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Factors Influencing Blockchain Technologies Adoption in Supply Chain Management and Logistic Sectors: Cultural Compatibility of Blockchain Solutions as Moderator

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Abstract: The rapid advancements in blockchain technology have heralded a new era for various industries, including the supply chain and logistics. However, despite the promising opportunities, the adoption of blockchain within supply chain and logistics still needs to be explored, especially in Saudi Arabia. This study investigated the impact of technological, organizational, and environmental factors on blockchain adoption among Saudi supply chain and logistics companies. The study also tested cultural compatibility's moderating role in solving blockchain issues. A quantitative method approach was employed, utilizing a survey questionnaire. Data were gathered from various stakeholders across the industry, including managers, IT experts, and logistics professionals. The findings indicate that relative advantage, top management support, and competitors influence blockchain technology adoption significantly and positively. However, openness to innovation use has an insignificant effect on adoption. Government support demonstrates the strongest positive influence on blockchain adoption, whereas vendor orientation and support showed an insignificant impact. Both blockchain technology adoption and the cultural compatibility of blockchain solutions significantly enhance operational excellence, but the moderating effect of cultural compatibility of blockchain solutions shows no effect on operational excellence. This study stands out as one of the first explorations into blockchain adoption in the supply chain and logistics sector within the Saudi context, identifying the factors contributing to blockchain's successful implementation for operational excellence.

Keywords: technological; organizational and environmental factors; blockchain adoption; operational excellence; cultural compatibility; Saudi supply chain and logistics sectors

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1. Introduction

The COVID-19 pandemic suddenly and quickly forced businesses to use technological applications to maintain operations and secure business continuity. Technologies like Artificial Intelligence (AI), big data, Internet of Things (IoT), Machine Learning (ML), and other cutting-edge emerging technologies are used to implement Industry 4.0 [1]. In fact, with the increased connectivity and the use of internet-based technologies that come with Industry 4.0, supply chain management systems (SCMs) and logistics systems require higher protection from security threats and crimes than ever before [2,3]. Therefore, protection is needed in all aspects of communication, authentication, supply chain management, and logistics authorization [4]. The costs and impacts of such attacks and crimes in SCMs are substantial and potentially have an adverse effect on both logistics and overall SCM and organizational reputation [5,6]. Integrating blockchain into logistics and supply chains should be an organization's top technology objective.

While the use of blockchain technology in SCM has been examined in various contexts, there is a gap in the literature that focuses particularly on the Saudi supply chain and logistics sector with cultural capabilities to adopt SCM [7]. SCM in the Saudi supply chain and logistics sector requires strong alignment with local cultural norms and business practices, technological readiness to integrate advanced SCM systems, and organizational flexibility to adapt to SCM-driven changes, all supported by supportive government policies and robust infrastructure. Notably, various regions have empirically tested the technology–organization–environment (TOE) framework, which clarifies the factors that influence technological adoption [4,8,9]. However, there needs to be more in the Saudi Arabian context regarding extensive technological, organizational, and environmental factors. A focused investigation is necessary because of Saudi Arabia's distinctive socioeconomic environment and its Vision 2030, which strongly emphasizes technological change [10,11]. In addition, there is awareness that the adoption of blockchain technologies in supply chain and logistics organizations in Saudi Arabia is increasing, offering enhanced transparency, security, and efficiency in operations.

Furthermore, several studies have discussed the advantages and consequences of adopting blockchain in supply chains (such as operational improvements, increased transparency, and efficiency), and these results are frequently discussed in general or non-regional contexts [12,13]. Operational excellence is yet to be thoroughly investigated due to blockchain adoption in the Saudi supply chain and logistics sector [14]. The Saudi supply chain's innate operational dynamics, including a long history of oil exports and intricate trade relations, respond differently to blockchain-driven changes than its counterparts worldwide [15,16]. Furthermore, the cultural aspect of technology adoption is still under review. Although cultural compatibility has been shown to either help or hinder the successful integration of technologies [17,18], little is known about the influence of cultural compatibility on the relationship between the adoption of blockchain technology and operational excellence. Given that Saudi Arabia has a unique cultural landscape, it is crucial to investigate how cultural quirks may interact with technological compatibility and, as a result, affect supply chain operational excellence [19,20].

Accordingly, this research aims to explore the factors that influence the effect of blockchain technology in the Saudi supply chain and logistics sector. Despite widespread curiosity about blockchain technology and its potential uses, there is little knowledge regarding how an integrated model of 'the diffusion of innovation theory (DOI) [21,22]', and 'technology–organization–environment (TOE) [4]' affects the Saudi supply chain and logistics sector. Therefore, this research aims to shed light on the existing landscape of blockchain implementation in Saudi SCM and logistics and highlight the aspects that should be taken into account to promote its wider adoption. The findings from this study will help policymakers and industry practitioners in Saudi Arabia learn more about the opportunities and challenges presented by blockchain technology in the region.

The research aims to identify the key factors that influence the adoption of blockchain technologies in the Saudi SCM and logistics sector. Therefore, the study designs the following research questions:

1. Do technological, organizational, and environmental factors influence the adoption of blockchain in the Saudi supply chain and logistics sector?
2. Does blockchain technology adoption influence operational excellence in the Saudi supply chain and logistics sector?
3. Does the cultural compatibility of blockchain solutions moderate the relationship between adopting blockchain technology and operational excellence?

This section provided the background of the study including the problem statement, research gaps and then research objectives. The next section explains the literature review and theoretical development of the hypotheses and final theoretical model. The following section explains the research methodologies, while the section after reveals the findings of the survey data collected from stakeholders in the Saudi Arabia supply chain and logistic

organizations. The final section reveals the discussion of the findings including managerial implications, limitations and future directions.

2. Literature Review and Theoretical Model

2.1. Supply Chain, Logistics and Industry 4.0 Technologies

The extensive literature on the subject provides a thorough grasp of the multifaceted impact of blockchain adoption across various industries. Javaid et al. [1] and Nath et al. [2] highlight how blockchain can improve environmental sustainability and how it affects supply chains for clothing. In their exploration of Industry 4.0 technologies, Vaidya et al. [3] and Chittipaka et al. [4] emphasize the importance of blockchain technology in developing economies. Meanwhile, Al-Gahtani [7] and Malik et al. [8] investigate the technology–organization–environment (TOE) framework, in particular contexts like Saudi Arabia and Australia, and Çolak [5] and Taherdoost [6] provide models for blockchain acceptance. Lu et al. [9] and Ahmadi et al. [10] look into the potential applications of blockchain in fields like healthcare and elder care. Comparing Marengo and Pagano [11] to Wong et al. [12] and Gökalp et al. [13], who concentrate on supply chain management, they offer a systematic review spanning nations and industries. Tripathi et al. [14] and Zhu et al. [15] discuss blockchain's paradoxical nature in supply chains and its role in operational excellence. In addition, Nguyen et al. [17] and Tran et al. [18] examine the adoption factors of blockchain technology in particular areas, such as Ho Chi Minh City. Treiblmaier [16] presents a sustainable approach combining blockchain technology with the physical internet. Finally, Orji et al. [19] and Sarfraz et al. [20] assess the impact of blockchain in industries such as freight logistics and tourism, demonstrating its wide and varied applicability in various fields and locations.

