

Designing Optimal Strategies for E-Commerce Supply Chains:

Contracts and Optimisation Modelling Approach

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ABSTRACT

Supply chain organisations have been showing a greater interest in embedding e-commerce applications into their operations due to its significant benefits. These benefits include greater efficiency, lower costs, and simplified transaction processes. The exponential increase in consumer demand for online shopping has heightened the importance of improving operational effectiveness and performance in e-commerce supply chains. Presently, the operational paradigm of these supply chains is shifting towards implementing advanced technologies to enhance operational effectiveness. However, several operational and decision-making issues directly impede the performance outcomes of e-commerce supply chains. These include ineffective coordination and integration, unproductive costs, asymmetric information, and conflicts of interest. Hence, there is a need to explore optimal strategies that can improve the operational effectiveness of e-commerce supply chains while eliminating such decision-making problems. This research investigates how to design optimal strategies to eliminate decision-making and strategic interaction issues in e-tailing supply chains based on contracts and optimisation modelling approach.

This study considers the operational context of small/medium scale and start-up e-tailer supply chains, which consist of an e-tailer, product supplier and a third-party logistics (3PL) operator. This study develops four models based on game theory concepts, supply chain contracts, accounting methods, and blockchain technology while adopting a multi-objective optimisation (MOO) approach to solve these models. In the first model, a cost-sharing contract is developed, considering the operational context of the e-tailer supply chain to derive optimal supply chain strategies. The contract model aims to eliminate issues of information asymmetry, ineffective coordination and sub-optimal costs. The findings reveal that the proposed cost-sharing contract obtain optimal outcomes with significant cost reductions to overall supply chain costs and eliminate asymmetric information. In the second model, the base contract model is extended by introducing consistent incentives through a dynamic cost-sharing contract to obtain long-term integration. The consistency constraints ensure high incentive levels over multi-period operations, thereby guaranteeing that the supply chain members remain within the total contract period. Therefore, it reduces the possibility of re-negotiation and enables long-term integration. Different accounting methods change cost information, and therefore, it is vital to identify a suitable accounting method to measure costs and obtain accurate information for e-commerce supply chains. Thus, this study analyses the impact of various accounting methods used to estimate costs on supply chain contract designs and cost minimisation. Finally, the feasibility

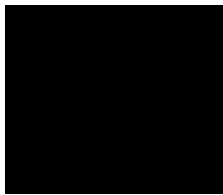
of implementing blockchain technology is discussed to address the strategic issues, and its benefits are compared with a traditional e-commerce supply chain operation. Blockchain implementation ensures complete information sharing and thus improves transparency and streamlines the operational flow of the e-commerce supply chain. The findings highlight that blockchain technology can improve e-commerce supply chain operations substantially, with cost minimisation.

Overall, this research contributes to the knowledge of supply chain management by demonstrating the use of several optimal strategies to create effective e-commerce supply chain outcomes. The research findings also provide insights for managers and decision-makers to improve performance levels in real-world e-commerce supply chain organisations.

STUDENT DECLARATION

I, Liyanawaduge Sahani Manogna Rathnasiri, declare that the PhD thesis entitled “Designing Optimal Strategies for E-commerce Supply Chains: Contracts and Optimisation Modelling Approach” is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature:



Date: 30/11/2020

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LIST OF ABBREVIATIONS

3PL	Third Party Logistics
ABC	Activity Based Costing
AS	Agency Selling
B2B	Business to Business
B2C	Business to Consumer
C2B	Consumer to Business
C2C	Consumer to Consumer
CCA	Current Cost Accounting
CSCMP	Council of Supply Chain Management Professionals
CSR	Corporate Social Responsibility
DPoS	Delegated Proof of Stake
ERP	Enterprise Resource Planning
FC	Fixed Cost
FVA	Fair Value Accounting
HCA	Historical Cost Accounting
HHT	Hand Held Terminal
IC	Incentive Compatibility
IFRS	International Financial Reporting Standards
IoT	Internet of Things
IR	Individual Rationality
LP	Linear programming
KKT	Karush-Kuhn-Tucker
MIP	Mixed Integer Programming
MILP	Mixed Integer Linear Programming
MOO	Multi-objective Optimisation
NLP	Non Linear Programming

O2O	Online to Offline
PoA	Proof of Authority
PoW	Proof of Work
PoS	Proof of Stake
PBFT	Practical Byzantine Fault Tolerance
RFID	Radio Frequency Data Identification
SEM	Structural Equation Modelling
TC	Total Cost
TCO	Total Cost of Ownership
USA	United States of America
VC	Variable Cost

PUBLICATIONS

Conference Papers & Proceedings

Rathnasiri, S, Ray, P, Islam, SMN & Vega-Mejía, CA 2019, 'E-commerce supply chain cost optimisation with incentive compatibility constraints', *2019 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI)*, Zhengzhou, China, 6-8 November 2019, pp. 253-257, doi: 10.1109/SOLI48380.2019.8955039 at <https://ieeexplore.ieee.org/document/8955039>

Rathnasiri, S, Islam, SMN & Ray, P 2020, 'Application of blockchain technology in optimising e-tailer supply chain costs: public and consortium blockchains', *5th North American International Conference on Industrial Engineering and Operations Management (IEOM 2020)*, Detroit, Michigan, USA at <http://www.ieomsociety.org/detroit2020/papers/557.pdf>

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Rathnasiri, S, Islam, SMN & Ray, P 2020, 'Impact of accounting methods on supply chain contracts: analysis based on e-tailer supply chain costs', *Accepted for presentation at the 2nd International Conference on Industrial Engineering and Operations Management, Harare, Zimbabwe on December 8-10, 2020* at <http://www.ieomsociety.org/harare2020/papers/396.pdf>

- Received the Best Track Paper Award (Supply Chain)

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Rathnasiri, S, Ray, P & Islam, SMN, 'Optimising e-commerce supply chain costs through blockchain technology implementation', submitted for publication in *Information & Management* (Under the first round of review).

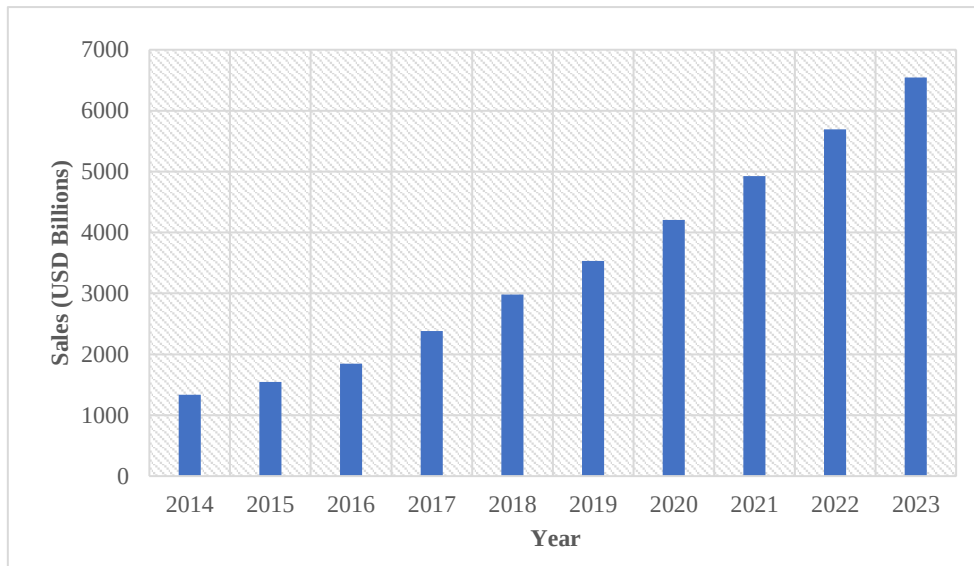
Rathnasiri, S, Ray, P, Islam, SMN & Vega-Mejía, CA 'Designing a cost-sharing contract for e-tailer supply chain operations', submitted for publication in *Management Decision* (Under the first round of review).

CHAPTER 1 : INTRODUCTION

1.1 Background of the Study

Within the last two decades, the utilisation of e-commerce applications in business operations has developed significantly, mainly due to benefits such as higher efficiency levels, lower costs, simplified transaction processes, faster responses to customer requirements and increased market share (Lu & Liu 2015; Ovalle & Marquez 2003). E-commerce has enabled huge reductions in transaction costs, especially in online banking and retailing (Strand & Strandänger 2016). The popularity of online selling has created e-tailing platforms, through which manufacturers use online retail channels to sell their goods with the collaboration of third-party logistics operators (Wang, Yu & Shen 2019). Online shopping has become an essential daily activity for some consumers and, as a result, competition among online retailing platforms has increased rapidly (Jiang et al. 2011).

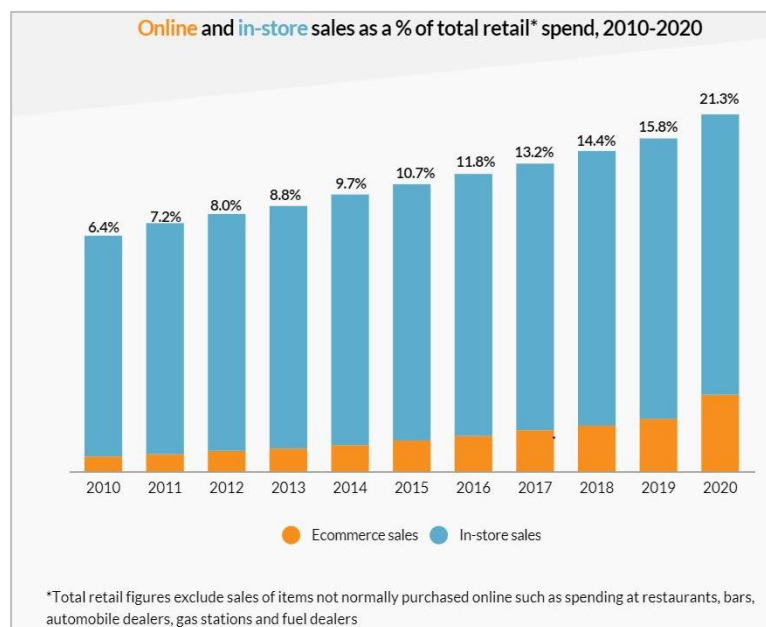
The rapid growth in e-commerce operations around the globe has indicated a 10% to 20% annual growth each year in most countries (Chaffey 2015). According to the statistics of eMarketer, retail e-commerce sales have shown a significant growth, indicating 28% and 22.9% in 2017 and 2018, respectively. It was expected that revenue from online retailing would reach up to USD 3.535 Trillion in 2019 and USD 5 Trillion in 2020 (Lipsman 2019). The e-commerce retail sales growth from 2014 to 2023 is illustrated in Figure 1.1, highlighting the exponential growth of the market (Clement 2019). By May 2020, total retail e-commerce sales reached USD 3.94 trillion, with the Asia-Pacific region leading the market (at USD 2.4 Trillion in sales), followed by North America and Europe (Cramer-Flood 2020). Figure 1.1 also illustrates that the current global pandemic has further elevated online sales, although the overall output has been affected by the global economic recession. Consequently, the actual sales by the end of 2020 might be different from the forecasted volumes.



Source: (Clement 2019)

Figure 1.1 E-commerce retail sales around the world (From 2014 to 2023)

As shown in the USA Census of 2015, e-commerce sales had a market share of more than 50% in total manufacturing activities. According to the newest statistics of the USA Census Bureau, the total share of e-commerce retails sales as a percentage of total sales is 14% in the fourth quarter of 2020 (FRED 2021). Figure 1.2 illustrates the penetration of e-commerce sales in the USA from 2010 to 2020, and it is visible that the e-commerce penetration is progressively increasing.

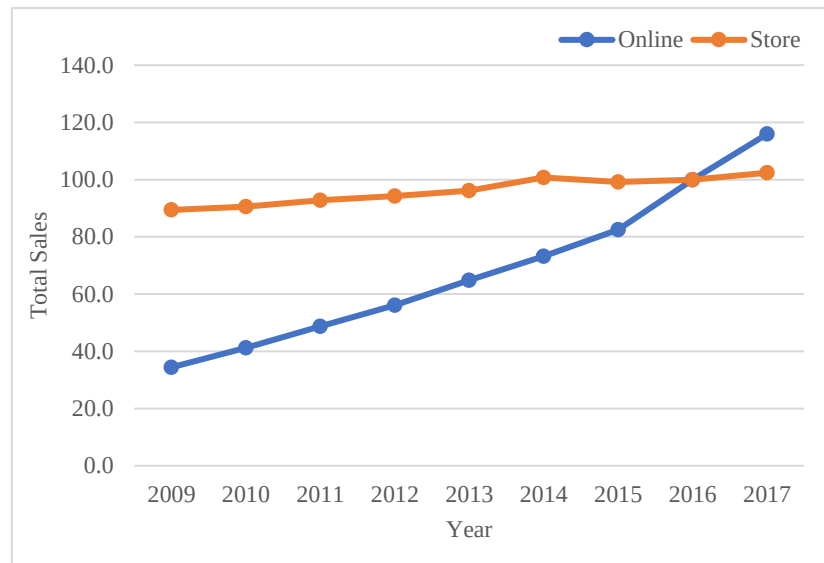


Source: (Digital Commerce 360 2021)

Figure 1.2 E-commerce retail spend as a percentage of total retail sales of the USA from 2010 to 2020

The comparison between online-only and brick and mortar retail sales in the UK also shows that the demand for online shopping is significantly growing. According to the Office for

National Statistics data, online sales have started growing at a steady rate since 2009, and it had surpassed the brick and mortar sales in 2017.



Index: 2016 = 100

Source: (Office for National Statistics 2018)

Figure 1.3 Comparison between online and brick and mortar sales in the UK from 2009 to 2017

The significance of e-commerce supply chain operations is further confirmed by the numerous success stories of e-commerce operations such as Amazon, eBay, Priceline, Pinterest, Pandora, Zillow and Alibaba (Turban et al. 2017; Yu et al. 2016). According to the analysis of eMarketer 2019, Amazon is presently leading the online retailing market in the USA, owing 47% sales share for 2019 (Wilson 2019).

Despite the dominance of these large online retailers, there has been a significant boom in new online ventures entering the market, with their marketability and sales enhanced by social media and mobile commerce (Kerick 2019). These small/medium scale online retailing businesses include ventures such as Kapruka, Booktopia and SHOWPO. Kapruka¹ is an online retailer based in Sri Lanka, focused on delivering different products from suppliers around the country. Booktopia, an online book e-tailer,² and SHOWPO, an online fashion e-tailer,³ are two prominent e-tailers in the Australian market, which also operate in a similar context to Kapruka. All these e-tailers started small and grew their business operations successfully, becoming leading operators in their respective countries. Nevertheless, managing an online business is challenging due to rapid changes in operational contexts and extreme competition.

¹ <https://www.showpo.com/>

² <https://www.booktopia.com.au/>

³ <https://www.showpo.com/>

It leads that many new small/medium scale online retailers find it difficult to sustain their businesses in the long term (Pi & Wang 2020). Thus, it is crucial to investigate optimal strategies for small/medium scale and start-up e-tailer supply chains to obtain effective performance outcomes.

Although the importance of e-commerce has been widely acknowledged, globalisation has created complexities in the e-commerce supply chain context that require further exploration (Yu et al. 2016). Complexities such as reliability, fault tolerance, security, time and cost in e-business approaches have created difficulties when effectively working with the entire supply chain market (Handfield & Nichols 2003). Therefore, researchers have given wide attention to analysing decision-making issues, which affect the effective outcomes of the e-commerce supply chains (Siddiqui & Raza 2015; Yu et al. 2015). Within the context of strategic decision-making, information sharing (Pei & Yan 2019), transparency in information sharing (Zhou et al. 2018), collaboration and coordination issues (Wang, Guo & Wang 2017; Zhang, M et al. 2019) and ineffective incentive mechanisms (Liu, Shang & Lai 2015) are some of the frequently discussed issues. Therefore, finding optimal strategies to minimise decision-making issues to improve e-commerce supply chain performances is important.

Generally, supply chain members focus on their individual performance outcomes rather than the overall supply chain performance (Cachon 2003). They rarely evaluate the impact of their individual myopic strategies on overall supply chain outcomes and, hence, generate sub-optimal results within the decentralised operations (Fugate, Sahin & Mentzer 2006). Since e-commerce supply chains operate largely within a globalised environment, where supply chain members are located distantly and externally (Kamal & Irani 2014), successful integration, cooperation, and strategy formulation among different supply chain players are vital to ensuring customer satisfaction and competitive advantage. Besides, e-tailers face severe pressure to reduce product prices, improve delivery flexibility, and deliver superior customer service levels in cost-effective ways (Strand & Strandänger 2016). In that context, supply chain cost reduction has been identified as an essential strategy for gaining competitive advantage and deriving higher income levels, thus leading to higher market value and increased earnings per share (Pettersson & Segerstedt 2013). Therefore, cost minimisation can be adopted as a successful strategy in achieving these objectives (Sabet, Yazdani & De Leeuw 2017).

In contrast to traditional bricks and mortar retailers, e-commerce supply chains involve the management of significant volumes of information, data storage and data integration with different supply chain partners (Liu & Li 2019). It has created a paradigm shift towards smart

operations based on the Internet of Things (IoT) and disruptive technologies (Ben-Daya, Hassini & Bahroun 2019). Among these disruptive technologies, blockchain is emerging as an important innovation for addressing several decision-making issues of supply chains relating to information sharing, trust and transparency, security, accountability, efficiency and operational costs (Fernández-Caramés & Fraga-Lamas 2018; Kshetri 2018).

Specifically, in e-commerce supply chains, accurate information plays a vital role, since the operational effectiveness mainly depends on the correct information circulation than the physical attributes of the supply chain (Liu, Shang & Lai 2015). It leads to improved trust, integration, and effective operations. In supply chain operations, each party may keep private information about internal operational costs such as raw material costs, processing costs and handling costs (Cao et al. 2013). However, often it is difficult to obtain real-time, accurate data and to integrate this information with the other supply chain members (Turban, Aronson & Liang 2005). Therefore, information asymmetry issues are a primary factor to be considered when developing optimal strategies in online retailing. Supply chain organisations use different accounting methods to derive this information. As obtaining accurate data is imperative for e-tailer supply chains, accounting methods used to measure this information and its impact need to be explored to generate accurate and truthful supply chain outcomes as it is a gap in the current literature.

This study, therefore, investigates how to achieve optimal e-commerce supply chain outcomes while eliminating the issues of ineffective coordination and integration, asymmetric information, conflicts of interest, and ineffective cost management.

The issues related to strategic interactions and decision-making are broadly discussed in the extant literature by incorporating the applications of game theory and contract theory models (Siddiqui & Raza 2015). Many studies have integrated game-theoretic models with supply chain contracts to derive effective coordination among different parties while generating better operational outcomes for those players (Chakraborty, Chauhan & Vidyarthi 2015; Jiang, Wang & Liu 2016; Sarmah, Acharya & Goyal 2006; Wang, Guo & Efstathiou 2004). The game theory models are also used in e-commerce supply chain studies with many focused on deriving optimal strategies, finding out the optimal channel structures and deriving better channel options to deliver goods to their customers (Chiang, Chhajed & Hess 2003; Li et al. 2016; Xiao & Shi 2016; Yan 2008). However, less attention has been given to the models related to actual operations, including multi-echelons or multi-players. The existing literature is focused mostly

on two-echelons or two-player models (Yue & You 2014). The operational outcomes within multi-periods are also critical for any supply chain; however, the impact of time dependent operations has been overlooked when the effective contracts are formulated in the supply chain studies (Gao 2015).

New technology adoption is a rapidly growing area of interest in the literature on improving supply chain performance. Within the context of integration, information sharing and optimisation of supply chain operations, blockchain technology related applications are getting an increasing attention from the supply chain research community (Wamba & Queiroz 2020). While the importance of blockchain adaptation has been vastly recognised, the challenges, decisions and operational frameworks within the supply chain management context are still part of an emerging academic discussion (Saber, S et al. 2019; Wamba & Queiroz 2020). Therefore, it creates opportunities to explore blockchain technology applications in e-commerce supply chain operations and its significance in addressing the issues considered in this study.

1.2 Research Questions and Objectives

Based on the above discussion, this study addresses the following key research questions:

1. *How to optimise supply chain costs and resolve issues of asymmetric information, coordination and conflicts of interests in e-commerce supply chains using contract models?*
2. *How to design effective strategies to achieve long-term integration among e-commerce supply chain members using dynamic contracts?*
3. *What are the effective cost measurement techniques that can improve supply chain contract outcomes for e-commerce supply chain operations?*
4. *How a disruptive technology such as blockchain helps in resolving the strategic issues related to information sharing, transparency and cost optimisation?*

This study considers the operational context of a small/medium scale, three-level, e-tailer supply chain in a multi-period setting. Within this context, mathematical models based on supply chain contracts, accounting methods and blockchain technology have been developed to answer the research questions.

The following study objectives were developed in this study to answer the research questions:

1. To develop a cost-sharing contract model to address ineffective coordination, integration and information asymmetry in e-commerce supply chain operations.
2. To design a dynamic cost-sharing contract model to achieve optimal outcomes and long-term integration in e-commerce supply chain operations.
3. To analyse the impact of accounting methods used for cost measurement on e-commerce supply chain costs and contract outcomes.
4. To apply blockchain technology in resolving the strategic issues of asymmetric information, integration and sub-optimal costs in e-commerce supply chain operations.

The first objective is to develop a cost-sharing contract model based on game-theory concepts to align the objectives of all players. It is designed to optimise supply chain costs while addressing the asymmetric information and integration issues in e-tailer supply chains. The second objective is to extend the proposed cost-sharing contract model, considering the dynamic operational aspects over multiple periods of the e-tailer supply chain. As cost is the critical objective of this study, the third research objective is developed to analyse the different accounting methods used to measure costs in supply chain organisations, which results in different cost information towards the proposed contract outcomes. The final research objective is to implement blockchain technology in the e-commerce supply chain to examine the benefits of improving supply chain performance and optimise supply chain costs, information sharing and integration beyond traditional e-commerce operations.

A comprehensive literature review on e-commerce modelling studies, game theory models in supply chain operations, supply chain contracts formation, applications of supply chain contracts and the adoption of blockchain technology in supply chain operations are carried out to address all research objectives. Following the review, research gaps and limitations are identified.

1.3 Research Methodology

This thesis considers a contract and optimisation modelling approach while designing optimal strategies for e-commerce supply chains. In supply chain optimisation studies, the main objective is linked either to cost minimisation or profit maximisation (Snyder & Shen 2011). This research focused on developing models based on cost minimisation. The rationale for this is that when different parties collaborate in seeking a single goal, achieving adequate profits to cover their respective operational costs is extremely important; otherwise, the collaboration would not be effective for any party (McGuigan, Moyer & Harris 2014).

As already indicated, the extant literature supports the incorporation of game theory concepts in designing optimal strategies. This study broadly analyses the theoretical concepts related to game theory, contract theory, information asymmetry, cost measurement based on accounting methods, and blockchain technology adoption to address the research questions and objectives.

Online retailing supply chains operate across a variety of operational structures. They can vary according to the channel structure, pricing strategies and technology adaptation. Within these operational frameworks, e-tailing and agency selling (AS) are considered two of the most prominent e-commerce operations in business to consumer (B2C) markets. Presently, third-party re-selling and dual-channel/omnichannel structures are also getting widespread attention (Pi & Wang 2020). However, re-selling (e-tailing) operations are the dominant selling format in the e-commerce supply chains generally used by online stores (Abhishek, Jerath & Zhang 2016). Some well-known examples of e-tailing operations are Walmart, Zappo, JD.com and Sunning.com, with all these e-tailers purchasing goods from manufacturers and selling them to consumers via their online markets (Fan, Yin & Liu 2020). Operating as a pure e-tailer is easy and cost-effective and, hence, more suited for small/medium scale and start-up e-commerce supply chains. For example, Amazon has also started its operations as a re-selling e-tailer (Pi & Wang 2020). Since this study is focused on small/medium scale or start-up operations, a pure e-tailing channel structure was considered to develop the models, where the e-tailer acts as the merchant and does the re-selling.

The proposed models were tested based on hypothetical data, which is a commonly used method in the supply chain literature investigating similar issues. This study adopted a multi-objective optimisation (MOO) solution approach to solve these models. The models were programmed using an optimisation solver tool based on AMPL modelling language. Numerical analysis was conducted to assess the implications of the models and to shape the findings of this study.

1.4 Contribution of the Research

1.4.1 Contribution to Theory

The study makes several important theoretical contributions to the supply chain literature. Researchers have given substantial attention to game theory applications in supply chain studies (Simchi-Levi, Chen & Bramel 2014). When supply chain institutes are defined as multi-player, decentralised operations, game theory can be applied as a strategic tool in optimisation

modelling (Nagarajan & Sošić 2008). Integrating with all levels or acting independently is a critical decision that needs to be considered carefully in a multi-echelon supply chain because it affects the overall profit or cost of the supply chain (Mahdiraji et al. 2014). Therefore, by using game theory-based contract modelling to derive optimal strategies in the e-commerce supply chain, this study adds to the body of literature in game theory, contract theory, and supply chain management. However, multi-echelon/multi-player supply chain optimisation based on game theory has been less explored in the literature (Yue & You 2014). Hence, the proposed contract models in this research augment the knowledge in deriving optimal strategies of multi-level/multi-player contract models related to supply chain decision-making.

As asymmetric and incomplete information is a critical factor in real supply chain operations (Kaya & Caner 2018), information asymmetry issues can be addressed by creating effective supply chain contracts. Accurate information is vital for e-commerce operations. This research analyses the impact of information asymmetry issues on operational outcomes and the strategies used to eliminate these issues. Therefore, the findings of this study expand the knowledge in e-commerce supply chain studies. Furthermore, the contract model developed in this study integrates operational and contract related constraints, which generally has been overlooked in previous studies when contract models are formulated. Therefore, this study contributes to the literature by integrating the supply chain operational model with a game theory-based contract design. This could influence important decision outcomes. Although contract theory models under information asymmetry are discussed in many supply chain studies, few adopt sharing contracts (Shen, Choi & Minner 2018). Therefore, this study further contributes by addressing the cost information asymmetry issues through the design of a cost-sharing contract model that can effectively resolve these issues and generate efficient e-commerce supply chain operations.

Furthermore, the existing contract models are focused mostly on single period operational aspects, which is not valid in practice. Since supply chains operate essentially within intertemporal scenarios, the dynamic aspects of implementing contracts need to be analysed (Gao 2015). However, discussions relating to the re-negotiation and stability of dynamic contracts are not evident in the existing supply chain literature, even though these aspects are vital to developing long-term contract models. Therefore, this study creates new knowledge and contributes to the dynamic contract literature in supply chain management by introducing consistency constraints to the contract model. These constraints can minimise the potential of re-negotiation and enable long-term integration.

While cost minimisation has been studied extensively, no attempt has been made to determine how these costs are measured when effective strategic interactions are formulated among supply chain members. In addition, the cost concepts have a significant game theory and contract theory implications for strategy formulation, information revelation, cooperation, and contract design, as cost management is related to strategic decisions of firms (Perloff 2014). Therefore, this study integrates the impact of accounting information on the outcomes of e-commerce supply chain operations within the contractual framework, as no clear evidence of this area has been found in the literature. Hence, this study creates new knowledge by analysing the importance of accounting measurement towards contract modelling within an e-commerce supply chain operational setting.

