Transactions on Quantitative Finance and Beyond

www.journal-tqfb.com

Vol. 1, No. 1 (2024) 1–14.

Paper Type: Original Article

Investigating the Impact of Blockchain Technology Adoption on Integration and Economic Sustainability of the Automotive Supply Chain: a Bayesian Structural Equation Modeling Approach

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Citation:

Received: 14 March 2023 *Revised: March 2023* *Accepted:02/05/2023*	Esmaeilian, Gh., Rezaiyan Fardoie, S., Hourali, M., & Farbod, E. (2024). Investigating the impact of blockchain technology adoption on integration and economic sustainability of the automotive supply chain: a Bayesian structural equation modeling approach. *Transactions on quantitative finance and beyond, 1*(1), 1-14.

Abstract

As changes in information technology have a significant impact on the structure of companies, integration within the supply chain, which exists directly or indirectly in the structure of any company, can be beneficial for company performance. This study examines the indirect impact of customer responsiveness integration within the supply chain on the economic sustainability of the supply chain through the adoption of blockchain technology as a dynamic capability component in the automotive industry using a Bayesian Structural Equation Modeling (BSEM) approach. The statistical population of the study consists of experts, supervisors, and managers of automotive companies, with 123 individuals selected through non-probability sampling. To assess the validity of the questionnaire, opinions of experts were sought, and Cronbach's alpha was used to determine the reliability of the questionnaires. The SEM-AMOS24 software was used to analyze the research hypotheses and examine the validity of the model using BSEM. The findings of the study indicate that internal integration, including customer and supplier integration, and external integration within the supply chain, have a significant impact on the relationship between blockchain technology adoption and the economic sustainability of the supply chain. Additionally, customer responsiveness about Supply Chain Integration (SCI) and economic sustainability is achieved by attracting desirable domestic and foreign investors.

Keywords: Economic sustainability, automotive supply chain, sustainable supply chain, blockchain technology, Bayesian structural equation modeling.

1 | Introduction

The automotive industry is considered a key industry due to its extensive connectivity with pre- and post-industrial chains. It has great potential for job creation and economic development. The manufacturing of

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automobiles involves various technologies such as metal, chemical plastics, wood, fabric, insulation, electrical glass, metallurgy, design, and more. Therefore, the automotive industry ranks second in terms of backward linkage coefficient among industries in the country. Some estimates suggest that for every car produced, two jobs are created, with 17% being direct employment (automotive manufacturing and parts manufacturing) and 83% being indirect employment (upstream industries and automotive service activities) [1]. In Iran, this industry has experienced numerous ups and downs since its initial establishment in the 1960s. Until the early 1990s, the approach of this industry in the country was based on manufacturing under the license of foreign companies. However, over time, developments took place towards the creation of its production chain, and the automotive parts industry took shape in Iran. Iran's strategic cooperation with the automotive industry, which was initially limited to the United States and Europe, expanded towards European and East Asian partners after the revolution. It leaned more towards becoming an automotive pole with a stronger focus on France and cooperation with Peugeot, and another pole with South Korea and cooperation with Kia Motors. In addition to these two brands, domestic automakers also had collaborations with several other European and Asian brands. These collaborations continued for a while until they faced international sanctions, which posed a challenge to them [2].