The term "supply chain" describes the integrated system of actions, people, and businesses producing and distributing goods, from acquiring raw materials to delivering the finished goods to customers [21,23]. On the other hand, the planning, implementation, and management of the movement and storage of goods, services, and information throughout the supply chain is the specific focus of logistics [22]. The efficiency and capability of supply chain and logistics, both of which are essential to the operation of the global economy, have been significantly improved by technological advancements [24]. Real-time tracking and verifiable data exchange have become more widely available due to integrating technologies like blockchain into supply chain and logistics, strengthening transparency, traceability, and security. Incorporating blockchain, cloud computing, and Industry 4.0 into supply chains and logistics has revolutionized operations in the digital age, resulting in improved visibility, teamwork, and lower costs [24,25]. According to studies by Agi and Jha [21] and Akhavan and Philsoophian [23], blockchain technology transforms stakeholders by promoting trust, resiliency, and collaboration. Additionally, by implementing digital solutions, businesses have been able to react quickly to shifting consumer demands while ensuring optimal inventory management, predictive analytics, and efficient operations [9]. In a time of rapid technological advancements and changing consumer expectations, this digital shift promotes sustainability, robustness, and efficiency.

In the supply chain and logistics sector, technologies, such as drones, robotic systems and other remotely operated systems are adopted to facilitate the movement, storage, and distribution of goods and improve order fulfilment and customer service [26]. Industry 4.0 technologies promote the connection of physical items such as sensors, devices and enterprise assets, both to each other. Blockchain improves operational efficiency and collaboration, but researchers also stress the importance of contextual factors like regional dynamics and cultural compatibility in supply chain success [11,19]. Blockchain has also been investigated in agriculture and elderly care, demonstrating its broad applicability [9,27]. Therefore, blockchain's integration into supply chains transforms logistics, but it requires a deep understanding of technological, organizational, and environmental factors.

2.2. Digital Supply Chain, Logistics Customer Service Using Blockchain Technology

The recent literature proves blockchain technology integration with digital supply chains and logistics customer support. In this way, Attaran [28] highlights the role of digital technology enablers in supply chain management, emphasizing the revolutionary potential of blockchain technology to improve supply chain efficiency and transparency. Kache and Seuring [29] support this, pointing out that the nexus of supply chain management and big data analytics presents a prime opportunity for blockchain application, providing unmatched visibility and traceability in logistics processes. In their discussion of supply chain evolution, MacCarthy et al. [30] emphasize the need to incorporate cutting-edge technologies like blockchain to improve the responsiveness and capabilities of the supply chain.

In addition, Kadłubek [31] discusses how blockchain helps improve the quality management of logistics services, arguing that the technology's immutability and transparency greatly increase customer trust and service reliability. Research like Tripathi et al. [14] and Zhu et al. [15] explore how supply chain research can overcome its current paradox and achieve operational excellence through blockchain as part of Industry 4.0. Treiblmaier [16] offers a thorough analysis and suggests fusing blockchain technology with the physical internet to accomplish supply chain management and logistics sustainability. Additional evidence for this comes from Nguyen et al. [17], Tran et al. [18], and Orji et al. [19], who together emphasize the useful applications and advantages of blockchain in a range of supply chain scenarios, including enhancing the efficacy and efficiency of customer service. By addressing blockchain's role in the digital transformation of the supply chain and logistics in the tourism sector, Sarfraz et al. [20] expand the scope and demonstrate its flexible application across various industries.

2.3. Integration of the Diffusion of Innovation Theory (DOI) and Technology–Organization–Environment (TOE)

The research framework captures the relationship between TOE dimensions and blockchain adoption. The study uses the literature to weave a coherent narrative integrating DOI and TOE frameworks to propose the research hypotheses. In line with the DOI's core concept, the "relative advantage" highlights a new technology's advantages over its predecessor [1,3]. Blockchain has advantages over traditional supply chain systems in decentralization, transparency, and security [6]. Organizational hierarchy affects technological adoption, so "top management support" is essential. Javaid et al. [1] mentioned this when discussing environmental sustainability in the context of Industry 4.0. "Openness to innovation use" is an organization's willingness to adopt new technologies, supporting adoption idea that perceived usefulness drives technology adoption [21].

External pressures like "competitor influence" and "government support" influence an organization's technology adoption. Chittipaka et al. [4] stressed this for emerging market supply chains. In Amini and Jahanbakhsh Javid's [22] study on cloud computing adoption, external environment and vendor support played a role. "Vendor orientation and support" help organizations transition to blockchain. Moving forward, the "cultural compatibility of blockchain solutions" mediates blockchain adoption and operational excellence. It supports the idea that technology should fit an organization's culture to be effectively integrated [32]. Only a cultural fit helps an organization use technology to improve operations. The research framework integrates DOI and TOE, supporting blockchain adoption in supply chain and logistics. These theories shed light on different adoption factors, and when combined, they form a robust model to understand the many factors that influence organizations to adopt blockchain technology.

2.4. Technological Factor and the Adoption of Blockchain Technology

Blockchain technology in supply chain management has grown in popularity, attracting many studies [2,4,5]. Much of the literature discusses the multifaceted factors and diverse frameworks that drive blockchain adoption in different sectors [8,12]. Ah-

madi et al. [10] examined information system adoption, emphasizing the importance of technology uptake in public institutions. Blockchain's revolutionary role in supply chain dynamics contrasts with this understanding. Many scholars have studied blockchain adoption in apparel supply chains [2] and emerging markets [4], but the technology–organization–environment (TOE) framework is commonly used. This framework illuminates organizational, technological, and environmental blockchain adoption factors. Chai [33] and Treiblmaier [16] discuss knowledge sharing and sustainable logistics, showing how blockchain is used in various supply chain contexts.