Finally, this research adds new knowledge related to blockchain technology adaptation in supply chain management, in which the current literature demonstrates a growing interest and the early stages of investigation (Wamba & Queiroz 2020). The extant literature does not show clear evidence of the costs involved in implementing blockchain systems into existing supply chain operations or whether blockchain implementation can lead to cost minimisation in supply chain operations. A very little evidence is found related to how blockchain implementation affect the supply chain operational outcomes (Chang et al. 2018). A few studies related to blockchain have considered e-commerce supply chains; however, none of these studies has examined the operational costs and blockchain implementation and management costs that directly affect the design of cost optimisation strategies. These aspects are addressed in this study. This study also provides insights into identifying the most appropriate blockchain system for e-tailer supply chain operations to minimise strategic issues relating to information sharing, transparency and integration while minimising costs. Therefore, the findings of this study augment the literature and the knowledge of using blockchain technology relating to supply chain management.

1.4.2 Statement of Significance

Given its focus on designing optimal strategies for e-commerce supply chain operations, this study generates several pragmatic implications for stakeholders in real-world e-commerce supply chains.

Firstly, an e-tailer supply chain organisation could implement the proposed contract models to improve its operational effectiveness and minimise costs. Since this study includes key players in e-commerce supply chains such as product suppliers, e-tailers and third-party logistics (3PL)

operators, all stakeholders will gain better operational viewpoints to help them align their interests in achieving optimal results. In particular, the findings create a platform for all agents to manage and re-visit their operational aspects to maximise their individual goals and the overall performance of the entire supply chain.

Secondly, the contract model developed in this study could be incorporated by organisations in the e-commerce supply chain to implement effective contracts among their partners. As the contract model generates optimal supply chain costs for the overall operations, ultimately, it could help generate a competitive pricing strategy and thereby attract more customers. Furthermore, the findings of this study highlight the optimal cost-sharing levels that generate minimal supply chain costs. This outcome will provide insights for making strategic decisions for all supply chain members before formulating a contract. The contract outcomes will be beneficial from the consumer's point of view as well, as e-tailers can offer competitive pricing strategy, allowing consumers to purchase products for a low cost.

As the proposed contract model eliminates hidden information issues, partners in the e-commerce supply chain could embed these models to create successful cooperation strategies by sharing information. This would lead to enhanced levels of trust and effective operations. Primarily, this contract model could be implemented by small/medium-scale or start-up e-tailer organisations because it encourages collaboration with new partners to expand their business operations and enable a trustworthy operational environment. For small-scale or start-up organisations, getting established in the market with stable supply chain partners could help ensure successful operations and survival in the market.

The dynamic contract approach emphasises consistent incentives throughout the contract period, which enables long-term integration and eliminates the re-negotiation opportunities for members of the contract. Therefore, e-tailer organisations could decide on strategies to implement consistent incentive schemes to maintain long term integration with their supply chain partners. It would be operationally beneficial in the long-term to attract more customers, expand market share and reduce operational costs, and thus help achieve long-term sustainability in the e-commerce market.

Since the contract models of this study were developed for a universal platform, it could also be used by any e-commerce-based organisation around the world to design optimal supply chain strategies.

E-commerce organisations could use the findings derived through analysing the impact of accounting methods used to measure costs on supply chain contracts to analyse the accuracy of their respective supply chain partners' information before entering into long-term contracts. This analysis could also provide supply chain members with insights when selecting the most appropriate cost measurement system, thus minimising operational costs and achieving a competitive advantage for their organisations.

Finally, e-commerce supply chain members could obtain significant managerial insights into adopting an innovative technology in their supply chain, such as blockchain, which has huge investment and operational costs. The findings generated from comparing the results of the blockchain adopted supply chain with traditional e-commerce supply chain operations highlight the key determinants of blockchain system costs and the feasibility of incorporating such a system into small/medium scale e-commerce supply chain.

The outcomes of this research not only benefit e-commerce supply chain businesses but also academics in the supply chain field. Since contract models, accounting issues and blockchain implementation are discussed in this research, the theoretical models and parameters of this study can be utilised in creating new optimisation models and pathways for further academic contributions in the field of supply chain management.

1.5 Summary of Major Findings

This section presents a summary of the main findings of this study.

- The cost-sharing contract designed for the three-player e-commerce supply chain operation, which includes the product supplier, e-tailer and the 3PL operator, generates significant cost reductions to the overall supply chain. This can be used to create a competitive edge within their stipulated market by operating with a cost leadership strategy. With the overall cost reduction, the e-tailer can offer the goods for competitive pricing for the customers, which will be highly advantageous in attracting more customers. Therefore, the proposed cost-sharing contract delivers Pareto-improved outcomes for the overall supply chain and the individual players, hence improving the e-tailer supply chain performances.
- The proposed design of the cost-sharing contract eliminates the information asymmetry issues by adopting the revelation principle strategy in which all players reveal their

actual costs to obtain the benefits of the contract. The incentive compatible cost-sharing ensures that the players do not receive benefits by reporting false costs.

- Designing consistency incentives for the dynamic operational setting of the e-commerce supply chain ensures that the supply chain members have a guarantee of their incentive levels in each period, enabling the stability of the contract model. Therefore, the dynamic contract proposed in this research provides re-negotiation proofness and eliminates the requirement for deviating from the contract. Hence, the proposed dynamic contract enables long-term integration and improves collaboration among supply chain players. This outcome is crucial for small/medium-scale or start-up businesses to implement vertical integration with their supply chain partners.
- The proposed contract models derive win-win outcomes for all supply chain members compared to the decentralised e-commerce operation. It was evident when compared with the benchmark model with no-contract operations.
- Cost measurement based on accounting information has implications for both supply chain costs and contract outcomes. Historical cost accounting (HCA) method safeguards against manipulation from asymmetric information, and thus, it is the better accounting approach for contracts. Fair value accounting (FVA) derives better cost optimisation of the supply chain operational costs than HCA, but it can be used to manipulate information. Furthermore, the analysis indicates that incentive compatibility constraints eliminate the possibility of adopting creative accounting methods in supply chain organisations, which can be used to modify or declare false cost information.
- Blockchain implementation inherently eliminates information asymmetry and creates improved transparency in e-commerce supply chain operations. Most importantly, blockchain implementation significantly reduces supply chain costs when compared with traditional supply chain operations. The analysis further reveals that consortium blockchains are better suited to implementation in small/medium scale e-tailer supply chains, although it requires higher investment costs. In contrast, public blockchain systems are costly in long-term operations, and the transaction costs are one of the key cost drivers in determining these outcomes. Moreover, the analysis highlighted interesting managerial insights in determining critical cost drivers for blockchain implementation in an e-commerce supply chain operation.

1.6 The Organisation of the Thesis

The thesis structure is described in this section. The thesis is organised into seven chapters, including this opening chapter. Figure 1.2 presents a summary of each chapter in this thesis.

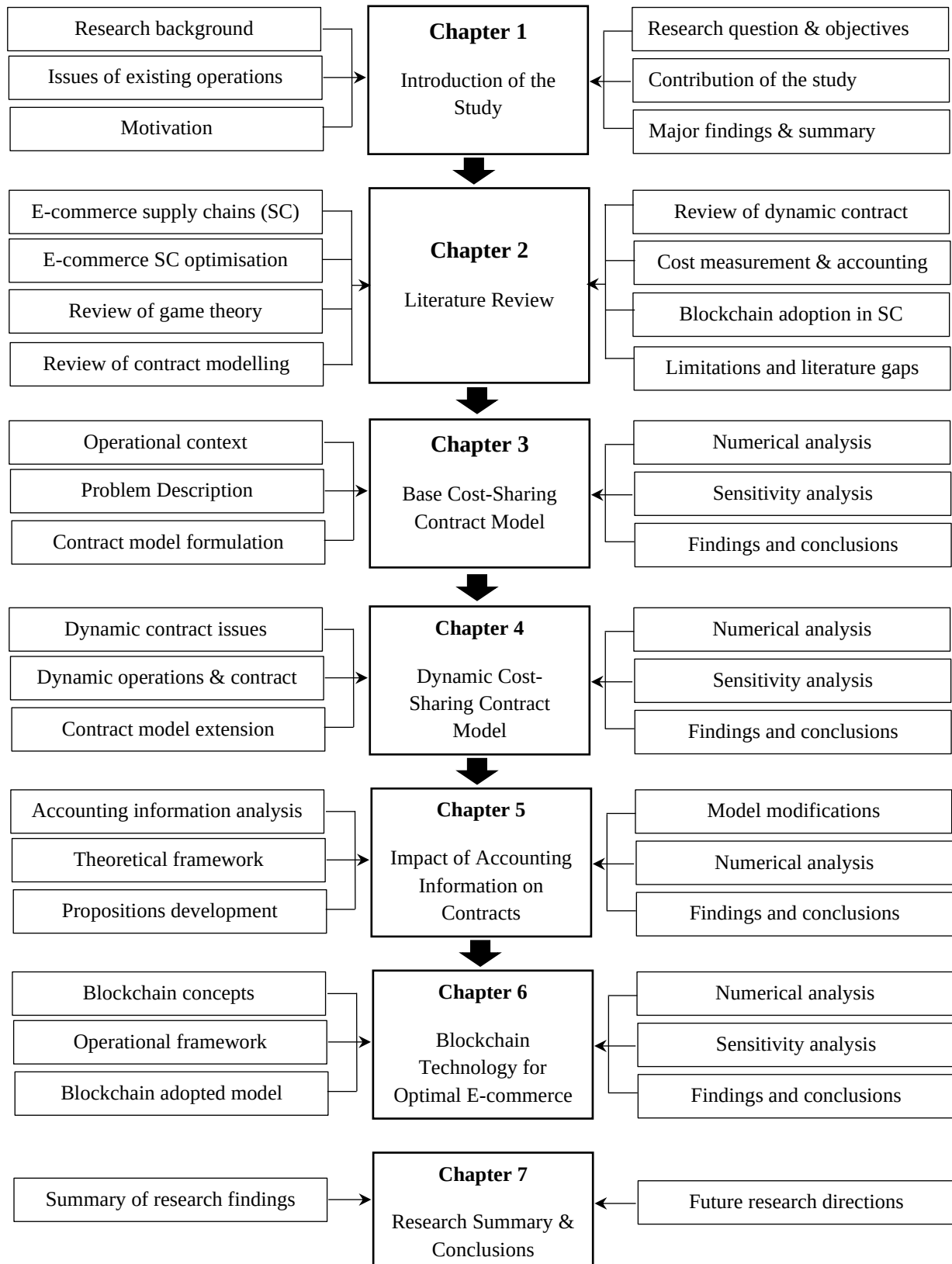


Figure 1.4 Structure of the thesis

With reference to the relevant literature, this introductory chapter has provided an understanding of the significance of e-commerce supply chain operations and the issues related to strategic decision-making. The literature gaps and motivation for conducting this research have been explained, and the research questions and objectives are defined. The contribution to knowledge and the practical significance of this study, along with a summary of its key findings, have also been discussed in this chapter.

Chapter 2 presents a comprehensive evaluation and critical review of the relevant literature. These literature relate to e-commerce and traditional supply chain operations, e-commerce-based supply chain optimisation studies, game theory applications in the supply chain optimisations, supply chain contracts, dynamic game theory modelling, the importance of financial information and disruptive technology adaptation. Finally, it outlines the limitations of the existing literature and highlights the gaps that have motivated to conduct this study.

Chapter 3 presents the base contract model developed based on game theory concepts for the e-commerce supply chain operation. This chapter addresses information asymmetry and coordination issues by designing a cost-sharing contract considering cooperative game concepts to derive optimal results. The model background, approach to the contract model design, model equations, and constraints are comprehensively discussed with relevant justifications. Numerical analysis is conducted to derive model results based on the simulation data. Based on this analysis, the main findings are discussed, followed by a summary of the conclusions drawn from the model and its impact on e-commerce supply chain operations.

Chapter 4 extends the base cost-sharing contract model discussed in Chapter 3 to analyse the dynamic aspects of contracts of the e-commerce supply chain operations. A dynamic contract approach is discussed by incorporating multi-period operations and consistent incentives into the contract. Numerical simulation is conducted to identify the effect of dynamic parameters on the contract performance, and model comparison is carried out in the model results analysis. The findings are discussed based on the numerical results, and the chapter concludes by highlighting the significant findings.

Chapter 5 discusses the impact of the cost measurement used by different supply chain members on the contract outcomes. As the cost measurement aspects are linked directly to accounting information, the chapter analyses the relationship between the accounting methods used by the e-commerce supply chain members. A numerical analysis is conducted to determine the impact of the different accounting methods on contract outcomes.

Chapter 6 analyses how blockchain technology implementation affects the e-commerce supply chain operations in terms of eliminating information asymmetry issues and generating optimal costs. This chapter discusses the technical aspects of blockchain implementation in e-commerce supply chain operations. It presents a blockchain framework and a modified model that incorporates blockchain-related costs and integrates operational aspects. A numerical analysis is then discussed, and the results are compared with traditional e-commerce operations to determine the improved impact of blockchain technology on supply chain performance. Finally, the findings of the models are discussed, and conclusions are drawn.

Chapter 7, the final chapter, presents an overall summary of the research, highlighting the limitations of the presented models. In addition, this chapter outlines suggestions for future research directions in detail.

CHAPTER 2 : LITERATURE REVIEW

2.1 Introduction

This chapter discusses the existing literature related to this study and provides a critical review based on the issues and objectives considered in this research. As this study is focused on developing strategies to optimise e-commerce supply chain operations, literature related to e-commerce supply chain optimisation, supply chain modelling strategies, game theory applications in the supply chain optimisation, supply chain contracts, and new technological adaptation are analysed in detail. The main aim of this chapter is to investigate how to resolve the strategic decision issues related to information sharing, integration and managing supply chain costs among the key players in e-commerce supply chains. Gaps and limitations in the current literature pertaining to the objectives of this research are also identified and analysed, highlighting the rationale for carrying out this study.

2.2 Supply Chain Management - Definitions

The previous literature has provided a variety of definitions for the supply chain management. Handfield and Nichols (2003, p. 8) defined it as:

the integration and management of supply chain organisations and activities through cooperative organisational relationships, effective business processes, and high levels of information sharing to create high-performing value systems that provide member organisations a sustainable competitive advantage.

According to Hanne and Dornberger (2017), the official supply chain management definition is derived from the Council of Supply Chain Management Professionals (CSCMP). This organisation defined it as the process that encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, the CSCMP definition also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. As per the above definition, effective integration, coordination and collaboration are essential aspects that are embedded inherently in supply chain management.

2.3 E-commerce Supply Chain Operations

2.3.1 Types of E-commerce Operations

E-commerce is defined as ‘The process of buying, selling, transferring, or exchanging products, and/or information via computer networks, including the internet’ (Turban, Aronson & Liang 2005, p. 747). E-commerce operations are primarily segregated according to the type of transactions as Business to Business (B2B), Business to Consumer (B2C), Consumer to Business (C2B), Consumer to Consumer (C2C), intra-business, mobile commerce or social commerce (Han, Xu & Chen 2018; Turban, Aronson & Liang 2005). These are explained as follows:

- The B2B market is considered the largest e-commerce market in which transactions occur between business organisations (Cirman et al. 2018). In the B2B market, the purchasing risk is higher, because if a buyer orders the wrong or mismatching products, the outcomes of an entire business line can get disrupted (Yu et al. 2016).
- B2C is the second largest market in e-commerce operations, with transactions happening between a business and a consumer. Well-known online retailers such as Amazon, eBay and Alibaba fall mainly under this category (Cirman et al. 2018). In this market, sellers are retailers that operate in the online marketplace and are known as e-tailers (Turban et al. 2017). In the B2C market, consumers place the order directly with the e-tailer after visiting their website. The e-tailer then dispatches the purchased products to the consumer’s doorstep (Yu et al. 2016).
- C2B is when consumers use online channels to sell their goods to businesses or individual organisations. In this market, consumers use C2B channels to bid on products and services (Turban et al. 2017).
- C2C is when transactions occur between individual organisations or consumers through an online platform. The best known examples of this segment are Airbnb, Uber, and Shopify. Even online sellers such as Amazon and eBay also have a segment of C2C operations (Cirman et al. 2018).
- Intra-business commerce refers to internal departments and individuals within a single organisation carrying out online commercial transactions (Turban et al. 2017).
- Mobile commerce relates to consumers purchasing goods and services using mobile applications.
- Social commerce uses social media as selling channels for goods and services.

2.3.2 Comparison of E-commerce Supply Chains with Traditional Supply Chain Operations

With rapid developments in technology, e-commerce has revolutionised traditional brick and mortar operations, drastically reducing the consumer's need to visit a physical store (eds. Domadenik, Koman & Redek 2018). With e-commerce operations gaining wider usage around the globe, internet retailing has become the new operational concept in typical retail supply chains (Kumar, Tiffany & Vaidya 2016). However, despite the many benefits of e-tailing, it also has its drawbacks. These include the inability to try the product, a lack of trust, high shipping and handling costs, challenging logistics operations due to outsourcing, and lower levels of customer service (Kumar, Tiffany & Vaidya 2016). E-commerce supply chain operations differ in order fulfilment processes, logistical requirements, customer service quality expectations, access to demand and supply information, goods return policies, cost and profit structures, and the degree of market segmentation than the traditional supply chain operations (De, Hu & Rahman 2013). Table 2.1 shows the major differences between traditional retailing and e-tailing.

Table 2.1 Major differences between retailer and e-tailer operations

Factors	Traditional retailer (brick and mortar/physical retailer)	E-tailer (online retailer)
Supply chain costs	High costs, more disruptions	Low costs, more efficient
Competition	Local, and comparatively lower competition	Very high global competition
Customer base	Local, high levels of loyalty	Wide range from both local and global, less loyalty (switch brands)
Customer relations	Face to face, high stability	Anonymous, less stability
Technology adaptation	Store based technologies such as point of sale, self-checkouts, information kiosks	All processes are done using technology (order fulfilment, payments, ordering, comparison and review of consumers, delivery of digital products and services)
Prices	Prices are stable, with less frequent changes, but comparatively expensive	Frequent price changes, but comparatively less expensive
Customisation	Not frequent and expensive	Highly frequent and inexpensive
Compliance to market trends	Slow	Swift
Product delivery	Customer picks up from store	E-tailer delivers the product to the customer's doorstep
Information	Fairly visible to other members	Not visible to other members
Collaboration with others	With known parties and stable	With external parties and not reliable
Contracts	With internal and external partners	With external partners

Source: (Edwards, McKinnon & Cullinane 2010; Turban et al. 2017)

The operational processes of traditional brick and mortar supply chains and e-tailer supply chains are shown in Figure 2.1 to further illustrate the differences between these two supply chain operations (Kumar, Tiffany & Vaidya 2016).

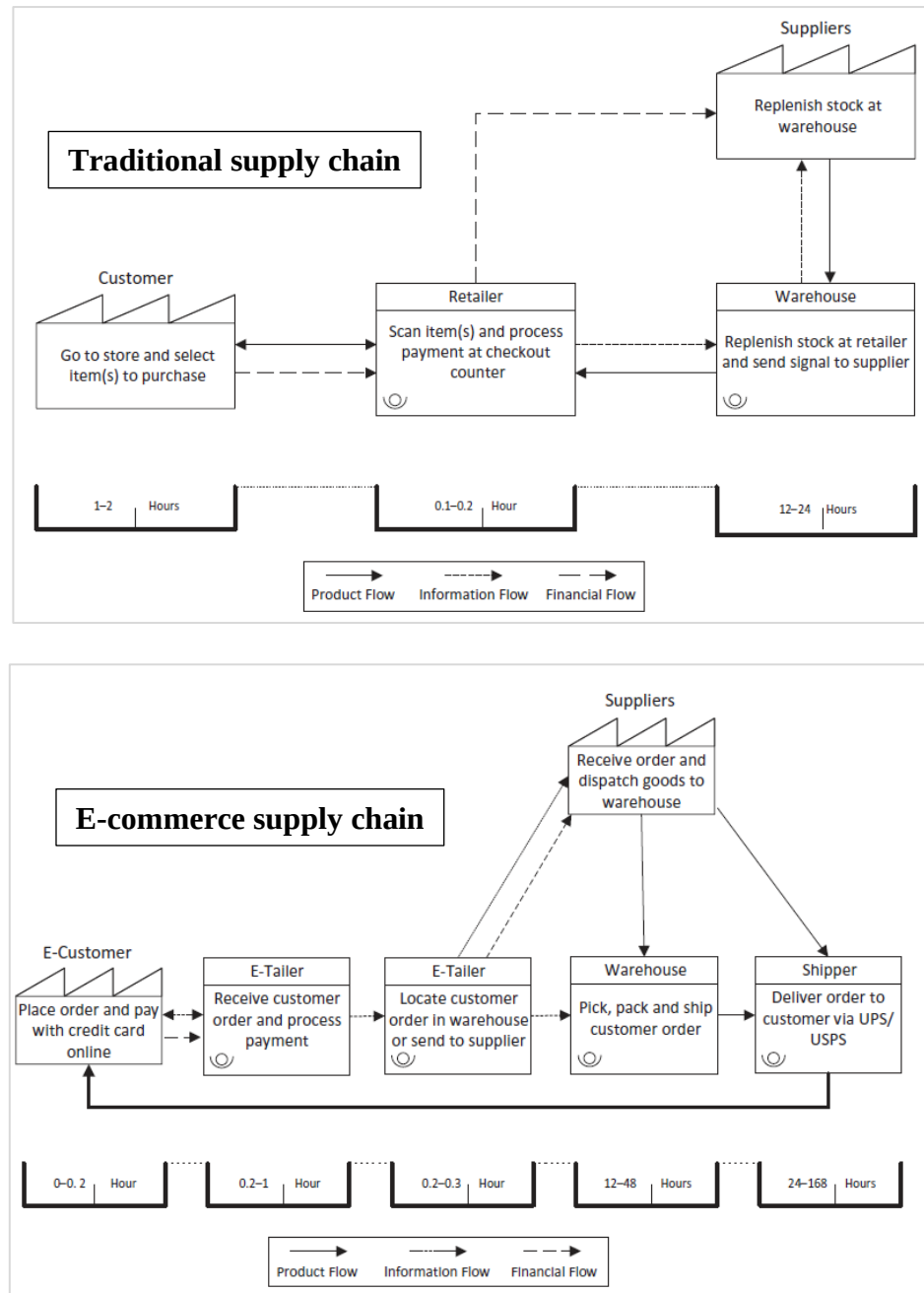


Figure 2.1 Traditional and e-commerce supply chain processes

As shown in Figure 2.1, e-commerce supply chain operations have more complexities, especially in the handling process. As highlighted in the operational time estimation, the material fulfilment cycle is longer than it is in the traditional supply chain. However, e-commerce supply chains can reach into global markets and often carry a wider variety of goods than traditional chains (Kumar, Tiffany & Vaidya 2016).

E-tailing operations face swifter changes in business scope and boundaries when compared with traditional retailers that operate in concreated settings and focus on long-term operations. Online operations create infinite and huge competition levels, generating a platform for the most successful e-tailers to thrive in the market, while other smaller players struggle to survive in the long-term (Pi & Wang 2020). Therefore, both operational attributes, as well as external factors and market requirements, differentiate e-tailing operations from traditional retailers.

2.3.3 E-commerce Channel Structures

E-commerce supply chain operations are segregated into different operational frameworks or channel structures. The main operational frameworks, based on the analysis of Pi and Wang (2020), are illustrated in Figure 2.2.

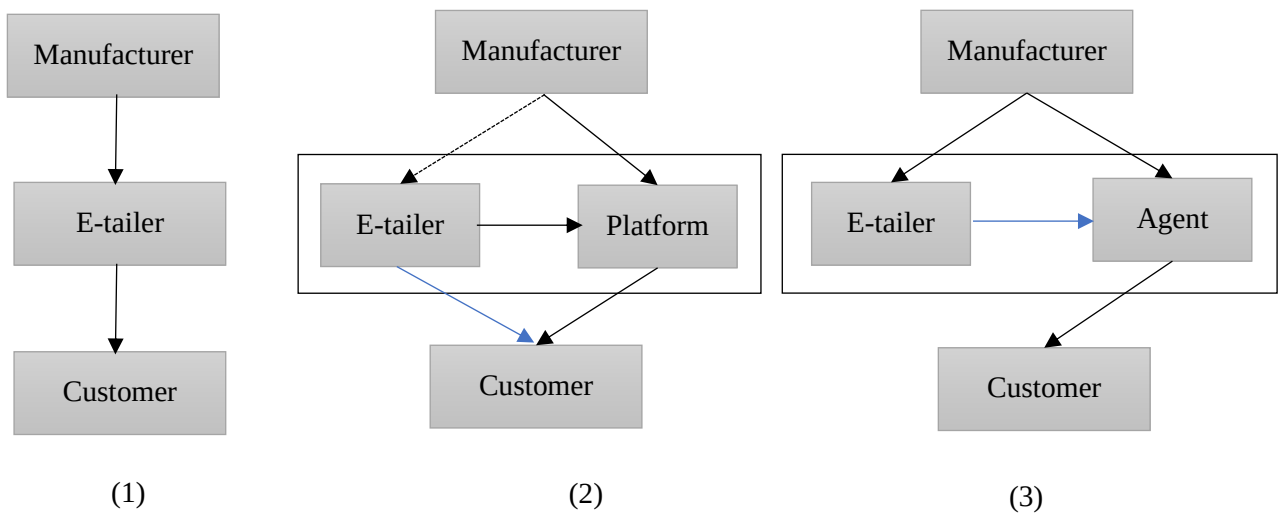


Figure 2.2 E-commerce supply chain channel structures

In channel structure 1, the e-tailer acts as the merchant, purchasing products from the manufacturer and selling them to the customer at a profit. In this scenario, the e-tailer purchases the product from the manufacturer or supplier for a fixed wholesale price and sells the product using its online channel for a determined retail price (Abhishek, Jerath & Zhang 2016). This operational framework is the most common approach when e-tailers commence operations. For example, Amazon started its operations with online book selling using this approach. In channel structure 2, the e-tailer creates a platform that allows manufacturers to join their operations through payment of a transaction fee. In this case, the e-tailer either re-sells through the platform or directly sells to the customer. In practice, re-selling, in which the e-tailer is the merchant, and the platform are the two most common operational structures (Liu & Ke 2019). In channel structure 3, a third-party agency operates the platform and manufacturers are not

involved in the selling process. In this scenario, the e-tailer only owns the platform service while an agent sells the product to customers.

2.4 Methodology Used to Search and Screen Literature

An extensive literature review was carried out in this chapter to identify the current literature related to this study. First, title and abstract screening were conducted using specific keywords to identify relevant journal articles in databases such as Web of Science, SCOPUS and IEEE Explore. These keywords are listed in Table 2.2. The search focused on identifying journal articles that explored supply chain optimisation, supply chain coordination, or optimal strategies related to e-commerce and general supply chains. After this search, hand searching and screening was also conducted to identify important articles, not indexed in the databases, in the field of supply chain management related to the issues discussed in this study.

Table 2.2 Keywords used to search literature

Keywords	Number of studies
Supply chain coordination and online retailer	249
Online retailing supply chain	449
Supply chain coordination and e-commerce	13
E-commerce supply chain optimisation	10
Dynamic contracts/multi-period contracts	35

E-commerce supply chain operations have been well studied in the past decade as it is an important and rapidly growing area within supply chain operations. As this research is focused mainly on the strategic issues in online retailing (e-tailing), only studies relevant to these strategic issues were considered in the analysis after the title and abstract screening. These are summarised in Table 2.3 (In section 2.5).

