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Blockchain technology in supply chains – improving end-to-end business performance

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Aim: Blockchain technology (BCT) is a relatively new technological development, promising strong gains in the areas of product traceability and visibility, end-to-end coordination (E2E), governance, and efficiency of supply chains. The aim of this study is to gain a better understanding of the impact of BCT on these performance measures.

Design / Research methods: Hypotheses were tested with survey data from 119 supply chain professionals from Northern American SMEs.

Conclusions / findings: The results confirm the positive impacts of BCT on all performance measures. E2E coordination is the integration of information, goods, and money within an organisation or supply chain. E2E coordination appeared to benefit from the use of BCT, enabling information sharing in a safe way. The findings suggest that BCT use fosters E2E coordination, which in its turn also positively affects financial performance.

Originality / value of the article: Despite the increasing interest in and use of, BCT, there is little empirical evidence for the effect on supply chain performance. Many studies are anecdotal and lack empirical evidence.

Implications of the research: Companies should acknowledge the impact of BCT use on the various supply chain performance measures. Implementing and using BCT is likely to foster improvement in a wide range of performance indicators.

Limitations of the research: Companies use different types, versions, varieties, and forks of blockchain, all having their own strong and weak points. Future studies could investigate and include the nuances within different forks of BCT. This study focusses on the benefits of BCT use. Future studies could investigate the negative impacts and side-effects of BCT.

Key words: Blockchain technology, product traceability, operational efficiency.
JEL: M1

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1. Introduction

Current organisations are eager to increase the effectiveness and operational strength of their business (Becker, Kahn 2003; Vo et al. 2019). Continuous outsourcing and specialisation have typically increased the emphasis on cost reduction of organisations and have therefore led to the increased need to optimize their competitiveness and performance. One way to improve the performance of an organisation is to increase the performance of its supply chain (Söderberg, Bengtsson 2010; Tortorella et al. 2018).

Within the last few decades, a large array of technological advances and developments have been introduced to the world (Alicke et al. 2019), with many organisations adopting and implementing these technological solutions in search of operational or organisational performance gains (Casado-Varaa et al. 2018). This search has led to many costly dead-ends, in cases where technology could not succeed in delivering the increase in performance that they promised (Alicke et al. 2017). In some cases, these solutions even came with their own set of new problems; for example, in the case of the usually inflexible and rigid manufacturing-resource-planning (MRP) (Umble et al. 2003). MRP software often cannot deal with 'uncertainties and volatilities of the real world, in which machines break down, suppliers fail to deliver, and customers change their minds' (Alicke et al. 2017).

In many cases, it has become clear that technological advancement and solutions can never take the place of operational quality and the use of best practices within supply chains, such as effective cross-functional collaboration (Laurent, Leicht 2019), adherence to the pillars of the SCOR model (McCormack et al. 2008; Miri-Lavassani, Movahedi 2018), or ensuring that the organisation's employees are a good fit within the team (Kooij, Boon 2018).

Current organisations and supply chains, however, have a wide selection of promising technology at their disposal, many of which have cascaded down from different kind of fields, such as blockchain technology (BCT), the Internet-of-things, artificial intelligence (AI), or the general push for digitisation. What most technologies also have in common is that they all promise substantial performance gains.

The three areas of technological innovation that deserve a better understanding to what extent they are driving organisational performance in modern supply chains, are end-to-end (E2E) coordination, BCT, and traceability. These areas have attracted much attention, both academically and professionally, throughout recent history (Tjahjono et al. 2017; Tortorella et al. 2017; Hill et al. 2018; Nandi et al. 2020), and have been claiming specific performance gains, either in error reduction (Salah, Rahim 2018), improving product visibility (Treiblmaier 2018), or improving supply chain efficiency (Alicke et al. 2019).

Despite the increasing recent interest in, and use of, BCT, there is little empirical evidence for the effect it has on supply chain performance (Casado-Varaa et al. 2018); many studies are anecdotal and lack empirical evidence. To study the effects that these new developments have on the performance of supply chains, a quantitative survey was carried out among supply chain professionals from North American SMEs.

2. Literature Review

2.1 Blockchain Technology

BCT is generally referred to as a distributed data structure, a decentralised network, or, most commonly, distributed ledger technology (DLT) (Kshetri 2018). BCT was introduced for the first time, at least in the context of the Bitcoin protocol, in 2008 (Nakamoto 2008). The technology was introduced by the person, or group of people, that goes by the name of Satoshi Nakamoto (Nakamoto 2008; Seebacher, Schüritz 2017). With the introduction of the technology by Nakamoto, it became useable as a protocol that is open, transparent, and secure and eliminates the need for a central governing body (Seebacher, Schüritz 2017).

