is calculated by using the information entropy method

(Shannon, 1948), which allows us to calculate the average de-entropy by the $MDE_t^{Di} = \frac{H_t^{Di}}{N(T_t^{Di})}$, where $N(X)$ denotes the cardinal number of different elements in set X.

Step 3 Finding the maximum average de-entropy. The maximum averages de-entropy and its corresponding set $T_{\max}^{Di}$ is found among all T_t^{Di}. Similar to Step 2–4. The receiving node-set T^{Re} is established and the maximum average de-entropy $T_{\max}^{Re}$ is calculated.

Step 4 Finding the threshold value. According to the $T_{\max}^{Di}$ and $T_{\max}^{Re}$ obtained from the above steps, the first m elements from T^* is extracted as the new set T^{Th} that includes all elements of $T_{\max}^{Di}$ and $T_{\max}^{Re}$. Finally, the smallest t_{ij} of T^{Th} is the threshold value λ.

3.2.3 ISM approach

The ISM approach transforms complex relationships into a hierarchical structure model by straightening out the interrelationships between different elements. The implementation steps are as follows:

Step 1 Constructing the initial reachability matrix (IRM). If the element i in the T affects other elements more than λ, which is considered that i can directly affect others and those relationships are assigned 1. On the contrary, the relationship is assigned 0 and finally, the IRM is constructed.

$$G = \begin{cases} 1, T_{ij} \geq \lambda, i = 1, \ldots, n \\ 0, T_{ij} \geq \lambda, i = 1, \ldots, n \end{cases} \tag{9}$$

Step 2 Developing final reachability matrix (FRM) from IRM. Transitivity between the factors is checked following the relation "if A is related to B, and B is related to C, then A is related to C", then the FRM is calculated.

Step 3 Obtaining the partition level of the factors. For each factor, the reachability and antecedent sets are constructed. The reachability set includes all elements that are influenced by the factor i, whilst the antecedent set includes all elements that influence i. An intersection set is made up of the shared components of these sets. If all factors in the intersection set and reachability set are the same, the factors are elevated to the top of the ISM hierarchy. This top-level component is then distinguished from the others. This procedure of level splitting continues until all levels are acquired.

Step 4 Constructing the hierarchical structure. Based on FRM and level partitioning, transitivity between factors was removed from obtained digraph and the final hierarchical structural model is developed.

4 Results

To define the contextual relationships between different factors, we first evaluate the data obtained from experts and generate the average relation matrix in Table 5. Besides, we provide a graphic to better present the data. Figure 3 shows that these factors do have a close link, with some of them having a high effect relation of larger than 3, including complexity (S2) on relative advantage (S1), top management support (S4) on organisational readiness (S5), competitive pressure (S6) on top management support (S4), and government support (S7) on top management support (S4).

Table 5 Average relation matrix of factors

Factors	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
Relative advantage (S1)	-	2.588	2.882	2.353	2.647	2.176	2.765
Complexity (S2)	3.059	-	2.882	2.588	2.471	2.176	2.118
Compatibility (S3)	2.647	2.588	-	2.529	2.647	2.353	1.647
Top management support (S4)	2.412	1.941	1.941	-	3.294	2.647	2.059
Organisational readiness (S5)	2.471	2.353	2.529	2.765	-	2.353	1.824
Competitive pressure (S6)	2.235	2.059	2.412	3.118	2.882	-	1.882
Government support (S7)	2.412	2.059	1.824	3.000	2.294	2.647	-

Figure 2 Average matrix plot for factors (see online version for colours)