However, the activities of the automotive supply chain are dynamic and changeable, leading to operational inefficiencies [3]. To cope with these inefficiencies, information sharing is necessary. With the emergence of the fourth industrial revolution, the automotive industry has witnessed extensive deployment of sensors, the use of big data techniques, and improvement in computational power, and storage capacity [4]. Furthermore, the automotive industry heavily relies on suppliers of parts and raw materials from various locations, hence transparency and accountability are crucial for efficient supply chains [5]. Like any other supply chain, the automotive supply chain faces significant pressure to increase transparency and reduce uncertainty. Such pressures have created a need for strong and reliable technology for information sharing and monitoring among automotive supply chain stakeholders [6]. As a result, automotive industries have explored Industry 4.0 technologies and adopted blockchain technology for their supply chain activities [7]. Additionally, the acceptance of blockchain technology in the automotive supply chain facilitates the traceability of key equipment by collecting performance and durability data of vehicles as telematics information. This can help automotive industries effectively plan their business operations [8]. Recent advancements in information and communication technology have demonstrated that the intervention of these technologies offers a promising approach to enhancing supply chain processes [9]. Furthermore, previous studies have shown that information and communication technology enhances the integration of supply chain processes to manage the significant increase in information volume and complexity among different supply chain partners [10]. On the other hand, Industry 4.0 technologies, along with information and communication technology, strengthen process integration and lead to organizational performance sustainability [11]. Although previous studies justified investments in information and communication technology for Supply Chain Integration (SCI) and sustainable supply chain performance [12], others have found that these investments have failed to create a sustainable impact on organizational performance [13]. The contradictions in these findings encourage researchers to further explore the relationship between SCI, the acceptance of information and communication technology, and sustainable supply chain performance. SCI plays a crucial role in improving collaboration among supply chain participants [10]. Blockchain provides a secure storage for all supply chain transactions that is easily accessible to all supply chain partners, enhancing the level of SCI [14]. Previous studies have identified SCI as an important mediating variable in the literature on sustainable supply chain performance, subject to various independent and dependent variables [15]. Blockchain has the potential to enhance SCI and contribute to trade excellence and sustainability. The use of blockchain in the supply chain improves organizational productivity and performance by enabling end-to-end integration of product and process data [16]. Polim et al. [17] propose blockchain as a technology capable of integrating high-volume information. In this study, blockchain is viewed as a dynamic capability that enables the integration, creation, and reconfiguration of internal and external competencies to address rapidly changing environments [18]. Furthermore, the literature on organizational capabilities indicates that internal integration and external integration of a company are related to each other and lead to improved performance [19], which led the authors to select the structure of SCI in the current research. On the other hand, according to previous research, information sharing, facilitated by information technology, has been a requirement for excellent supply chain management [20]. Sharing vital information with a system, individuals, or business level is known as information sharing. An organization needs to respond to four important statements to enhance the outcome of information sharing: 1) What information is shared, 2) With whom is the information shared, 3) How is the information shared, and 4) When is the information shared [21]. Quality customer response helps prevent redundancy, reduce costs, and increase responsiveness [22]. Therefore, the main objective of this study is to examine the indirect impact of customer responsiveness integration in the supply chain on the economic sustainability of the supply chain through the acceptance of blockchain technology as a dynamic capability component in the automotive industry.

2 | Theoretical Background and Hypothesis Development

2.1 | SCI in the Automotive Sector

SCI is a broad research topic in supply chain management, aiming to increase value for end customers. SCI has three dimensions: "process integration," "supplier integration," and "customer integration" [23]. Customer integration refers to the extent to which a company collaborates with its customers to envision the future and engage in mutual planning [24]. Customer integration involves the two-way flow of information, services, and materials between the central company and customers. Customer integration helps organizations develop accurate demand forecasts, adapt to demand fluctuations, and implement postponement strategies [25]. Supplier integration refers to the extent to which a company partners with its suppliers to manage its inter-organizational processes, strategies, and behaviors in a coordinated and manageable manner to meet customer needs with minimal costs and rapid delivery [25]. Supplier integration, through knowledge sharing, reduces uncertainty [26]. Process integration provides easy access to a unified company database and connects all functional units of the company through a highly integrated information system [27]. Process integration enables all departments to have access to useful information for tracking and retrieving inventory status across the supply chain [28]. The three dimensions of SCI are further classified into two primary components: external integration and internal integration [25], which are used in the proposed model in this study. Customer value is provided through effective and efficient flows of financial resources, products, and information through inter- and intra-organizational collaboration in strategic, tactical, and operational dimensions of business processes [28]. SCI is achieved by involving upstream and downstream stakeholders and digitally linking them to intra- and inter-organizational business processes [23]. The role of SCI, based on existing literature, is a significant variable that affects supply chain performance [25].