BCT can be used to record and store information in blocks. Each block of information contains a hash of the previous block, a timestamp, and the data of the actual transaction (Wonga et al. 2019). These blocks of information can contain financial transactions, personal information, or messages between people or organisations. BCT is unique in the sense that information is not stored in one central location but is managed entirely decentralised, making it difficult to corrupt. Its transactions, which are time stamped (Sharples 2016), are published and shared with all other users within the chain and are stored in the network using peer-to-peer technology. The verification process, in combination with the used encryption, secures the data so that only authorised members have access to the information in the blockchain (Wang et al. 2018). Since 'trust' is coded into the blockchain, there is no need for central governing bodies (Gaehtgens, Allan 2017). When the transaction is verified and authorised by at least 51% of the users in the specific chain, the information is added to a new block. This system makes it easy to check which subsequent blocks of information are related to each other, which makes the technology '*secure by design*' (Falazi et al. 2019).

2.2 Blockchain Technology in Supply Chains

BCT is generally considered to be an emerging, foundational technology. In September 2015, nine financial institutions including Goldman Sachs, J.P Morgan and Barclays, built a new financial infrastructure that was based on BCT (Underwood 2016). As a result of this, many young companies in the Fintech industry were founded that based their business upon this new technology. Supply chains were somewhat slower to understand the potential of the technology but have since been implementing and restrategising the still young technology (Hackius, Petersen 2017). One of the major performance gains for supply chains that the use of BCT should result in is to give all nodes in the entire supply chain network access to the same data, resulting in unanimous agreement among the whole network (Tapscott, Tapscott 2018). Furthermore, in the area of transparency and visibility, which are traditionally difficult areas to improve, BCT should result in significant gains (Abeyratne, Monfared 2016). Furthermore, BCT is showing also considerable promise in terms of traceability, which has gained substantial traction in recent years, from both legal and ethical points of view (Dabbene et al. 2014). As a result, both from the professional and academic world, the use of BCT is considered to offer considerable promise and potential for supply chains (O'Marah 2017) or is even able to 'transform the supply chain and disrupt the way we produce, market, purchase and consume our goods' (Dickson 2016). Several sources cite and assume BCT to be a 'disruptive' technology (Treiblmaier 2018), but according to the definition of Iansiti and Lakhani (2017), the term ‘foundational’ as applied to this technology would be more appropriate, as it can lead to the ‘enabling’ of many other types of technology and developments (Iansiti, Lakhani 2017; Hald, Kinra 2019; Buer 2019).

Studies have shown that the use of BCT can indeed lead to higher levels of reliability, transparency, and efficiency through its unique set of characteristics (Treiblmaier 2018). Furthermore, Kshetri (2018) found that the implementation and use of BCT strongly correlated with several typical performance indicators commonly used in SCM, such as cost, speed, and flexibility. It is believed that BCT can lead to these improvements through a large array of applications, on which Petersen et al. (2017) has performed a study in which 49 different applications where BCT could be used were studied. These applications were then grouped into three main clusters: product tracking, product tracing, and supply chain finance.

In contrast, in the same study by Petersen (2017), it was also shown that there remain large numbers of conservative organisations that are hesitant to invest in and implement BCT by claiming that it is unclear exactly how the use of BCT can lead to performance improvement and how it is affecting the employees of organisations. This might be the result of having little knowledge about blockchain (Kersten et al. 2017), uncertainty about the barriers to implementation (Hackius, Petersen 2017), or fear of BCT being hype (Banker 2017). Furthermore, scepticism remains regarding the general innovativeness and applicability in the real world or an association with money laundering (Cong, He 2019).

2.3 Product Visibility and Traceability

In recent developments, BCT has been proposed to provide increased levels of traceability and standardisation in communication and data formats (Westerkamp et al. 2020). The use of BCT can in this way serve as a foundational technology in order to enable or improve traceability (Francisco, Swanson 2018). It is able to do this by enabling the users of the technology to attach a record of information to the blocks of information within the blockchain that contain all the product’s history (Ølnes et al. 2017). Records of information are added during all transactions between blocks, are stored for an infinite amount of time, and are indelible and impossible to adjust or modify. In the case of private blocks, the information records are only available to predetermined members. When the records need to be publicly available, the public blockchain is used. The use of BCT in supply chains could therefore lead to a higher level of visibility of the status, position, and condition of information or goods within the whole supply chain, which is argued to lead to higher levels of traceability (Hald, Kinra 2019).