Geographic and industry-specific factors also affect blockchain adoption. Sumarliah et al. [34] examined blockchain's use for Halal traceability in Indonesia, indicating a regional application. Numerous studies, such as Marengo and Pagano's [11] study on blockchain adoption in countries and Çolak's [5] supply chain model, highlight the technology's transformative potential. These studies demonstrate blockchain's potential to transform global supply chains due to various factors. Therefore, the study offers a research hypothesis:

H1. *The relative advantage of technology significantly and positively influences the adoption of blockchain technology in the Saudi supply chain and logistics sector.*

2.5. Organizational Factors and the Adoption of Blockchain Technology

Organizational factors, including top management support and openness to innovation are good antecedents to the adoption of blockchain technology [8,35]. The literature strongly suggests that top management support is crucial to blockchain adoption. Chong et al. [36] and Akhavan and Philsoophian [23] found that top management sets a technology adoption strategy. Top management support is expected to significantly and positively affect Saudi Arabia, where technological innovation is increasingly recognized as essential to supply chain and logistic operations [7]. Leadership support provides resources and shows employees that blockchain adoption is essential. Several studies [12,37] emphasize that top management support is necessary to allocate financial and human resources for technology adoption. This is crucial for blockchain, which requires significant infrastructure and training investments. Top management's resource allocation can significantly affect blockchain adoption in Saudi Arabia, where companies increasingly use blockchain for supply chain and logistical improvements.

Top management support also overcomes organizational change resistance, which is a standard technology adoption barrier [38]. Leaders who promote blockchain technology and its benefits are more likely to convince employees to come on board. Top management support can help overcome resistance and promote innovation and technology adoption in the Saudi supply chain and logistics, where traditional practices are deeply ingrained. Therefore, the study offers a research hypothesis:

H2. *Top management support significantly and positively influences the adoption of blockchain technology in the Saudi supply chain and logistic sector.*

Numerous studies [2,39] show that open-minded organizations are more likely to adopt new technologies like blockchain. In Saudi Arabia, where innovation and technology-driven solutions are valued to boost competitiveness, innovation-focused organizations are expected to be more open to blockchain in their supply chain and logistics operations. The Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. [40] emphasizes user acceptance and technology adoption readiness in an organization. These models emphasize innovation use and user readiness to boost organizational excellence [5,14,41]. In the Saudi supply chain and logistics sector, companies encouraging employees to try new technologies and adapt are more likely to adopt blockchain successfully.

Given the growing global interest in blockchain technology and its potential to revolutionize supply chain and logistics, Saudi Arabian companies that value innovation are

more likely to see blockchain as a competitive advantage [9,18]. This mindset encourages proactive blockchain application exploration and adoption, supporting the hypothesis that openness to innovation use positively affects Saudi blockchain adoption. Therefore, the study offers a research hypothesis:

H3. *Openness to innovation use significantly and positively influences the adoption of blockchain technology in the Saudi supply chain and logistic sector.*

2.6. Environmental Factors and the Adoption of Blockchain Technology

Competition forces companies to adopt new technologies to stay competitive [42]. Saudi supply chain and logistics firms compete fiercely for market share and efficiency gains, so the fear of falling behind technologically drives blockchain adoption. Organizations that see competitors adopting blockchain may feel compelled to follow to stay competitive [42]. The benefits of being first in technology adoption are well-documented [43]. Saudi supply chain and logistics early adopters who successfully implement blockchain to streamline operations could gain a competitive advantage by setting industry standards and becoming trusted partners. This first-mover advantage encourages other companies to adopt blockchain to avoid losing efficiency and industry relationships [9,24].

Industry-specific blockchain consortiums and associations generally set technology adoption standards [43]. Industry initiatives by competitors influence blockchain technology adoption [42]. In Saudi Arabia, where many organizations realize blockchain potential for transparency and efficiency, competitive firms joining these consortia help develop and adopt blockchain standards in the supply chain and logistics sector. Based on the literature pieces of evidence, the study offers a research hypothesis:

H4. *Competitor influence significantly and positively influences the adoption of blockchain technology in the Saudi supply chain and logistic sector.*

Government regulation and support boost technology adoption [44,45]. In Saudi Arabia, where government entities are interested in blockchain for land registry and cross-border payments [46], a supportive regulatory environment encourages supply chain and logistics organizations to explore blockchain solutions without legal or compliance concerns [45]. Governments often offer grants, subsidies, or incentives to adopt new technologies [47]. Vision 2030 in Saudi Arabia emphasizes technology-driven economic diversification. Incentives or funding from the government makes blockchain adoption in supply chain and logistics more appealing by reducing organizations' financial burden.

Government agencies can help industry and technology companies form strategic partnerships. Saudi Arabia's government-led initiatives to connect sectors and promote digital transformation can help supply chain and logistics organizations find suitable technology partners and solutions providers, accelerating blockchain adoption. Based on the literature studies, the study offers a research hypothesis:

H5. *Government support significantly and positively influences the adoption of blockchain technology in the Saudi supply chain and logistic sector.*

Technical expertise is frequently needed for blockchain adoption [48]. Vendors who provide blockchain solutions and support by offering training, advice, and technical support to Saudi supply chain and logistics companies fill this knowledge gap. When companies have access to dependable vendor support that aids them in navigating the complexities of the technology, they are more likely to adopt blockchain [4,8]. Blockchain solutions frequently need to be integrated with existing systems and tailored to the particular requirements of an organization [12]. Vendors with a strong focus on customization and seamless integration make the adoption process more manageable [1,29]. Vendor support that provides customized solutions can be incredibly alluring in Saudi Arabia, where organizations have various supply chain and logistics needs.

Technology adoption decisions are heavily influenced by the standing and performance of technology vendors [48]. Having trustworthy and dependable vendors with a track record of successful implementations inspires confidence in Saudi Arabia, where organizations hesitate to adopt relatively new technologies like blockchain. Potential adopters in Saudi Arabia's supply chain and logistics industry develop trust by receiving vendor orientation and support. Therefore, the study offers a research hypothesis:

H6. *Vendor orientation and support significantly and positively influence the adoption of blockchain technology in the Saudi supply chain and logistic sector.*

2.7. The Adoption of Blockchain Technology and Operational Excellence

There are several justifications and arguments to support hypothesis H6, which states that the adoption of blockchain technology has a significant and positive impact on operational excellence in the Saudi supply chain and logistics sector. The ability of blockchain technology to offer unmatched transparency and traceability within supply chains is one of its main advantages. By way of illustration, Kayikci et al. [49] highlighted how blockchain technology promotes operational excellence, particularly in perishable food supply chains during outbreaks. The adoption of blockchain technology in organizations is directly linked to achieving operational excellence, enhancing efficiency and transparency in processes [43]. This is crucial for industries like the food industry, where tracing product origins and confirming their authenticity is crucial for consumer confidence and legal compliance. The complexity and size of Saudi Arabia's supply chains, increased transparency and traceability help the country achieve operational excellence by lowering fraud, enhancing product integrity, and fostering trust among all parties involved [7].