In this analysis, operational setting and methodology were used as filters to identify relevant articles. Game theory has been used extensively in e-commerce supply chain literature, and therefore, studies with game theory models were included for further analysis (summarised later in this chapter in Table 2.4). The literature was then analysed based on the type of game theory models, coordination strategies, and the objective of those studies. Incentive contracts are widely used in developing collaborative and win-win outcomes, as emphasised by Cachon (2003) and Tsay, Nahmias and Agrawal (1999). Therefore, studies related to contract

modelling in e-commerce and supply chains were also selected for further investigation, as shown later in Table 2.5.

Information plays a vital role in e-commerce supply chain operations, as successful operations primarily depend upon it. Hence, it is essential to consider issues relating to hidden information. Therefore, contract models that explored asymmetric information issues were analysed, as illustrated later in Table 2.6.

In contract modelling literature, most studies have focused on static operations. However, multi-period and long-term operations are crucial for successful long-term operations. This study focuses on supply chain integration in the long run. Therefore, dynamic contract models in the literature were analysed to explore how effective contracts are formulated within multi-period operations. Finally, cost measurement and technology adaptation were also analysed, as these are relevant to making strategic decisions in e-commerce supply chains.

2.5 Analysis of E-commerce Supply Chain Studies

Previous studies have given much attention to analysing effective decision-making in e-commerce supply chain management (Nof et al. 2015). Numerous methods have been applied in the literature to design optimal supply chain operations. Siddiqui and Raza (2015) investigated e-supply chain modelling/design/implementation and concluded that the main methodologies used are empirical analysis followed by mathematical modelling. As this study is focused on designing optimal strategies for e-commerce supply chain operation, the literature based on model designs was analysed to obtain further insights (see Table 2.3).

Table 2.3 highlights the decision-making issues in e-commerce supply chain operations that have been studied over an extended period of time. For this analysis, only modelling related work was considered, with these studies primarily focused on methods such as empirical research, and mathematical modelling based on simulation, optimisation or analytical solutions. The analysis further reveals that game theory has been utilised extensively by researchers in addressing issues related to optimal decisions, supply chain coordination, and designing supply chain equilibrium models. At the same time, many other researchers have considered mathematical modelling methods and empirical models to derive optimal supply chain outcomes.

Table 2.3 Analysis of e-commerce supply chain studies focused on decision-making strategies/issues

#	Authors	Focus area	Supply chain type				Methodology				Solution approach
			Pure e-tailer	Dual-channel/ Online to Offline(O2O)	The online platform (Fee commission)	Hybrid model	Game theory models	Coordination contracts	Mathematical models	Empirical analysis	
1	Zhang and Zhang (2020)	Demand information sharing strategy with multi-channel operations		x	x		x				Analytical solutions
2	Yu, Huo and Zhang (2020)	Effect of information technology on e-commerce supply chain performance	x							x	Structural equation modelling (SEM)
3	Yuan et al. (2020)	Dual-channel, closed-loop supply chain coordination		x			x				Analytical solutions
4	Xu, Fu and Fan (2020)	Optimal supply chain coordination with a service sharing mechanism		x			x	x			Analytical solutions
5	Xu, Zhang and He (2020)	Supply chain coordination based on delivery time sensitivity		x			x	x			Analytical solutions
6	Wang, Y et al. (2020b)	Maximising profits of the e-commerce supply chain with extended warranty services			x		x				Analytical solutions
7	Wang, Fan and Deng (2020)	Optimal cooperative advertising strategies			x		x				Analytical solutions
8	Wang, Y et al. (2020a)	Coordination of green e-commerce supply chain with fairness concerns			x		x	x			Analytical and numerical solutions
9	Tang and Yang (2020)	A fresh product supply chain with financing strategy with online to offline (O2O) channel operations		x			x				Analytical solutions
11	Shu, Qu and Wu (2020)	Coordination of online retailing with logistics service and pricing levels	x				x	x			Analytical and numerical solutions
12	Qiongqiong, Xiaodong and Bin (2020)	Optimal pricing decisions for online channel entry		x			x				Analytical solutions
13	Matsui (2020)	Optimal bargaining time for wholesale price in dual-channel supply chain		x			x				Analytical solutions

14	Li, Zhang and Tayi (2020)	Impact of showrooming to O2O supply chains		x					x		Analytical solutions (equilibrium analysis)
15	Lei, He and Huang (2020)	Optimal channel structure with online and offline for two-period supply chain		x			x				Analytical solutions
16	Lamba et al. (2020)	Identifying the barriers of e-commerce reverse logistics supply chain operations	x							x	Fuzzy analytical hierarchical process (AHP)
17	Jin et al. (2020)	Optimal strategies for buy online return to physical store (BORP) adoption in omnichannel		x			x				Analytical solutions
18	Jia and Li (2020)	Optimal decisions and distribution strategy			x			x			Analytical solutions
19	Guo et al. (2020)	Impact of pre-sales service and lead time on channel choice		x				x			Analytical solutions
20	Fan, Yin and Liu (2020)	Horizontal cooperation of online retailers with a platform scheme	x			x		x			Analytical solutions
21	Dutta et al. (2020)	Optimal design for sustainable reverse supply chain	x						x		Multi-objective optimisation (MOO)
22	Zhu and Lin (2019)	Optimal advertising strategy for e-commerce platform			x		x				Analytical solutions
23	Zhou, Zhao and Wang (2019)	Optimal pricing decisions for dual-channel supply chain with asymmetric information		x				x			Analytical solutions
24	Zhao, Hu and Meng (2019)	Analysis of return freight policy of online retailers	x						x		Analytical solutions
25	Zhang, J et al. (2019)	Optimal coordination strategy for low price promotion of online retailers	x					x			Analytical solutions
26	Zhong et al. (2019)	Cooperative distribution strategy in e-commerce service logistics supply chain	x					x			Analytical solutions
27	Xu et al. (2019)	Optimal channel structure in dual-channel supply chain		x				x			Analytical solutions
28	Wang, Yu and Jin (2019)	The optimal strategy to increase capital for small/medium scale enterprises (SMEs)			x			x	x		Analytical and numerical solutions
29	Vakulenko et al. (2019)	Role of last-mile delivery for online retailer performance	x							x	SEM
30	Song, Song and Sun (2019)	Determinants of omni-channel supply chain integration		x						x	Mixed methods analysis
31	Saberi, Z et al. (2019)	Planning of assortment selling prices for small-scale online retailing supply chain	x				x				Heuristics model with algorithm solutions

32	Pi, Fang and Zhang (2019)	Optimal pricing and service strategy for dual-channel supply chain		x			x				Analytical solutions
33	Pei and Yan (2019)	Effective information sharing based on return policy	x				x				Analytical solutions
34	Pagès-Bernaus et al. (2019)	Facility location model to minimise uncertainties with in house and outsourcing strategies	x						x		Stochastic programming and Simheuristics
35	Mondal, Giri and Maiti (2019)	Pricing and greening strategies for closed-loop dual-channel supply chain		x			x				Analytical solutions
36	Modak and Kelle (2019)	Maximising profits in a dual-channel supply chain with stochastic variables		x			x				Analytical solutions
37	Liu and Ke (2019)	Optimal pricing and coordination strategy for dual-channel supply chain		x	x		x				Analytical solutions
38	Li, Zhang and Liu (2019)	Designing a procurement strategy for e-tailer with drop-shipping	x				x				Analytical solutions
39	Li, Zheng and Liu (2019)	Profit maximising pricing strategy for dual-channel retailer supply chain			x		x				Analytical solutions
40	Li, Li and Sun (2019)	Influence of showrooming effect on dual-channel supply chain		x			x				Analytical solutions
41	Choi, Chen and Chung (2019)	Eliminating channel conflicts in O2O fashion supply chain		x				x			Analytical solutions
42	Adivar, Hüseyinoğlu and Christopher (2019)	A performance management framework for omni-channel retail supply chain		x						x	Exploratory research process
43	Wang and Ng (2018)	Analysis of channel establishment, pricing and consumer recognition in e-tailing and dual-channel retail	x	x			x				Analytical solutions
44	Tian et al. (2018)	E-tailer's operational models based on channel structures	x		x	x	x				Analytical solutions
45	Rofin and Mahanty (2018)	Optimal channel selecting strategy based on customer preference	x	x	x		x				Analytical solutions
46	He et al. (2018)	Optimal channel strategy with reference quality effect	x	x			x				Analytical solutions
47	Chen, Nan and Li (2018)	Optimal pricing strategy for online retailing platforms			x		x				Analytical solutions
48	Zhang and Wang (2017)	Optimal channel selection for short lifecycle product supply chain		x					x		Analytical solutions
49	Kong et al. (2017)	Optimal pricing and service strategy for O2O closed-loop supply chain		x			x	x			Analytical solutions
50	Ji and Sun (2017)	Low carbon strategy to maximise profits of e-commerce platforms using big data	x		x				x		Non-linear mixed integer programming (NLMIP)

51	Gao et al. (2017)	Impact of bullwhip effect with price discounts on online retailing	x	x					x		Analytical solutions
52	Acimovic and Graves (2017)	Inventory replenishment policy to mitigate spill over and whiplash	x						x		Heuristic based stochastic programming
53	Xiao and Shi (2016)	Pricing and channel priority strategies for dual-channel supply chains with supply shortages		x				x			Analytical solutions
54	Wang, Yang and Wang (2016)	Optimal decisions to improve supply chain profits		x			x				Analytical solutions
55	Roy, Sana and Chaudhuri (2016)	Optimal supply chain outcomes by introducing an online channel for two-echelon supply chain		x			x				Analytical solutions
56	He et al. (2016)	Impact of logistics service level and advertising on dual-channel supply chain		x			x				Analytical solutions
57	Deng et al. (2016)	Inventory location strategy for closed-loop e-commerce operations	x						x		Hybrid ant colony optimisation
58	Cheng, Li and Jiang (2016)	An optimal choice for inventory rationing, service levels and hybrid channel strategy	x			x			x		Simulation analysis
59	Batarfi, Jaber and Zaroni (2016)	An optimal strategy for profit maximisation on dual-channel supply chain		x					x		Analytical and numerical solutions
6	Abhishek, Jerath and Zhang (2016)	Deciding re-selling or agency selling (AS) is beneficial	x		x		x				Analytical solutions
61	Shang and Yang (2015)	Optimal profit-sharing contracts for dual-channel supply chain		x				x			Analytical solutions
62	Pei, Paswan and Yan (2014)	E-tailer's return policy for consumer behaviour levels	x							x	SEM
63	Cao (2014)	Optimal decisions and coordination models for dual-channel supply chains with market demand disruptions		x			x	x			Analytical solutions
64	Li, Lu and Talebian (2015)	Comparison of price, delivery time and inventory for traditional and online retailers	x			x			x		Analytical solutions
65	Canetta, Cheikhrouhou and Glardon (2013)	Modelling hybrid demand flow for e-commerce order flow				x			x	x	Quantitate and qualitative analysis
66	Ryan, Sun and Zhao (2012)	Designing system equilibrium for an online retailer selling through platform system			x		x				Analytical solutions

67	Mohebbi and Li (2012)	Designing an agent-based e-Supply network to create long term partnerships	x						x		Algorithm based global optimisation solutions
68	Mahar, Salzarulo and Wright (2012)	Dynamic pick up site inclusion policy to manage inventory levels		x					x		Simulation analysis
69	Griffis et al. (2012)	Impact of referrals for order fulfilment of online retailing	x							x	SEM
70	Chen, Zhang and Sun (2012)	Manufacturer's optimal pricing strategies for profit maximisation in dual-channel supply chains		x			x	x			Analytical solutions
71	Xia and Zhang (2010)	Impact of online channel addition for retailer supply chain		x					x		Descriptive analysis
72	Chiang and Feng (2010)	Pricing and lot size decisions of a retailer and e-tailer supply chain with a drop shipping operation	x				x				Analytical solutions
73	Cai (2010)	Optimal channel selection and coordination strategies for dual-channel supply chains		x			x	x			Analytical solutions
74	Bretthauer, Mahar and Venakataramanan (2010)	Optimal strategies for inventory and distribution in a dual-channel operation		x					x		Non-linear programming (NLP)
75	Mahar, Bretthauer and Venkataramanan (2009)	An optimal strategy for fulfilment in a dual-channel retailer supply chain		x					x		Simulation and numerical analysis
76	Iyer, Germain and Claycomb (2009)	The factors affecting B2B e-commerce supply chain performance and integration	x							x	Regression
77	Huang, Jiang and Tang (2009)	Performance assessment model for online retailer supply chain	x							x	Majority aggregation
78	Nagurney et al. (2005)	Designing a three-tier supply chain equilibrium model		x					x		Analytical solutions and algorithm-based simulation

The type of e-commerce supply chain was also considered in this analysis to identify the areas of focus within the supply chain research community. Based on the main operational settings, pure e-tailer models (re-selling/e-tailer as a merchant), dual-channel models (O2O/omni-channel), e-commerce platform models, as well as hybrid operational models, were the main focus of this analysis. Recently, growing attention has been given to dual-channel/omni-channel operations in the extant literature; nonetheless, pure e-tailer models and platform models have also been studied by numerous authors.

Generally, the dual-channel modelling studies have aggregated game theory models to derive optimal supply chain solutions. These studies relate specifically to optimal channel structure or channel selection (Cai 2010; Guo et al. 2020; He et al. 2018; Lei, He & Huang 2020; Qiongqiong, Xiaodong & Bin 2020; Rofin & Mahanty 2018; Wang & Ng 2018; Xu et al. 2019; Zhang & Wang 2017), channel addition and conflicts (Choi, Chen & Chung 2019; Roy, Sana & Chaudhuri 2016; Xia & Zhang 2010), and designing optimal pricing/service/distribution strategies (Bretthauer, Mahar & Venakataramanan 2010; Cao 2014; Chen, Zhang & Sun 2012; He et al. 2016; Kong et al. 2017; Liu & Ke 2019; Mahar, Salzarulo & Wright 2012; Mondal, Giri & Maiti 2019; Pi, Fang & Zhang 2019; Xiao & Shi 2016).

Studies that consider pure e-tailer operations have also used game theory models (Chiang & Feng 2010; Fan, Yin & Liu 2020; Li, Zhang & Tayi 2020; Pei & Yan 2019; Saberi, Z et al. 2019; Shu, Qu & Wu 2020), empirical analysis (Griffis et al. 2012; Huang, Jiang & Tang 2009; Iyer, Germain & Claycomb 2009; Lamba et al. 2020; Pei, Paswan & Yan 2014; Vakulenko et al. 2019; Yu, Huo & Zhang 2020) and mathematical models based on simulation and optimisation (Acimovic & Graves 2017; Deng et al. 2016; Dutta et al. 2020; Mohebbi & Li 2012; Pagès-Bernaus et al. 2019) to derive optimal supply chain solutions and improve supply chain performance.

As indicated earlier, as this research is focused on pure online retailing, studies that applied game theory models were explored in more detail. These studies focused on the areas of supply chain coordination, optimal strategies for distribution, pricing and services. Shu, Qu and Wu (2020) explored optimal pricing and logistics service strategies for online retailing by using coordination contracts, revenue-sharing and cost-sharing. This study underlines the fact that when e-commerce supply chains commence their businesses, they prefer using a re-selling strategy with online channels due to the low cost of operations and higher demand levels. The authors considered the logistics service quality of online retailers with free shipping policies,

through which the e-tailer uses either 3PL services or their own distribution strategy. Fan, Yin and Liu (2020) studied the horizontal cooperation of online retailers, with both pure e-tailers and retailers with online platform schemes considered. This study provides insights on how to achieve horizontal cooperation using a coordination contract approach in a decentralised supply chain when competing e-tailers with different operational settings exist in the market. Zhang, J et al. (2019) explored an optimal pricing strategy within capacity expansion decisions when low price promotion exists. Similar to the approach used by Fan, Yin and Liu (2020), Zhang, J et al. (2019) also discussed supply chain coordination using a revenue-cost-sharing type contract. Zhong et al. (2019) also used game theory models to derive supply chain coordination for e-commerce service supply chains. Distribution using a cooperative strategy was the main focus of this study.

Saberi, Z et al. (2019) analysed assortment planning for small-scale e-tailers, which is essential when large suppliers do not provide the goods. The authors designed a model to manage the product assortment of e-tailers effectively using game theory. Pei and Yan (2019) explored the value of information sharing when the e-tailer has a full return policy, which is one of the crucial aspects of online retailing supply chains. Using game theory models and a coordination contract, this study designed a cooperative strategy with contracts to derive a win-win outcome for all supply chain members. Chiang and Feng (2010) and Li, Zhang and Liu (2019) both explored the impact of drop shipping strategies on pricing and procurement using game theory models.

He et al. (2018), Rofin and Mahanty (2018), and Wang and Ng (2018) focused on dual-channel supply chain operations, although they compared these dual-channel operations with pure e-tailer models. Tian et al. (2018) analysed all three types of operational settings to derive the most beneficial channel structure: re-selling, platform or hybrid operations. This study found that order fulfilment costs and the degree of competition are two prominent factors that determine the e-tailer's channel structure. Abhishek, Jerath and Zhang (2016) explored the most profitable operations in online retailing by comparing both re-selling (pure e-tailer operations) and AS (platform operations). The findings of this study indicate that the choice of re-selling or AS depends on external factors, such as the market, demand and competition levels, with online retailers gaining more benefits from one method than the other. Achieving similar outcomes in their studies, Abhishek, Jerath and Zhang (2016) and Tian et al. (2018)

conclude that an online platform operation is not necessarily the best option for small-scale or commencing online retailers.

It is noteworthy to observe that various mathematical modelling approaches have been used in the literature to examine pure e-tailer models. According to the analysis, as summarised in Table 2.2, these studies incorporated solution approaches such as MOO (Dutta et al. 2020), stochastic programming with heuristics (Acimovic & Graves 2017; Pagès-Bernaus et al. 2019), non-linear programming (NLP) (Ji & Sun 2017), algorithm based simulations (Cheng, Li & Jiang 2016; Deng et al. 2016; Mohebbi & Li 2012), and analytical solutions (Gao et al. 2017; Li, Lu & Talebian 2015; Zhao, Hu & Meng 2019). The objective of all these studies was to create optimal supply chain outcomes, with a general focus on the areas of optimal supply chain network design, maximising profits, optimising inventory policies and designing long-term partnerships. As well as mathematical modelling approaches, empirical models have also been used in the literature to analyse pure e-tailer operations, specifically structural equation modelling (SEM) solution approaches (Griffis et al. 2012; Pei, Paswan & Yan 2014; Vakulenko et al. 2019; Yu, Huo & Zhang 2020).

The investigation of e-commerce supply chain modelling studies discloses that game theory modelling is the most widely used approach for obtaining optimal solutions to issues related to strategic interactions and decision-making. Therefore, this research also adopted game theory concepts to analyse supply chain decision-making issues. Therefore, game theory concepts and studies that used game theory are discussed in the next section.

2.6 Game Theory in Supply Chain Management Optimisation

2.6.1 Game Theory - Concepts and Definitions

Game theory was developed as an influential tool in decision-making and interactive optimisation situations in which the decisions of one party affect another party's payoff (Allen et al. 2013; Cachon & Netessine 2006; Kogan & Tapiero 2007; Narahari 2014; Simchi-Levi, Chen & Bramel 2014). Game theory was initially defined as a mathematical tool but later developed as a strategic tool in the fields of social sciences and empirical studies. It has now evolved and is used in many disciplines, including economics, politics, operations and supply chain management (Geisler 2014). Game theory is defined as a mathematical model that creates interactions of conflict or cooperation among rational and intelligent decision-makers (Narahari 2014). It has also been described as a tool that can be used to consider the strategic

interactions of a situation (Perloff 2014). Game theory is crucial when applied to a competitive environment in which different parties have a mutual impact on the final outcomes (Kogan & Tapiero 2007; Samuelson & Marks 2015; Simchi-Levi, Chen & Bramel 2014).

The main components of a game are players, strategies, utility functions and payoff functions (Matsumoto & Szidarovszky 2016; Narahari 2014; Simchi-Levi, Chen & Bramel 2014). Generally, game theory is based on a key assumption that all agents included in the game are rational players, meaning that the agent is consistently making decisions for their own benefit. As described in Matsumoto and Szidarovszky (2016), a simple game scenario could be mathematically denoted as follows:

N = Number of players

S_k = Strategy set of player k ; ($k=1,2,3, \dots, N$)

ϕ_k = Payoff function of player k ($\phi_k: S_1 \times S_2 \times S_3 \times \dots \times S_N \rightarrow \mathbb{R}$)

In this setting, $s_1, s_2, s_3, \dots, s_N$ are the strategy selections of player $s_k \in S_k$ ($k=1,2,3, \dots, N$)

Then the game could be denoted as:

$$\Gamma(N; S_1, S_2, S_3, \dots, S_N; \phi_1, \phi_2, \phi_3, \dots, \phi_N)$$

When the normal form of a game is considered, a player selects either a pure strategy or a mixed strategy. In pure strategy selection, the player selects a particular strategy, and in the mixed strategy selection, the player selects a random strategy from a set of strategies. However, the mixed strategy method is not utilised in supply chain management as it is not possible to randomly select operational decisions in supply chain games (Cachon & Netessine 2006).

Games are classified into different forms. Narahari (2014) described the main classifications of games as non-cooperative and cooperative, static and dynamic, strategic form and extensive form, games with perfect and imperfect information and games with complete and incomplete information. Narahari (2014) also identified types of games, such as Stackelberg, differential, evolutionary, stochastic and repeated games. Game theory has many facets, and considering the collaboration level of different parties, two game theory methods are identified as non-cooperative and cooperative game theory (Simchi-Levi, Chen & Bramel 2014). Non-cooperative game theory is applied when players make independent decisions, while

cooperative game theory is applied when players create agreements aligned to specific rules and principles that must be followed (Simchi-Levi, Chen & Bramel 2014).

Non-cooperative static games are solved using the Nash equilibrium, when players choose strategies simultaneously in a single period. In a cooperative game, players are capable of forming coalitions and creating side payments to derive binding agreements (Cachon & Netessine 2006). Perloff (2014) discussed game theory in terms of static and dynamic games. In static games, players choose strategies simultaneously, and the game is played once. In dynamic games, players may be aware of other player's strategies and play simultaneously within a specific timeframe. Understanding all of these different parameters in expressing a game was crucial to identifying the most suitable game model that could be applied in the optimisation of this study.

2.6.2 Applications of Game Theory Modelling in Supply Chain Management

Supply chains typically operate in decentralised environments, with different players acting in their own self-interests, thus creating conflicting situations in decision-making and inefficiencies in operations (Kogan & Tapiero 2007). In such conflicting decision settings, game theory can be used to derive higher performance outcomes in supply chain operations.

For example, consider an operational setting where the manufacturing manager and sales manager has to manage a possible incentive conflict. The marketing manager is focused on fulfilling customer demand without any shortages, while the manufacturing manager is focused on achieving operational efficiency. This scenario generates a conflict between individual goals if the management of the organisation is rewarding each party according to those goals. A game theory model could be applied in this scenario to eliminate any conflict of interest and achieve a common objective (eds. Chatterjee & Samuelson 2014).

Many studies have used game theory modelling to achieve efficient coordination between different players in supply chains, as summarised in Table 2.4. When analysing this literature, factors such as the type and objective of the game model, applicability of the incentive contract, and the number of players were considered.