2.4 End-to-End Coordination

End-to-end coordination (E2E coordination) is the integration of all flows of information, goods or money within an organisation or supply chain. It is generally argued that in order to achieve successful supply chain collaboration, actors within a supply chain are required to approach supply chains with a holistic and end-to-end perspective (Burnette, Dittmann 2018). This is the result of the notion that any decision or action in any part of a supply chain can affect results in all other areas. These decisions and actions, therefore, need to be understood by the actors within supply chains to manage, improve and ultimately reach end-to-end coordination and collaboration (Burnette, Dittmann 2018). Historically, supply chains without collaboration or end-to-end coordination have typically endured additional costs or have struggled with customer relations more than supply chains with more advanced E2E coordination (Alicke et al. 2019; Burnette, Dittmann 2018).

It is generally believed that higher E2E coordination will lead to better organisational performance of the supply chain through better visibility, control and traceability of the products, services or pieces of information that is contained within the supply chain (Alicke et al. 2019; Yu et al. 2017). The study by Alicke et al. (2019) shows that supply chains with higher-than-average performance have higher levels of investment in formal roles created to improve E2E coordination across their business units, functions, and sites.

By improving E2E coordination, participants and actors are more likely to understand the location of goods in transit, they will be able to determine the status of customs documents more efficiently and view other types of data in more efficient or less restrictive ways (Nowiński, Kozma 2017). This will lead to a more efficient supply chain. BCT is believed to be able to enable enhanced E2E coordination as a result of the increased visibility of products, goods and information within the supply chain (Hald, Kinra 2019). BCT can achieve this because of the potential of every node within a blockchain to be able to see all other nodes, and this information is passed on instantly to all participants and actors within the supply chain possessing the predetermined authority.

2.5 Supply Chain Governance and Efficiency

Another potential development that is enabled by the use of BCT is the creation of algorithms that are enforced or executed when certain conditions are met, which is a concept that is also known as a 'smart contract'. Smart contracts were first envisioned in 1994 by Szabo (1996), when he defined a smart contract as "machine-readable transaction protocols which create a contract with pre-determined terms". Several years later, the definition for smart contracts developed into 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' (Szabo 1996). Smart contracts are not simply digital contracts, nor do they merely rely on the implementation of AI. What makes smart contracts 'smart' is that they allow terms contingent on fully decentralised consensus; are completely tamper-proof; and are fully automated, enforced, and executed when a predetermined set of conditions are met. Because of these characteristics, smart contracts have low transaction fees compared to the traditional systems, which often require a trusted third party such as a notary or legal officer in order to enforce and execute the terms of an agreement.

Smart contracts can run on BCT, where they have the ability to facilitate, execute, and enforce the terms of an agreement. When smart contracts run on BCT, the conditions of the agreement are formulated in code, which is then transferred to a blockchain, which can be either private or public. After the predetermined conditions of the contract are met, the contract is then automatically executed without any assistance or governance of third-parties or central forms of governance. Additionally, by being tamper-proof, it is not possible to change the internal logic or conditions at any time unless there is a consensus of all parties involved. The use of BCT in a supply chain therefore stimulates data availability, visibility, security, and benefits of using common language and terminology (Casado-Varaa et al. 2018). Because of the inherent nature of BCT, the data surrounding the terms and execution of the contract are visible for all predetermined users and parties involved with the smart contract. It is therefore often argued that organisations can benefit from the use of smart contracts and thus improve the governance and efficiency of their supply chains (Hald, Kinra 2019). These concepts are generally associated with improved supply chain performance (Treiblmaier 2018).

2.6 Supply Chain Performance

Supply chain performance (SCP) is a term that can be explained, defined, and constructed in many different ways (Beamon 1999; Mani et al. 2017). One way to construct SCP is to use organisational performance, operational performance, and environmental performance (Inman, Green 2018). Another way would be to use supplier performance, customer satisfaction, and financial performance as indicators for SCP (Li et al. 2006; Yu et al. 2017; Benton et al. 2020). In this way of looking at SCP, an organisation would be able to understand what is happening at the input and the output side of its supply chain, combined with the financial performance indicators, to be able to understand the performance of its supply chain.

Supplier performance can also be defined in many different ways: quality of the products of the supplier (Mani et al. 2017); the products' lead-time; and the supplier's stability (Chang, Lin 2019), number of errors (Mani et al. 2017), price levels compared to their competition (Li et al. 2006), and other factors. It is essential to know the levels of performance at the supplier side of a supply chain, as supplier performance is a key driver in the overall SCP (Mani et al. 2017; Yang, Zhang 2017; Al-Shboul et al. 2017).