2.2 | Blockchain Technology in the Automotive Industry

Researchers consider blockchain as an innovation that combines information and communication technology with SCI, incorporating various other information and communication technologies such as software development tools, encryption technology, database technology, and data analytics [29]. In a supply chain, blockchain provides a high level of integration and serves as a unified source of information for all supply chain partners [30]. Blockchain supports all areas of the supply chain, including planning, procurement, manufacturing, and delivery, ultimately enabling transparency in transactions [31]. Manufacturing industries, supply chain management, retail, and leasing are some key functional areas of the automotive supply chain that can leverage blockchain technology [32].

Additionally, blockchain can be used for identifying and reporting counterfeit parts, making product recalls more cost-effective, and facilitating faster and more secure transactions by eliminating intermediaries [33]. The new wave of digital transformation has compelled automotive companies to innovate and embrace new technologies. Automotive companies need to shift their focus from optimizing sales prices to optimizing the cost of the product lifecycle, creating competitive advantage, and unlocking new business opportunities [11].

2.3 | Blockchain as a Component of Dynamic Capabilities Theory

"Capability is considered dynamic when it enhances an organization's capacity for decision-making, problem-solving, identifying opportunities and threats, and reallocating existing resources" [34]. Perks et al. [35] argue that blockchain brings together all supply chain partners to create value by fulfilling assigned tasks that are achieved through the dynamic configuration of supply chain resources. Dynamic capability is defined as the "ability of an organization to purposefully create, extend, or modify its resource base" [36]. According to the theory of dynamic capabilities, organizations can create "value" by improving supply chain processes and resources. The primary value drivers of blockchain include increased transparency, immutability, audibility of transactions, reliability, and trustworthiness [11]. It is expected that these value drivers will reduce transaction-based costs, add new services, delineate organizational boundaries, and automate decision-making in the supply chain [37].

2.4 | Sustainable Supply Chain Performance in the Automotive Sector

Sustainable supply chain performance plays a crucial role in the overall success of an organization. Timely and efficient supply chain assessment contributes to the development, execution, and monitoring of strategies [38]. As supply chains extend in scope and activities, event tracing becomes a significant challenge. Customers and buyers will perceive real value in products or services when supply chains provide transparency and present details of various historical events related to the product or service. Transforming the supply chain into a digital ecosystem requires the opening up of existing interdependencies among supply chain participants and access to information for all supply chain participants. All supply chain participants are crucial for the successful integration of collective value creation and shared responsibility [11]. Many previous studies dealing with sustainable supply chains have highlighted the inclusion of economic, environmental, and social dimensions of sustainability [39].

The current research focuses on economic sustainability instead of short-term goals such as profitability improvement and efficiency. It emphasizes the ability of organizations in the automotive supply chain to achieve long-term financial performance. Thus, this research defines the economic sustainability of the supply chain as a driver of improving the financial performance of both the organization and the supply chain through systematic and strategic alignment of multiple business functions [40].

2.5 | Blockchain Technology Adoption and Sustainable Supply Chain Performance

The involvement of multiple actors in a supply chain network leads to a lack of transparency and accountability [41]. Therefore, as digitalization has advanced in the supply chain field, blockchain improves secure transactions, enhances transparency, and enables product traceability [42], resulting in cost reduction and improved performance of sustainable supply chains [43]. Other benefits of blockchain include increased accountability and auditing [42], prevention of fraud [22], privacy, cybersecurity, and protection [42], as well as improved financial processes [44]. The trust level provided by active blockchain in the supply chain is a fundamental element in developing supply chain relationships and improving sustainable supply chain performance [45].