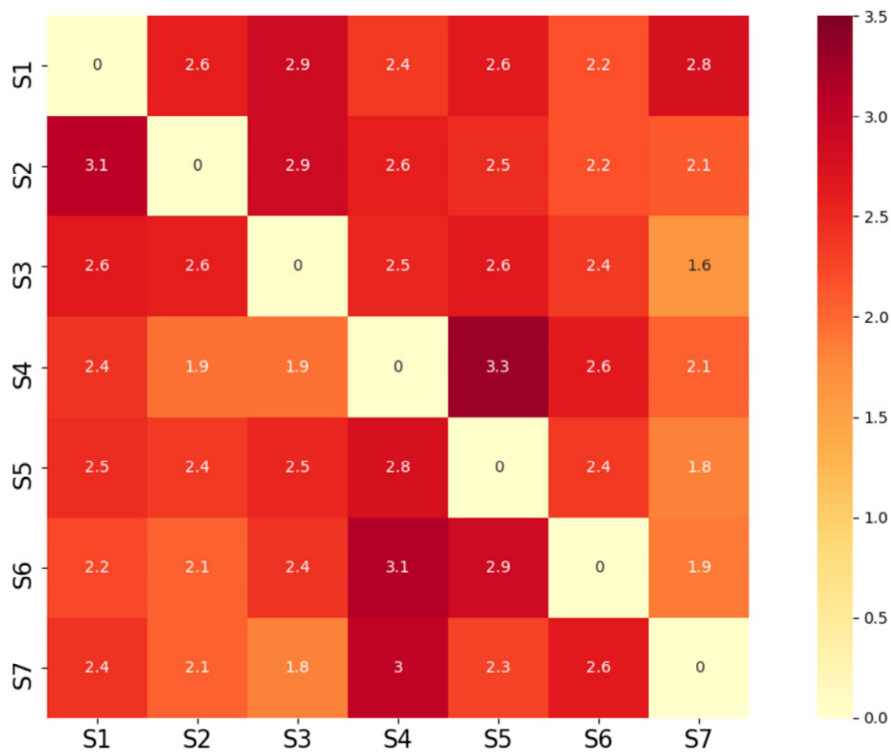


Table 6 Total relation matrix of factors

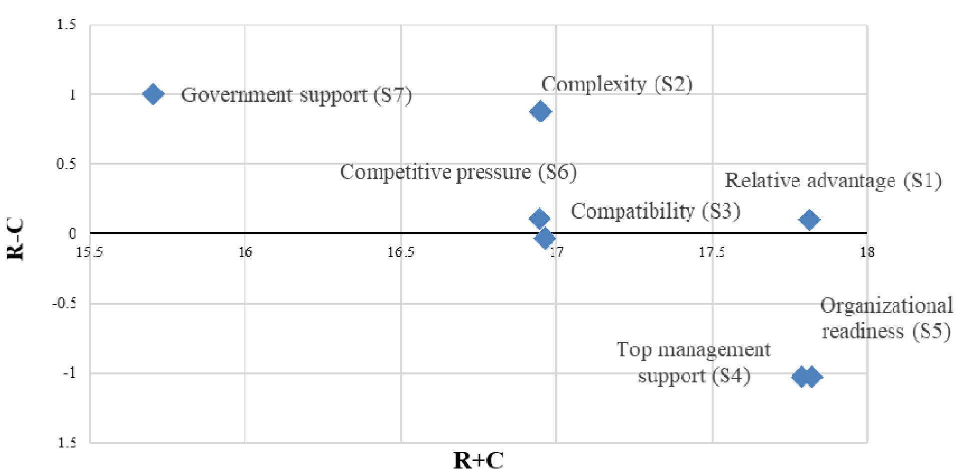
Factors	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*Rsum*	*R + C*	*R – C*	*Group*
Relative advantage (S1)	1.202	1.228	1.304	1.402	1.418	1.260	1.142	8.957	17.813	0.101	Cause
Complexity (S2)	1.355	1.087	1.299	1.406	1.405	1.254	1.108	8.914	16.949	0.878	Cause
Compatibility (S3)	1.276	1.168	1.092	1.340	1.349	1.205	1.035	8.465	16.963	-0.033	Effect
Top management support (S4)	1.252	1.127	1.186	1.195	1.367	1.208	1.045	8.381	17.788	-1.026	Effect
Organizational readiness (S5)	1.258	1.148	1.215	1.341	1.200	1.196	1.036	8.394	17.820	-1.031	Effect
Competitive pressure (S6)	1.264	1.150	1.226	1.376	1.370	1.088	1.052	8.526	16.943	0.109	Cause
Government support (S7)	1.249	1.128	1.176	1.347	1.317	1.206	0.931	8.353	15.702	1.003	Cause
Csum	8.856	8.035	8.498	9.407	9.425	8.417	7.350				