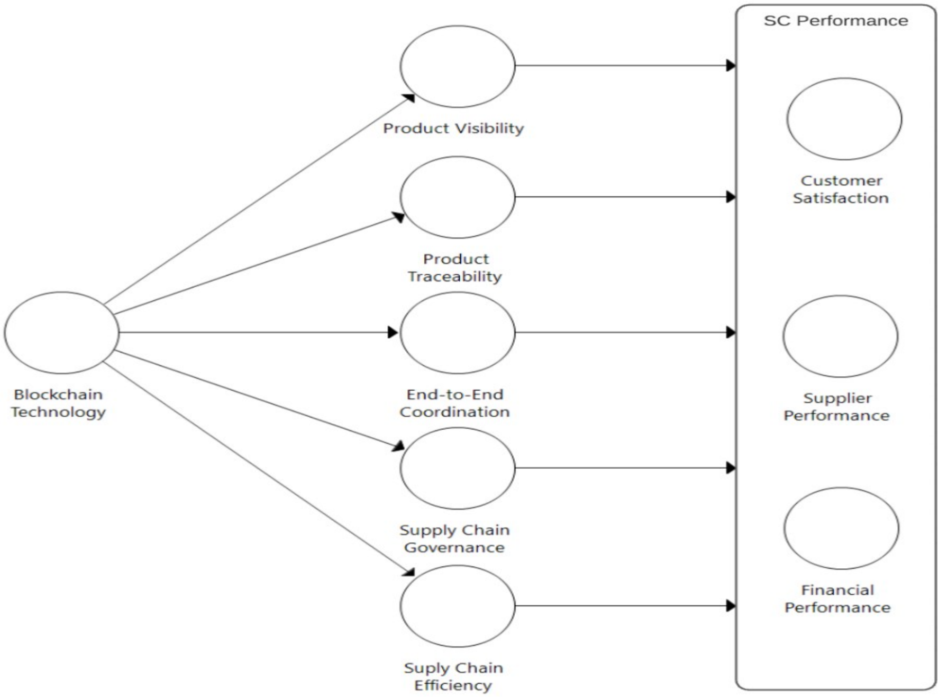
Customer satisfaction is, similarly to supplier performance, an essential driver of overall SCP, as it is a strong indicator for the organisation's own SCP. There exist many ways to measure customer satisfaction (McColl-Kennedy, Schneider 2010), though given the rather subjective nature of it, simply asking a customer to what extent they are enjoying the experience of engaging in business with the other side could be sufficient (Cengiz 2010).

In some cases, customer satisfaction could be defined as a customer 'who receives significant added value' (Hanan, Karp 1989), which is based on the assumption that when a customer received the required product or service, the satisfaction levels will rise. The financial SCP is a strong indicator for its overall strength and performance and particularly useful as an indicator when it is compared to the financial performance indicators with the industry average (Tortorella et al. 2018).

3. Research model

The literature shows that the use of BCT can improve the performance and effectiveness of a supply chain in several ways. Product visibility, product traceability, end-to-end coordination, supply chain governance, and supply chain efficiency are all areas where supply chains are believed to be able to benefit from BCT. As shown in **Błąd! Nie można odnaleźć źródła odwołania.**, SCP is constructed from customer satisfaction, supplier performance, and financial performance. It can, however, also be measured separately in order to understand the area where BCT has the strongest effect.

Figure 1: Research Model



Source: authors' own elaboration

4. Methodology and instrument

A self-administered survey was conducted between February and March in 2021, using a diverse sample consisting of companies of different sizes, industries, and ages. A Dun and Bradstreet database was used to acquire a large number of contact details of Northern American (including Canada) based supply chain professionals. This type of database was used as they are known for their high-quality data and as it was deemed to be important to acquire both email addresses and telephone numbers of potential respondents. For the selection of the sample of companies, three different criteria were used. The first criterion is that the respondent company should be from a pre-defined region to be able to cancel out the effects that external environments may play (Kull et al. 2014).

The second criterion is that the respondents should be from a diverse range of industries, such as construction, manufacturing, food, fashion, retail, and others, as supply chain development has been expanding in a wide range of different companies throughout the years (Handfield, Nichols 2015). The industry categorisation was carried out using the Global Industry Classification Standard (GICS 2020) on the 'industry' level. The third and last criterion is that the specific respondent that was asked to fill in the survey has a direct relationship to SCM within the company in order to accurately answer the questions in the survey. The higher-ranking person within this scope was preferred, as this tends to be a more reliable source of information (Podsakoff et al. 2003).

The questionnaire used for this study consist of three parts. The first part focused on the level of use of BCT within the supply chain. The items of the first part were developed based on a modified version of the previously tested and validated questionnaire used by Kamble et al. (2018). Secondly, several performance indicators of the supply chain such as product visibility, product traceability, and end-to-end coordination were studied. To measure this, a modified version of the previously tested and validated questionnaire by Al-Shboul et al. (2017) was used. Constructs of this survey were used in a modified form to accurately measure the levels of these performance indicators. Thirdly, the supply chain performance in a more traditional sense was measured. This was done by focusing on *supplier performance*, *customer satisfaction*, and *financial* supply chain performance.