2.6 | Blockchain Technology Adoption, SCI, and Sustainable Supply Chain Performance

Blockchain digitally integrates multiple stakeholders and facilitates product tracking and transaction settlement through process automation and smart contract execution [46]. The SCI provided by blockchain is highly secure and prevents unauthorized access to stored information [47]. Blockchain enables exceptional levels of SCI, harmonizing customer, supplier, and manufacturer information [11]. Kshetri [42] suggests integrating blockchain with the Internet of Things to identify the source of supply chain disruptions, which can successfully address crises during product recalls. Similarly, integrating blockchain with other emerging technologies reduces uncertainty, and increases supply chain transparency [14], process integration [48], and traceability [49]. Blockchain enhances the privacy, auditability, and operational efficiency of supply chains [50]. Literature indicates that SCI affects sustainable supply chain performance [19]. Recent studies analyze the impact of integration technologies based on communication technologies such as the Internet of Things [51] and supply chain information systems [52] on sustainable supply chain performance.

Table 1. Blockchain studies in the automotive supply chain domain.

Authors	Method	Algorithm	Application
Shih et al. [53]	Empirical case study	Network encryption hash function	Vehicle communication
Sharma et al. [54]	Empirical case study	Ethereum blockchain platform	Autonomous vehicles
Guo et al. [55]	Empirical case study	Digital signature algorithm	Vehicle network
Dayana et al. [56]	Empirical case study	Hyperledger Fabric	Vehicle tracking
Sushmetha and Vairamuthu [57]	Empirical case study	Encryption	Air pollution
Xu et al. [47]	Conceptual	Encryption	Communication encryption for vehicles
Lei et al. [58]	Empirical case study	Encryption	Communication encryption For vehicles
Kang et al. [59]	Conceptual	Encryption	Plug-in hybrid electric vehicle
Sharma et al. [60]	Empirical case study	Study block-vehicle	Network for vehicle communication
Farahbakhash Mohammadi [61]	Conceptual	_____	Performance of supply chain management in Iran Khodro
Hossein Golzar and Pilevari Salmasi [62]	Empirical case study	Fuzzy inference system	Automotive industry
Zahedi and Khanchah [63]	Conceptual	_____	Supply chain management in the automotive industry
Aghajani Mir et al. [64]	Empirical case study	BWM method	Challenges of implementing blockchain technology in the supply chain
Sharaj Sharifi et al.[65]	Case study	Partial least squares method	Impact of blockchain on SCI
Farbod and Hamidieh [66]	Case study	Partial least squares method	Impact of supply chain agility on financial performance with a focus on supply chain disruption structure

"Hossein Golzar and Pilevari [62] conducted a research titled 'providing a model for evaluating the impact of blockchain technology on supply chain performance using fuzzy inference systems in the automotive industry'. They concluded that all factors of the designed fuzzy inference system exhibited logical behavior toward the inputs.

Aghajani Mir et al. [64] conducted research titled 'identification and prioritization of challenges in implementing blockchain technology in supply chain using group bwm approach'. They found that security, technical, and organizational challenges are the most important challenges faced by companies in implementing this technology. Among all the sub-indicators of the research challenges, scalability, privacy/confidentiality, and cyber-attacks were found to be of the highest importance. Sharaj Sharifi and Mirfalah [65] conducted a research titled 'the impact of blockchain on SCI with the mediating role of information technology capability'. They concluded that blockchain has a positive impact on SCI. Therefore, this study conceptualizes blockchain as a dynamic capability by accepting the theory of dynamic capabilities. It examines its direct impact on internal and external SCI and its indirect impact on sustainable supply chain performance. Embracing blockchain technology in a manufacturing company is essential for synchronizing the flow of products and information within and across the supply chain. Hence, the findings of this study can assist policymakers and supply chain professionals in developing relevant policies for the automotive industry, considering customer responsiveness.