The TOE framework supports how technological, organizational, and environmental factors affect innovative technology adoption, as Chittipaka et al. [4] and Malik et al. [8] mention. These factors significantly increase supply chain effectiveness, adaptability, and responsiveness when used with blockchain technology [4,22]. By implementing blockchain technology in the Saudi supply chain and logistics industry, as advised by the TOE framework, operations are streamlined, inter-organizational collaborations are improved, and operational excellence can be increased. Resilience was mentioned in Akhavan and Philsoophian's [23] discussion of the mediating role of blockchain in enhancing supply chain collaboration. Organizations in the Saudi supply chain improve stakeholder collaboration, reduce the risks associated with central failures, and achieve a more resilient and effective supply chain operation by utilizing blockchain's decentralized and secure nature. Based on the literature pieces of evidence, the study offers a research hypothesis:

H7. *The adoption of blockchain technology significantly and positively influences operational excellence in the Saudi supply chain and logistic sector.*

2.8. Moderating Role of Cultural Compatibility of Blockchain Solutions

Incorporating blockchain technology into various industries has become a hot topic in recent academic research, and its interaction with cultural compatibility, particularly in diverse settings, has drawn more and more attention. The importance of perceived innovation attributes in the Saudi Arabian context is highlighted by Al-Gahtani's [7] study on adopting computer technology, which suggests that specific cultural factors significantly affect the adoption and success of technological innovations. This suggests that compatibility between the technology and regional cultural norms, values, and practices is essential for blockchain technology adoption in the Saudi supply chain and logistic sector. In order to ensure that technological advancements are compatible with the local environment and promote operational excellence, it is crucial to understand cultural compatibility [7]. Supply chain management increasingly recognizes blockchain as a transformative tool to boost operational effectiveness. Studies by Guan et al. [37] and Kucukaltan et al. [50] shed light on the potential of blockchain in supply chain management, highlighting its

capacity to address issues like resource dependency and alignment in the supply chain sector. According to Vos and Boonstra [51], successful implementation and subsequent benefits of the technology depend on cultural values and technology adoption being in line. This alignment catalysis in the Saudi Arabian context, strengthening the link between blockchain adoption and excellent supply chain and logistics operations.

In addition, Venkatesh et al. [40] emphasized the importance of cultural factors and personal beliefs in determining technology adoption behaviors in their seminal work on the Unified Theory of Acceptance and Use of Technology. Inferring from this, one might contend that cultural compatibility in Saudi Arabia's supply chain and logistic sector can significantly increase the positive effects of blockchain technology on operational excellence, as the acceptance and ensuring efficient use of the technology would be enhanced in a culturally congruent environment [40]. Based on the literature studies, the study develops a research hypothesis:

H8. *Cultural compatibility significantly and positively moderates the relationship between adoption of blockchain technology and operational excellence in the Saudi supply chain and logistic sector.*

Finally, the study develops the theoretical model in Figure 1.

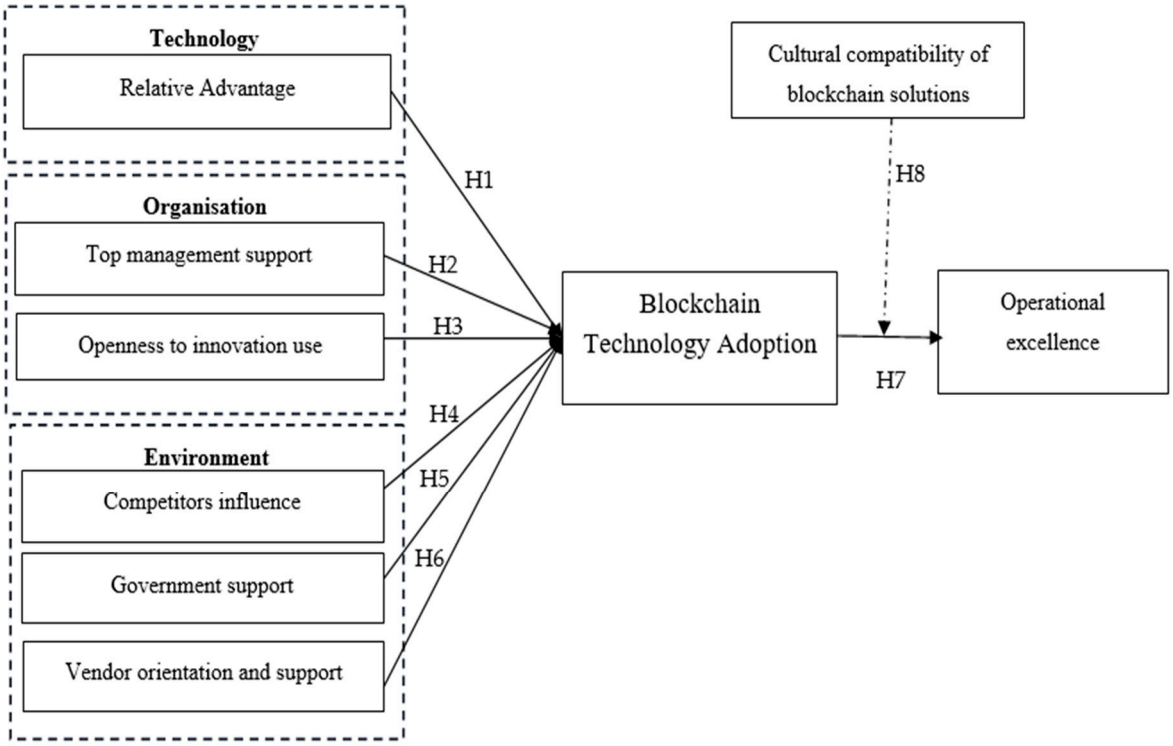

Figure 1. Theoretical model.

3. Research Methodology

3.1. Research Design

In order to collect data from a sizable sample and generate statistically significant results, academic and industrial research has long recognized and used the adoption of a quantitative research design, particularly the survey questionnaire method. The survey questionnaire approach is especially useful for standardizing the measurement of attitudes, perceptions, and behaviors, allowing for the generalizability of results [40]. As demonstrated in studies on technology adoption [7,52,53], it also enables researchers to measure relationships between variables and test hypotheses with empirical evidence. Therefore, the study employed a quantitative research design by following a survey questionnaire approach.

3.2. Data Collection Procedures

The study targeted stakeholders (managers, IT experts, and logistics professionals) from 71 Saudi Arabian supply chain and logistics companies. The selection of targeting stakeholders is to perceive the use of blockchain technologies in supply chain and logistic organizations/companies. The study needs to examine how the stakeholders perceive the use of blockchain technologies in Saudi Arabian supply chain and logistic organizations. The study targeted medium and large organizations because they have strong financial career and higher resources to tackle with technological problems. As stratified data collection is essential to quantitative research, a survey questionnaire approach was chosen to collect precise, structured data, mirroring the strategies advocated by Creswell [54]. According to Creswell [54], one of the advantages of quantitative research is that it provides a clear, numerical pathway to understanding complex phenomena in the target industries. A stratified random sampling approach was chosen to ensure the survey's inclusiveness, covering various aspects and units within these organizations. The decision was based on its ability to guarantee adequate representation for each division or segment within these companies, resulting in increased external validity [55]. The prudent use of this method is essential, especially in light of the complexity of supply chain and logistics businesses, which may cover a range of industries and operational nuances.