Table 1. Constructs and measurements

Construct	Variable	Items	Source
Blockchain Technology	BCT Usage		
Performance variables	Product Visibility	Change Information Sharing	*Al-Shboul et al. (2017)*
		Information Sharing with Partners	*Al-Shboul et al. (2017)*
		Core processes information sharing with partners	*Al-Shboul et al. (2017)*
		Informing partners about changing events	*Al-Shboul et al. (2017)*
	Product Traceability	Tracking information within value chain	*Pisani (2018)*
		Location knowledge of manufacturing	*Pisani (2018)*
		Known inventory of primary materials	*Pisani (2018)*
		Production location information available in machine readable format	*Pisani (2018)*
		Efficient tracing back of information	*Pisani (2018)*
	E2E Coordination	All functions with high level of coordination	*Al-Shboul et al. (2017)*
		Cross-functional teams for process design/improvement	*Al-Shboul et al. (2017)*
		Information system integrates through entire organisation	*Al-Shboul et al. (2017)*
		Cross-over activities with partners	*Al-Shboul et al. (2017)*
		Full system visibility shared with partners	*Al-Shboul et al. (2017)*
		Lower cost of distribution than competition	*Al-Shboul et al. (2017)*

Table 2. Cont.

Construct	**Variable**	**Items**	**Source**
	SC Governance	Operational and strategic gains through collaboration	*Khandakar (2009)*
		Different stakeholders working together	*Khandakar (2009)*
		Measuring the responsiveness throughout entire organisation	*Khandakar (2009)*
		Suppliers meeting high quality standards	*Khandakar (2009)*
		Suppliers motivated to minimize SC errors	*Khandakar (2009)*
	SC Efficiency	Return on Investment higher than industry average	*Al-Shboul et al. (2017)*
		Growth in ROI	*Al-Shboul et al. (2017)*
		Profit margin on sales higher than industry average	*Al-Shboul et al. (2017)*
		Overall competitive position	*Al-Shboul et al. (2017)*
		Cost associated with held inventory better than industry average	*Al-Shboul et al. (2017)*
Supply Chain Performance	Supplier Performance	Suppliers meeting delivery schedules	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Suppliers providing efficient operational environment	*Benton et al. (2020), Al-Shboul et al. (2017)*
	Customer Satisfaction	Meeting customer's delivery schedules	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Meeting customer's quality standard	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Providing efficiant operational environment to customers	*Benton et al. (2020), Al-Shboul et al. (2017)*
	Financial Performance	Total cost of recourses better than industry average	*Ishtiaque (2020)*
		Cash-to-Cash Time Cycle better than industry average	*Al-Shboul et al. (2017)*

5. Results

Frequency distributions of the respondents and industries were first examined. As shown in Table 2, the majority (62.5%) of the respondents held the position of manager in their respective companies. No bias due to the respondent's position was found.

Table 2. Position by the respondents

		Frequency		
	Position	**Abs.**	**(%)**	**Cumulative Percentage**
Valid	President	0	0	0
	Manager	70	62.5	62.5
	Consultant	24	21.4	83.9
	Other	18	16.1	100.0
	Not informed	0	0.0	100.0
	Total	112	100	
Total		**112**	**100**	

Source: authors' own research

In total, 26% of the respondents were industrial production companies, 22% were in Health Care, and 20% were in Finance. The remaining 32% were service providers or in retail. No bias for any industry segment was found.

For this study, blockchain-using organisations were targeted. In total, 26% of the respondents reported very low levels of BCT, 69% reported Low or Moderate levels of BCT, and 5% reported High levels of BCT usage.

Factor analysis was used to understand to what extent the used items are relevant to the constructs they are considered part of. To ensure the reliability of the research, items were eliminated from their respective constructs in case the factor loading on their intended constructs was below the minimum recommended level of 0.50 (Hair et al. 2006). After the initial factor analysis, it became clear that some items did not meet the lower threshold of 0.50, and these items were thus removed. After consolidating the research model, the results are as shown in Table 3 and Table 4.

Table 3. Construct reliability and validity

Construct	Items	CA	CR	AVE
(1) Blockchain Technology	1	1	1	1
(2) Product Visibility	5	0.72	0.81	0.47
(3) Product Traceability	5	0.74	0.83	0.49
(4) End-to-End Coordination	6	0.70	0.80	0.40
(5) Supply Chain Governance	6	0.71	0.80	0.41
(6) Supply Chain Efficiency	5	0.68	0.80	0.44
(7) Supply Chain Performance	7	0.77	0.83	0.42