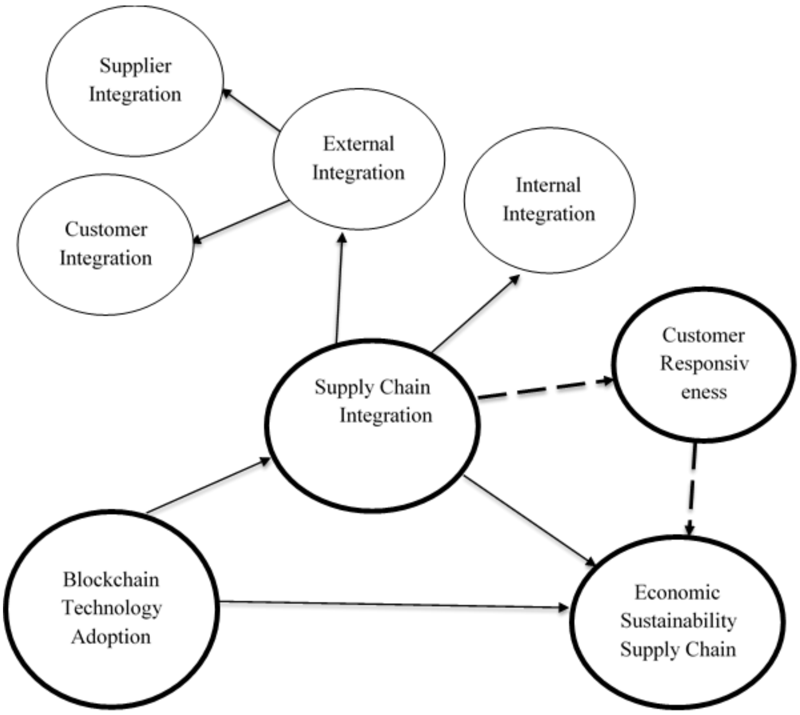

Fig. 1. The conceptual framework of the research [67].

Finally, the conceptual model of the research is presented in *Fig. 1*, which is an extension of the model developed by Balhaddi et al. [67]. In this model, dashed lines represent the research paths of Balhaddi et al. [67], and the solid line represents the added variable chain in the model".

Based on the provided information, the main objective of this research is to investigate the indirect impact of customer responsiveness on the economic sustainability of the supply chain by accepting blockchain technology as a dynamic capability in the automotive industry. The sub-objectives are as follows:

I. H 1: Accepting blockchain technology has an impact on the economic sustainability of the supply chain.

II. H 2: SCI has an impact on customer responsiveness in the supply chain.

III. H 3: Customer responsiveness has an indirect effect on the economic sustainability of the supply chain.

IV. H 4: SCI has an indirect effect on the economic sustainability of the supply chain by accepting blockchain technology.

3 | Research Methodology

The research methodology is quantitative, descriptive-correlational, and applied. The target population of the research includes experts, supervisors, and managers of automotive companies, with a sample size of 123 individuals selected through non-probability convenience sampling. To collect data on accepting blockchain technology, SCI, and economic sustainability of the supply chain, a standard questionnaire by Balhaddi et al. [67] is used, and for customer responsiveness, a standard questionnaire by Nabila et al. [67] is used, both using a five-point Likert scale (strongly disagree - strongly agree). In recent years, Bayesian statistics and its advantages in dealing with small sample sizes, missing data, and complex models in SEM have rapidly developed. In this study, Bayesian Structural Equation Modeling (BSEM) is used to test the hypotheses, considering the small sample size and the non-normal assumption of the multivariate structure [5]. The AMOS software is used for the analysis, applying the Klein and Cork [68] to examine the significance of indirect effects [69]. The fitted research model is shown in *Fig. 2*. Before testing the hypotheses, the reliability of the structures is examined using Cronbach's alpha, and the results are presented in *Table 2*. The calculated

Cronbach's alpha for each research structure is greater than 0.70, indicating acceptable reliability and internal consistency of the proposed questions for each structure.