Table 2.4 Summary of game theory modelling studies in supply chain management

#	Author	Type of game model			Objective	Incentive contracts	No. of echelons/ Levels	Players
		Non-cooperative	Cooperative	Stackelberg				
1	Canbulut, Köse and Arik (2020)	x	-	-	Supply chain coordination	Revenue-sharing	Two	Manufacturer-retailer
2	Guo et al. (2020)	-	-	x	Optimal channel configuration strategy	-	Two	Manufacturer-retailer
3	Jin et al. (2020)	x	-	-	Optimal strategy for BORP adoption	-	Two	Two retailers-consumers
4	Lei, He and Huang (2020)	x	-	-	Optimal channel structure	-	One	Online retailer-offline retailer
5	Matsui (2020)	x	-	-	Optimal bargaining wholesale price	-	Two	Manufacturer-retailer
6	Nicoletti and You (2020)	-	-	x	Profit optimisation	-	Two	Refinery-crude oil suppliers
7	Pakseresht et al. (2020)	-	-	x	Sustainable optimisation	-	Multi	Green product family-green supply chain
8	Qiongqiong, Xiaodong and Bin (2020)	-	-	x	Optimal pricing strategy	-	Two	Two manufacturers-one retailer
9	Rahimi-Ghahroodi et al. (2020)	-	-	x	An optimal contract for multi-resource emergency supply chain	Price only and revenue-sharing	Two	Local service provider-emergency supplier
10	Shu, Qu and Wu (2020)			x	Optimise logistics service quality	Cost-sharing, revenue-Sharing	Two	Manufacturer-online retailer
11	Tang and Yang (2020)	-	-	x	Optimal financing strategy for O2O fresh supply chain	-	Two	Supplier-retailer
12	Wang, Y et al. (2020a)			x	Supply chain coordination	Cost-sharing	Two	Manufacturer-online platform
13	Wang, Y et al. (2020b)	-	-	x	Optimal profit generation with extended warranty	-	Two	Seller-e-platform
14	Xu, Fu and Fan (2020)	-	-	x	Supply chain coordination	Service cost-sharing	Two	Brand supplier-offline store
15	Xu, Zhang and He (2020)			x	Supply chain coordination	Wholesale price, cost-sharing	Two	Manufacturer-retailer
16	Yuan et al. (2020)	-	x	-	Supply chain coordination	Wholesale price	Three	Manufacturer-retailer-online recycler

17	Zhang and Zhang (2020)	x	-	-	Equilibrium information sharing strategy	-	Two	Supplier-e-tailer
18	Halat and Hafezalkotob (2019)	-	-	x	Carbon regulation policy for optimal inventory decisions	-	Multi	Government-green supply chain (Suppliers-distributors-retailers)
19	Li et al. (2019)	-	-	x	Channel cooperation	-	Two	Collector-manufacturer
20	Li, Li and Sun (2019)	-	-	x	Optimal service strategy with showrooming effort	Wholesale price	Two	Manufacturer-retailer
21	Li, Zhang and Liu (2019)	-	-	x	Effective procurement strategy	-	Two	Manufacturers-e-tailer
22	Li, Zheng and Liu (2019)	-	-	x	Optimal profit and pricing strategy	-	Two	Retailer-manufacturer
23	Liu and Ke (2019)	-	-	x	Optimal channel structure and pricing strategy	-	Two	Manufacturer-e-commerce platform
24	Liu et al. (2019)	-	-	x	Optimal strategies for corporate social responsibility (CSR) implementation	-	Three	Government-retailer-suppliers
25	Modak and Kelle (2019)	x	-	x	Supply chain coordination	Quantity discount and franchise fee	Two	Manufacturer-retailer
26	Mondal, Giri and Maiti (2019)	x	-	-	Optimal pricing and greening strategy	-	Two	Manufacturer-retailer
27	Parsaeifar et al. (2019)	x	-	x	Supply chain coordination to maximise profits	-	Three	Manufacturer-suppliers-retailers
28	Pei and Yan (2019)	-	-	x	Supply chain coordination	Wholesale and profit-sharing	Two	Supplier-e-tailer
29	Pi, Fang and Zhang (2019)	-	-	x	Optimal pricing and service strategy	-	Two	Manufacturer-two retailers
30	Saberi, Z et al. (2019)	-	-	x	Optimal assortment pricing strategy	-	Two	Supplier-e-tailer
31	Wang, Yu and Jin (2019)	-	-	x	Optimal pricing and service strategy	Cost-sharing	Two	Manufacturer-e-platform
32	Wei et al. (2019)	-	-	x	An optimal shared distribution system	Revenue-sharing	Two	Sharing distribution company-express company
33	Xu et al. (2019)	-	-	x	Optimal channel structure selection	-	Two	Manufacturer-retailer

34	Zheng et al. (2019)	x	x	-	Supply chain coordination	-	Three	Manufacturer-distributor-retailer
35	Zhong et al. (2019)	-	-	x	Cooperative distribution strategy	Revenue-sharing	Two and Three	E-commerce mall-logistics service provider and terminal distributors
36	Zhu and Lin (2019)	-	-	x	Optimal advertising strategy	-	Two	E-commerce platform-advertiser
37	Chen, Nan and Li (2018)	-	-	x	Optimal pricing strategy based on wholesale pricing and agency pricing	-	Two	Manufacturer-retailer
38	He et al. (2018)	-	-	x	Impact of reference quality of products	-	Two	Supplier-retailer
39	Jamali and Rasti-Barzoki (2018)	-	-	x	Pricing and determining eco-friendliness of products	-	Two	Manufacturer-retailer
40	Moradinasab et al. (2018)	-	-	x	Profit maximisation and minimising pollution	-	Multi	Government & oil company
41	Raj, Biswas and Srivastava (2018)	-	-	x	Supply chain coordination	Wholesale price, linear two-part tariff, cost-sharing and revenue-sharing	Two	Supplier-buyer
42	Rofin and Mahanty (2018)	-	-	x	Optimal channel selection strategy for a manufacturer with multiple channel choice	-	Two	Manufacturer-retailer and e-tailer/company store and e-tailer/retailer and e-marketplace
43	Tabrizi, Ghodsypour and Ahmadi (2018)	x	-	-	Higher performance levels for fish supply chain	-	Two	Fish farm and retailer
44	Tian et al. (2018)	-	-	x	Optimal channel structure	-	Two	Supplier-e-tailer
45	Wang and Ng (2018)	x	-	-	Comparison of traditional e-tailing and dual-channel retailing	-	One	New retail and online retail firm
46	Kong et al. (2017)			x	Optimal pricing and service strategy	Revenue-sharing	Two	Supplier-retailer
47	Li, Ryan and Zeng (2017)	-	-	x	Supply chain Coordination	Wholesale price and adjustment contracts	Two	Single supplier and multi-retailers

48	Hjaila et al. (2017)	x	-	x	Enterprise wise optimisation (EWO)	-	Two	Vendor and client external
49	Yue and You (2017)	-	-	x	Optimal supply chain design & planning	-	Two	Leader-follower
50	Abhishek, Jerath and Zhang (2016)	-	-	x	Selling strategy to maximise profits	Wholesale price	Two	Manufacturer-e-tailer
51	Arani, Rabbani and Rafiei (2016)	-	-	x	Supply chain coordination	Revenue-sharing option contract	Two	Manufacturer-retailer
52	He et al. (2016)	-	-	x	Optimal logistics service and pricing levels	-	Two	Manufacturer-retailer
53	Hu et al. (2016)	-	-	x	Supply chain coordination	Revenue-sharing	Three	Manufacturer-distributor-retailer
54	Modak, Panda and Sana (2016)	x	-	x	Supply chain coordination	Quantity discount with a franchise fee	Three	Manufacturer-distributor-retailer
55	Roy, Sana and Chaudhuri (2016)	-	-	x	Optimal stock level, sales price and service levels	-	Two	Manufacturer-retailer with online and traditional channel
56	Taleizadeh and Noori-daryan (2016)	-	-	x	Cost minimisation	-	Three	Manufacturer-retailer-supplier
57	Wang, Yang and Wang (2016)	-	-	x	Effective channel structure	-	Two	Manufacturer-retailer or online platform
58	Xiao and Shi (2016)	x	-	-	Optimal pricing and supply strategy	-	Two	Manufacturer-retailer or online platform
59	Avinadav, Chernonog and Perlman (2015)	-	-	x	Pricing and quality investment strategies	Consignment revenue-sharing	Two	Mobile app retailer and developer
60	Chakraborty, Chauhan and Vidyarthi (2015)	x	-	x	Supply chain coordination	Wholesale price, revenue-sharing	Two	Two manufacturers and a retailer
61	Ghosh and Shah (2015)	-	-	x	Supply chain coordination	Cost-sharing	Two	Manufacturer-supplier
62	Kovács and Grzybowska (2015)	-	x	-	Supply chain coordination	-	Two	Three logistics service providers
63	Cao (2014)	-	-	x	Supply chain coordination	Revenue-sharing	Two	Manufacturer-retailer
64	El Ouardighi (2014)	x	-	x	Improve supply product quality using	Wholesale price and revenue-sharing	Two	Manufacturer-supplier
65	Mahdiraji et al. (2014)	x	-	-	Supply chain coordination for pricing, inventory and marketing	-	Three	Retailers-manufacturers-suppliers
66	Slimani and Achchab (2014)	x	-	-	Minimise logistics cost	-	Two	Supplier-retailer

67	Yue and You (2014)	x	-	x	Optimal supply chain design	-	Three	Supplier–manufacturer–customer
68	Lee and Yang (2013)	x	-	-	Designing optimal supply chain contract	Two-part tariff, quantity discount	Two	Two suppliers-one retailer
69	Zamarripa et al. (2013)	x	x	-	Effective supply chain planning strategy	-	Multi	Factories-distributors
70	Babich et al. (2012)	-	-	x	The first best solution to the optimal supply chain	Buyback contract	Two	Supplier-retailer
71	Chen, Zhang and Sun (2012)	-	-	x	Optimal coordination strategy based on contracts	Two-part tariff and profit-sharing	Two	Manufacturer-retailer
72	Lei, Li and Liu (2012)	-	-	x	Optimal contracts for mitigating risks	Wholesale price	Two	Supplier-retailer
73	Ryan, Sun and Zhao (2012)	-	-	x	Optimal channel choice and pricing strategy	Revenue-sharing with a fixed fee	Two	Online retailer-online marketplace or online channel
74	Fiestras-Janeiro et al. (2011)	-	x	-	Centralised multi-client inventory model	-	-	Multiple agents
75	Cai (2010)	-	-	x	Optimal channel selection and coordination strategy	Revenue-sharing	Two	Supplier-retailer
76	Chiang and Feng (2010)			x	Channel choice for optimal pricing	-	Two	Manufacturer-retailer or e-tailer
77	Zhao et al. (2010)	-	x	-	Supply chain coordination	Option contract	Two	Manufacturer-retailer
78	Li, Zhu and Huang (2009)	-	x	-	Supply chain coordination	Consignment contract with revenue-sharing	Two	Manufacturer and retailer
79	Hennet and Arda (2008)	x	x	x	Supply chain coordination	Linear-price, Transfer price	Two	Producer and supplier
80	Sarmah, Acharya and Goyal (2006)	x	x	-	Maximise vendor profit and minimise supply chain cost	Quantity discounts	Two	Single vendor and buyer
81	Wang, Guo and Efstathiou (2004)	x	-	-	Supply chain coordination	Profit-sharing	Two	One supplier and n retailers
82	Li et al. (2002)	-	-	x	Supply chain coordination	-	Two	Manufacturer-retailer

As evident in Table 2.4, the literature reviewed in this study spans from 2002 to 2020. This highlights the importance of using game theory as a suitable application tool to achieve optimal supply chain outcomes. The studies reviewed focused mainly on either supply chain coordination or deriving optimal strategies to improve supply chain performance. A large number of studies have developed Stackelberg game models in which leader-follower game scenarios are considered. Often, incentive contracts or coordination contracts are associated with these studies, particularly when the objective is related to supply chain coordination.

However, many of the models in these studies were designed for two-echelon or two-player supply chains. More recent literature concentrates on multi-echelon/multi-player supply chain optimisation, as supply chains are operated in complex environments and include more than two echelons (Jiang, Wang & Liu 2016). While there are fewer studies on multi-echelon/multi-player game models, these studies were analysed in-depth to identify how the models were developed.

Yue and You (2014) discussed a multi-echelon approach, developing a non-cooperative game model with a solution derived using the Nash equilibrium. Zamarripa et al. (2013) also developed a non-cooperative game model for a supply chain planning problem. This study focused on minimising total supply chain costs by considering the operational constraints between factories and distribution centres. Their model was developed as a MOO problem, and competitive and cooperative scenarios of players were taken into account in developing the game model. Moradinasab et al. (2018) discussed a multi-player petroleum green supply chain and developed a Stackelberg game by considering government as the leader and petroleum companies and distribution centres as the followers. This network model was tested as MOO problem with fuzzy programming techniques.

Modak, Panda and Sana (2016) considered a Stackelberg game and a bargaining approach in which two different contracts were defined by considering two players at a time. Hu et al. (2016) considered supply chain coordination for a three-echelon supply chain, with revenue-sharing contracts presented based on Stackelberg games between manufacturer-distributor and manufacturer-retailer to derive optimal order quantities and wholesale prices. Taleizadeh and Noori-daryan (2016) also discussed a three-echelon game, developing two Stackelberg game models for manufacturer-retailer and manufacturer-supplier, since their focus was on evaluating the pricing and inventory policy decisions from the manufacturer's viewpoint. Both

Hu et al. (2016) and Taleizadeh and Noori-daryan (2016) used a similar approach to develop game models, although the latter did not use incentive contracts to design optimal strategies.

Zhong et al. (2019) examined the most profitable distribution strategy for e-commerce service supply chains, considering both two and three-stage supply chains. Stackelberg game models were developed focusing on the cooperative distribution among the players using revenue-sharing to test the supply chain coordination levels. Zheng et al. (2019) studied the supply chain coordination strategy with the retailer's fairness concerns for a three-echelon, closed-loop supply chain consisting of manufacturer, distributor, and retailer. The authors developed cooperative game theory models to derive coordination levels. The supply chain coordination in a three-stage, closed-loop supply chain was also analysed by Yuan et al. (2020), mainly focusing on the impact of online recycling on supply chain profit maximisation. A cooperative game-based approach was used to determine the optimal supply chain profits, considering manufacturer-retailer interactions and the third-party online recycler in their study.

Halat and Hafezalkotob (2019), Parsaeifar et al. (2019), and Pakseresht et al. (2020) have focused on optimising multi-echelon supply chain operations using Stackelberg game theory models. However, all these studies adopted optimisation solution approaches, specifically bi-level MOO, as the authors considered operational scenarios that included operational constraints and multiple players. However, none of these studies considered incentive contracts to create coordinating outcomes for supply chain operations.

The investigation, as outlined in this section, emphasised the extent to which game theory-based optimisation has been applied in supply chain management. Both analytical solutions and optimisation modelling approaches have been used to resolve issues and derive optimal outcomes. It is important to note, however, that less attention has been given to multi-player models within operational contexts, even though these models are more relevant to actual operations. Incentive contracts also play a significant role in game theory applications, as they are used to bind supply chain partners to more cooperative and coordinating outcomes. Moreover, the analysis revealed that there are even fewer studies that use incentive contracts in multi-echelon or multi-player game models. This is a limitation that needs to be addressed. Based on the above analysis, the next section discusses game theory-based incentive contracts and contract modelling studies that have been used to develop win-win and cooperative strategies.

2.7 Contract Modelling in Supply Chain Management

2.7.1 Supply Chain Contracts

Essentially, supply chains are required when two or more parties work together, interactively and operate based on partnerships. Therefore, partners in supply chain operations must agree on how they will interact with each other (Voß & Woodruff 2006), resulting in the development of supply chain contracts (Simchi-Levi, Chen & Bramel 2014). Contractual agreements were first introduced in the field of economics, and contracts are discussed within the context of organisational employment arrangements (Bolton & Dewatripont 2005). Contracts are defined as a set of parameters used to reinforce the contribution of each partner via profit, cost-sharing or better performance levels to achieve equilibrium (Hennet & Arda 2008). Supply contracts are identified as powerful tools that can be used to ensure adequate supply and demand is maintained throughout operations (Simchi-Levi, Chen & Bramel 2014). Most importantly, one of the main motivations of contract implementation in supply chains is to create win-win outcomes for all parties (Van Der Rhee et al. 2010). As argued by Bahinipati, Kanda and Deshmukh (2009), supply chain coordination achieves integration among its members, aligning supply chain decisions to achieve common objectives, improve efficiency, match supply and demand requirements, and generate consumer surpluses. Therefore, generating supply chain coordination is crucial for optimal supply chain performance.

Often supply chain members are self-focus, and hence, poor performance outcomes are generated. Therefore, contracting is one of the powerful strategies to derive optimal outcomes, which aligns the individual objectives with overall supply chain's objectives (Cachon 2003). Supply chain contracts are applied to achieve coordination and collaboration when issues of strategic decision-making are discussed (Cachon & Netessine 2006; Simchi-Levi, Chen & Bramel 2014). A contract that could align the goals of each individual party in the supply chain along with the goals of the total supply chain is categorised as a contract of coordination (Simchi-Levi, Chen & Bramel 2014). It acts as an incentive to different parties, who have diverse objectives to share information and collaboratively work with each other (Cachon 2003).

Voß and Woodruff (2006) identified the main components of a supply chain contract as the decision rights of each party, information, pricing mechanisms (including incentives), bounds on the commitments such as upper and lower bounds, allocation methods, time factors, if transportation is required, quality and return, and buy back policies. As discussed by Simchi-

Levi, Chen and Bramel (2014), parties in a supply chain contract must agree on factors such as pricing and discounts, minimum and maximum quantities, the quality of the materials and products, lead times and return policies. Tsay, Nahmias and Agrawal (1999) also conducted a classification of supply chain contracts based on the specification of decision rights, pricing, minimum commitment levels, quantity flexibility, buyback or return policies, allocation rules, lead times and quality. Höhn (2010) added several other parameters such as horizon length (duration of the contract), periodicity of ordering (number of times that orders are placed) and information sharing (the type of information shared between the players). These factors are important when designing and executing successful supply contracts. Based on these classifications, numerous contract types have been introduced in the supply chain literature.

Cachon (2003), Simchi-Levi, Chen and Bramel (2014), and Snyder and Shen (2011) described the main contract types discussed in the supply chain literature as the wholesale price contract, the revenue-sharing contract, the buyback contract, and the quantity flexibility contract. These are explained in more detail as follows:

- The wholesale price contract is defined in newsvendor models in which a supplier provides a wholesale price to the retailer, and the retailer places an order that is proportionately related to the wholesale price (Simchi-Levi & Bramel 2014). However, this contract itself cannot coordinate supply chain operations as a double marginalisation effect is created when both the supplier and the retailer add a mark-up value to their prices (Becker-Peth & Thonemann 2016).
- The revenue-sharing contract incorporates a revenue-sharing fraction in the contract, meaning the retailer shares a fraction of his revenue with the supplier, including sales revenue and salvage revenue (Snyder & Shen 2011). This contract is defined as a risk-sharing contract between two players because when the retailer shares a fraction of his revenue, the supplier tends to reduce his wholesale price as he receives an additional benefit (Simchi-Levi & Bramel 2014). In the supply chain literature, revenue-sharing contracts are identified as one of the most frequently used contract types (Canbulut, Köse & Arik 2020).
- The buyback contract has the capacity to coordinate the supply chain as the supplier and retailer share the risk (Simchi-Levi & Bramel 2014). The contract also includes the wholesale price declared by the supplier. The supplier receives benefit from the retailer

as the retailer pays a unit price for the unsold stocks, which is less than the wholesale price (Cachon 2003; Snyder & Shen 2011).

- The quantity flexibility contract is similar to the buyback contract as the supplier shares the retailer's risk of unsold inventory. However, the supplier fully compensates for the unsold inventory rather than paying a partial price, as in the buyback contract (Cachon 2003; Snyder & Shen 2011). This contract coordinates the supply chain from the supplier's end as the supplier's optimal order quantity is equal to the supply chain's optimal order quantity (Snyder & Shen 2011).

Recent contract modelling literature indicates that several other contract types have been introduced beyond the traditional contract models described above. According to Zhang, J et al. (2019), other contract types include option contracts, commitment contracts, compensation contracts, delay in payment contracts, and delivery lead time contracts. Among these other types of contracts, cost-sharing contracts are identified as an extended version of the traditional revenue-sharing contract models (Becker-Peth & Thonemann 2016) and are analysed extensively in extant studies.

2.7.2 Information Asymmetry

Information asymmetry is defined as one party having material facts or information that the other party does not. This could generate adverse effects since the more informed party could gain an advantage over the less informed party by exploiting the information (Perloff 2014; Samuelson & Marks 2015; Scott 2015). A significant outcome of information asymmetry is opportunism, created by adverse selection and moral hazard (Perloff 2014). Adverse selection refers to the issues of hidden information, while moral hazard refers to hidden actions (Bolton & Dewatripont 2005).

Information asymmetry is a common issue when partnerships or joint ventures are created between independent parties (McGuigan, Moyer & Harris 2014). In real-world business operations, partners keep private information about their cost structures, which may not be accessible to other parties. However, the success of a joint venture is dependent on the revelation of true costs because each party needs to generate adequate operating profits to cover its operational costs. In online supply chains, information imbalance is a common issue as supply chain partners have few physical interactions, and there is a greater likelihood of hidden information.

These information asymmetry issues are mainly linked to the Principal-Agent problem discussed as a subset of game theory in a number of studies (Samuelson & Marks 2015). Rasmusen (2007) discussed information asymmetry in relation to five areas. They are moral hazard with hidden action; post-contractual hidden knowledge; adverse selection; signalling; and screening. According to the analysis of Cachon and Netessine (2006), when players of a game have unequal information authority, information structure creates different game scenarios, described as signalling, screening, or Bayesian games. In a signalling game, the player with the most information makes the first move; in the screening game, the player with the least information makes the first move by offering a menu of contracts to reveal the actual information. Bayesian games occur when all players of the game move simultaneously, unlike in the signalling and screening games (Cachon & Netessine 2006).

2.7.2.1 Adverse Selection

Adverse selection occurs when a more informed party exploits information when entering into a transaction or contract (Perloff 2012; Scott 2015). Adverse selection issues arise before a contract is signed or before the uninformed party enters into the contract (Cachon 2003). In the contract literature, asymmetric information related to adverse selection creates two different scenarios: screening or signalling. When the uninformed party offers the contract, it is described as a screening problem; when the party with more information offers the contract, it is defined as a signalling problem (Bolton & Dewatripont 2005). In such cases, contracts need to include clear outcomes, which can be ensured by the revelation of true costs, defined as the *Revelation Principle* (Bolton & Dewatripont 2005).

Revelation principle includes incentive compatible revelation mechanism to ensure that the objective of a partnership or joint venture is compatible with the objectives of all the agents in that group (McGuigan, Moyer & Harris 2014). In an optimal incentive contract, a revelation mechanism eliminates the issue of information asymmetry but not the partnership or incentive contract itself. It enables partners to create self-enforcing reliance relationships, which create benefits and improve the outcomes of the contract (McGuigan, Moyer & Harris 2014). When decentralised players in a typical e-commerce supply chain act to achieve vertical collaboration, a similar situation as a joint venture is created. Therefore, the correct revelation of the information in the contract imposed by different players is essential to generate effective outcomes.

2.7.2.2 Moral Hazard

Moral hazard arises when the actions/transactions of the more informed party are hidden from the less informed party during contract negotiations or transactions (Perloff 2012; Scott 2015). In employment contracts, moral hazard problems can be eliminated by offering rewards for good performance such as bonus payments and stock options, or through punishment for bad performance such as layoffs (Bolton & Dewatripont 2005).

2.7.3 Review of Supply Chain Contracts

As indicated earlier, supply chain contracts have been analysed extensively, mostly using game theory models (see Table 2.3). Govindan, Popiuc and Diabat (2013) stated that incentives in supply chain contracts could be categorised under either forward or reverse supply chain coordination. Incentives related to forward supply chain coordination focus on price or quantity discounts, time incentives and information access; while incentives related to reverse supply chain coordination focus on quantity, quality, time, and price. The authors argued that contract designs generally focus on reverse supply chain coordination, and therefore, more research is needed relating to forward supply chain coordination. Contracts require proper rules and incentives to achieve effective outcomes. Defining proper corporate rules, including accounting methods, transfer pricing schemes, performance measurement criteria and operational constraints, could eliminate the inefficiencies in incentive schemes in decentralised supply chain contracts (Lee & Whang 1999).

Table 2.5 provides a review summary of studies on supply chain contracts associated with decision-making and optimisation in supply chains. This analysis represents a filtered version of Tables 2.3 and 2.4. In this analysis, the type of contract, objective function, information structure, operational control and number of players or number of echelons of the supply chains were considered.

Table 2.5 Review of supply chain contracts

#	Author	Contract type	Objective function		Information structure		Operational control		No. of players/ echelons
			Profit	Cost	Symmetric	Asymmetric	Decentralised	Centralised	
1	Canbulut, Köse and Arik (2020)	Revenue-sharing	x	-	x	-	-	-	Two
2	Fan, Yin and Liu (2020)	Wholesale price	x	-	-	x	x	-	Two
3	Jia and Li (2020)	Wholesale price	x	-	x	-	-	-	Two
4	Rahimi-Ghahroodi et al. (2020)	Price only, Revenue-sharing	x	-	x	x	-	-	Two
5	Shu, Qu and Wu (2020)	Cost-sharing, Revenue-sharing	x	-	x	-	x	x	Two
6	Wang, Y et al. (2020a)	Cost-sharing	x	-	x	-	x	x	Two
7	Xu, Fu and Fan (2020)	Service cost-sharing, Profit-sharing	x	-	x	-	x	-	Two
8	Xu, Zhang and He (2020)	Wholesale price, cost-sharing	x	-	x	-	-	-	Two
9	Yuan et al. (2020)	Wholesale price	x	-	x	-	x	x	Two
10	Basu, Liu and Stallaert (2019)	Buyback contract	x	-	x	x	x	-	Two
11	Chen, Li and An (2019)	Option contract	x	-	-	x	x	-	Two
12	Choi, Chen and Chung (2019)	Wholesale price, Profit-sharing	x	-	x	-	x	x	Two
13	Li, Li and Sun (2019)	Wholesale price	x	-	x	-	-	-	Two
14	Liu et al. (2019)	Transfer payment	x	-	-	x	x	-	Two
15	Modak and Kelle (2019)	Quantity discount and Franchise fee	x	-	x	-	x	x	Two
16	Pei and Yan (2019)	Wholesale and Profit-sharing	x	-	-	x	-	-	Two
17	Song and He (2019)	Cost-sharing, Revenue-sharing	x	-	x	-	x	x	Three
18	Wang, Yu and Jin (2019)	Cost-sharing	x	-	x	-	x	-	Two
19	Wei et al. (2019)	Revenue-sharing	x	-	x	-	x	x	Two
20	Zhang, J et al. (2019)	Revenue-cost-sharing	x	-	x	-	x	-	Two
21	Zhong et al. (2019)	Revenue-sharing	x	-	x	-	x	x	Two and three

22	Zhou, Zhao and Wang (2019)	One price and two-price contract	x	-	x	x	x	-	Two
23	Kaya and Caner (2018)	Wholesale price, Linear, cost and Revenue-sharing	x	-	x	x	x	x	Two
24	Kerckamp, van den Heuvel and Wagelmans (2018)	Quantity discount	-	x	-	x	-	-	Two
25	Raj, Biswas and Srivastava (2018)	Wholesale price, Linear two-part tariff, Cost-sharing and revenue-sharing	x	-	x	-	x	x	Two
26	Song and Gao (2018)	Revenue-sharing	x	-	x	-	x	x	Two
27	Taleizadeh and Rabie (2018)	Quantity discount, Cost-sharing	x	-	x	-	x	x	Two
28	Wang et al. (2018)	Wholesale price with transfer payment	x	-	-	x	x	-	Two
29	Ye, Li and Yang (2018)	Risk sharing	x	-	x	-	x	x	Two
30	Zhang and Zhang (2018)	One-part linear and Two-part non-linear	x	-	-	x	-	-	Two
31	Zhou, Guo and Zhou (2018)	Service cost-sharing	x	-	x	-	-	-	Two
32	Chen et al. (2017)	Wholesale price	x	-	x	x	-	-	Two
33	Li, Ryan and Zeng (2017)	Wholesale price and Adjustment contracts	x	-	x	-	x	x	Two
34	Kong et al. (2017)	Revenue-sharing	x	-	x	-	x	x	Two
35	Wang, Guo and Wang (2017)	Wholesale price	x	-	-	x	x	-	Two
36	Wu, Li and Shi (2017)	Two-part tariff	x	-	-	x	x	-	Two
37	Yang et al. (2017)	Wholesale price	x	-	x	x	-	-	Two
38	Abhishek, Jerath and Zhang (2016)	Wholesale price	x	-	x	-	-	-	Two
39	Arani, Rabbani and Rafiei (2016)	Revenue-sharing option contract	x	-	x	-	x	-	Two
40	Hu et al. (2016)	Revenue-sharing	x	-	x	-	-	-	Two & Three
41	Li and Li (2016)	Revenue-sharing	x	-	x	x	-	-	Two
42	Modak, Panda and Sana (2016)	Quantity discount with a franchise fee	x	-	x	-	x	x	Three

43	Jiang, Wang and Liu (2016)	Cost-sharing	x	-	x	-	x	x	Three
44	Avinadav, Chernonog and Perlman (2015)	Consignment revenue-sharing	x	-	x	-	x	x	Two
45	Chakraborty, Chauhan and Vidyarthi (2015)	Wholesale price, Revenue-sharing	x	-	x	-	-	-	Two
46	Ghosh and Shah (2015)	Cost-sharing	x	-	x	-	x	-	Two
47	Lei et al. (2015)	Revenue-sharing	x	-	x	x	x	x	Two
48	Liu, Shang and Lai (2015)	Knowledge Sharing	-	x	-	x	-	-	Two
49	Shang and Yang (2015)	Profit-sharing	x	-	x	-	x	x	Two
50	Zissis, Ioannou and Burnetas (2015)	Quantity discount	-	x	x	x	x	x	Two
51	Cao (2014)	Revenue-sharing	x	-	x	x	x	x	Two
52	El Ouardighi (2014)	Wholesale price, Revenue-sharing	x	-	x	-	x	x	Two
53	Fang, Ru and Wang (2014)	Wholesale Price	x	-	x	x	x	-	Two
54	Feng, Moon and Ryu (2014)	Wholesale Price	x	-	-	x	x	-	Two
55	Xu et al. (2014)	Revenue-sharing	x	-	x	-	x	x	Two
56	Cao et al. (2013)	Wholesale Price	x	-	x	-	x	x	Two
57	Deng, Xie and Xiong (2013)	Gain/Loss sharing	x	-	-	x	-	-	Two
58	Kim and Netessine (2013)	Wholesale price	x	-	x	-	x-	-	Two
59	Lee and Yang (2013)	Two-part tariff, Quantity discount	x	-	x	x	-	-	Two
60	Wang (2013)	Wholesale price, Revenue-sharing, Quantity flexibility	x	-	x	-	-	-	Three
61	Babich et al. (2012)	Buyback	x	-	x	x	x	x	Two
62	Cakanyildirim et al. (2012)	Profit-sharing	x	-	x	x	-	-	Two
63	Chen, Zhang and Sun (2012)	Two-part tariff, Profit-sharing	x	-	x	-	x	x	Two
64	Lei, Li and Liu (2012)	Linear wholesale price	x	-	x	x	-	-	Three

65	Ryan, Sun and Zhao (2012)	Revenue-sharing with fixed fee	x	-	x	-	-	-	Two
66	Özer and Raz (2011)	Wholesale price with a fixed fee	x	-	x	x	-	-	Two
67	Cai (2010)	Revenue-sharing	x	-	x	-	x	x	Two
68	Zhao et al. (2010)	Option contract	x		x	-	-	x	Two
69	Van Der Rhee et al. (2010)	Revenue-sharing	x	-	x	-	-	-	Three
70	Li, Zhu and Huang (2009)	Consignment contract with revenue-sharing	x	-	x	-	x	x	Two
71	Hennet and Arda (2008)	Linear-price, Transfer price	x	-	x	x	x	x	Two
72	Long-ying, Yong-qi and Zhang-sheng (2007)	Revenue-sharing	x	-	x	-	x	x	Three
73	Shou-feng, Ming-jia and Li-jiao (2007)	Revenue-sharing	x	-	x	-	-	-	Three
74	Corbett, Zhou and Tang (2004)	Wholesale price, One part linear and two-part non-linear with side payments	x	-	x	x	-	-	Two
75	Wang, Guo and Efstathiou (2004)	Profit-sharing	-	x	-	x	x	-	Two

Many previous studies have focused generally on traditional contracts such as wholesale price, revenue-sharing, quantity discounts, but other types of contracts such as cost-sharing, profit-sharing, risk-sharing, option contracts, consignment contracts and two-part tariff contracts have attracted increasing attention in the literature. Several authors who analysed wholesale price contracts extended their contract models with either a franchise fee model (Modak & Kelle 2019) or transfer pricing model (Wang 2013; Wang et al. 2018). Numerous other studies have referred to multiple contracts when wholesale price contracts are presented in their papers, combining these with cost-sharing, revenue-sharing, profit-sharing and linear contracts (Choi, Chen & Chung 2019; Kaya & Caner 2018; Pei & Yan 2019; Raj, Biswas & Srivastava 2018; Xu, Zhang & He 2020). The main reason for using multiple contracts is because the wholesale price contract alone cannot achieve supply chain coordination. However, the wholesale price contract is identified as the benchmark contract model in supply chain contract literature, and therefore, numerous studies have developed models around it.