Source: authors' own research

Table 4. Construct validity

	(1)	(2)	(3)	(4)	(5)
(1) Product Visibility	**0.69**				
(2) Product Traceability	0.72	**0.70**			
(3) End-to-End Coordination	0.66	0.74	**0.63**		
(4) Supply Chain Governance	0.54	0.56	0.66	**0.64**	
(5) Supply Chain Efficiency	0.59	0.66	0.68	0.69	**0.66**
AVE	0.47	0.49	0.40	0.41	0.44
Composite Reliability	0.81	0.83	0.80	0.80	0.80

Source: authors' own research

Table 5 shows that the Fornell-Larcker criterion was not reached, which is explained by the relatively low AVE of all five constructs. Therefore, a more elaborate HeteroTrait-MonoTrait (HTMT) ratio of correlations-analysis was performed to understand to what extent issues with multicollinearity might be expected (Henseler et al. 2015).

SmartPLS, version 3.3.3 was used to carry out PLS regression. It can deal effectively with research models that contain highly intercorrelated variables that are surrounded by substantial amounts of random noise (Jöreskog, Wold 1982). To calculate the path coefficients, factor loadings, construct reliability, and validity measures, the regular PLS algorithm was used. To generate the *t*-statistics and *p*-values, bootstrapping based on 3,000 samples was used. This methodology was consistent throughout this whole research. After loading and running the model in SmartPLS3, the model converged at the seventh iteration, which leads to the results shown in Figure and in **Błąd! Nie można odnaleźć źródła odwołania.**. When the five constructs explained by BCT are examined, it becomes clear that all five constructs show strong relationships. Path coefficients are between 0.446 and 0.617, R^2 between 0.192 and 0.375, and all relationships are significant with *p*-values lower than 0.01. When the construct of SCP is examined, it becomes clear that its variance is explained with an R^2 of 0.675 by its five predicting constructs, with product traceability having the strongest relationship with a path coefficient of 0.234. The *p*-values, indicating the levels of statistical significance, are between 0.019 and 0.097, indicating moderately to strongly significant relationships.

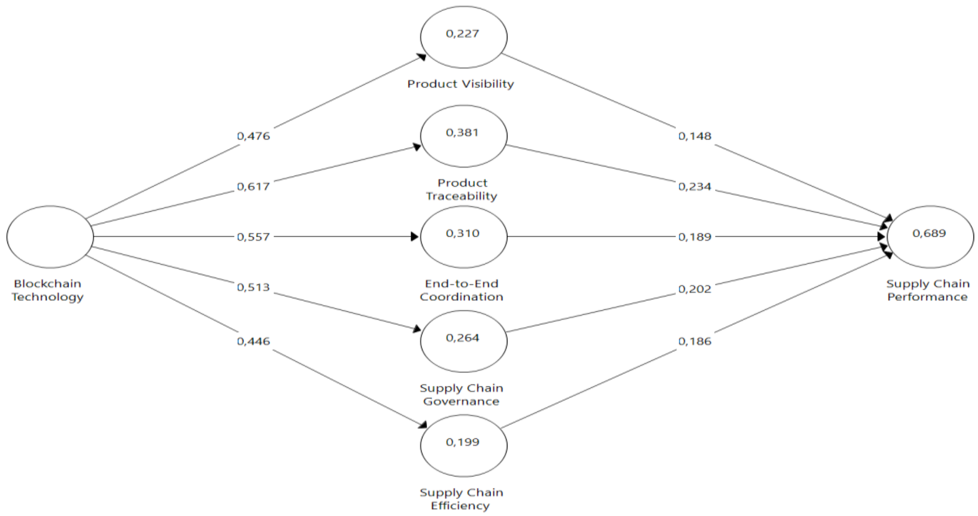
Table 5. HTMT criterion results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
(1) Blockchain Technology						
(2) End-to-End Coordination	0.66					
(3) Product Traceability	0.72	0.88				
(4) Product Visibility	0.55	0.76	0.82			
(5) Supply Chain Efficiency	0.54	0.89	0.82	0.72		
(6) Supply Chain Governance	0.60	0.85	0.69	0.65	**0.91**	
(7) Supply Chain Performance	0.61	0.84	0.82	0.74	0.83	0.78