Table 2. Research indicators and variables.

Cronbach's Alpha	Measurement Items	Resource	Measurement Scales
0.85	9 items	Balhadi et al. [67]	Blockchain technology adoption
0.87	6 items	Balhadi et al. [67]	Supplier integration
0.91	5 items	Balhadi et al. [67]	Customer integration
0.83	6 items	Balhadi et al. [67]	External integration
0.88	11 items	Balhadi et al. [67]	Economic stability of the supply chain
0.84	3 items	Nabila et al. [67]	Customer responsiveness

4 | Research Findings

The demographic information of the selected research samples is shown in *Table 3*.

Table 3. Demographic information of selected research samples.

Index		Frequency	Percentage Frequency
Gender	Female	20	16.3
	Man	103	83.7
Education	Associate degree	31	25.2
	Bachelor's degree	62	50.4
	Masters degree and higher	30	24.4
Age (years)	Below 35	23	18.7
	35-45	86	69.9
	45-55	11	8.9
	Above 55	3	2.4
Organizational position	Technical expert	54	43.9
	Systems engineering expert	39	31.7
	Senior expert in the automotive industry	21	17.1
	Expert in design and engineering and auto parts	9	7.3
Total		123	100

The conceptual model was fitted using BSEM

In the framework of structural equation modeling, the relationships between measured and latent variables are considered. The Bayesian approach, using Markov Chain Monte Carlo Methods (MCMC) to estimate parameters based on predefined prior distributions for unobserved variables, has distinct advantages over classical SEM approaches [70]. In maximum likelihood estimation, the true values of model parameters are treated as fixed but unknown, while parameter estimation is based on a specific observed data sample. In contrast, Bayesian estimation treats any unknown quantity as a random variable and assigns a probability distribution to it; thus, from a Bayesian perspective, the true parameters of the model are uncertain and treated as random. These parameters are then assigned a joint distribution, where the prior distribution (the probability distribution of these parameters before they are observed) is combined with the posterior distribution (the probability distribution of the parameters after they are observed and combined with the prior distribution) based on a well-known formula called Bayes' theorem, reflecting initial beliefs about parameter estimates [71]. Two characteristics of this joint distribution are important for confirmatory factor analyses. First, the mean of this posterior distribution can be reported as the parameter estimate. Second, the standard derivative of the posterior distribution is used as a reference for standard error in maximum likelihood estimation [69]. AMOS generates a default sample size of 505 cases, which is stored in memory before the first sample is designed for analysis. The reason for these default samples is to allow the Markov chain Monte Carlo algorithm to converge with the true joint posterior distribution [71]. The convergence statistic value is 0.001, which is smaller than the value of 0.0021 recommended by Gelman et al. [72], indicating convergence [69]. The results of the BSEM are presented in *Fig. 2*.