It is evident that most supply chain contracts are focused on the objective of profit maximisation. However, cost minimisation is another critical objective in real operational aspects. The extant literature provides examples of cost minimisation issues among individual players, as well as the overall supply chain when different players interact using contracts (Krajewski, Ritzman & Malhotra 2010). Studies such as Kerkkamp, van den Heuvel and Wagelmans (2018) and Zissis, Ioannou and Burnetas (2015) are focused on the objective of cost minimisation.

The analysis of centralised and decentralised operational settings is another important aspect considered in studies that are mainly focused on supply chain decision issues or achieving supply chain coordination applying contract models. However, not all studies consider these aspects, with numerous papers discussing contracts without referring to centralised or decentralised models (Abhishek, Jerath & Zhang 2016; Canbulut, Köse & Arik 2020; Chakraborty, Chauhan & Vidyarthi 2015; Chen et al. 2017; Fan, Yin & Liu 2020; Kerkkamp, van den Heuvel & Wagelmans 2018; Li, Li & Sun 2019; Pei & Yan 2019; Ryan, Sun & Zhao 2012; Zhang & Zhang 2018; Zhou, Guo & Zhou 2018).

Similar to the findings from the game theory applications analysis (see Table 2.4), the review of contract models indicates that most studies are focused on two-players or two-echelons of the supply chain system. Only a few studies have developed contract models for three-echelon or three-player scenarios (Hu et al. 2016; Jiang, Wang & Liu 2016; Long-ying, Yong-qi &

Zhang-sheng 2007; Modak, Panda & Sana 2016; Shou-feng, Ming-jia & Li-jiao 2007; Song & He 2019; Van Der Rhee et al. 2010; Wang 2013; Zhong et al. 2019). All these studies emphasise the importance of contract development in multi-echelon, multi-player settings in supply chain operations that relate to actual operational settings. However, the information structures considered in all of these studies is symmetric and common knowledge.

This finding creates further opportunities to explore the formulation of effective contract models for optimising supply chain outcomes in multi-player/multi-echelon settings. Contract developments and their impact on supply chain outcomes within the context of multi-player or multi-echelon operational contexts are further examined in Chapter 3.

2.7.4 Review of Contract Modelling Studies with Asymmetric Information

Many studies have assumed common knowledge exists among all parties in the supply chain, despite the fact that actual operations indicate otherwise (Kaya & Caner 2018). As a result, the supply chain literature discusses contract models developed to eliminate information asymmetry issues (see Table 2.5). As the efficiency of e-commerce supply chains depends more on information management than on the management of tangible facilities, addressing issues of information asymmetry is crucial (Liu, Shang & Lai 2015). Incomplete information is an issue in both upstream and downstream supply chains, relating to such areas as production costs, production forecasts, customer demand and buyer cost structures (Lei et al. 2015). Similarly, addressing these issues relies on the assumption of the rationality of members included in the contract (Voigt 2014). As illustrated in Table 2.5, studies that explored the asymmetric information issues in contract models were investigated further.

Predominantly, studies that did explore asymmetric information incorporated a screening contract approach (see Table 2.6). The menu of contracts is widely discussed in relation to the screening contract approach in these studies (Wang et al. 2018). It is evident, therefore, that adverse selection issues have been considered in these works on supply chain contract models. These contract models include incentive compatibility constraints and individual rationality constraints to reveal the actual costs. The discrete probabilistic approach is adopted primarily in several studies to showcase information asymmetry, considering high and low probabilities (Cao et al. 2013; Chen et al. 2017; Zissis, Ioannou & Burnetas 2015). Few studies have used equilibrium strategies or transfer payment methods to derive true cost revelations in the contracts.

Within this analysis, it is evident that the type of asymmetric information frequently relates to costs. Numerous studies have considered production costs (Cakanyıldırım et al. 2012; Fang, Ru & Wang 2014; Feng, Moon & Ryu 2014; Hennes & Arda 2008; Lei et al. 2015; Özer & Raz 2011; Wang, Guo & Wang 2017; Wang et al. 2018), holding costs (Cao et al. 2013; Hennes & Arda 2008; Kerckamp, van den Heuvel & Wagelmans 2018; Zissis, Ioannou & Burnetas 2015), buyer's costs in general (Corbett, Zhou & Tang 2004; Li & Li 2016), capacity investment costs (Kaya & Caner 2018), and CSR costs (Liu et al. 2019). This outcome aligns with the findings of an extensive review of supply chain contracts conducted by Shen, Choi and Minner (2018). The authors emphasised that cost information asymmetry issues were the most analysed issues in the supply chain literature, followed by demand information asymmetry. Hence, analysing cost information asymmetry is crucial for supply chain operations. Babich et al. (2012), Lee and Yang (2013), Lei, Li and Liu (2012), Pei and Yan (2019), and Zhou, Zhao and Wang (2019) have studied demand information asymmetry. Risk levels have also been studied by Basu, Liu and Stallaert (2019), Deng, Xie and Xiong (2013), and Rahimi-Ghahroodi et al. (2020) using the degree of risk, degree of losses, and failure rates, respectively.

Several other studies have used different asymmetric information in their research, such as retailer platform scheme types in online retailing (Fan, Yin & Liu 2020), customer's heterogeneity (Wu, Li & Shi 2017), and knowledge levels in e-commerce service supply chains (Liu, Shang & Lai 2015).

Another interesting observation is that, with the exception of the study of Feng, Moon and Ryu (2014), all other contract models have contemplated only two-level or two-player supply chain scenarios. Again, this created an opportunity to focus more on designing contract models in multi-level supply chains within the asymmetric information setting.

Even though Table 2.6 presents a small sample of the information asymmetry issues identified in the supply chain literature (which are filtered from the previous Tables), the findings align with those of other review studies such as Arshinder, Kanda and Deshmukh (2011), and Shen, Choi and Minner (2018).

Table 2.6 Review of supply chain contracts with asymmetric information

#	Author	Contract type	Type of information asymmetry	Menu of contracts		IC	IR	Other strategies	Operational control		Demand		No. of Supply chain levels	Applied industry
				Yes	No				De-centralised	Centralised	L	S		
1	Fan, Yin and Liu (2020)	Wholesale price	Retailer's platform scheme	-	x	-	-	Equilibrium strategy	x	-	x	-	Two	Online retailing
2	Rahimi-Ghahroodi et al. (2020)	Price only, Revenue-sharing	Failure rate	x	-	x	x	-	-	-	-	-	Two	Multi-resource emergency supply chain
3	Basu, Liu and Stallaert (2019)	Buyback contract	Degree of risk aversion	x	-	x	x	-	x	-	-	x	Two	General
4	Chen, Li and An (2019)	Option contract	Production cost	x	-	x	x	-	x	-	-	x	Two	Perishable product supply chain
5	Liu et al. (2019)	Transfer payment mechanism	CSR cost	-	x	-	-	Misreporting factor	x	-	-	x	Two	General with CSR
6	Pei and Yan (2019)	Wholesale and Profit-sharing	Demand	-	x	-	-	Bayesian equilibrium	-	-	-	x	Two	E-commerce
7	Zhou, Zhao and Wang (2019)	One price and two-price contract	Demand	x	-	x	x	-	x	-	-	x	Two	Dual-channel retailing
8	Kaya and Caner (2018)	Wholesale price, Linear, Revenue and Cost-sharing	Capacity investment cost	x	-	x	x	-	x	x		x	Two	General
9	Kerkkamp, van den Heuvel and Wagelmans (2018)	Quantity discount	Holding cost	x	-	x	x	-	-	-	-	x	Two	General
10	Wang et al. (2018)	Wholesale price with transfer payment	Production cost	x	-	x	x	-	x	-	x	-	Two	General
11	Zhang and Zhang (2018)	One part linear and two-part nonlinear	Demand	x	-	x	x	-	-	-	-	x	Two	General
12	Chen et al. (2017)	Wholesale price	Production cost	x	-	x	x	-	-	-	-	x	Two	E-commerce (Dual channel)
13	Wang, Guo and Wang (2017)	Wholesale price with transfer payment	Production cost	-	x	-	-	Transfer payment & allocation	x	-	-	x	Two	General

14	Wu, Li and Shi (2017)	Two-part tariff	Customer heterogeneity	x	-	x	x	-	x	-	-	x	Two	Retailer supply chain
15	Yang et al. (2017)	Wholesale price	Retailer's cost	x	-	x	x	-	-	-	x		Two	Dual-channel supply chain
16	Li and Li (2016)	Revenue-sharing	Vendor's service quality and costs	x	-	x	x	-	-	-	x	-	Two	Service outsourcing
17	Lei et al. (2015)	Revenue-sharing	Production costs	x	-	x	x	-	x	x	-	x	Two	General
18	Liu, Shang and Lai (2015)	Knowledge sharing	Knowledge level	-	-	x	x	-	-	-	-	x	Two	E-commerce service supply chain
19	Zissis, Ioannou and Burnetas (2015)	Quantity Discount	Inventory holding cost	x	-	x	x	-	x	x	x	-	Two	General
20	Fang, Ru and Wang (2014)	Wholesale price	Production cost	x	-	x	x	-	x	-	-	x	Two	Assembly supply chain
21	Feng, Moon and Ryu (2014)	Wholesale price	Production cost	x	-				x	-	-	x	Multi	General
22	Cao et al. (2013)	Wholesale price	Holding Costs	x	-	x	x	-	x	x	x	-	Two	Dual-channel supply chain
23	Deng, Xie and Xiong (2013)	Gain/Loss sharing	Degree of loss aversion	x	-	x	x	-	-	-	-	x	Two	General
24	Kim and Netessine (2013)	Wholesale price	Production cost	x	-	x	x	-	x	-	-	x	Two	General
25	Lee and Yang (2013)	Two-part tariff, Quantity discount	Demand	x	-	x	x	-	-	-	-	x	Two	General
26	Babich et al. (2012)	Buyback	Demand	x	-	x	x	-	x	x	-	x	Two	General
27	Cakanyildirim et al. (2012)	Profit-sharing	Production cost	x	-	x	x	-	-	-	-	x	Two	General
28	Lei, Li and Liu (2012)	Linear wholesale price	Demand and production costs	x	-	x	x	-	-	-	-	x	Two	General
29	Özer and Raz (2011)	Wholesale price with a fixed fee	Supplier's production cost, Manufacturer's processing cost	x	-	x	x	-	-	-	-	x	Two	General
30	Hennet and Arda (2008)	Linear-price, Transfer price	Production cost, Inventory cost	-	-	-	-	Bargaining mechanism	x	x	-	x	Two	General

31	Corbett, Zhou and Tang (2004)	Wholesale price, One part linear and two-part non-linear with side payments	Buyer's cost	x	-	x	x	-	-	-	x	-	Two	General

IC = Incentive Compatibility, IR = Individual Rationality, L = Linear, S = Stochastic

In supply chain operations, operational constraints limit the capacity of outcomes and, hence, addressing them is critical to achieving optimal outcomes. Even though operational constraints are considered in the mathematical optimisation modelling, no adequate analysis was found in the literature within the context of contract modelling. To support this finding, none of the studies listed in Table 2.6 considered operational constraints in the contracts developed.

It is important to see that the demand function discussed in these studies can be segregated into linear demand functions or deterministic variables, as well as stochastic variables. In recent studies, more attention has been paid to stochastic demand models as supply chain operations face uncertainties in the market. However, linear demand functions have also been created in previous studies to simplify the complex contract modelling structures.

The type of contracts discussed in the literature has also been analysed to identify any gaps in the research. Wholesale contracts are the most referred contract type, either on their own or combined with side or transfer payments in studies within asymmetric information settings. Revenue-sharing contracts are discussed by a several studies and buyback, quantity flexibility, cost-sharing and option contracts attract the least attention (Table 2.6). Shen, Choi and Minner (2018) concluded that sharing contracts are the least discussed in the supply chain literature in addressing issues of asymmetric information. This created an opportunity to examine further the adoption of sharing contracts to eliminate asymmetric information issues. Therefore, the sharing contracts discussed in the existing literature, as shown in Table 2.7, were explored further to identify how they were formulated to eliminate asymmetric information in supply chains.

Rahimi-Ghahroodi et al. (2020) developed a revenue-sharing contract model with the failure rate of logistics service as the asymmetric information in multi-resource emergency supply chains. To eliminate the failure rate, a menu of contract was presented, comprising a portion of revenue-sharing with the emergency shipment costs of the supplier. The findings of this study reveal that the revenue-sharing contract maximises profit when asymmetric information is present more than the price-only contract, which is based on wholesale price. The true nature of the market depicted by asymmetric demand information was investigated by Pei and Yan (2019) in terms of increasing profits and creating a cooperative outcome for both supplier and e-tailer in the context of e-tailer supply chains. However, these authors used Bayesian equilibrium as the solution approach, unlike the screening contract approach used by the other authors. Lei et al. (2015) discussed information asymmetry between supplier and retailer, with

the supplier keeping information about their cost structure private and the retailer having an inaccurate inventory. A revenue-sharing contract model based on game theory was developed in this study to achieve coordination by addressing the information asymmetry issues. Li and Li (2016) developed a revenue-sharing mechanism to determine an optimal contract strategy when the vendor's costs and service quality were asymmetric in a service outsourcing supply chain. A revenue-sharing portion and a lump sum payment were included in the menu presented by the service seller. The findings of this study indicate that revenue-sharing under asymmetric information motivates the seller to invest in improving service quality, which ultimately results in maximising profits. According to Kaya and Caner (2018), cost-sharing contracts under information asymmetry achieve the best optimal solutions for supply chain operations compared to revenue-sharing, wholesale price contracts and linear contracts when implemented for capacity investment costs. These authors derived optimal solutions using screening contracts between supplier and manufacturer to reveal the cost information of the investment. Liu, Shang and Lai (2015) developed a knowledge-sharing incentive model in an e-commerce service supply chain under a principal-agent game model with information asymmetry. The knowledge-sharing model was considered as an incentive contract, designed to minimise information asymmetry and uncertainty issues. These authors discussed knowledge sharing in relation to knowledge complementarity, knowledge integration and risk attitudes.

In summary, the majority of studies have adopted a screening contract approach, even when sharing contracts are formed, and cost-sharing and knowledge-sharing models have been the focus of only two studies. Hence, examining on the sharing contracts, as mentioned above, will generate a significant contribution to the literature.

2.8 Dynamic Contract Applications in Supply Chain Management

As supply chains are time reliant operations, the relationships among the players are stable and long-term (Zhao et al. 2014). Therefore, it is crucial to define contracts in effectively formulating long-term partnerships and operations within supply chains based on multi-period operations. It is applicable to e-commerce supply chain operations as well. Hence, the concepts of dynamic contracting are discussed in this section, as this study focuses on developing effective long-term integration among supply chain members. It should be noted that when contracts become dynamic in nature, complications arise in terms of the contract principals (Salanié 2005). Bolton and Dewatripont (2005), and Salanié (2005) have discussed dynamic

contract issues extensively in terms of economic applications, which are mainly applied to employment and insurance contracts within principal-agent frameworks. However, supply chain operational aspects such as inventory levels, ordering costs, and demand are not included and, therefore, dynamic contract applications within supply chain operations need to be analysed with due consideration of these operational aspects, which can generate different outcomes than the dynamic employment contracts (Gao 2015).

2.8.1 Dynamic Games

Generally, dynamic contracts are combined with dynamic game concepts and, hence, the dynamic game concepts that relate to formulating dynamic contracts are discussed in this section. Game theory models are either played in static or dynamic scenarios. Dynamic games can be played either sequentially or simultaneously (Perloff 2014).

The issues pertaining to dynamic gaming aspects are crucial to achieving deriving optimal outcomes. When a game is repeated over time, information within the game plays a critical role in affecting the outcomes of the game, since players may have perfect information about other players based on their previous moves (Perloff 2014). According to the analysis of Rasmusen (2007), when a game repeats over time, the rules of the game will not be changed, but the history of the game will be changed.

Rasmusen (2007) analysed games that occur in a sequential manner and argued that a sub-game perfect equilibrium should be achieved in each sub-game of the sequential play. When the game consists of sequential moves, Rasmusen (2007) argued that the game should fulfil the sequential rationality, which ensures each player maximising their payoff at each point of the game while also considering re-optimising future payoffs. As per his discussion, by achieving sequential rationality, sub-game perfect equilibrium can be generated.

When a principal-agent game is repeated over several periods of time among the same set of players, many equilibria could be generated as the equilibria of a one-period model can be repeated over all other periods of time (Molho 1997; Mueller & Trost 2018). Molho (1997) further argued that for a long-term contract to be feasible, future payments either in the form of punishments for cheating/bad outcomes or in the form of rewards for good performance and reputation could be incorporated.

2.8.2 Dynamic Contracts

Even though the literature on supply chain contracts is extensive, many of the contract models presented are based on static frameworks. Studies related to dynamic contract modelling are scant (Gao 2015), but a few prominent studies in the supply chain literature were analysed in this review, as shown in Table 2.7.

Commitment, re-negotiation and dynamic stability are critical features that determine the outcomes of dynamic contracts, as discussed below:

2.8.2.1 Commitment

When a dynamic contract is proposed, it must bind all parties for all periods (Salanié 2005). The issue of commitment is segregated into four categories: full, long-term, short-term, and no commitment (Salanié 2005). Each of these commitment levels generates different contract aspects, and understanding this concept is crucial when defining and selecting the type of contract. Commitment to a contract is based on such factors as the setup of the contract, the reliability of the parties who entered into the contract, and the penalties set to discourage parties from breaking the contract. When one party breaches a contract, it is regarded as a unilateral decision, but by imposing penalties, it can be avoided (Salanié 2005).

In a full commitment contract, the revelation principle is applicable. Parties interact once and, hence, there is no requirement for re-negotiation (Salanié 2005). When the full commitment contract is implemented, no significant change is generated as the parties involved in the contract are committed to a single comprehensive term of contracts at the initial negotiation period. Therefore, the long-term aspect of the full commitment contract creates almost a static contract (Bolton & Dewatripont 2005; Macho-Stadler & Pérez-Castrillo 2001; Salanié 2005). A full commitment contract must ensure that the agent receives compensation as the agent is exposed to some risk when selecting and committing to the contract (Fudenberg & Tirole 1990).

Long-term contracts are subject to re-negotiation as the commitment only lasts for a certain period (Salanié 2005). When a contract is executed within an information asymmetry environment, such as in adverse selection with a revelation principle, or adverse selection with signalling and moral hazard, the contract may extend towards re-negotiation (Bolton & Dewatripont 2005).

Contracts created with short-term commitment are similar to those created with long-term commitment. Under this scenario, the contract should be proposed in a way that neither party can unilaterally breach the contract (Salanié 2005). Contracts imposed with no commitment mean that any party engaged in the contract has the power to breach or end the contract unilaterally in any period. In this scenario, the principal may exploit the information revealed by agents to prevent the creation of another contract. Therefore, agents may be unwilling to share truthful information. This is defined as the ratchet effect (Salanié 2005). The ratchet effect exists when the agent's hidden information is considered as continuous rather than considered with two discrete probabilities (Macho-Stadler & Pérez-Castrillo 2001).

2.8.2.2 Re-negotiation Proofness

When the optimal contract has a possibility of re-negotiation, re-negotiation proof contract constraint should be included in the contract (Bolton 1990; Bolton & Dewatripont 2005; Salanié 2005). As articulated by Bolton (1990), when the re-negotiation is a possibility, the proposed contract should not only be incentive compatible but also re-negotiation proof. This concept is explained as no party engaged in the contract is not taking any action to re-negotiate the terms of the contract in the intermediate state when a new period starts within a long-term contract (Macho-Stadler & Pérez-Castrillo 2001). This is emphasised by the study of Fudenberg and Tirole (1990), as the contract can be defined as re-negotiation proof when the principal or the agent does not require to re-negotiate at the interim stage of the contract operation. However, in this setting, the revelation principle does not stand optimal yet, holds a weaker position (Salanié 2005). A contract is renegotiation proof when the principal does not choose to deviate from the original contract at the renegotiation stage based on his beliefs of the agent's effort (Fudenberg & Tirole 1990). Cesar, Fandel and Trockel (1994) also explained that the equilibrium outcome must remain consistent to avoid re-negotiation. In a cooperative setting, this scenario is described as internal consistency.

2.8.2.3 Dynamic Stability

Cooperative games are focused on deriving group optimality or Pareto efficient solutions, in contrast to non-cooperative games. In a cooperative game setting, group optimality and individual rationality are two significant conditions to be fulfilled. Moreover, in a dynamic game scenario, both these conditions must remain optimal throughout the game period in order for all players to remain within the contract, thus binding all players together (Yeung & Petrosyan 2012). Therefore, when a cooperative game is operated within an optimal trajectory,

the outcomes of the game must be consistent and stable at each point in time during the game (Yeung & Petrosyan 2006; Yeung & Petrosyan 2012). This concept is defined as the principle of dynamic stability in cooperative game solutions (Yeung & Petrosyan 2006; Yeung & Petrosyan 2012). Re-negotiation proofness, re-coordination and Pareto perfection are notions within the dynamic stability principle that are used to determine whether the game has not deviated in future subgames (Rasmusen 2007). Therefore, dynamic stability relates to the condition of re-negotiation proofness, as the optimal solutions of the contract remain stable and consistent throughout the period and, hence, no player wants to deviate from the original contract.

2.8.3 Review of Dynamic Contract Models

As mentioned above, several dynamic contract models have been analysed in this study. This analysis considered the contract type, solution approach, objective, asymmetric information, re-negotiation conditions, applied industry, number of supply chain levels, and the nature of the contract time period. These factors are important as this study focuses on the asymmetric information settings and long-term integration of e-tailer supply chain operations.

By analysing the data related to dynamic supply chain contracts, it is evident that supply chain coordination and optimal supply chain strategies are the main focus of dynamic contracts similar to static contract models. Sharing contracts and wholesale price contracts are used broadly in formulating dynamic contracts. Kogan and Tapiero (2007) discussed multi-period contract models using non-cooperative game theory models with the Nash equilibrium, applying the wholesale price contract model in deriving supply chain coordination. Chiang (2012), Sheng et al. (2017), and Wang and Sun (2019) also utilised wholesale price contract models to develop optimal pricing strategies for supply chain optimisation. Gao (2015) developed a revenue-sharing contract, and De Giovanni (2017) developed a profit-sharing contract. At the same time, cost-sharing contracts were developed by several other studies (Bondareva & Pinker 2018; Brusset & Agrell 2015; Zhao et al. 2014; Zhou & Ye 2018).

Table 2.7 Review of dynamic contract models

#	Authors	Contract type	Solution approach	Objective	Supply chain levels	Players	Information			Re-negotiation	Applied industry	Infinite/finite periods
							Symmetric	Asymmetric				
								Moral hazard	Adverse selection			
1	Buratto, Cesaretto and De Giovanni (2019)	Consignment contract	Stackelberg equilibrium	Supply chain coordination	Two	Manufacturer-retailer	x	-	-	-	General	Infinite
2	Mobini, van den Heuvel and Wagelmans (2019)	Procurement with a side payment	Bi-level optimisation	An optimal contract for lot-sizing	Two	Supplier-retailer	x	x	-	-	General	Finite multi periods
3	Wang and Sun (2019)	Wholesale price	Stackelberg equilibrium	Optimal wholesale pricing strategy	Two	Manufacturer-retailer	x	-	-	-	Dual-channel supply chain	Infinite
4	Bondareva and Pinker (2018)	Cost-sharing with Financial penalties	Dynamic equilibrium	Improve quality	Two	Supplier-retailer	x	-	-	x	Retail sector of China	Finite multi-periods
5	Wan and Chen (2018)	Option contract	Dynamic programming	Supply chain performance	Two	Supplier-retailer	x	-	-	-	Inventory and order management	Finite multi periods
6	Wu, Feng and Chen (2018)	Consignment contract with revenue-sharing	Stackelberg equilibrium	Supply chain coordination	Two	Manufacturer-retailer	x	-	-	-	General	Infinite
7	Zhang and Wang (2018)	Two-part Tariff	Stackelberg equilibrium	Optimal pricing strategy for channel coordination	Two	Manufacturer-retailer	x	-	-	-	Dual-channel supply chain	Finite multi periods
8	Zhou and Ye (2018)	Cost-sharing and wholesale price	Stackelberg equilibrium	Supply chain coordination	Two	Manufacturer-retailer	x	-	-	-	General	Infinite
9	De Giovanni (2017)	Profit-sharing	Stackelberg equilibrium	Supply chain coordination	Two	Manufacturer-retailer	x	-	x	-	Closed loop supply chain	Infinite

10	Sheng et al. (2017)	Wholesale price	Stackelberg equilibrium	Optimal price only contract	Two	Supplier-retailer	x	-	-	-	General	Finite
11	Worthmann et al. (2016)	Option contract	Optimal control	Optimal information sharing mechanism	Two	Smart parts factory-smart assembly factory	x	-	-	-	Smart supply chain	Infinite
12	Gao (2015)	Revenue-sharing	Dynamic programming	Optimal inventory policy	Two	Supplier-Buyer	-	-	x	-	General	Infinite
13	Brusset and Agrell (2015)	Cost-sharing for investment	Stackelberg Equilibrium	Supply chain coordination	Two	Manufacturer-supplier	-	-	x	x	General	Finite multi periods
14	Zhao et al. (2014)	Cost-sharing	Nash & Stackelberg Equilibrium	Supply chain coordination	Two	Logistics service provider and integrator	x	-	-	-	Logistics service sector	Infinite
15	Chiang (2012)	Wholesale price	Open-loop myopic and feedback equilibrium	Optimal pricing strategy to derive channel efficiency	Two	Manufacturer-retailer	x	-	-	-	General	Infinite
16	Jørgensen (2011)	Franchise contract	Stackelberg equilibrium	Supply chain coordination	Two	Manufacturer-retailer	x	-	-	-	General	Infinite
17	Taylor and Plambeck (2007)	Relational contract	Non-cooperative bargaining	Supply chain coordination	Two	Supplier-buyer	x	x	x	-	General	Finite multi periods

All of these dynamic contract models are focused on two-player supply chain models, as noted in the analysis of general supply chain contracts discussed earlier in this chapter. Within this context, manufacturer-retailer models were given the greatest attention. Also, these studies did not consider any specific operational setting, but rather considered general supply chain settings with supplier-retailer operations. The impact of hidden information, which is a crucial element in contract development, is given little attention, with most of these studies assuming symmetric information. Therefore, the literature does not provide an adequate analysis of dynamic contract formulation when asymmetric information exists in supply chain operations. As previously discussed, the concept of re-negotiation is a decisive factor in long-term contract models, but very few studies focused on this aspect (Bondareva & Pinker 2018; Brusset & Agrell 2015).