Source: authors' own research

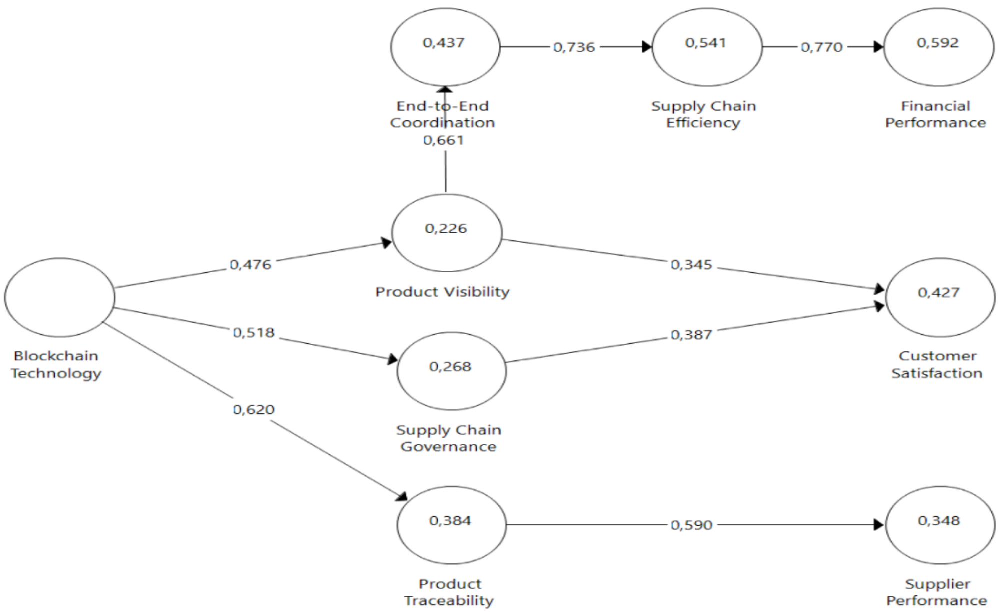
As discussed in the literature review, SCP can be constructed from supplier performance, customer satisfaction, and financial performance, and the five constructs can thus be tested on these three constructs of SCP individually. This model was constructed and loaded into SmartPLS. Figure 3 shows our final empirically validated model.

Figure 2. Research model results



Source: authors' own research

Figure 3. Final research model



Source: authors' own research

6. Conclusions and discussion

Continuous outsourcing and specialisation within organisations have increased the emphasis on cost reduction and have therefore led to the increased need to optimize their competitiveness and performance. The use of blockchain technology is a promising way to improve supply chain performance. In this study, we found significant effects of the BCT use on product visibility, product traceability, end-to-end coordination, supply chain governance, and supply chain efficiency. In addition, these factors positively impacted the supply chain performance. Finally, when SCP is separated into supplier performance, customer satisfaction, and financial performance, this research has concluded that product visibility and supplier governance are strong and significant drivers of customer satisfaction, that product traceability is a strong and significant driver of supplier performance, and that end-to-end coordination and supply chain efficiency are strong and significant drivers of financial performance.

6.1 Positive effects of BCT

The results of this research indicate that, as was hypothesised, the use of BCT can lead to improved visibility and traceability of products in a supply chain. Traceability was also found to have a strong effect on supply chain performance, which is in line with the experience of many organisations. For example, the large American retail chain Walmart has claimed that product traceability of their mangoes, all the way back to their source, improved from 7 days to a mere 2.2 seconds (HyperLedger 2018) after implementing IBM's Hyper Ledger. Hyper Ledger is a blockchain fork that uses BCT specifically to improve the traceability of products (HyperLedger 2021).

End-to-end coordination (E2E coordination) is the integration of all flows of information, goods, or money within an organisation or within a supply chain. End-to-end coordination is believed to benefit from the use of BCT from the increased visibility of all nodes in the supply network and, as a result, trust can be established between different entities within the network that might not be familiar with each other. Unfamiliar entities may be hesitant to share information in fear of undermining each other's business (Sharma 2020). BCT can enable the sharing of information in a safe way and on a predetermined basis, even on a case-to-case basis if desired. The results of this study indicate that the use of BCT may lead to improved E2E coordination, which in its turn also has a positive effect on supply chain performance.

The use of BCT in a supply chain stimulates data availability, visibility, security, and benefits from using common language and terminology (Casado-Varaa et al. 2018). Because of the inherent nature of BCT, the data surrounding the terms and execution of the contract are visible for all predetermined users and parties involved with the smart contract. It is therefore often argued that organisations can – through the use of smart contracts – improve the governance and efficiency of their supply chains (Hald, Kinra 2019). We found that the use of BCT is indeed able to improve the governance and efficiency in supply chains. Supply chain governance and efficiency both have a positive effect on SCP as well. Interestingly, when the effect of supply chain efficiency on financial SCP is studied, SC efficiency has a very strong and statistically significant effect. This may be because in an efficient supply chain few resources are wasted, which would lead to a better financially performing supply chain.