To further examine the direct or indirect relationship between the factors, we then calculate the total relation matrix (T) and present the results in Table 6. Besides, we gain the value of *R* and *C* and construct the cause-effect relationship diagram with the degree of prominence (*R* + *C*) on the x-axis and the causal degree (*R* – *C*) on the y-axis. We depict the digraph depicting causal relationships among factors in Figure 4, and the factors are split into two groups: compatibility, top management support, and organisational readiness are divided into the effect group, while relative advantage (S1), complexity, competitive pressure, and government support are divided into the cause group. As shown in Table 7, among the factors in the cause group, government support has the largest (*R* – *C*) value of 1.003 which indicates that government support has significant importance for BT adoption. Following government support, complexity is another critical factor of BT adoption with the (*R* – *C*) value of 0.878. As for the effect group, the (*R* – *C*) value of compatibility is almost zero, which means that compatibility is hardly affected by the cause factors. In contrast, organisational readiness has the least (*R* – *C*) value of –1.031 and the influence received index *C* of 9.425 is the highest among all the factors. It suggests organisational readiness is highly dependent on other factors. Similarly, top management support is also highly influenced by others. Besides, organisational readiness and top management support are still important for BT adoption owing to its high (*R* + *C*) value.

Table 7 Relative weights

Rank	*Cause-effect group criteria*	*R-C*	*Group*
1	Government support (S7)	1.003	Cause
2	Complexity (S2)	0.878	Cause
3	Competitive pressure (S6)	0.109	Cause
4	Relative advantage (S1)	0.101	Cause
1	Compatibility (S3)	-0.033	Effect
2	Top management support (S4)	-1.026	Effect
3	Organisational readiness (S5)	-1.031	Effect

Figure 3 Cause-effect relationship diagram (see online version for colours)



Through the above analysis, we obtain the causal relationship and relative importance between factors, but the hierarchical structure between factors is not yet clear. Therefore, we apply the MMDE algorithm to get the threshold of 1.304 and transform the total relation matrix into the IRM as shown in Table 8. Considering the transitivity rule, we derive the FRM in Table 9.

Table 8 The initial reachability (I.R.) matrix

Factors	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
Relative advantage (S1)	0	0	0	1	1	0	0
Complexity (S2)	1	0	0	1	1	0	0
Compatibility (S3)	0	0	0	1	1	0	0
Top management support (S4)	0	0	0	0	1	0	0
Organisational readiness (S5)	0	0	0	1	0	0	0
Competitive pressure (S6)	0	0	0	1	1	0	0
Government support (S7)	0	0	0	1	1	0	0