Direct contact information was obtained from the companies for the targeted participants, guaranteeing a trustworthy source and streamlining the engagement procedure [56]. Working with these companies was essential in obtaining information about potential respondents. The study upheld ethical standards at every stage, ensuring participant information was handled carefully to protect their privacy [57]. Because of its accessibility, user-friendly interface, and robust data management capabilities, Google Docs was used to structure the survey questionnaire.

Participants in the study's sample size came from 71 supply chain and logistics companies, providing a thorough understanding of the sector's practices and difficulties in Saudi Arabia. To ensure the conclusions drawn were representative of the industry, it was decided to approach such a diverse range of companies [58]. Links to the survey were distributed through a variety of communication channels, including emails and corporate communication tools, to encourage as much participation as possible.

Reminders were periodically sent to potential respondents during the designated data collection period to encourage participation and increase response rates. According to Fan and Yan [59], such reminder techniques significantly increase the likelihood of longitudinal studies receiving a sizable number of responses. A predetermined number of responses from the initial group of respondents were compiled. After careful data-cleaning procedures [60], a subset of these was deemed valid for the analysis. The study's rigorous methodologies and engagement strategies are demonstrated by the achieved response rate, which aligns with standards established by Baruch and Holtom [61] for scholarly research. Of the 557 top-level employees contacted, 415 responses were retrieved. However, data cleaning, an essential step in ensuring the integrity and reliability of the results [60], led to removing 12 responses that needed to be completed or appropriate. Thus, the final dataset for analysis comprised 403 responses. A 72.35% response rate is commendable, especially given that rates above 50% in academic surveys are often considered acceptable [61].

3.3. Instrumental Scales

The study adapts the measurement scales from the previous studies. The validity and reliability of the studies were higher than 0.70 [62]. The study comprises various constructs, which were each defined by a specific number of items sourced from notable academic references. The construct "relative advantage" uses three items, referenced from studies by Yang et al. [53], Oliveira et al. [52], Mohammed et al. [45], and Al-Gahtani [7]. "top management support" is measured with four items by Chong et al. [36]. Both "openness to use innovation" and "competitor influence" utilize three items each, the former solely from Chong et al. [36] and the latter combining insights from Yang et al. [53] and Chong

et al. [36]. "Government support" and "vendor orientation and support" each incorporate three items sourced from Chong et al. [36], with the latter also referencing Shamout et al. [63]. "Blockchain technology adoption" employs three items based on Ahmadi et al. [10] and Chong et al. [36]. "Operational performance" is explored through four items from Naway and Rahmat [41]. Lastly, "cultural compatibility of blockchain solutions" is constructed from three items anchored in the work of Vos and Boonstra [51]. These constructs and their associated items, rooted in their respective academic sources, offer a structured approach to exploring blockchain adoption. Appendix A shows the measurement of the research variables.

3.4. Data Analysis

Given the benefits and areas of expertise of each software, using SPSS (https://www.ibm.com/products/spss-statistics, accessed on 28 October 2023) for demographic data and Smart PLS 4 for testing validity, reliability, and structural equation modeling (SEM) is consistent with the preferences of many researchers in the field. Since its inception, the study used the SPSS tool for demographic statistics. It excels at managing and analyzing demographic data and provides descriptive and inferential statistics that help comprehend the sample's makeup and characteristics [64]. However, Smart PLS 4, a more recent addition to the SEM technique, was picked for its reliable path modeling with latent variables capabilities, mainly when the research model is complex or the data do not follow a normal distribution [62]. Additionally, its use in assessing validity and reliability is regarded as the gold standard, ensuring that the study's constructs are consistent and measure what they are intended to measure [65]. Thus, researchers can take advantage of the strengths of both tools by combining SPSS and Smart PLS 4, resulting in thorough analysis and precise results.

4. Results

4.1. Demographic Information

The demographic data shown in Table 1 provide important details about participants in the Saudi logistics and supply chain industry. Male respondents comprise 61.3% of the total, while female respondents comprise 38.7%. The majority of participants (83.1%) are between the ages of 26 and 40, indicating a relatively young professional population. Regarding the sectors represented, the manufacturing sector accounts for more than half of the respondents (51.1%), which is closely followed by the hotels and restaurants sector (42.4%). With 2.7% and 3.7%, respectively, the retail and other sectors make up a small percentage. The respondents have a good understanding of blockchain technology, as 87.3% reported being familiar with it, leaving only 12.7% in the dark. This high awareness may indicate that the Saudi logistics and supply chain sector knows new technologies and their potential effects. It means proper awareness about using blockchain technologies are the necessary part of Vision 2030 in Saudi Arabia.

4.2. Assessing Model Validity and Reliability

The study used a PLS algorithm with 5000 subsamples to assess the validity and reliability of the measurement scales. The study now turns to the factor loadings and the average variance extracted (AVE) to assess the convergent validity of the measurements in Table 2. According to Hair et al. [62], factor loadings should be 0.70 or higher for acceptable convergent validity, though loadings between 0.60 and 0.70 are considered sufficient. All items in Table 2 have factor loadings above 0.70, which is noteworthy and shows the higher factor loadings. The fact that it is still within acceptable bounds supports the robustness of the factor loadings. According to Hair et al. [62], AVE, representing the overall variance captured by the construct, should be greater than 0.50 for satisfactory convergent validity. The fact that every construct in Table 2 exhibits an AVE greater than 0.50 in this regard supports the sufficiency of convergent validity across scales.

Table 1. Demographic information.

Variables	Categories	Frequency	Percent	Valid Percent	Cumulative Percent
Gender	Male	247	61.3%	61.3%	61.3%
	Female	156	38.7%	38.7%	100%
Age	Younger than 25 years old	40	9.9%	9.9%	9.9%
	26–40 years old	335	83.1%	83.1%	93.1%
	More than 40 years old	28	6.9%	6.9%	100%
Industry	Manufacturing	206	51.1%	51.1%	51.1%
	Hotels and restaurants	171	42.4%	42.4%	93.5%
	Retail	11	2.7%	2.7%	96.3%
	Other	15	3.7%	3.7%	100%
Awareness	Aware of blockchain technology	352	87.3%	87.3%	87.3%
	Not aware of blockchain technology	51	12.7%	12.7%	100%

Table 2. Assessing validity and reliability.