6.2 Impact on supply chain performance

The results show particularly strong and significant effects of product traceability and SC governance on supply chain performance and moderately strong effects of the other three constructs on SC performance. To be able to put this into a more practical context, we need to zoom in on exactly which parts of a supply chain these performance gains find their origin in. If we look at customer satisfaction, then the results suggest that increased product visibility and SC governance are the strongest drivers. In the case of product visibility, the reasons for this might be found in the growing tendency (MAI-Solutions 2020) – not necessarily limited to BCT – of organisations to display current inventory levels on E-commerce websites, showing the phase of production that a made-to-order product is in, or even the live location of food ordered from a delivery restaurant. This could lead to higher levels of customer satisfaction. In the case of SC governance, the effect is harder to understand. Supply chains with higher levels of governance may be in better control of the nodes within the network, which in turn can lead to better and more concise communication towards customers, shorter lead times, and possibly even lower costs. More elaborate research would have to be designed and executed in order to fully understand the underlying drivers of supply chain governance on SCP.

We found that the strongest driver for supplier performance in our study was product traceability. As several publications suggest (Xu et al. 2019; Lu, Xu 2017; Dabbene, Gay 2011) to have traceability of products, especially if this traceability finds its origins in BCT, strong relationships and partnerships need to be built and formed between organisations and their suppliers. Even if just one of the suppliers of an organisation does not incorporate BCT in their part of the supply chain, the traceability of the products is – at least partly – lost, and full traceability cannot be achieved. Organisations that managed to have very good traceability of their products are therefore expected – through the requirement of BCT-induced traceability itself – to show strong supplier performance as well. Because having product traceability thus relies strongly on the extent to which organisations and their suppliers are willing to cooperate, the increased performance in suppliers that is witnessed will most likely not even be a direct result of using BCT but merely an interesting side effect.

Finally, in the case of the financial performance of a supply chain, two drivers stand out: end-to-end coordination and supply chain efficiency. For the latter driver, this might not be hard to understand. An efficient supply chain wastes few resources, and if there is little waste in terms of manpower, machinery, or money, higher financial performance can be expected. End-to-end coordination, in contrast, is a more interesting driver of financial performance, even though the effect it has is less strong. Obviously, product visibility facilitates and improves end-to-end coordination, which can in turn positively impact supply chain efficiency and financial SC performance. Apparently, if products are more visible to all responsible stakeholders in a supply chain, the coordination through the whole supply chain can and will improve. Actors in the supply chain are in turn believed to use this information to make better decisions that will in turn improve the efficiency of a supply chain as well. This will eventually lead to better financial results.

6.3 Recommendations for practitioners

One might easily question the usefulness of new technologies such as blockchain technology. The results of this study appear to confirm the merits and positive effects of BCT use. Companies should acknowledge the impact of blockchain technology use on product visibility and traceability, E2E coordination, and supply chain governance and efficiency. Implementing and using BCT is likely to foster improvement in a wide range of performance indicators. The strongest effect of BCT appears to be on product traceability which is directly related to the financial performance of supply chains. Organisations that are interested in improving their supplier and financial performance and are willing to invest in implementing new technologies could look at BCT as a serious driver for these two SC performance aspects.

6.4 Limitations and recommendations for research

The geographical location of an organisation might – due to geopolitical reasons – influence both the likelihood of implementing and using BC and the effects that using this technology might have. The conclusions and results of this study should be evaluated in the context of the research method. Since the study only included companies from North America, the results cannot without hesitation be generalized to companies in other countries and regions. If this study would have been replicated in a broader, more global setting, the researchers should account for possible biases due to geopolitical differences which might alter some of the results of our study. Future studies could include the geographical location of organisations as a control variable in the conceptual model. In addition, future studies should try to enlarge the number of respondents. The response was, after removing the entries with more than 15% missing data, 112. We encountered two validity issues. The first issue is that the CA value for the construct of supply chain efficiency is 0.68, while most literature points at 0.70 being the lower threshold to expect strong internal validity. The second issue is that of discriminant validity. An HTMT, Monte Carlo-based analysis was performed between all reflective constructs, resulting in an HTMT value of 0.91 between supply chain efficiency and supply chain governance, while common literature generally considers two reflective constructs to be valid from 0.90 or lower.

Even though both thresholds, that of CA and that of HTMT, are breached by a minimal amount, future studies could be designed to overcome these issues.

In this study, different types of DLT have been aggregated into 'BCT'. In reality, many different types, versions, varieties, and forks of blockchain exist, and they all have their own strong and weak points. Several forks of blockchain, for example, have been created specifically to enhance product visibility and traceability. Others, however, have focussed mainly on the implementation and use of smart contract, to enhance transactional efficiency and governance. Some technologies have even specifically been developed to make life hard on producers of counterfeit products. It is clear that because all technologies have different use cases, their effect on supply chain performance might differ along with them. Future studies could investigate and include the nuances within different forks of BCT. This study focusses on the benefits of BCT use. Future studies could investigate the negative impacts and side-effects of BCT, such as issues related to inefficiencies/cost, regulatory uncertainties, privacy, and (resource) dependencies.

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