Table 9 The final reachability (F.R.) matrix

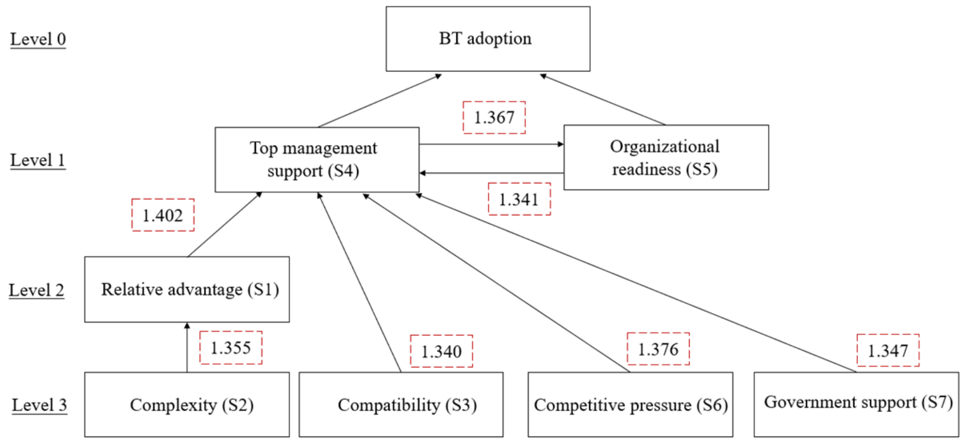
Factors	*S1*	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*
Relative advantage (S1)	1	0	0	1	1	0	0
Complexity (S2)	1	1	0	1	1	0	0
Compatibility (S3)	0	0	1	1	1	0	0
Top management support (S4)	0	0	0	1	1	0	0
Organisational readiness (S5)	0	0	0	1	1	0	0
Competitive pressure (S6)	0	0	0	1	1	1	0
Government support (S7)	0	0	0	1	1	0	1

Once we gain the FRM, it is partitioned into different levels for further constructing the hierarchical model. Finally, using the FRM and the level partitions of factors in Table 10, we construct the hierarchical model with three layers. The model reveals that complexity, compatibility, competitive pressure, and government support are four basic factors to constitute a hierarchical structure. Only relative advantage, which is influenced by complexity, is present in the second layer. Lastly, consistent with the previous analysis, organisational readiness and top management support belong to the first layer, which is heavily influenced by other high-level factors, particularly those in the third layer.

Table 10 Level partitions of the reachability matrix

Factors	*Reachability set*	*Antecedent set*	*Intersection*	*Level*
Relative advantage (S1)	1, 4, 5	1, 2	1	II
Complexity (S2)	1, 2, 4, 5	2	2	III
Compatibility (S3)	3, 4, 5	3	3	III
Top management support (S4)	4, 5	1, 2, 3, 4, 5, 6, 7	4, 5	I
Organisational readiness (S5)	4, 5	1, 2, 3, 4, 5, 6, 7	4, 5	I
Competitive pressure (S6)	4, 5, 6	6	6	III
Government support (S7)	4, 5, 7	7	7	III

Figure 4 IIn integrated DEMATEL-MMDE-ISM-based model for BT adoption (see online version for colours)



5 Discussion

The results in Figure 5 demonstrate that the most significant factors driving BT adoption are complexity, compatibility, competitive pressure, and government support. Of these four factors, government support plays the most significant role; in contrast, complexity is another important factor followed by compatibility and competitive pressure. It is interesting to note that these four factors in BT adoption are weighted more than the other three factors. According to DOI theory and the TOE framework, when an emerging technology is in its early stages of development, potential adopters pay more attention to the characteristics of the technology and the dynamics of the external environment (Angelis and Ribeiro Da Silva, 2019). As for BT adoption, BT is still nascent (Erol et al., 2022), the imperfection of policy, the complexity and the difficulty of compatibility are the main reasons why enterprises still hesitate to adopt it (Mathivathanan et al., 2021). Besides, relative advantages in the second layer, which is impacted by complexity, are the next most significant element. Before determining whether to embrace BT, organisations must first assess the benefits that BT may provide in comparison to existing technologies (Kamble et al., 2021). However, BT is the confluence of several disciplines, even the fundamentals are challenging to grasp, both theoretically and technically (Toufaily et al., 2021). The level of complexity of BT will influence organisations' perception of relative advantage. Therefore, more efforts will be required in reducing the level of complexity of BT adoption.