Scales	Items	Factor Loadings	Cronbach's Alpha	Composite Reliability	AVE
Blockchain technology adoption	BCA1	0.818	0.797	0.881	0.711
	BCA2	0.840			
	BCA3	0.871			
Competitor influence	CMP1	0.870	0.844	0.905	0.761
	CMP2	0.871			
	CMP3	0.877			
Cultural compatibility of blockchain solutions	CCB1	0.827	0.770	0.867	0.684
	CCB2	0.835			
	CCB3	0.819			
Government support	**GOV1**	**0.854**	**0.789**	**0.875**	**0.700**
	GOV2	0.781			
	GOV3	0.872			
Openness to innovation use	OPN1	0.822	0.714	0.840	0.636
	OPN2	0.809			
	OPN3	0.760			
Operational excellence	OPE1	0.837	0.868	0.910	0.717
	OPE2	0.806			
	OPE3	0.885			
	OPE4	0.856			
Relative advantage	RAD1	0.704	0.707	0.793	0.561
	RAD2	0.782			
	RAD3	0.758			
Top management support	TOP1	0.760	0.769	0.852	0.590
	TOP2	0.775			
	TOP3	0.790			
	TOP4	0.747			
Vendor orientation and support	VES1	0.877	0.870	0.920	0.793
	VES2	0.907			
	VES3	0.888			

Indicators such as Cronbach's alpha and composite reliability are used when it comes to construct reliability. Ringle et al. [65] and Hair et al. [62] agree that values greater than 0.70 are acceptable for both metrics and indicate reliable constructs. Table 2 shows that all constructs comfortably exceed this limit, demonstrating their dependability.

It is important to note that composite reliability frequently beats Cronbach's alpha because it does not assume that the indicators in the latent variable have equal loadings. The reliability of the constructs is further demonstrated in the current dataset by the composite reliability metrics, which are comparable to or superior to their corresponding Cronbach's alpha values. Based on these findings and comparisons with the benchmarks of Hair

et al. [62] and Ringle et al. [65], it is possible to reveal that the constructs in Table 2 have convergent validity and reliability.

The degree to which a construct differs from others is measured by its discriminant validity. For assessing discriminant validity in PLS-SEM, Henseler et al. [66] proposed the Heterotrait–Monotrait (HTMT) ratio as a superior approach. The HTMT ratio contrasts the average of the correlations of indicators within a single construct (MONOTRAIT) with the correlation between constructs (HETEROTRAIT). The constructs in question are sufficiently distinct, supporting discriminant validity if the HTMT value falls below the threshold, which is typically set at 0.90 by Henseler et al. [66].

All the HTMT ratios in Table 3 are less than the 0.90 cutoff. This is a good sign because it implies that the scales used in the study are discriminatory to one another. For instance, the HTMT ratio for the "blockchain technology adoption" and "competitor influence" constructs is 0.648, which is well below the 0.90 cutoff and indicates that the two constructs are distinct. Other pairwise combinations that support the discriminant validity of the constructs include "cultural compatibility of blockchain solutions" and "government support" with a ratio of 0.539 and "openness to innovation use" and "relative advantage" with a ratio of 0.887, respectively (the highest HTMT value in the table but below the threshold). This confirms a good discriminant validity.

Table 3. Heterotrait–Monotrait (HTMT) ratio.

Scales	1	2	3	4	5	6	7	8
Blockchain technology adoption								
Competitor influence and pressure	0.648							
Cultural compatibility of blockchain solutions	0.849	0.539						
Government support	0.714	0.617	0.700					
Openness to innovation use	0.659	0.837	0.564	0.712				
Operational excellence	0.721	0.670	0.686	0.849	0.713			
Relative advantage	0.761	0.759	0.678	0.744	0.887	0.694		
Top management support	0.711	0.760	0.667	0.699	0.774	0.727	0.816	
Vendor orientation and support	0.545	0.607	0.659	0.629	0.651	0.693	0.589	0.642

4.3. Assessing Path Model

The study used a 5% significant level, so the *t*-value should be higher than +1.96 [62,65]; it has a beta value of 0.153, a *t*-value of 2.687, and a *p*-value of 0.007. Table 4 shows the direct and moderating effects. It was discovered that the direct effect of Relative advantage on the adoption of Blockchain technology was statistically significant, so hypothesis H1 is accepted. This suggests that the relative advantage has a significant positive impact on the spread of the technology based on Blockchain. In a similar vein, the effect of top management support on blockchain technology adoption was statistically significant, with a beta value of 0.168, a *t*-value of 2.785, and a *p*-value of 0.005, so the hypothesis H2 is also accepted. This finding lends credence to the idea that top management support is essential in increasing the use of blockchain technology. In contrast, the effect of openness to innovation use on the adoption of blockchain technology was not statistically significant, as evidenced by a beta value of 0.000, a *t*-value of 0.001, and a *p*-value of 0.999; therefore, hypothesis H3 is rejected. Openness to innovation use was a factor in the development of blockchain technology. This suggests that openness to the use of innovations does not significantly influence the adoption of blockchain technology. With a beta value of 0.166, a *t*-value of 2.675, and a *p*-value of 0.007, the influence of competitors was shown to have a significant impact on the adoption of blockchain technology. In addition, the support of the government was shown to have a strong significant effect on the adoption of blockchain technology with a beta value of 0.286, t value of 5.086, and *p*-value of 0.000, so hypothesis H5 is accepted. However, as evidenced by a beta value of 0.065, *t*-value of 1.281, and *p*-value of 0.200, vendor orientation and support did not present a significant impact on the adoption of blockchain technology, so hypothesis 6 is rejected. With a beta

value of 0.417, a *t*-value of 7.107, and a *p*-value of 0.000, the effect of adopting blockchain technology on operational excellence was prominently significant, so the hypothesis H7 is accepted. This finding highlights the significance of blockchain technology in improving operational excellence.

Table 4. Direct and moderating effects.

Direct and Moderating Effects	Beta Values	*t* -Values	*p* -Values
H1. Relative advantage → Blockchain technology adoption	0.153	2.687	0.007
H2. Top management support → Blockchain technology adoption	0.168	2.785	0.005
H3. Openness to innovation use → Blockchain technology adoption	0.000	0.001	0.999
H4. Competitor influence → Blockchain technology adoption	0.166	2.675	0.007
H5. Government support → Blockchain technology adoption	0.286	5.086	0.000
H6. Vendor orientation and support → Blockchain technology adoption	0.065	1.281	0.200
H7. Blockchain technology adoption → Operational excellence	0.417	7.107	0.000
Cultural compatibility of blockchain solutions → Operational excellence	0.294	5.057	0.000
H8. Cultural compatibility of blockchain solutions x Blockchain technology adoption → Operational excellence	0.020	0.503	0.615

Regarding the moderating effect, it was found that the direct impact of cultural compatibility of blockchain solutions on operational excellence was significant, with a beta value of 0.294, *t*-value of 5.057, and *p*-value of 0.000. However, the moderating effect of cultural compatibility of blockchain solutions between adopting blockchain technology and operational excellence was not significant, as suggested by a beta value of 0.020, *t*-value of 0.503, and *p*-value of 0.615. Therefore, hypothesis H8 is rejected.