Based on the above analysis, it can be concluded that more analysis is needed for dynamic contract implementation that considers aspects of re-negotiation and asymmetric information.

2.9 Cost Measurement and the Impact of Proper Accounting Methods on Supply Chain Contracts

Cost minimisation is a critically important objective in supply chain coordination (Dror, Hartman & Chang 2012). An efficient supply chain's primary goal is to fulfil customer demand at the lowest possible cost. Hence, each supply chain member must pay attention to cost saving methods, such as collaboration and effective supply chain integration (Leng & Parlar 2009). As a result, obtaining accurate cost data is vital for all supply chain activities and processes to improve productivity and profitability (Askarany, Yazdifar & Askary 2010). Cost data also provides a clearer picture of actual supply chain outcomes than any other source (Pettersson & Segerstedt 2013). Therefore, knowing the actual cost structure of supply chain operations is imperative in developing effective cost minimisation strategies.

Since cost minimisation is widely used as an optimisation objective in the supply chain (Snyder & Shen 2011), it is vital to identify how different supply chain members determine their cost values. In this context, cost measurement plays an essential role, with accounting methods and accounting information driving cost measurement outcomes in an organisation. Accounting information plays a vital role in operations management as it affects decision-making aspects such as inventory management, cost of sales, management of materials, work in process, and finished products (Horngren et al. 2014). Therefore, e-commerce supply chain organisations must identify appropriate accounting methods to demonstrate accurate and transparent

financial information. This affects operational decisions and strategic outcomes, as the correct information is the most influential asset of online supply chains.

Cost concepts have significant game theory and contract theory implications for strategy formulation, information revelation, cooperation, and contract design, as cost management relates to the strategic decisions of firms (Perloff 2014). While cost minimisation has been well studied, no attempt has been made to determine how these costs are measured when effective strategic interactions are formulated using supply chain contracts. A detailed explanation of cost measurement and its impact based on accounting methods is provided in Chapter 5.

2.10 Disruptive Technology Adaptation on Designing Optimal Supply Chains

Supply chain organisations invest huge sums of money in technological developments such as Enterprise Resource Planning (ERP) systems, network software development and artificial intelligence (Bidar & Islam 2020). Among these technological advancements, disruptive technologies are rapidly transforming business operations around the world due to their impact on traditional processes. These technological advancements have resulted in the creation of different innovative platforms that have re-defined the supply chain and logistics operations. Advanced digitalisation of supply chains provides support in facing uncertainties and changes in trade operations, as well as impacting policies around the world (Saenz 2020). Within this context, digital operational platforms combined with artificial intelligence are gradually replacing traditional ERP systems in the present world (Herbert 2019). Blockchain technology is one of the most popular of these innovative technologies and is gradually being adopted by supply chains. It is expected to be part of mainstream business operations by 2025, changing the operational landscape of supply chains worldwide (Moore 2018).

Blockchain acts as a distributed ledger, which holds all information about transactions that occurred within the supply chain, in a chain of blocks operated in a decentralised setting (Dolgui et al. 2019). It enables a higher level of transparency and traceability of the data circulation within the supply chain. As the information in each block is verified with a consensus mechanism, the information cannot be altered and, therefore, the blockchain is immutable from external parties (Subramanian 2017).

As blockchain technology showcases solutions for effectively handling information and improving operational efficiency (Liu & Li 2019; Nakasumi 2017), it is crucial to evaluate the

impact of blockchain implementation for e-commerce supply chains. Blockchain can improve real-time data communication, reduce operational costs (e.g., production and inventory costs), enhance trust among the partners, generate faster and low-cost transactions, reduce lead times and minimise bottlenecks (Bai & Sarkis 2020; Saberi, S et al. 2019). Thus far, blockchain is not a widely applied concept among supply chain organisations worldwide. However, several renowned organisations have adopted this technology to streamline their operations, such as Maersk, Amazon, Walmart and Nestle (Kshetri 2018). Toyota has implemented blockchain into its supply chain to enable real-time information sharing among manufacturers, factories, suppliers, and service providers to reduce recall rates, unauthentic products and to increase customer security (Kshetri & Loukoianova 2019). Also, major Chinese online retail giants such as Alibaba and JD.com have implemented blockchain into their operational systems (Fuzamei 2018).

Subramanian (2017) describes the main characteristics that a blockchain system offers, such as distributed storage and listing, transactional validity, anonymity, improved levels of privacy, traceability and immediacy, all of which are extremely useful for electronic marketplaces. The decentralisation aspect of blockchain systems enables small/medium scale e-commerce operators to improve their operational trustworthiness. Also, blockchain generates secure and transparent payment schemes with digital currencies while eliminating consumer disputes in online purchases (Fuzamei 2018). Therefore, e-commerce operations could gain significant benefits from blockchain systems within their supply chains. However, despite the fact that there is a collective interest in studying the impact of blockchains, limited research has been done in relation to integrating e-commerce supply chain operations and blockchain implementations.

2.10.1 Blockchain Concepts

Blockchain concepts were first introduced with cryptocurrency concepts in 2008 by Satoshi Nakamoto to establish an electronic money trading system (Liu & Li 2019). Blockchain systems concentrate all data into individual blocks and stores them in all computers logged into the system, thereby creating a sequence of transactions based on data in each block (Tönnissen & Teuteberg 2019).

Blockchain implementation is becoming a widely discussed topic among academics. Blockchain is defined as the fifth evolution in the field of computer science and is recognised as the trust layer of the internet (Laurence 2017). The literature related to blockchain systems

is disseminated across multiple disciplines, and this study focuses on analysing blockchain implementation related to supply chain management. Keyword combinations such as “Blockchain” and “Supply Chain”, “Blockchain” and “E-commerce”, “Blockchain” and “Smart contracts”, and “Blockchain” and “Consensus mechanism” were used in the Web of Science, Science Direct, Springer and IEEE databases to identify the relevant literature. Blockchain system attributes and key operational features relevant to blockchain system implementation are discussed in Chapter 6. The next section summarises the analysis of blockchain implemented supply chain modelling studies.

2.10.2 Application of Blockchain in Supply Chain Management

Technology has become a key attribute in eliminating supply chain inefficiencies, and researchers have begun looking into the application of blockchain systems to improve supply chain management (Bai & Sarkis 2020). The key benefits of blockchain applications have been identified as traceability, transparency and trust issues in information sharing, improving supply chain efficiency through designing smart contracts and reducing supply chain operational costs. It also provides improved benefits for supply chain coordination and strategic decision-making issues (Bidar & Islam 2020).

Despite the growing interest in blockchain applications in supply chain management, studies that consider efficiency improvements and cost reductions in this field are scant. Several studies have incorporated smart contract-based modelling in improving operational efficiency, as smart contracts facilitate the blockchain implementation within supply chains (Manupati et al. 2020). Algorithm-based analysis is the leading solution approach in these studies. A few studies have considered modelling approaches in e-commerce supply chains (Li, Shen & Huang 2019; Liu & Li 2019; Yang et al. 2019). Chang et al. (2018) considered the degree of blockchain implementation in relation to the information sharing level and blockchain set-up costs to study how blockchain implementation can improve the supply chain operations and profit maximisation. However, this study did not consider how blockchain system improves the total costs of the online retail industry or analysed the the impact of blockchain implementation on an online supply chain setting. Therefore, further exploration into developing models using blockchain adaptation is timely to improve online supply chain performances.

Table 2.8 Analysis of mathematical model developments based on blockchain systems in supply chains

Authors	Area of focus	Model development	Solution approach	Type of blockchain	Smart contracts	Blockchain costs/information	Main findings for supply chain improvement
Bai and Sarkis (2020)	Transparency	Blockchain integration appraisal model for sustainable supply chain operations	Hesitant fuzzy sets and regret theory-based sensitivity analysis	-	No	Transparency level associated with blockchain implementation	A framework for decision-makers to understand regret and rejoice levels of selecting a most suitable blockchain system
Hayrutdinov, Saeed and Rajapov (2020)	Supply chain coordination	Contractual models based on information sharing effort of the blockchain system	Analytical solutions for supply chain coordination	-	No	Blockchain investment cost/effort	Information sharing effort under the blockchain system improves the supply chain profit
Kamble, Gunasekaran and Sharma (2020)	Relationships between blockchain enablers in the agriculture supply chain	A model developed to determine the critical blockchain enablers of agriculture supply chain	Interpretive Structural Modelling (ISM) and decision-making trial and evaluation laboratory	-	No	Blockchain enablers	The most significant blockchain enabler is traceability for agriculture supply chain, which will help to define strategies for real-time data
Manupati et al. (2020)	Supply chain greening costs	Blockchain-based smart contract to trigger carbon emission costs to supply chain optimisation	Mixed-Integer Nonlinear Programming (MINLP) Model	Consortium	Yes	Supply chain greening costs	The blockchain-based system triggers the high greening costs and improves the performance with reducing costs
Wang, Z et al. (2020)	Traceability and information sharing	Blockchain-based framework in precast construction with smart contract implementation	Smart contract algorithms	Consortium	Yes	Order, production, transportation, delivery costs	Reduction of supply chain costs with improved information sharing
Dolgui et al. (2019)	Supply Chain Scheduling	Blockchain oriented Smart contract for multi-processor flexible flow shop scheduling	Algorithm development, optimal control and discrete optimisation	-	Yes	Order delivery times and costs of the delivery volume	Development of fully flexible flow shop scheduling using blockchain-based smart contract
Liu and Li (2019)	Product Traceability	Multi-chain structure model for blockchain system design of cross border e-commerce operation	Algorithm-based solutions using Deterministic Hierarchical Wallet technique	Decentralised blockchain	No	The multi-chain data structure of information shared via blockchain	Improving trust but challenging to implement a single system for a cross border operation.
Longo et al. (2019)	Information sharing and trust	Supply chain simulation model using a discrete event-based approach	Software connector based on Java	Public	No	Transaction costs	Blockchain-enabled information sharing improves the supply chain cost and revenue

Chang et al. (2018)	Supply chain design and operations	Mathematical model using optimal control to design an optimal supply chain design with blockchain	Analytical solutions with numerical testing	-	No	Degree of blockchain implementation, blockchain setup cost	Blockchain implementation, which improves the information sharing, reduces order quantity levels, inventory levels and target pricing. It also concludes that enabling blockchain at earlier stages of the product life cycle is more beneficial.

2.11 Limitations and Gaps in the Existing Literature

This chapter has outlined an in-depth analysis of e-commerce supply chain modelling studies, game theory-based modelling, contract modelling, as well as blockchain adopted models in the extant literature in the field of supply chain management. As noted above, game theory-based contract modelling approaches have been analysed extensively by previous researchers. However, there are several areas in which that literature is insufficient and, accordingly, this study focuses on addressing these research gaps and augmenting knowledge in the supply chain literature.

E-commerce supply chain related issues have been given wide attention, with game theory approaches are considered as the principal methodology adopted in a considerable amount of literature focused on optimal supply chain outcomes, optimal operational strategies and supply chain coordination. However, small/medium-scale e-commerce operational settings are not so well addressed in the literature, despite the huge global demand for online sales that is creating growing opportunities for new business ventures in the online retail market. Addressing this gap, this study proposes an optimal operational strategy for small/medium-scale online e-tailer supply chains.

Even though game theory-based modelling is studied extensively, studies related to multi-player or multi-stage supply chain operations are limited (Yue & You 2014). This is also the case in the supply chain contract literature. Since actual e-commerce supply chain operations comprise multi-stages/players, this research will augment knowledge by considering the impact of decision-making issues on multi-stage/multi-player supply chain operations.

Furthermore, the previous literature suggests that no adequate contract modelling has been found in relation to sharing contract formulations when asymmetric information exists (Shen, Choi & Minner 2018). Accurate information is a vital asset in online supply chains, as they depend more on information than physical assets. Hence, investigating how an effective contract can be designed to eliminate the adverse effect of asymmetric information will enhance knowledge in the literature. The impact of operational constraints on supply chain contract modelling has generally been ignored in previous works needs to be explored to provide realistic evidence related to supply chain operations, which will be addressed in this study.

Moreover, the extant literature provides little evidence related to multi-period contracts in supply chain operations (Gao 2015). Studies on the impact of asymmetric information within dynamic operational supply chain settings are even scarcer, thus creating a further opportunity to explore in that area and enhance knowledge. The re-negotiation of contract models in long-term operations, which connects with the dynamic stability of contract outcomes and effective long-term partnerships, are the least explored in the supply chain literature. Hence, more studies are required to address this gap in the literature, especially related to small/medium scale or start-up business ventures, as these supply chains need to expand their operational networks with successful integration.

While researchers in the accounting field have continuously debated the selection of suitable accounting methods in firms, no study has been found that analyses the impact of using these methods to measure costs within a supply chain contract framework. As adopting appropriate accounting methods can result in the production of accurate information in supply chain organisations, it is necessary to examine the accounting methods that create better supply chain outcomes for contracts within asymmetric information.

Technological advancements derived through disruptive technologies also create a significant impact on optimising supply chain outcomes. The literature related to such technological advancements on supply chain management is evolving. As blockchain technology inherently constitutes effective operational outcomes mainly relating to effective costs, information sharing, eliminating asymmetric information and effective integration, the impact of blockchain implementation on e-commerce supply chain operations needs substantial attention. This study addresses this research gap and adds new knowledge on how to use blockchain systems to optimise e-commerce supply chain outcomes by improving information sharing and minimising costs.

2.12 Conclusion

This chapter has critically reviewed the literature related to e-commerce supply chain operations in terms of modelling and optimisation, with the methodology taken as a key determinant in the analysis. Game theory models have been analysed extensively, revealing that coordination contracts are frequently combined with optimal supply chain strategies in the literature. Numerous supply contract models have been reviewed to identify areas that require more attention and are appropriate for eliminating issues of asymmetric information, ineffective supply chain costs and integration. Consequently, asymmetric information related

contract modelling was examined further as it is more relevant to online operations. Multi-period and dynamic contract modelling concepts were also discussed in detail, with the limitations and gaps in the literature identified to explain the motivation for conducting this study in designing optimal e-commerce supply chain operations. The impact of cost measurement in supply chain contracts was also discussed in terms of identifying the present gaps in the supply chain literature. Finally, a review was carried out in relation to the blockchain adopted modelling research in the supply chain literature to determine how it might improve e-commerce supply chain performance by eliminating issues of information sharing, integration and ineffective costs.

From the next chapter onwards, the research objectives are discussed using an optimisation modelling approach. Chapter 3 focuses on formulating an effective cost-sharing contract model to optimise e-tailer supply chain costs while eliminating asymmetric cost information.

CHAPTER 3 : THE BASE COST-SHARING CONTRACT MODEL FOR OPTIMAL E-COMMERCE SUPPLY CHAIN OPERATIONS

3.1 Introduction

In Chapter 2, the literature gaps and limitations in the extant research were identified. The literature review disclosed that game theory-based contract modelling is widely used as an effective approach in addressing strategic decision issues in supply chains. This study also adopted this approach, seeking to address the first research objective by designing an effective contract model for an e-commerce supply chain operation in this chapter. The model was designed to address the strategic issues of ineffective costs, information asymmetry and coordination. As the literature revealed, less attention is given to multi-player/multi-echelon contract models and formulating sharing contracts. Hence, as previously noted, this study addresses this research limitation and focuses on developing a sharing contract within the asymmetric information setting in e-commerce supply chain operations. From this chapter onwards, the mathematical models developed to achieve each research objectives of the study are discussed.

The remainder of this chapter is organised as follows. Firstly, this chapter elaborates on contract models developed in multi-player/multi-echelon settings, followed by a discussion on cost-sharing contract models in the supply chain literature related to this study. Section 3.3 discusses the operational context of the e-tailer supply chain, and Section 3.4 explains the problem identified in the given operational setting. The model formulation is presented in Section 3.5. Then, Section 3.6 discusses the solution approach and Section 3.7 describes the numerical analysis for the base model. In Section 3.8, the base contract model is extended to assess the optimal cost-sharing levels and model validity. Key findings are discussed in Section 3.9, and Section 3.10 concludes the chapter.

3.2 Previous Studies Related to Multi-Echelon and Sharing Contracts

3.2.1 Multi-Echelon Contract Models

The contract literature showcased several studies that have adopted multi-player/multi-echelon contract models in supply chains, although less research is available in this context compared to studies of two-stage or two-player models. Therefore, in this section, the contract models

with multi-echelon/multi-players are discussed in detail to obtain insights for the model formulation of this research.

Song and He (2019) developed contract models for a fresh agricultural product supply chain. This supply chain operated via an online platform with a fresh produce e-commerce enterprise, a 3PL service provider, and the community convenience store. A cost-sharing contract was developed to share the freshness keeping costs of the 3PL service provider jointly. In addition, a revenue-sharing contract was formulated to share the revenue of the e-commerce enterprise with the 3PL service provider and the community convenience store, to coordinate the supply chain performance. Zhong et al. (2019) developed a revenue-sharing contract model for e-commerce service supply chains to derive a cooperative distribution strategy. A two-player model between the e-commerce mall and the 3PL service provider was developed in the first phase and then extended to a model between the e-commerce mall, express delivery companies and the terminal distributors. The authors compared decentralised and centralised operational settings in both two-stage and three-stage supply chain operations. Their findings prove that a revenue-sharing model with a profit distribution ratio coordinates the supply chain for all three players.

Hu et al. (2016) proposed revenue-sharing contracts for a three-player supply chain in which the manufacturer presented the contract to the distributor, and the distributor offered a contract to the retailer. This contract included a revenue-sharing fraction and wholesale prices. The operational decisions of ordering quantity and manufacturing quantity were made based on the outcomes of the contract in this study, with the objective being supply chain coordination. Modak, Panda and Sana (2016) also considered a three-stage supply chain, which included a manufacturer, distributors and duopolistic retailers. The authors studied supply chain coordination in the Cournot, Collusion and Stackelberg behaviours of retailers. They applied a decentralised setting with no coordination and supply chain coordination by using a quantity discount with franchise fee contracts. The contracts developed in the study of Modak, Panda and Sana (2016) are similar to those offered by Hu et al. (2016), but they developed a joint contract model through their use of both quantity discounts and franchise fee contracts. The findings of their study reveal that quantity discounts with franchise fees deliver supply chain coordination, although it did not provide win-win outcomes for all players of the game.

Jiang, Wang and Liu (2016) formulated a centralised cost-sharing mechanism for a three-echelon supply chain, including a manufacturer, 3PL operator and retailer. The cost-sharing

mechanism focused on the logistics costs of the supply chain. It was applied to increase profit generation across the overall supply chain while motivating the 3PL operators to improve their service levels and achieve efficient coordination. Wang (2013) developed a wholesale price contract with transfer pricing, a revenue-sharing contract and a quantity flexibility contract in an e-commerce service supply chain to achieve coordination. The outcomes of these contracts prove that all contract models could be incorporated to derive optimal supply chain benefits.

Van Der Rhee et al. (2010) developed a revenue-sharing contract for a multi-echelon single-period supply chain, in which a single contract was negotiated for all parties in the supply chain to sign. This method is known as a spanning contract, with the most downstream player initiating the contract along with revenue-sharing. Shou-feng, Ming-jia and Li-jiao (2007) discussed supply chain coordination based on a revenue-sharing contract for a three-echelon supply chain with a single player at each level. This study used a pair-wise contract approach in which a portion of an adjacent player's revenue is shared in designing the contract approach. Finally, Long-ying, Yong-qi and Zhang-sheng (2007) studied supply chain coordination in a three-echelon supply chain using a revenue-sharing contract.

All the above-described studies mainly used revenue-sharing contracts. A couple of studies developed cost-sharing, as well as quantity discount contracts to obtain supply chain coordination. Therefore, these studies further underline that the use of sharing contracts is more suitable for multi-player models. However, no study described above incorporated asymmetric information settings and analysed its impact on supply chain coordination when multiple players are included. This is a crucial aspect of e-commerce supply chain operations and addressed in this chapter.

3.2.2 Cost-Sharing Contract Models

As previously mentioned, when asymmetric information exists, which is often the case in online operations, contract model development requires a different approach. Since there is limited research in the supply chain literature on sharing contracts within asymmetric information settings, this study sought to identify what type of sharing contract should be developed. According to the previous literature, revenue-sharing is the most common contract type among the sharing contracts. However, there are several other sharing contract types, such as cost-sharing, profit-sharing, and risk-sharing. As this study is focused on a small scale/start-up online retailing supply chains, cost optimisation is a critical consideration. When the main

focus of a supply chain is cost, a cost-sharing contract is formulated, as also used in several other studies (Ghosh & Shah 2015).

As discussed in Chapter 2, cost-sharing contracts have been researched by numerous supply chain scholars. In this chapter, it is necessary to analyse how the sharing has been defined in these studies and how this affects optimal supply chain outcomes.

Shu, Qu and Wu (2020) studied supply chain coordination using cost-sharing and revenue-sharing contracts developed for e-tailer supply chains. The authors considered a typical e-tailer supply chain model to generate an optimal strategy in coordinating between retailing price and logistics service quality. The cost-sharing contract was formed between the manufacturer and e-tailer, with the manufacturer paying a portion of the freight costs. The findings of this study reveal that a cost-sharing contract alone cannot coordinate the supply chain, and hence, revenue-sharing was incorporated to achieve coordination. Wang, Y et al. (2020a) designed a cost-sharing joint commission contract for a green e-commerce platform supply chain. These authors proposed cost-sharing to achieve supply chain coordination, with the e-platform adjusting the commission given to the manufacturer based on the service cost. The cost-sharing contract designed in this study coordinated the supply chain and increased the manufacturer's profit when the cost-sharing increased.

Xu, Zhang and He (2020) described a delivery cost-sharing contract for a dual-channel supply chain with an online platform. In this approach, the platform shared a fraction of its delivery cost apart for the commission paid as the contract. The proposed delivery cost-sharing contract delivered better coordination levels than the wholesale price contract, and the online platform's power was a key determinant of the level of coordination. Xu, Fu and Fan (2020) also studied a supply chain coordination strategy within an O2O supply chain in which online and offline stores shared their services to achieve cooperation. This study proposed that the brand supplier shares a portion of the service sharing cost of the franchisee's offline store. The results indicated that a service cost-sharing contract alone could not coordinate the supply chain in the franchise mode of O2O operations perfectly, but it did derive Pareto improvement. Zhou, Guo and Zhou (2018) also discussed service cost-sharing contracts in a dual-channel supply chain in which the manufacturer shared the retailer's service effort cost by free-riding the retailer's pre-sales services. In this scenario, the service cost-sharing did coordinate the supply chain, in contrast to the findings of Xu, Fu and Fan (2020).

As outlined earlier, Song and He (2019) designed a freshness keeping cost-sharing contract for a three-player fresh supply chain selling via an e-commerce channel to achieve supply chain coordination. This study concluded that cost-sharing alone could not achieve coordination perfectly, but by combining revenue-sharing and cost-sharing, the supply chain can be coordinated. Wang, Yu and Jin (2019) analysed small scale e-tailer supply chain operations with capital constraints to derive an optimal operating strategy. These authors considered service cost-sharing or a loan strategy to eliminate the impact of capital constraints and improve service quality. The service cost-sharing with the manufacturer improved the profit maximisation of the platform and thereby improved service quality. In this scenario, the manufacturer determined the cost-sharing ratio. Raj, Biswas and Srivastava (2018) discussed sharing greening investment costs in sustainable supply chains. Their findings suggest that to achieve a win-win outcome, the buyer can only share up to 20% of the supplier's greening costs. Taleizadeh and Rabie (2018) analysed profit maximisation using quantity discount and cost-sharing contract models for a two-echelon green supply chain. The cost-sharing contract was developed between manufacturer and retailer, with the retailer sharing a fraction of the greening costs and expecting the manufacturer to sell products with a lower wholesale price. Cost-sharing contracts were shown to increase profits more than quantity discount contracts in that study.

Jiang, Wang and Liu (2016) designed a logistics cost-sharing contract for a three-level supply chain to improve the benefits of the 3PL service provider using both centralised and decentralised scenarios. The cost-sharing portions were determined by both manufacturer and retailer in decentralised and centralised settings to improve the logistics service level. The authors found that the centralised cost-sharing coordinates the supply chain perfectly as it collectively improves the profits of the chain. Ghosh and Shah (2015) discussed a cost-sharing contract in a retailer-manufacturer supply chain to determine the strategic impact of cost-sharing on choosing greening initiatives. The contract findings indicate that when the greening cost is higher, the sharing fraction is lower, and when the greening costs are lower, the sharing fraction is higher. On the other hand, when the customer's sensitivity to the greening product is high, the cost-sharing also increases. This study also emphasises that a cost-sharing contract is highly beneficial to the overall supply chain. Kaya and Caner (2018) proposed cost-sharing contract models in which the manufacturer shares a portion of the supplier's capacity investment cost and, based on that, offers a wholesale price for the supplier. These authors suggested that a cost-sharing contract within the context of information asymmetry provides

the best optimal solution for supply chain operations when implemented for capacity investment costs and when compared to revenue-sharing and wholesale price contracts.