Furthermore, first-layer factors such as top management support and organisational readiness are influenced by higher-level factors, particularly those in the third layer such as relative advantages, compatibility, competitive pressure, and government support. In TOE framework, the factors at the organisational level are the softer aspects, which are influenced by the factors at the technical and environmental levels (Bradford et al., 2014; Bosch-Rekveldt et al., 2011). Specifically, the organisation's perception of the relative advantages from BT will directly affect the attitudes of the top managers to adopt BT. BT adds substantial value to companies by improving transaction efficiency (Wong et al., 2020a), providing transparent data (Kouhizadeh et al., 2021), and sharing information (Guggenberger et al., 2020). Those relative advantages are used as a guideline for senior management decision-making. Second, as Kamble et al. (2021) have discovered, compatibility has an impact on top management support. Because the more compatible BT is with users' existing ideas, previous habits, and present demands, the more likely senior managers are to improve perceived usefulness and encourage BT adoption (Clohessy et al., 2020). Third, competitive pressure can also influence top manager support. The reason is that the number of participants in the BT market is increasing, as is the market's size (Dutta et al., 2020). When faced with competition from upstream and downstream in the supply chain, top managers, as key strategic decision-makers, are more inclined to support the creation of new skills to improve their competitive position (Hsu et al., 2019). Fourth, top management support for BT adoption is influenced by government support. BT is still in the development stage, and there are many regulatory loopholes (Chang et al., 2020; Janssen et al., 2020). Companies contemplating BT adoption must evaluate the legal concerns posed by these uncertainties, which causes senior executives to maintain a strategic distance from the technology (Zamani and Giaglis, 2018). The government's support can dispel the concerns of top managers about the uncertainty, thereby encouraging the top managers to support adopting BT (Wong et al., 2020b).

Finally, we discover that top management support and organisational readiness had an impact on one another. Because the use of BT is still in its early stages and is characterised by a high level of complexity and uncertainty (Yadav and Singh, 2020), the company must guarantee that relevant resources are managed and allocated effectively. Top managers may control the resources of all parties engaging within the company since they are the creators and decision-makers of the enterprise's internal strategy (Hsu et al., 2019). Therefore, their decision-making direction and behaviour will directly affect the organisation's resource readiness (Hsu et al., 2019). Besides, when organisational readiness for BT adoption is strong, management is more inclined to begin change, put out more effort and perseverance, and cooperate more effectively (Clohessy and Acton, 2019). Accordingly, organisational readiness, on the other hand, is a crucial reference point for senior managers when making decisions.

5.1 Theoretical contribution

Our research contributes to the literature in two ways. First, we demonstrate that distinct driving factors are not separated, but rather interact with one another. Specifically, the existing literature has noticed the interdependent connections among factors. On the one hand, most studies lack further empirical analysis on these subjects (Clohessy et al., 2020). On the other hand, although some studies, such as Wong et al. (2020b) explore the relationship between technological and organisational factors, they ignore the impact of environmental factors. Those lead to a fragmented understanding of different driving factors. In this paper, we take into account technological, organisational, and environmental factors and divide them into two groups: the cause group mainly consists of technological and environmental factors, whereas the effect group is made up of organisational factors. Besides, we discover that factors such as complexity, compatibility, and relative advantages will impact organisational factors including top management support and organisational readiness, which is line with the conclusions of Orji et al. (2020). Furthermore, we empirically confirm that organisational readiness and top management support affect each other. Finally, we discovered that environmental factors including competitive pressure and government support impact organisational factors and complexity affects the organisation's perception of relative advantages. Hence, these findings enrich the existing understanding of the antecedents of BT adoption.

Second, we explore the structural relationship between different driving factors and BT adoption. Previous research mostly focuses on the linear impact of factors on BT adoption, which only addresses the issue of 'whether' rather than 'how' and is also insufficient to assist BT participants in making decisions (Kamble et al., 2021; Wong et al., 2020b; Kamble et al., 2020). In our paper, we construct the hierarchical structure with three layers. The model reveals that complexity, compatibility, competitive pressure, and government support are four basic factors to constitute the hierarchical structure. These four factors are considered the fundamental determinants of BT adoption. Only relative advantage is presented in the second layer. Lastly, organisational readiness and top management support belong to the first layer and they are the most direct influence on the organisation's adoption of BT. Accordingly, these findings propose a new theoretical explanation for how various factors interact to affect a company's decision to adopt BT.