4.4. Assessing Model Fitness

R-square (R^2) values in structural equation modeling show how much of the variance in the dependent variable(s) can be accounted for by the independent variable(s) in the model. A R^2 value nearer 1 denotes a higher percentage of explained variance and, consequently, a better model fit. Figure 2 illustrates the SEM model, and the constructs of "blockchain technology adoption" and "operational excellence" have R^2 values in the table of 0.460 and 0.412, respectively. These values imply that the model's predictors account for a sizeable portion of the variance in both constructs. Along with the R^2 value, the adjusted R^2, which considers the number of predictors in the model and is frequently a more conservative estimate of fit, is also presented.

The adjusted R^2 values for "blockchain technology adoption" and "operational excellence" are, respectively, 0.452 and 0.408, which are very close to their respective R^2 values. This similarity demonstrates good model parsimony and shows that the number of predictors in the model does not increase the proportion of variance explained. Therefore, the model effectively explains the variation in the relevant constructs. In particular, the model's constructs account for 41.2% of the variance in operational excellence and 46% (or 0.460) of the variance in adopting blockchain technology. These principles emphasize the importance of the influences in this study on the adoption of blockchain technology and the subsequent operational excellence. Thus, the study offers insightful information about the primary forces behind adopting blockchain technology and its effects on business operations.

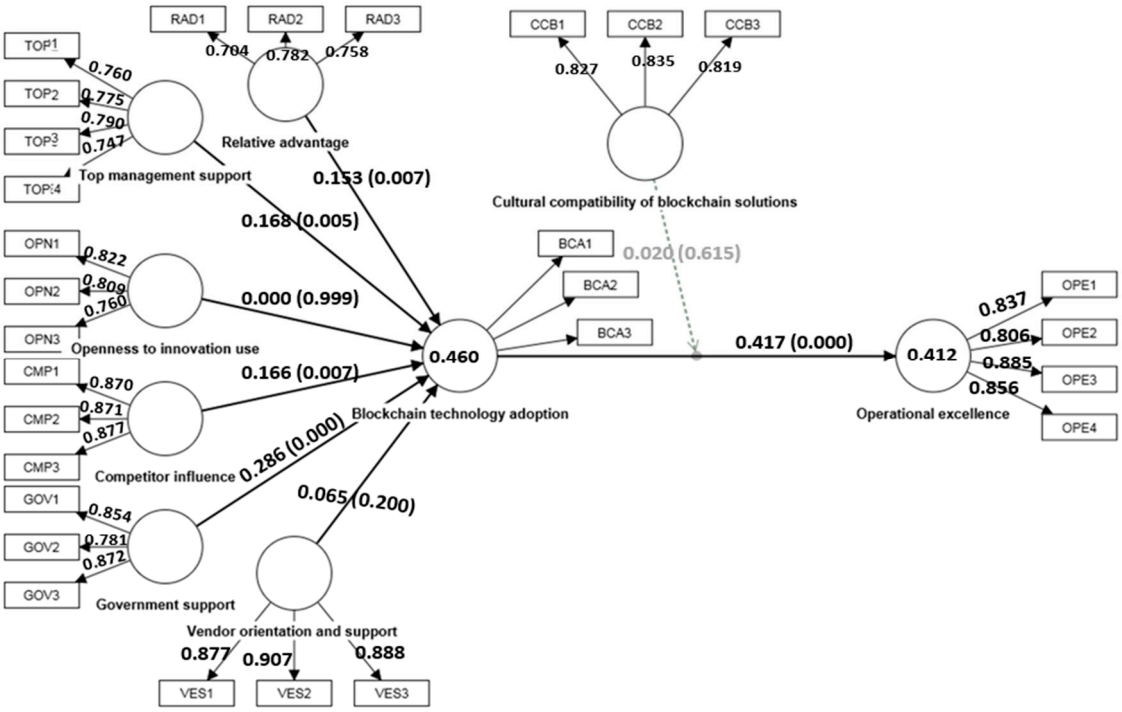

Figure 2. SEM model.

5. Discussion

The study has been conducted in Saudi supply chain and logistics by using a quantitative research method. The study examined the effect of using blockchain technology in Saudi medium and large supply chain and logistic organizations. The findings agree with earlier research, as the study showed how the findings of the present study align with the previous studies. Similar to the findings of H1 and H2 in the current study, Agi and Jha [21] revealed the role of relative advantage and top management support in facilitating blockchain technology adoption in supply chains and logistic organizations. In addition, Akhavan and Philsoophian's [23] findings, which emphasized the mediating role of blockchain in supply chain collaboration, are consistent with the significance of competitor influence in blockchain adoption, as shown in H4. Government support, which was important in influencing the adoption of blockchain technology (H5), is also consistent with the findings of Al-Gahtani [7] and Gökalp et al. [13], highlighting the importance of external macro-environmental forces in the adoption of technology.

On the other hand, openness to innovation use (H3) did not significantly affect blockchain adoption in supply chain and logistic organizations. This finding contradicts Ahmadi et al.'s [10] claim that innovation openness plays a crucial role in technology adoption in hospital settings. However, organizational contexts vary, so what holds for the adoption of blockchain in healthcare does not always apply to supply chains. Additionally, there was no discernible relationship between vendor orientation and support (H6) and the interaction between cultural compatibility of blockchain solutions and adoption (H8) regarding blockchain adoption and its subsequent impact on operational excellence. This is surprising given the importance of vendor support in blockchain integration that Amini and Jahanbakhsh Javid [22] mentioned. Despite initial expectations, openness to innovation has surprisingly not been a significant driver in the adoption of blockchain technology within supply chain and logistics organizations.

Additionally, the adoption of blockchain technology has a significant (H7) direct impact on operational excellence, which is consistent with findings from Akhavan and Philsoophian [23] and Chittipaka et al. [4]. This suggests that blockchain technology could improve operational capabilities, increasing the effectiveness of supply chains. It is also noteworthy how important cultural compatibility is in influencing operational excellence

without blockchain adoption acting as a mediator. This aspect does align with the significance of cultural compatibility in technology adoption and implementation, as mentioned by Benzidia et al. [24] and Ceptureanu et al. [67], despite not being directly hypothesized in earlier studies. The findings underscore the critical role of cultural compatibility in technology adoption and highlight the need to consider cultural factors in blockchain implementation strategies, even when not explicitly hypothesized in initial studies. To sum up, despite some discrepancies, especially about the non-significant hypotheses, the study's findings are generally consistent with prior research. The varying organizational contexts, regional variations, and the rapidly developing nature of blockchain technology may be responsible for these variations.