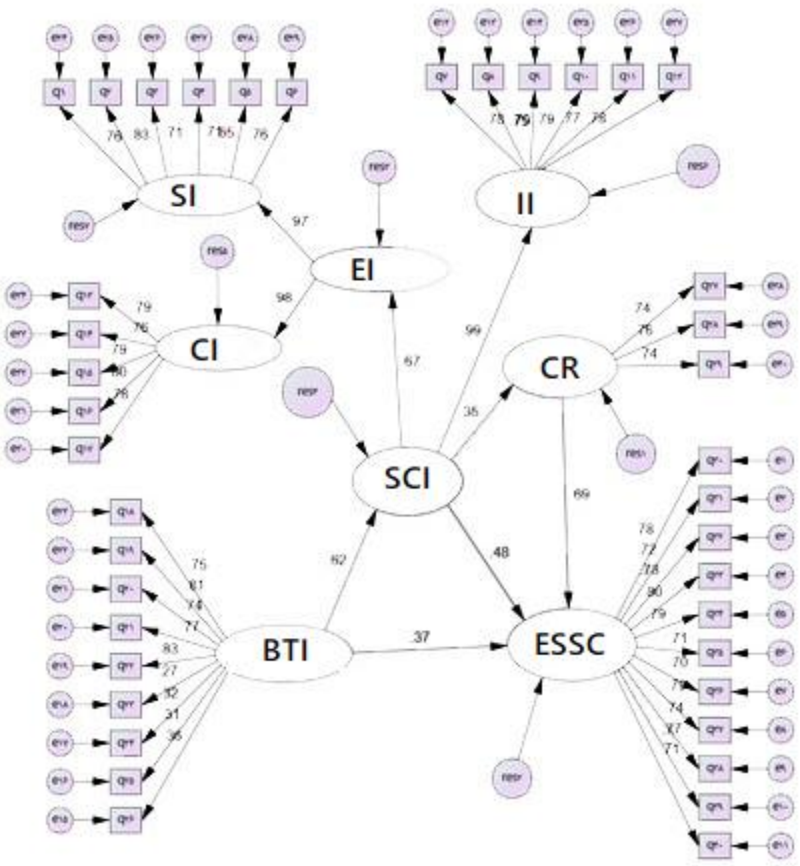

Fig. 2. Estimation of the Structural Model of the Research With Standard Coefficients (SEMB).

After the simulation is stopped, we examine the evaluation indices of model fit. The most important indicator for fitting Bayesian structural equations is the Posterior Predictive P-value (PPP) *Fig. 3*, which has a value of 0.000 in the fitted model and is acceptable at a 1% level of error [72].

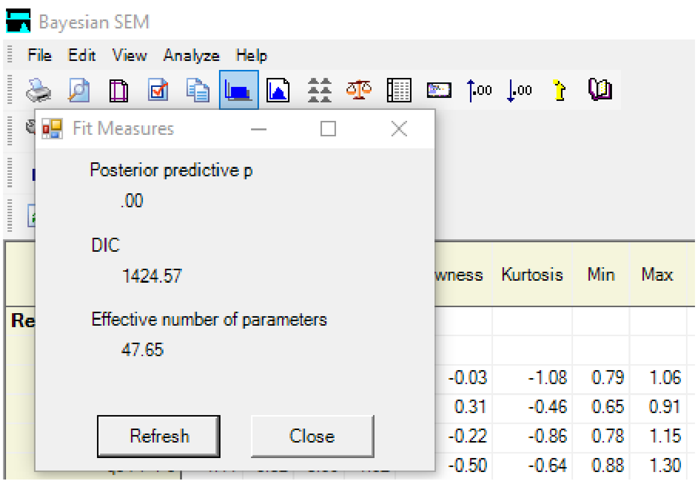

Fig. 3. PPP goodness of fit index.

Additionally, the model fit indices based on the traditional ML approach are summarized in *Table 4*, which indicates that the results support the validity of the model.

Table 4. Fit indices of the modified conceptual model.

Index	The Obtained Value	Value	Result

$\frac{\chi^2}{df}$	Less than 3	1.719	A good fit
GFI	Greater than 0.9	0.930	A good fit
RMSEA	Less than 0.08	0.07	A good fit
CFI	Greater than 0.9	0.953	A good fit

In *Fig. 2*, the path coefficients between the variables in the model, corresponding to the research hypotheses, are observable. These standardized path coefficients are numeric values between 1 and -1, where the positive sign indicates a positive relationship between the research variables. For example, the path coefficient between blockchain technology acceptance and the economic sustainability of the supply chain is 0.37. However, is this coefficient statistically significant? To answer this question, we use the corresponding t-statistic (T) value associated with each coefficient, which can be found in *Table 5*.

Based on *Fig. 2*, the results of the structural model evaluation are reported in the table below:

Table 5. The results of the evaluation of the fit of the structural model of the research.