5.2 Managerial implication

The findings of this research provide meaningful insights for potential BT adopters, BT service providers, and policymakers who are working to develop and implement BT. They should pay more attention to these identified as fundamental determinants of BT adoption including complexity, compatibility, competitive pressure, and government support.

First, as the most essential factor, government support should attract the attention of potential policymakers and BT adopters. For policymakers, they should further develop a strong BT regulatory system to break the BT regulatory dilemma. The ways include coordinating regulatory bodies and using innovative regulatory methods. For example, Japan implements industry self-regulation through the establishment of industry self-regulatory institutions (Su, 2020). The UK balances the contradiction between institutional supervision and technological development through the 'supervisory sandbox' model (Su, 2020). In addition, there is a significant need for government to increase support for companies adopting BT in various aspects, including technological development support, high-level talent support, the establishment of BT industry investment funds, application demonstration support, platform support, etc. At the same time, BT adopters should increase contact with the government and make full use of the preferential policies given by the government to improve the organisational readiness of the enterprise and reduce the risk of BT adoption.

Second, complexity is another important factor. Although many best-practice cases in the application of BT are existing (Cole et al., 2019), the technical complexity required for BT adoption should not be underestimated by organisations with relatively limited resources and knowledge. One approach to reducing the complexity of BT adoption is working closely with BT service providers and together explores how to focus on solving the complexity and restraint effects of BT applied to business processes. Tencent's general manager, YingWang, noted that the company aims to have close collaboration with industry partners and to empower them with cash, technology, and goods to jointly support the development of BT applications (Xu et al., 2019). Furthermore, the government can increase its research efforts on BT by combining universities and scientific research institutions to focus on researching how to break through the existing technical difficulties of BT and lower the threshold of BT applications.

Third, our findings indicate the compatibility of BT with the firm's existing technological architecture, processes, and practices affects top manager support, which implied that the enterprise business personnel should focus on developing technical architecture or simplifying business processes to improve compatibility. And then boost top managers' confidence and support for BT adoption. Finally, competitive pressure is an important external force that promotes top managers to adopt BT. Top managers should have a thorough understanding of the present competitive landscape surrounding BT and be prepared to confront the technology's potential opportunities and challenges.

6 Conclusions

Although extant literature has identified some factors related to BT adoption, the current understanding of the key driving factors related to BT adoption is vague. To fill this gap, we conduct a literature review and combine the DOI and TOE theories to determine seven important factors that affect BT adoption, namely, relative advantage, complexity, compatibility, top management support, organisational readiness, competitive pressure, and government support. We apply an integrated DEMATEL-MMDE-ISM approach to investigate the relative importance of these seven factors and obtain their hierarchical structure. In particular, the third layer contains the most important factor, namely complexity, compatibility, competitive pressure, and government support; the relative advantage is identified in the second layer, and top management support and organisational readiness are classified in the first layer. These findings thereby enrich the current BT adoption literature by providing a new understanding of different determinants. We also hope that our findings can help practitioners and policymakers improve measures to reduce barriers related to BT adoption.

Like other studies, our work can be strengthened in the following two respects. First, the integrated DEMATEL-MMDE-ISM approach utilised in this paper is based on the expert team's subjective evaluation of the dependency between the identified BT impacting factors. Even if our researchers are meticulous, the personal bias of the experts chosen may have an impact on the research results. Hence, future research could employ more diverse methods to confirm the findings of this study. Second, our study is conducted in China, and the findings may not apply to other developed countries with diverse backgrounds. Accordingly, it is recommended to conduct similar studies in other developed countries to generalise our findings.

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