5.1. Managerial Implications

The research findings offer insightful information for managers and other stakeholders in Saudi logistics and supply chain companies. First, there should be much focus on the advantages of blockchain technology and government support, as these factors directly link to its successful adoption. Acknowledging the role of rivalry and upper management's support in promoting blockchain adoption is also crucial. Reevaluating innovation strategies is necessary, as openness to innovation surprisingly has little effect on adoption. Furthermore, firms should prioritize blockchain integration if they want to improve operational performance given the strong correlation between blockchain adoption and operational excellence. Ultimately, aligning new technologies with organizational culture and values is critical, as it is necessary for the successful adoption of blockchain and attaining operational excellence.

The study's findings highlight the significance of understanding the potential benefits of blockchain technology in supply chain and logistic organizations. Blockchain technology provides Saudi supply chain and logistics organizations with improved transaction security, real-time tracking, and transparency. Support from top management is essential for the successful adoption of this technology. Therefore, the leadership in these companies must take the initiative to learn about the complexities of blockchain and then lead initiatives for its integration. Embracing such technological advancements could give Saudi businesses a competitive edge in the regional and international markets given supply chains' growing globalization and complexity.

The study's emphasis on how little openness to innovation affects the adoption of blockchain technology suggests that simply wanting to innovate may not lead to technology adoption. This implies for Saudi businesses that fostering an innovation culture should go beyond intention; it requires concrete actions, ongoing training, and strategic investment. It might be possible to work with tech companies and academic institutions to offer practical workshops and training sessions. Furthermore, managers can be helped by taking cues from the extensive literature, such as Al-Gahtani's [7] study on adopting technology in Saudi Arabia, to identify particular obstacles and develop solutions.

The importance of the external business environment is highlighted by the significant impact that competitor behavior and government support have on adopting blockchain technology. Saudi logistics and supply chain companies must constantly be on the lookout for market trends and their rivals' competitive strategies. A re-evaluation of one's strategies to maintain market relevance may be required if there is a significant shift toward blockchain in the industry. Additionally, businesses should take advantage of available government support and incentives for tech adoption given the Saudi government's Vision 2030 and its emphasis on technological advancement. In addition to streamlining the adoption process, alignment with national visions and strategies can create opportunities for potential partnerships and collaborations.

5.2. Limitations and Future Directions

There are inherent limitations to consider, although the study provides insightful information about the dynamics of blockchain adoption among Saudi supply chain and

logistics companies. The study could have ignored the nuances and particular difficulties small and medium-sized businesses face by concentrating primarily on larger enterprises. Furthermore, participant responses may have been influenced by cultural, geographic, or sector-specific biases, which may limit the generalizability of the results. Another drawback is that the study is cross-sectional, capturing the state of blockchain adoption at a particular time without examining its development or long-term effects.

Future research could use a longitudinal approach to monitor the development of blockchain adoption and its long-term effects given the dynamic nature of technology and business. Small and medium-sized businesses could be added to the scope to understand the entire industry better. In addition, exploring the unique opportunities and challenges blockchain presents within various supply chain and logistics industry segments can aid in creating more specialized strategies. Future research may also examine how blockchain interacts with other cutting-edge technologies, like artificial intelligence or the Internet of Things, to identify synergies in the supply chain industry.

5.3. Conclusions

The study targeted Saudi medium and large supply chain and logistic organizations to know how their stakeholders perceive the use of blockchain technologies in those organizations. The results show several significant implications of adopting blockchain technology and how it affects operational excellence. Notably, government backing is the most important factor in blockchain adoption with competition and top management following closely behind. Remarkably, there is no link between openness to innovation and blockchain adoption. The strong positive impact of blockchain technology adoption indicates that it plays a crucial role in operational excellence. Furthermore, the alignment of technology with organizational culture is crucial for operational excellence, and this is where blockchain solutions' cultural compatibility comes into play. However, the relationship between blockchain adoption and cultural compatibility has little effect on operational excellence, indicating that other factors are also more important in this relationship.

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Appendix A Measurement of Research Variables

Variable	Items	Reference
Relative Advantage	RA1: Blockchain technology enables our company to operate more efficiently.	Yang et al. [49], Oliveira et al. [48], Mohammed et al. [41], and Al-Gahtani [7].
	RA2: Blockchain technology allows us to perform specific tasks more quickly.	
	RA3: Our company expects that blockchain technology can help to reduce unnecessary costs.	
Top management support	TOP1: Our company's top management has provided strong leadership to engage with blockchain technology adoption.	Chong et al. [32].
	TOP2: Our company's top management recognizes the benefits of blockchain technology adoption.	
	TOP3: Our company's top management provides adequate resources required to adopt blockchain technology.	
	TOP4: Our company's top management is willing to take any possible risks associated with the adoption of blockchain technology.	
Openness to use innovation	OPN1: Our company actively monitors and assesses new technologies.	Chong et al. [32].
	OPN2: Our company implement new innovations to improve business process.	
	OPN3: Our company encourages employees to learn and use new technologies	
Competitor influence	CMP1: Our company is under competitive pressure to adopt blockchain technology.	Yang et al. [49], Chong et al. [32].
	CMP2: Some of our competitors adopted blockchain technology before we did.	
	CMP3: Our competitors know the importance of blockchain technology for their business	
Government support	GOV1: Government has provided incentives to early blockchain technology adopters.	Chong et al. [32].
	GOV2: There is sufficient training provided by the government to support blockchain technology adoption.	
	GOV3: Adequate legal safeguards exist to permit the utilization of blockchain technology.	
Vendor orientation and support	VES1: We received satisfactory assistance and technical support from our blockchain technology vendor.	Chong et al. [32]; Shamout et al. [59]
	VES2: We received adequate training from our blockchain technology vendor	
	VES3: In general, our blockchain technology vendor possess proficient technical expertise.	
Blockchain Technology Adoption	BCA1: Our company has already introduced and adopted blockchain technology to increase transparency and integrity in the process of supply chain and logistics.	Ahmadi et al. [10] and Chong et al. [32].
	BCA2: Our firm intends to use blockchain technology as much as possible to manage supply chain and logistics	
	BCA3: Our company will strongly advise others to adopt blockchain technology to manage supply chain and logistics.	
Operational excellence	OPE1: The use of blockchain technology in supply chain and logistics reduces transactional costs.	Naway & Rahmat [37]
	OPE2: The use of blockchain technology in supply chain and logistics reduces information processing.	
	OPE3: The use of blockchain technology in supply chain and logistics enhances customer service.	
	OPE4: The use of blockchain technology in supply chain and logistics improves responsiveness to market demands.	
Cultural compatibility of blockchain solutions	CCB1: Blockchain technology is consistent with our corporate culture.	Vos & Boonstra [47].
	CCB2: Blockchain technology fits with our company's principles of integrity	
	CCB3: Blockchain technology is consistent with our company's inclination towards transparency.	

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