Among all these studies, Kaya and Caner (2018) is the only one that considered asymmetric information within the supply chain. All others conducted their analysis based on the assumption of symmetric information. Most of these studies focused on two-player models. Hence, it is important to analyse how decision-making based on supply chain contracts affects multi-level supply chain settings. The literature discloses that sharing a portion of a specific cost is the primary approach of cost-sharing contracts, similar to the approach of revenue-sharing described by Cachon (2003). However, in cost-sharing contracts, the type of costs is diverse, including investment costs, greening costs, service costs, logistics costs, commission costs, among others. Therefore, a wider range of cost-sharing contracts is defined in the supply chain literature. In small/medium scale or start-up e-tailer operations, having effective supply chain costs is a major factor as it determines the survival of the business even when in a highly competitive market. Therefore, giving focus to operational costs is most important in this setting. In addition, operational constraints need to be incorporated in supply chain operations to determine the impact of constrained operations, as it is more relevant to actual operations. However, among the cost-sharing contract models studied, operational constraints and their impact have not been included in model formulation. This limitation is addressed in this study. In online operations, information sharing plays a vital role, and hence, it is unrealistic to ignore asymmetric information issues. Generally, these supply chain members operate in decentralised as well as distant settings, without any physical interaction. Therefore, they rely on accurate information. Based on these justifications, this research considers the elimination of asymmetric information with cost-sharing.

3.2.3 Eliminating Asymmetric Information with Screening Contracts

Incomplete information can be found in both upstream and downstream of a supply chain such as production cost, production forecast, customer's demand and buyer's cost structure (Lei et al. 2015). The review in Chapter 2 disclosed that the screening contracts and revelation principle are the most suitable approach in handling asymmetric information scenarios in contract modelling. Within that context, the menu of contracts is widely used to address the information asymmetry issues in those studies (Wang et al. 2018). The discrete probabilistic approach is adopted in several studies to showcase the information asymmetry considering high and low probabilities (Cao et al. 2013; Chen et al. 2017; Zissis, Ioannou & Burnetas 2015).

The cost-sharing model developed by Kaya and Caner (2018) has considered a screening contract approach where a menu of contract is presented to enable true cost revelation constrained with incentive compatibility and individual rationality constraints.

Hence, this study has utilised a similar approach in illustrating the information asymmetry issues for the upstream and downstream players. The model proposed in this study included production and distribution costs as the hidden cost information of the respective player, an approach that has not been adopted in any other studies. Moreover, existing studies have designed contract menus as directly proportionate to the costs and quantities (e.g., when a player has higher costs, the menu comprises higher wholesale prices and higher quantities). However, this study examines a different contract menu to analyse the impact of eliminating asymmetric information and proposes an inversely proportionate menu of contract. Based on these facts, a cost-sharing contract approach was adopted to address asymmetric information issues and create strategies to optimise costs and effective supply chain integration.

3.3 Operational Context of the E-tailer Supply Chain

In this study, a small/medium scale or start-up B2C e-tailer supply chain is considered as the operational context. As previously mentioned, several operational structures are available in online retailing, including the e-tailer as the merchant, the e-tailer as a platform through which transaction fees are paid for using the platform, and third party re-selling models. However, for start-up or small-scale operations, the most common structure in the real-world is the e-tailer operating as the merchant (Pi & Wang 2020), as it requires less capital investment, is easy to operate and has higher market demand. Therefore, this study considers the operational setting of the e-tailer as the merchant. It is also known as the re-selling model and is illustrated in Figure 3.1. The typical e-tailer (re-seller) supply chain consists of a three-stage structure, which was illustrated in Figure 2.2 in Chapter 2. Therefore, the e-tailer supply chain considered in this study also includes three-level supply chain structure with a product supplier, e-tailer and 3PL operator at each level.

As mentioned in Chapter 1, Kapruka, Booktopia and SHOWPO are some examples of e-tailers that follow the operational model shown in Figure 3.1. All these e-tailers have three-stage supply chain structures, including product suppliers and 3PL operators, and act as pure e-tailers. They sell products using an online marketplace with an added profit margin through their supply chain. These e-tailers purchase products from relevant product suppliers, store them in their distribution centres and deliver them directly to their customer's doorstep using

3PL operators. Therefore, the operational context described in this research is related directly to actual e-tailer operations in the real world.

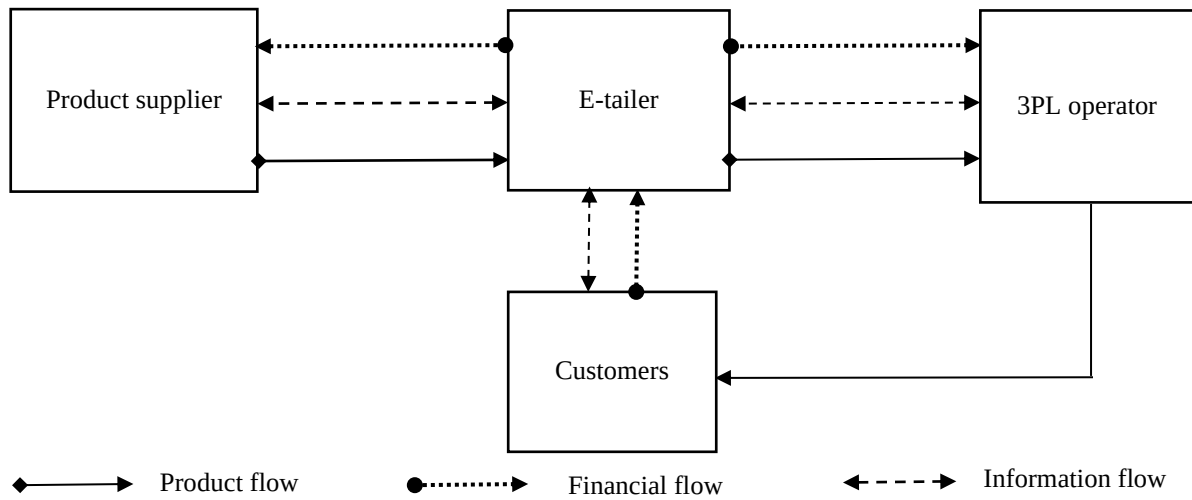


Figure 3.1 E-commerce supply chain flow and links

Figure 3.1 shows the flows and links of the e-tailer supply chain considered in this study. First, the e-tailer (he) receives a demand from the customer, and then he orders the relevant goods from the product supplier. When the product supplier offers the relevant quantity, the 3PL operator transfers the goods to the customer.

In online retailing, the distribution of physical products to the customer is the most crucial aspect, with 3PL services used extensively to fulfil the distribution operations (Shu, Qu & Wu 2020). 3PL operators such as DHL, UPS and FedEx carry out large scale and successful worldwide logistics operations (Xu et al. 2014). E-commerce supply chains are collaborative operations, as product suppliers, 3PL operators and customers collaborate with e-service providers/e-tailers, making this operation distinct from traditional retail supply chain operations (Wang et al. 2015). The proposed model in this study assumes that the 3PL operator only distributes the product to the customer's doorstep, and hence, no inventory is maintained with the player. In a traditional brick and mortar business, 3PL distribution to the customer is not involved, and hence, the cost of distribution to the final customer is not considered. In the e-tailer supply chain, the product price includes the supplier's product cost plus the 3PL operator's service cost.

Ensuring no stock-out situations is essential in any supply chain operation and in the operational scenario of this study, it is assumed that both the e-tailer and the product supplier maintain inventory at their warehouses. Indeed, it is a typical practice of e-commerce supply chains that e-tailers maintain inventory in their warehouses (Dutta et al. 2020). Maintaining

inventory not only prevents stock-out situations, but it also minimises late deliveries, incorrect item deliveries, and growing levels of customer dissatisfaction (Zhao & Cao 2004). In addition, due to severe competition in the online retail markets, customers have numerous options to buy substitute products. Therefore, stock-out situations can adversely affect start-up/small-scale operations as they can reduce sales and lose customers.

3.4 Problem Description

The e-commerce supply chain operation considered in this study is decentralised as each entity (the product supplier, the e-tailer, and the 3PL operator) operates as an individual organisation making its own decisions. Therefore, these players operate competitively, working to minimise their own costs rather than those of the overall supply chain. It potentially creates conflicts of interests among the players in the supply chain, as each player may want a different outcome. Therefore, optimal operational outcomes cannot be guaranteed for the overall supply chain; instead, this decentralised operation may generate sub-optimal solutions. However, to achieve benefits for the overall e-commerce supply chain, each player must work collaboratively with the others and must share a common objective. Therefore, effective vertical integration through successful collaboration and coordination is required among these players to minimise supply chain costs and achieve a higher market share (Kogan & Tapiero 2007), as it is crucial to achieving better operational performances (Gharakhani & Esfahani 2016; Liu, Shang & Lai 2015; Nagarajan & Sošić 2008).

Furthermore, as e-commerce operations are carried out based on information, without physical interactions among the players, each party may not be aware of the actual information of the other parties. Therefore, this operation includes asymmetric information. In this context, the e-tailer is both the main link, as well as the least informed party when considering the internal costs of each player. However, the e-tailer requires correct information to transfer funds and products to the customer, product supplier, and the 3PL operator (see Figure 3.1). As such, asymmetric information needs to be eliminated to generate accurate information sharing across the supply chain.

3.5 Model Description and Formulation

3.5.1 Overview of the Game Model

Considering these issues, all players need to create a common objective to achieve a higher market share and a competitive operating position through the minimisation of overall costs in

the e-tailer supply chain. Therefore, the coalitions of the cooperative game model are formulated in this study. In a cooperative game model, binding agreements should be developed to align the interests of players (Perloff 2014). Furthermore, it is necessary that these binding agreements should deliver a large payoff to every party included in the game (Ferguson 2014). Therefore, the strategic output of the game in this study is to create optimal outcomes for the supply chain operations through cost minimisation; the mechanism to achieve this objective is an effective cost-sharing contract. This game is developed for multi-period operations, also including operational constraints. Accordingly, all individual players who participate in this contract are expected to adhere to the common coalition formed, not focus solely on maximising their own benefits (Fiestras-Janeiro et al. 2011). The contract originates from the e-tailer, as the less-informed party, who proposes to share a fraction of the operational costs of both the product supplier and the 3PL operator to create a binding agreement and ultimately minimise the overall supply chain costs.

3.5.2 Notations of the Proposed Model

Table 3.1 Notations and descriptions of sets, indexes, parameters and decision variables

Notation	Description
Sets and indexes	
i	Time period (1,2,3.....n)
j	Players (1: product supplier, 2: e-tailer, 3: 3PL operator)
Parameters	
UC_i	The unit cost of production of supplier for the period i
α_i	Percentage increment/decrement of inventory holding cost of product supplier in the period i
HC_i	The unit cost of holding inventory at the e-tailer in period i
DC_i	The unit cost of distribution at the 3PL operator in period i
D_i	Customer demand in the period i
II_j	Initial Inventory of player j
W_{capj}	Maximum capacity of the warehouse of player j
M_{cap}	Maximum capacity of manufacturing of the product supplier
θ	Probability of occurring higher operational costs with the product supplier
γ	Probability of occurring higher operational costs with the 3PL operator
W_j	Weight allocation of player j
$P_{i,j}$	The fixed unit price paid by the e-tailer to the player j ; $j \neq 2$ in each period i
$k_j^{\%}$	The fraction of cost-sharing in % for player j ; ($j \neq 2$)
Decision variables	
q_i	Unit quantity produced by the supplier in the period i
d_i	Units demanded by the e-tailer from the supplier in the period i
$s_{i,j}$	Inventory level of each period i of the player j
$SC_{i,j}$	Shared costs by the e-tailer of the other players j
Other variables	
c_j	Individual total costs of the player j

3.5.3 Contract Approach

3.5.3.1 Menu of Contracts for Cost-sharing

The contract was developed using discrete probabilities to indicate the information asymmetry and adopting a screening contract approach along with the revelation principle to reveal the true costs of the players (Cachon 2003; Cao et al. 2013; Zissis, Ioannou & Burnetas 2015). The cost-sharing aspect of this contract is derived considering the asymmetric costs of the product supplier and the 3PL operator, as explained below.

In this contract, the e-tailer expects that the product supplier has high and low unit production costs as denoted with $\overline{UC}$ and $\underline{UC}$ which occur with a probability of θ and $1 - \theta$, respectively. Similarly, for the 3PL operator, the high and low unit distribution costs occur as $\overline{DC}$ and $\underline{DC}$ with the probability γ and $1 - \gamma$, respectively. Therefore, the e-tailer assumes that the costs of the product supplier and the 3PL operator have two distribution values and, accordingly, present the contract elements for both parties. The e-tailer proposes to share a fraction of the operational costs of the product supplier and the 3PL operator to minimise the total supply chain cost. Therefore, the e-tailer offers two contract options based on the probability of costs: $\{\overline{sc_{i,j}}, \underline{P_{i,j}}\}, \{\underline{sc_{i,j}}, \overline{P_{i,j}}\}$. This menu of contracts includes the sharing cost and the fixed unit price paid by the e-tailer to the product supplier and the 3PL operator. In this operational scenario, the unit price of the goods is determined by a two-part tariff that consists of a fixed fee and a variable fee, depending on the operational costs and demand. Therefore, the e-tailer incorporates a fixed unit fee, which has high and low values $\{\overline{P_{i,1}}, \underline{P_{i,1}}\}$ for the product supplier and $\{\overline{P_{i,3}}, \underline{P_{i,3}}\}$ for the 3PL operator.

When the e-tailer assumes higher operational cost probabilities for the other players, the e-tailer shares a lower fraction of other player's operational costs and vice versa, as the menu is designed inversely proportionate to the operational costs. Therefore, this study argues that sharing a lower proportion of operational costs when the e-tailer assumes higher operational costs with his upstream and downstream, encourages those players to minimise their operational costs. As such, when the e-tailer offers the contract to the product supplier, assuming that the product supplier has incurred a lower operational cost, the product supplier receives $\{\underline{sc_{i,1}}, \underline{P_{i,1}}\}$; while under the higher operational cost, the product supplier receives $\{\overline{sc_{i,1}}, \overline{P_{i,1}}\}$. Similarly, the 3PL operator receives two contract options from the e-tailer for low and high operational cost scenarios respectively: $\{\underline{sc_{i,3}}, \underline{P_{i,3}}\}, \{\overline{sc_{i,3}}, \overline{P_{i,3}}\}$.

3.5.3.2 The Sequence of the Contract

The sequence of the contract is given as follows. First, the e-tailer proposes the menu of contracts to the product supplier, then the product supplier selects the right menu and rejects the remaining menu. If the supplier rejects both menus, the contract is terminated. In this context, the e-tailer must present the contract to another potential supplier. However, if the product supplier selects the menu according to their operational cost levels, the correct

information is revealed to the e-tailer, and the contract is executed. Products are then delivered to the e-tailer's warehouse. Next, the e-tailer proposes the contract menu to the 3PL operator to deliver the products to the customers. The 3PL operator either rejects both menus or selects the correct menu of contract, rejecting the remaining. Subsequently, the actual operational costs are revealed to the e-tailer, and the cost-sharing contract is executed. Therefore, when the e-tailer proposes the contract to either player, he receives a signal about each player's accurate operational costs, and information asymmetry issues are eliminated.

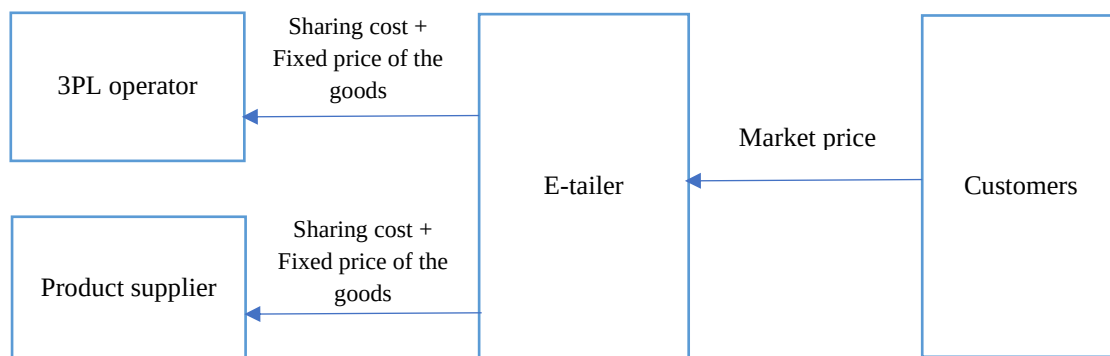


Figure 3.2 Financial flows of the e-tailer supply chain

The shared costs are then specified, and the cost-sharing boundaries are defined with the applicable incentive and participation constraints, enabling all parties to enforce the contract and resolve information asymmetry issues. Figure 3.2 illustrates the cash flow of the e-commerce supply chain model described in this study.

3.5.3.3 Summary of the Cost-sharing Contract

Based on the above described elements, the rules of the game and the contract adopted in this study are summarised as follows:

Players

Three players of the E-commerce Supply Chain: E-tailer; Product supplier; 3PL operator

Actions

In this cooperative game, players bind together with a cost-sharing contract.

1. The e-tailer's action is to offer contracts to both the product supplier and the 3PL operator and pay according to the selected action of both parties.
2. Both the product supplier and the 3PL operator have two actions and they select one action to either accept or reject the contract offered.

Order of the Play

1. The e-tailer initiates the contract at $t=1$ period by offering a cost-sharing contract to the product supplier and the 3PL operator, at which point the actual operational costs of either player are unobserved by the e-tailer. The contract is offered in the form of $(sc_{i,j}, P_{i,j})$, where $sc_{i,j}$ is the shared cost by the e-tailer with either the product supplier or the 3PL operator and the $P_{i,j}$ is the fixed unit price paid by the e-tailer to the product supplier or the 3PL operator.
2. The product supplier/3PL operator either accepts or rejects the contract.
3. If the product supplier/3PL operator rejects the contract, the game ends.
4. If the product supplier/3PL operator accepts the contract, they select the relevant menu of contract according to their actual operational costs, denoted as $\{\overline{sc_{i,j}}, \underline{P_{i,j}}\}, \{\underline{sc_{i,j}}, \overline{P_{i,j}}\}$.
5. According to the menu of contract selection, true costs are revealed, and the game starts.
6. The e-tailer places orders according to demand and inventory levels and then pays an output of either $\{\overline{sc_{i,j}}, \underline{P_{i,j}}\}, \{\underline{sc_{i,j}}, \overline{P_{i,j}}\}$ to the product supplier/3PL operator.

Payoffs

If the product supplier/3PL operator rejects the contract, $(sc_{i,j}, P_{i,j}) = 0$

If the product supplier/3PL operator accepts the contract,

- supplier's payoff is $UC_i \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) - sc_{i,1} - P_{i,1} \cdot d_i$
- 3PL operator's payoff is $[DC_i \cdot D_i - sc_{i,3} - P_{i,3} \cdot D_i]$
- E-tailer's payoff is $HC_i(s_{i,2} + s_{i-1,2}) / 2 + sc_{i,1} + P_{i,1} \cdot d_i + sc_{i,3} + P_{i,3} \cdot D_i$

(Payoffs differ as per the high and low-cost scenarios of the product supplier and 3PL operator but, the general payoffs can be elaborated as above).

3.5.4 Model Formulation

3.5.4.1 Assumptions

The proposed model was developed based on the following assumptions:

- i. The e-tailer supply chain has a single product (e.g., readymade garments, product accessories).
- ii. One product supplier and one 3PL operator are included in this model. While this is not common in actual operations, a small-scale e-tailer such as SHOWPO⁴ uses a single 3PL operator to manage its local operations in Sydney and another 3PL operator to handle USA orders. However, in contract modelling, this is a common assumption. Studies such as Shu, Qu and Wu (2020); Wang, Yu and Jin (2019) have also used a similar assumption when formulating contract models for online retail platforms.
- iii. The market is demand-driven and, hence, the e-tailer observes the demand before initiating the contract. This assumption is quite common in optimisation modelling studies (Dutta et al. 2020) and the contract literature (Mobini, van den Heuvel & Wagelmans 2019; Zissis, Ioannou & Burnetas 2015).
- iv. All players of the model are assumed to be rational decision-makers.

Further to the above assumptions, the selling price of this model is determined by the e-tailer based on the operational costs and the profit margin of the supply chain.

3.5.4.2 Modelling the Objective Function

In this model, the main aim was to create a cooperative decision-making approach among the supply chain members. Using this approach, decisions are made collectively by all participants of the contract to minimise the overall supply chain costs. Hence, the objective of this model is to minimise the overall cost of the e-commerce supply chain, consisting of the cost of the product supplier, e-tailer and 3PL operator. In supply chain operations, profit maximisation and cost minimisation are the two main objectives (Snyder & Shen 2011). In recent times, businesses have become more focused on finding strategies to minimise costs, which ultimately leads to profit maximisation. As the online retail market is highly competitive, increasing selling prices is not an appropriate strategy to improve supply chain profits, as the e-tailer needs to increase its market share by attracting more customers. For start-up/small-scale e-tailers,

⁴ <https://www.peoplevox.com/success-stories/showpo-warehouse-system-technology>

attracting more customers and increasing product sales are essential considerations and help guarantee long-term survival in the market. When supply chain costs are minimised, all supply chain partners, as well as the overall supply chain, benefit from minimal operational costs.

The findings of previous studies support this argument. For example, Kerkkamp, van den Heuvel and Wagelmans (2018); Wang, Guo and Efstathiou (2004); Zissis, Ioannou and Burnetas (2015) used cost minimisation as the supply chain objective in their respective models. Furthermore, Guo et al. (2017) highlighted the need for more attention to be given to developing contract models based on optimising supply chain costs in the contract literature, as this is a highly important but neglected area of research. Moreover, both Kerkkamp, van den Heuvel and Wagelmans (2018), and Zissis, Ioannou and Burnetas (2015) considered supply chain contracts within asymmetric information settings, adopting a menu of contracts to eliminate the impact of asymmetric information. This further justifies the selection of cost minimisation as the objective function of this study.

As discussed before, the product supplier, e-tailer and 3PL operator are individual organisations, who may focus more on their individual objectives than on overall supply chain costs, and hence, each supply chain partner has a conflicting objective. This situation provided the rationale for the adoption of cooperative game theory concepts in this study. In cooperative games, MOO is one solution approach, which enables Pareto-optimal solutions with a single decision-maker considering the interests of all players in the contract (Matsumoto & Szidarovszky 2016). This approach is also known as joint optimisation, with the weighted-sum method producing the optimal cooperative solution to the game (Cesar, Fandel & Trockel 1994). Previous studies, such as Kerkkamp, van den Heuvel and Wagelmans (2018), and Zamarripa et al. (2013), also used MOO solution approaches to develop optimal solutions in their contract and game models. Therefore, the objective function of the contract model is to minimise the overall costs of the e-tailer supply chain, which is formulated with weights allocated for each supply chain member's total individual costs, as below:

$$\text{Minimize } z = \sum_{\forall j} W_j \cdot (c_j) : \forall j \quad [3.1]$$

Here, z is the overall supply chain cost, and c_j is the individual total costs of the player for all players j .

(i) The individual cost objectives

$$c_1 = \sum_{\forall i} \left[\left(\theta(\overline{UC_i}) + (1-\theta)(\underline{UC_i}) \right) \cdot \left(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2 \right) - \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) \right. \\ \left. - \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \right] \quad [3.2]$$

$$c_2 = \sum_{\forall i} \left[HC_i(s_{i,2} + s_{i-1,2}) / 2 + \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) + \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \right. \\ \left. + \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) + \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \right] \quad [3.3]$$

$$c_3 = \sum_{\forall i} \left[\left(\gamma(\overline{DC_i}) + (1-\gamma)(\underline{DC_i}) \right) \cdot D_i - \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) \right. \\ \left. - \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \right] \quad [3.4]$$

Eq. (3.2) represents the total operational cost of the product supplier, which consists of the production and inventory holding cost of each period i with the sharing cost received from the e-tailer and the total fixed price paid by the e-tailer. Eq. (3.3) denotes the total operational cost of the e-tailer, which consists of the total inventory holding cost at the e-tailer's warehouse along with the cost-sharing and total fixed price paid to the supplier and the 3PL operator. Finally, the total cost of the 3PL operator is represented by Eq. (3.4), which includes the total distribution cost of the units demanded by the customer in each period i with the benefit received from the cost-sharing along with the total fixed price for the units distributed to the customer.

3.5.4.3 Constraints of the Model

The proposed contract model is subject to the following constraints. According to the screening contract approach, the contract models with asymmetric information include incentive compatibility and participation (individual rationality) constraints.

(ii) Incentive compatibility constraints

$$\overline{UC_i} \cdot q_i + \alpha_i \cdot \overline{UC_i} (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc_{i,1}} - \overline{P_{i,1}} \cdot d_i \geq \underline{UC_i} \cdot q_i + \alpha_i \cdot \underline{UC_i} (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc_{i,1}} - \underline{P_{i,1}} \cdot d_i \\ \forall_i, i > 1 \quad [3.5]$$

$$\underline{UC_i} \cdot q_i + \alpha_i \cdot \underline{UC_i} (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc_{i,1}} - \underline{P_{i,1}} \cdot d_i \geq \overline{UC_i} \cdot q_i + \alpha_i \cdot \overline{UC_i} (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc_{i,1}} - \overline{P_{i,1}} \cdot d_i \\ \forall_i, i > 1 \quad [3.6]$$

$$\overline{DC_i} \cdot D_i - \underline{sc_{i,3}} - \overline{P_{i,3}} \cdot D_i \geq \underline{DC_i} \cdot D_i - \overline{sc_{i,3}} - \underline{P_{i,3}} \cdot D_i : \forall_i \quad [3.7]$$

$$\underline{DC_i} \cdot D_i - \underline{sc_{i,3}} - \underline{P_{i,3}} \cdot D_i \geq \overline{DC_i} \cdot D_i - \overline{sc_{i,3}} - \overline{P_{i,3}} \cdot D_i : \forall_i \quad [3.8]$$

The incentive compatibility constraints guarantee that the product supplier and 3PL operator select the right menu of contracts and reveal true costs. Eq. (3.5) represents the incentive compatibility constraint for the product supplier. To select the right menu of contract, the total cost under a higher-cost state must be at least greater than the total cost under a lower-cost state. It motivates the product supplier to aim for maintaining lower operational costs. The incentive compatibility constraint represented in Eq. (3.6) ensures that the product supplier selects the correct menu of the contract. It is formulated as the total cost of the product supplier within the higher-cost state is equal or higher than the total cost under the lower-cost state, even if the product supplier receives a higher-cost share. Therefore, the supplier must select the right cost state to obtain the cost-sharing benefit from the contract. With this constraint, the product supplier does not receive a benefit by reporting lower costs when he has higher operational costs because the lower-cost state is less, even when the product supplier has a higher cost with a higher share. Similarly, Eq. (3.7) and Eq. (3.8) represent the incentive compatibility constraints for the 3PL operator. These constraints ensure that the 3PL operator selects the correct menu of contracts offered by the e-tailer and reveals their true costs. All these equations ensure that if the product supplier or the 3PL operator declares false or inaccurate costs when engaging in this contract, they do not receive better individual gains.

(iii) Individual rationality constraints

$$\overline{sc}_{i,1} \leq k_1^{\%} (\theta \cdot (\overline{UC}_i(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2)) + (1 - \theta) \cdot (\underline{UC}_i(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2))) \quad [3.9]$$

$$\overline{sc}_{i,3} \leq k_3^{\%} \cdot \{\gamma \cdot (\overline{DC}_i \cdot D_i) + (1 - \gamma)(\underline{DC}_i \cdot D_i)\} \quad [3.10]$$

$$\overline{sc}_{i,j} \geq \underline{sc}_{i,j} \geq 0; j \neq 2 \quad [3.11]$$

Eq. (3.9) acts as the participation constraint of the cost-sharing contract for the product supplier. The e-tailer cannot share the total operational costs of the product supplier; only a percentage can be shared. Accordingly, the e-tailer can only share up to the maximum percentage share allowed from the total cost of the product supplier under two cost states. These constraints ensure that the e-tailer has the incentive to initiate the contract and execute it with the product supplier. Similarly, for the 3PL operator, the participation constraints are given in Eq. (3.10). Therefore, the e-tailer only shares up to the allowed maximum percentage from the total distribution cost under the occurrence of two cost states. This ensures that the sharing cost of the lower-cost status of the supplier or 3PL operator does not exceed the sharing cost offered in the higher-cost state. It generates the maximum margin that the sharing cost reaches and, therefore, ensures that the higher benefit is received with the higher cost-share.