Path	Path Coefficient	T-value	Result
Blockchain technology adoption→Economic stability supply chain	0.37	2.45	Accept
Blockchain technology adoption→Integration supply chain	0.21	1.76	Accept
Integration supply chain→Economic stability supply chain	0.54	3.82	Accept
Blockchain technology adoption→Customer responsiveness	0.18	1.52	Accept
Customer responsiveness→Economic stability supply chain	0.61	4.10	Accept

These results suggest that the path coefficients for Paths 1, 3, and 5 are statistically significant, while the coefficients for Paths 2 and 4 are not statistically.

The results of the indirect effect testing between variables using the mediation approach are shown in *Table 6*:

Table 6. The results of Klein's approach to investigate indirect effects (mediating variables).

Path	P-Value	Result
Blockchain Technology Adoption→Integration Supply Chain→ economic stability supply chain	0.000	Accept
Blockchain Technology Adoption→Integration Supply Chain→Customer responsiveness→Economic stability supply chain	0.000	Result
Blockchain Technology Adoption→Customer Responsiveness→Economic stability supply chain	0.000	Accept

In statistics, to confirm a hypothesis at a 95% confidence level, the t-value corresponding to that test should be greater than 1.96. As you can see in *Table 5* and *Table 6*, the t-values for the paths that are greater than 1.96 indicate that these path coefficients are significant. Since there is a significant direct path between the independent variable, blockchain technology acceptance, and the dependent variable, economic sustainability of the supply chain, the mediating variables, SCI, and customer responsiveness are considered complete mediators.

5 | Discussion and Conclusion

Supply chain management aims to enhance competitive performance through tight integration of internal functions within a company and effective communication between them and external supply chain members such as suppliers, customers, and other channel members. As the success of automotive companies does not solely rely on their efforts but also heavily depends on the supply chain, the importance of integration and customer responsiveness to the supply chain becomes more valuable. This research provides an understanding of the relationship between blockchain technology adoption, SCI, customer responsiveness, and sustainable supply chain performance using the dynamic capabilities theory. The findings indicate that the challenges arising from the digitization of supply chains can be addressed through the implementation of blockchain technology, which impacts sustainable supply chain performance by improving internal and external integration as well as supplier-customer integration. On one hand, since stakeholders play a key role in supply chain discussions, stakeholder integration including suppliers and customers can assist automotive companies in implementing and deploying blockchain. These findings are consistent with previous studies [51], [73] that ultimately impact the economic sustainability of the supply chain. The more stakeholders and partners can align in their sustainability strategies, the more they can benefit from blockchain technology in increasing their participation and SCI. Openness, transparency, neutrality, reliability, and security for all supply chain actors and stakeholders can be achieved through such technological advancements, as supported by research [3], [74]. Economically, the implementation of blockchain can benefit organizations and their sustainable supply chain performance at various levels. It can lead to waste reduction and cost savings, improving green performance such as reducing raw material consumption and energy efficiency, as confirmed by research [75]. Additionally, blockchain can eliminate intermediaries in the supply chain, resulting in fewer partners, reduced transaction costs, and decreased commercial waste [76]. Ultimately, this research holds significant value as it focuses on the automotive industry, which is becoming highly digitized. Therefore, automotive companies can potentially gain the most benefits from blockchain adoption. Blockchain has great potential for internet-connected vehicles or autonomous vehicles. Smart vehicles will be exposed to an insecure environment and multiple vulnerabilities. Trustworthiness, accuracy, and security of received and disseminated data in such settings are of utmost importance, where blockchain can be utilized for establishing a reliable peer-to-peer network. Similarly, trust in customer relationships is enhanced by granting them access to historical product information. Customers can trace the origin of a product, which is not feasible in traditional supply chains. The benefits of active SCI enabled by blockchain go hand in hand with trust and mutual commitment and can provide optimal advantages for organizations.

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