(iv) Operational constraints

$$s_{1,1} = q_1 - d_1 + II_1 \quad [3.12]$$

$$s_{1,2} = d_1 - D_1 + II_2 \quad [3.13]$$

$$s_{i,1} = q_i - d_i + s_{i-1,1} : i > 1 \quad [3.14]$$

$$s_{i,2} = d_i - D_i + s_{i-1,2} : i > 1 \quad [3.15]$$

$$s_{i,j} \leq W_{capj} : \forall_i, \forall_j \quad [3.16]$$

$$q_i \leq M_{cap} : \forall_i \quad [3.17]$$

(v) Non-negativity constraints

$$q_i \geq 0; d_i \geq 0; s_{i,j} \geq 0; sc_{i,j} \geq 0, c_j \geq 0 \quad [3.18]$$

Eq. (3.12) and (3.14) denote the inventory levels maintained by the product supplier at the end of each period i . The final inventory at the end of the period i is the number of units that are left after covering the demand using the initial inventory and the produced units of the period i . Eq. (3.13) and (3.15) represent the inventory levels that should be maintained by the e-tailer to fulfil their operational requirements and the final inventory of period i should satisfy the requirement of actual demand from consumers. The ending inventory of player j in the period i cannot surpass the player's warehouse capacity, which is represented by Eq. (3.16). Eq. (3.17) denotes that the production quantity at each period i should be less than or equal to the maximum production capacity. Finally, Eq. (3.18) denotes the non-negativity constraints, which include all decision variables of the model.

3.6 Solution Strategy

Several extant studies provide evidence of game theory-based models being solved using optimisation, such as linear programming (LP) and non-linear programming (NLP) (Sohrabi & Azgomi 2020). Among these studies, Yue and You (2014, 2017), and Zamarripa et al. (2013) have used the MOO approach to derive supply chain coordination based on game theory concepts. Numerous examples are also found in the contract literature that has incorporated optimisation methods in obtaining solutions from contract models (Bansal, Karimi & Srinivasan 2007; Lieckens, Colen & Lambrecht 2015; Park et al. 2006). As the proposed contract model includes multiple objectives and a considerable amount of operational

constraints, the optimisation approach was used in this study to obtain the results of the proposed cost-sharing contract.

MOO uses several methods in deriving non-dominated solutions; the weighted sum method, Lexicographic method and the ϵ -constrained method are the most used methodologies (Matsumoto & Szidarovszky 2016). The lexicographic method provides ordinal preferences for each objective rather than assigning weights, and the process is conducted until a unique optimum is reached. However, it has a huge disadvantage since the optimisation process terminates in the first instance when an optimal solution is derived for the objective that has the highest preference (Arora 2017). In the ϵ -constrained method, only one objective is taken for the optimisation, with all other objectives converted into constraints, and then the model is solved (Sarker & Newton 2008). The weighted sum method is the most frequently adopted, easy to use approach in generating Pareto-optimal solutions compared to the other methods (Margolis et al. 2018; Sarker & Newton 2008). In the cooperative game scenarios, it is assumed that the decision-maker has the authority to decide the relative importance of each player's payoff and accordingly, weights are allocated (Matsumoto & Szidarovszky 2016). Most importantly, this method can generate all possible Pareto-optimal solutions (Arora 2017). Changing the weights allocated in the model gives all joint optimal solutions (Cesar, Fandel & Trockel 1994). Considering all these aspects and using a cooperative game approach, this study adopted the weighted sum method to convert the multiple objectives of the product supplier, e-tailer and 3PL operator into a single objective of minimising the overall supply chain cost.

3.7 Numerical Illustration and Results Discussion

3.7.1 Interpretation of Data

In this section, a numerical analysis is conducted to demonstrate the outcomes of the cost-sharing contract model. This covers the operational aspects of the e-commerce supply chain. Furthermore, sensitivity analysis is performed to show the impact of changes in the parameter values to the contract outcomes. The data for the proposed model was obtained from Ragsdale (2017) because this author has developed an operational model in a similar context, and the model has been tested and verified with optimal solutions. However, the contract model in this study required additional data related to e-tailer operations and, hence, spreadsheet simulation was carried out to complete the data requirement. The data related to all defined parameters are presented in Table 3.2.

The following assumptions were made in this numerical illustration:

1. The product supplier and the e-tailer have identical warehouses with similar operating capacities.
2. The number of periods taken into consideration is six.

Based on that, the data required for all defined parameters were gathered (as shown in Table 3.2).

Table 3.2 Data of the base contract model

Parameter	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
$\overline{UC}_i$	240	250	265	285	280	260
$\underline{UC}_i$	200	197	203	199	200	200
α_i	0.015	0.015	0.015	0.015	0.015	0.015
$MCAP$	10000	10000	10000	10000	10000	10000
$WCAP_j$	6000	6000	6000	6000	6000	6000
SS_j	1500	1500	1500	1500	1500	1500
II_1	2750	-	-	-	-	-
II_2	2500	-	-	-	-	-
D_i	1000	4500	6000	5500	3500	4000
HC_i	5.98	5.87	6.04	5.58	2.92	4.37
$\overline{DC}_i$	19.65	20.22	18.90	19.85	19.59	20.65
$\underline{DC}_i$	11.21	14.16	12.49	11.34	13.15	11.97
$\overline{P}_1$	100	100	100	100	100	100
$\underline{P}_1$	60	60	60	260	60	60
$\overline{P}_3$	10	10	10	10	10	10
$\underline{P}_3$	5	5	5	5	5	5

The first computer experiment was conducted by assuming the following parameter values: $\theta = 0.5$, $\gamma = 0.5$, $k_1^{\%} = 0.5$, $k_3^{\%} = 0.5$, $W_1 = 0.3$, $W_2 = 0.4$ and $W_3 = 0.3$. It is assumed that having higher costs with the product supplier and 3PL operator and the cost-sharing percentage is 50%. Weights are allocated, giving higher weight to the e-tailer as he initiates the contract and allocating equal values to other players.

3.7.2 Computer Experiments of Base Contract Model

The model developed is a linear programming problem and, hence, an optimisation solver tool was used to conduct the computer experiments using the data indicated in Table 3.2. The GUSEK (GLPK Under Scite Extended Kit) solver (Version 4.65) was used to program the model using AMPL modelling language. GUSEK⁵ is a widely used optimisation solver, which is open source, free software with a linear/integer programming solver. The GUSEK solver

⁵ <http://gusek.sourceforge.net/gusek.html>

uses the GNU Linear Programming Kit (GLPK) to solve large-scale LP models and integer programming models (Phillips 2013). AMPL is an extensively used modelling language in relation to optimisation modelling (Sarker & Newton 2008), and the GUSEK solver also uses the AMPL modelling language. The GUSEK solver generates optimal solutions for LP problems using the simplex algorithm, and when an optimal solution is obtained, the output files are indicated with “Optimal LP solution found”. When the solver cannot generate a feasible solution, the output file indicates “No feasible solution”.

3.7.3 Model Validity and Verification

In mathematical modelling, testing the model validity, which is also known as verification of the model, is a key attribute. Several methods are used for model validation and verification. Some of the most frequently used techniques are the graphical interpretation of model results, comparison to other models results, degenerate tests, event validity, extreme condition tests, face validity, internal validity, historical methods, parameter variability (sensitivity analysis), and predictive validation (Sargent 2013). The validation process generally includes descriptive, experimental, and analytical validation. Descriptive validation entails the development of the objective function, variables, coefficients, and the expected results of the model. Analytical validation expresses the practicability and robustness of the model under the relaxation of specified model assumptions. Finally, experimental validation describes the justification of the developed model based on tests carried out in the model analysis (Kalyebara & Islam 2014).

In this study, the models developed were validated using several techniques. Under descriptive validation, the objective functions, constraints, decision variables and parameters were defined in terms of the model requirement: the contract model formulation. When the model was formulated, it was tested via several necessary steps before reaching model solving by testing for errors in the equations, and checking the model feasibility results through optimisation software, generally known as de-bugging (Williams 2013). Then the experimental validation is conducted using numerical illustration as described in this section, where the results were tested and analysed. Parameter variability was also conducted using sensitivity analysis for the key parameters that might impact the modelling decisions, along with the graphical interpretation of the model results and comparison with other model findings.

3.7.4 Base Results Analysis

As discussed in Section 3.7.2, the contract model was executed in the GUSEK solver using the data shown in Table 3.2. The model output showed an optimal solution, as presented in Table 3.3.

Table 3.3 The optimal solution of the base contract model

Decision variables	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
q_i	0	7750	6000	2333	2167	0
d_i	0	4500	6000	5500	3500	0
$s_{i,1}$	2750	2750	6000	6000	2833	1500
$s_{i,2}$	2500	1500	1500	1500	1500	1500
$\overline{sc}_{i,1}$	1725	290175	128100	0	37644	0
$\overline{sc}_{i,3}$	3440	4770	8460	19305	5040	14270
$\underline{sc}_{i,1}$	0	0	0	0	0	0
$\underline{sc}_{i,3}$	0	0	0	0	0	0
c_1	2,463,070					
c_2	2,022,460					
c_3	155,765					
z	1,594,632.57					

One of the significant observations from Table 3.3 is that the lower sharing costs ($\underline{sc}_{i,1}$ & $\underline{sc}_{i,3}$) have a zero value in all periods of this contract design. It indicates that in the optimal contract, when the individual operational cost of the product supplier and the 3PL operator is at a high rate, none of the parties receives a benefit with cost-sharing from the e-tailer. Therefore, the cost-sharing aspect of this contract encourages players to achieve lower operational costs. As the cost-sharing contract was designed based on the revelation principle, the outcomes of this contract will motivate players to not only work towards maintaining lower operational cost but also to reveal the true costs. Therefore, this contract drives players in the e-commerce supply chain towards achieving lower cost operational outcomes. According to the cooperative game coalitions of this contract, the common payoff for all these players was to achieve minimum operational cost. Therefore, this cooperative game maintains the group rationality outcome and also, by delivering an optimal outcome, this cost-sharing contract delivers Pareto improvement for the operation.

The results indicated in Table 3.3 further elaborate that the supplier receives the highest cost share in period two, which is also accompanied by the highest production levels of the product supplier. Consequently, the second highest cost-share received by the product supplier is also

accompanied by the second highest production levels in period three. Therefore, this cost-sharing contract has more benefits for the product supplier when a higher production is to be carried out but with lower unit production cost. Similarly, the 3PL operator receives the highest cost-share at that period, which has the second highest demand from the customer. Nevertheless, the 3PL operator receives a higher cost-share in each period of the contract, while the product supplier does not receive a cost-share in period four or period six. The interesting fact is that the product supplier has zero production levels at period six, and also has lower production levels in period four. Therefore, the production levels of the product supplier have a direct relationship with the cost-share received. The results of the computer experiments in this model illustrate that cost-sharing depends on the inventory, production and demand variables, and the optimal outcomes of the cost-sharing contract in this e-commerce supply chain changes according to the operational factors in each period. Therefore, these results indicate that even though the contract design is executed with contract-related parameters, operational limitations and conditions have a significant impact on deciding the effectiveness of the contract. Hence, considering the impact of operational constraints on the contract models is extremely important.

3.7.5 Impact of Contract Parameters on the Outcomes of E-commerce Supply Chains

Since the cost-sharing portion of this contract is derived as a share of operational cost for higher and lower costs, the e-tailer needs to decide the maximum percentage to be shared to minimise both the individual costs and the overall supply chain cost. A sensitivity analysis was conducted to analyse the cost-sharing percentage, which is denoted by $k_1^{\%}$ and $k_3^{\%}$ (see Appendix F).

In this analysis, θ and γ are considered as 0.1 as this is the lowest possibility of having higher operational costs. Also, $w_1 = 1/3$; $w_2 = 1/3$; $w_3 = 1/3$ are taken into consideration. Figure 3.3 illustrates the impact of the cost-sharing percentage on total supply chain costs for each player, which is derived using results shown in Appendix F. As shown in the figure, $k_3^{\%} \leq 0.3$ generates an optimal solution. Therefore, the minimum cost-sharing percentage received by the 3PL operator is 30% for this contract to generate optimal results. However, this contract delivers minimum costs for the overall supply chain when the e-tailer shares a maximum percentage (i.e., 90%) of the product supplier's cost.

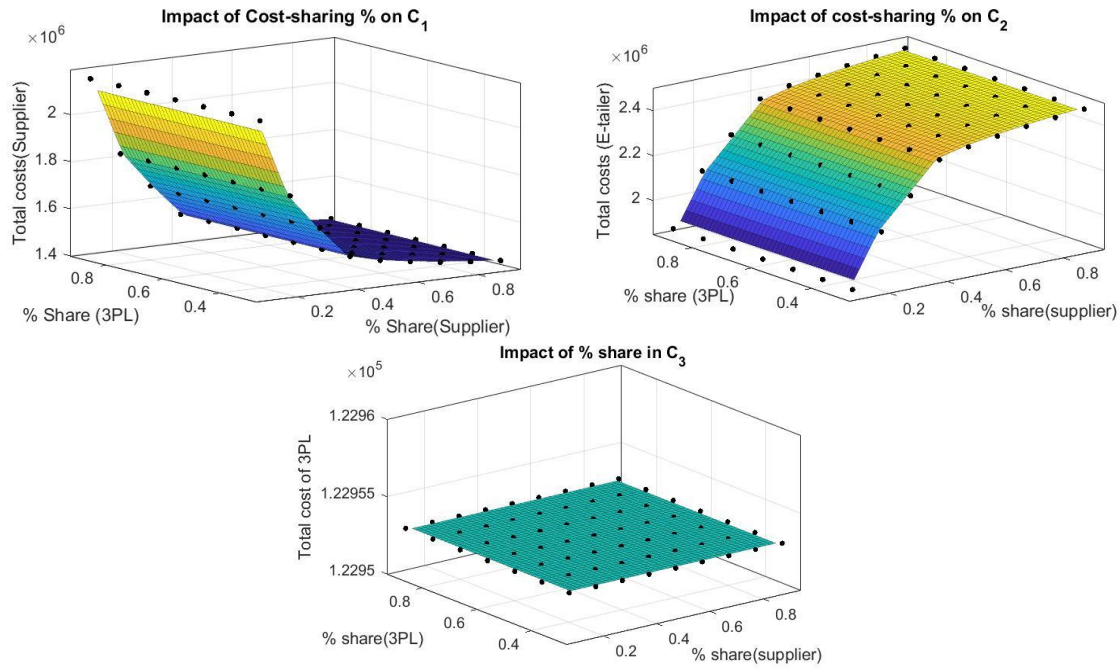


Figure 3.3 Impact of cost-sharing percentages on individual total costs

The analysis also shows that the total costs of the 3PL do not increase or decrease as per the change of $k_3^%$. Hence, the e-tailer can maintain a minimum sharing cost with the 3PL operator and obtain a cost-effective solution for this e-commerce supply chain. Therefore, the lowest overall cost (z) is derived when $k_1^% \leq 0.9, k_3^% \leq 0.3$. Since contract parameters and the demand values are considered as known parameters in this simulation, the costs of the 3PL operator become a known value, which is reflected in the contract parameters. However, this may not be valid when the demand is uncertain, which is one of the real operational challenges.

Looking at the individual costs, when $k_1^% \leq 0.9, k_3^% \leq 0.3$, the e-tailer does not have the lowest operational cost (see Figure 3.3). However, when the lowest cost values of the e-tailer are considered, the total supply chain cost increases. Since cooperative game coalitions are incorporated in the cost-sharing contract, the e-tailer must adhere to the rules of the game considering group rationality, which is to achieve minimal supply chain costs. As previously discussed, the group rationality of the contract is significant since the small-scale e-tailer supply chain needs to minimise overall supply chain costs to create a competitive pricing strategy for its customers.

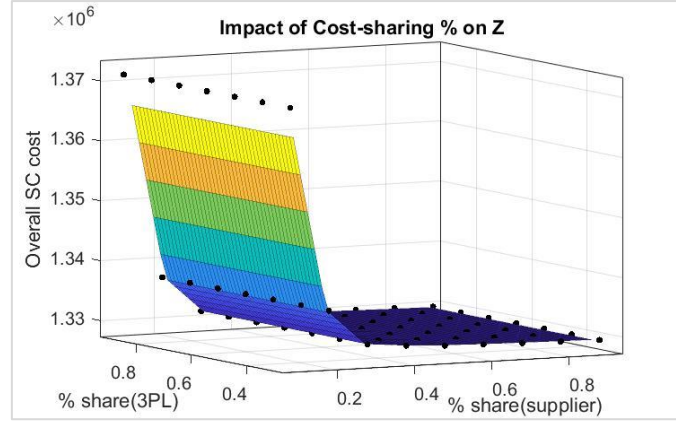


Figure 3.4 Impact of cost-sharing percentages on overall supply chain costs

Figure 3.4 illustrates the overall supply chain cost against the cost-sharing percentages $(k_1^{\%}, k_3^{\%})$. When z has the lowest value, the product supplier also has the lowest cost values, but the e-tailer's cost has increased. This is justified since sharing costs are increased in this scenario (see Figure 3.4) and is reflected through the cost of the e-tailer. Therefore, this contract emphasises that the e-tailer has to identify the optimal sharing percentage between the e-tailer and the product supplier to create a win-win situation. This is analysed further in the next section. Nevertheless, this analysis has proven that the cost-sharing contract upholds the minimal operational cost for the e-commerce supply chain and maintain cooperative game coalitions.

3.8 Extension of the Base Cost-Sharing Contract

The results based on the numerical analysis reveal that the designed cost-sharing contract model has important implications for optimal supply chains. However, further analysis is required to determine the optimal cost-sharing levels that can coordinate the supply chain. Therefore, the cost-sharing percentage $(k_{i,j}^{\%})$ was included in the contract as a decision-variable. It is defined as $0 \leq k_{i,j}^{\%} \leq 1$. The contract model becomes a non-linear problem with this modification. The number of contract periods were also increased with the model modification to conduct the numerical analysis. This allows for further testing of the model validity.

The AMPL model code, data file and the run code of the cost-sharing contract model is included in Appendix A.

3.8.1 Data

According to these extensions, the data for model testing are presented in Table 3.4. The additionally required data were generated using spreadsheet simulation.

Table 3.4 Data for model testing with extension

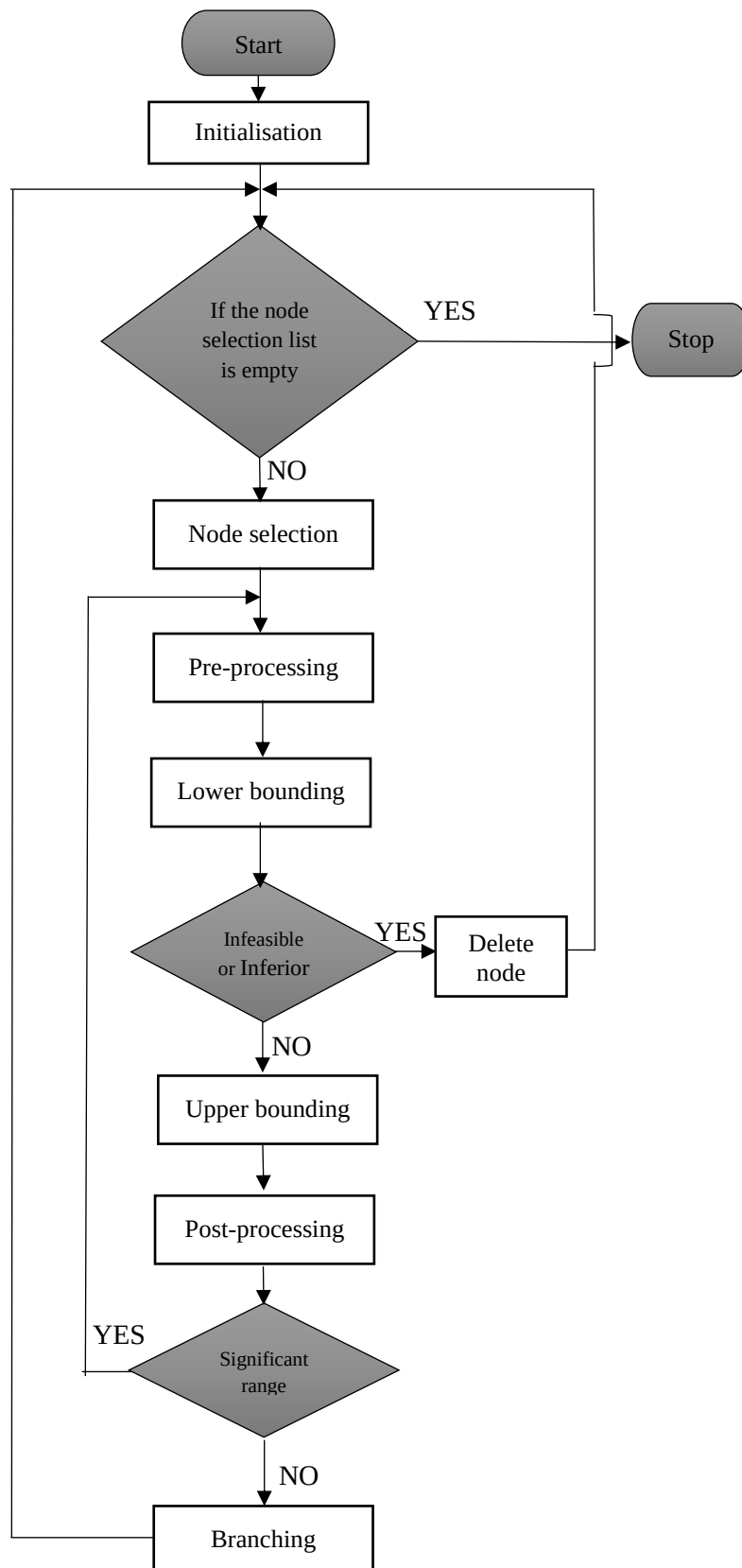
Parameter	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12
$\overline{UC_i}$	240	250	260	280	280	260	260	280	250	240	280	260
$\underline{UC_i}$	200	190	200	190	200	200	200	180	190	200	190	190
D_i	1000	4500	6000	5500	3500	4000	4500	5500	6000	4500	4500	5500
HC_i	5.98	5.87	6.04	5.58	2.92	4.37	4.68	4.52	5.46	5.91	5.91	4.82
$\overline{DC_i}$	19.65	20.22	18.90	19.85	19.59	20.65	19.56	18.94	21.45	20.07	19.26	18.99
$\underline{DC_i}$	11.21	14.16	12.49	11.34	13.15	11.97	13.08	12.75	12.21	12.39	11.47	12.07
$\overline{P_{i,1}}$	85	100	105	110	110	95	95	110	90	85	110	95
$\underline{P_{i,1}}$	60	55	60	55	60	60	60	50	55	60	55	55
$\overline{P_{i,3}}$	10	9	10	10	10	10	10	8	9	10	9	9
$\underline{P_{i,3}}$	5	7	6	5	6	5	6	6	6	6	5	5

Similar to the previous analysis, the probability of higher operational costs of the product supplier and the 3PL operator is assumed as 50%, and therefore, $\theta = 0.5$; $\gamma = 0.5$. Weights allocated for each player are assumed to be $W_1 = 0.3$; $W_2 = 0.4$; $W_3 = 0.3$, providing higher weight for the e-tailer as the initiator of the contract. In this analysis, $\overline{P_{i,1}}$ and $\overline{P_{i,3}}$ data are changed, considering the price variations in each period.

3.8.2 Computer Experiments

As the extended model includes non-linear constraints, it was solved as an NLP problem. This model was also programmed using AMPL modelling language and coded in the GUSEK solver. Due to the non-linear nature of the model, it was executed in the BARON solver,⁶ which is used for solving non-convex optimisation problems and deriving global optimality solutions. The BARON solver generates output files with the condition “Optimal within tolerances” when a global optimal solution is generated by using “Branch and Reduce Algorithms” (Sahinidis 2020). The branch and reduce algorithm employed by the BARON solver is illustrated below:

⁶ <https://neos-server.org/neos/solvers/minco:BARON/AMPL.html>



Source: (Sahinidis 2020)

Figure 3.5 Branch and reduction algorithm used in the BARON solver

The computer experiments were performed in the NEOS Optimisation Server, version 4.0⁷, which provides free access services for solving numerical optimisation problems. The BARON solver is included in the NEOS server and, therefore, free access was gained for executing the model through this server. These computer experiments were conducted using a Windows 10, 64-bit operating system with 8GB RAM.

3.8.3 Base Results Analysis with Extended Cost-Sharing Contract

The optimal solution generated for the given numerical data set is presented in Table 3.5.

Table 3.5 Numerical illustration of the optimal solution

Variables	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12
q_i	0	5348	4409	3315	2177	4000	6717	3283	6000	9000	0	5500
d_i	0	3000	6000	5500	3500	4000	4500	5500	6000	9000	0	5500
$s_{i,1}$	2750	5098	3507	1322	0	0	2217	0	0	0	0	0
$s_{i,2}$	1500	0	0	0	0	0	0	0	0	4500	0	0
$\overline{SC}_{i,1}$	2475	191724	0	0	0	100000	247492	0	150000	135000	0	165000
$\overline{SC}_{i,3}$	3440	18270	14460	19305	8540	14720	11160	23045	37440	16560	17055	16060
$\underline{SC}_{i,1}$	0	0	0	0	0	0	0	0	0	0	0	0
$\underline{SC}_{i,3}$	0	0	0	0	0	0	0	0	0	0	0	0
$k_{i,1}^{\%}$	0.17	0.27	0	0	0	0.26	0.24	0	0.22	0.14	0	0.24
$k_{i,3}^{\%}$	0.71	0.72	0.69	0.70	0.70	0.71	0.70	0.72	0.74	0.71	0.72	0.70
c_1	6757090											
c_2	5150360											
c_3	368145											
Z	4197710											

The solution derived the optimal cost-sharing percentages for the product supplier and the 3PL operator. Accordingly, $k_{i,1}^{\%} \leq k_{i,3}^{\%}$ in all periods of the contract. This has resulted as the product supplier's operational costs are higher than those of the 3PL operator. Moreover, the results indicate that in the optimal solution, the lower sharing costs ($\underline{SC}_{i,1}$ & $\underline{SC}_{i,3}$) produced a zero value for both the product supplier and the 3PL operator, similar to the results of the base contract model (see Table 3.3). According to the proposed menu of contract, the e-tailer offers a lower sharing cost when the product supplier and the 3PL operator have higher operational

⁷ <https://neos-server.org/neos/>

costs. Therefore, the zero-cost share indicates that the optimal setting of the contract does not offer cost-sharing benefits when the operational costs are high. This outcome indicates that the cost-sharing contract is coordinating, but further analysis is required to identify how it provides benefits for all players in the contract model.

Figure 3.6 shows the optimal cost-sharing percentages for the product supplier and the 3PL operator.

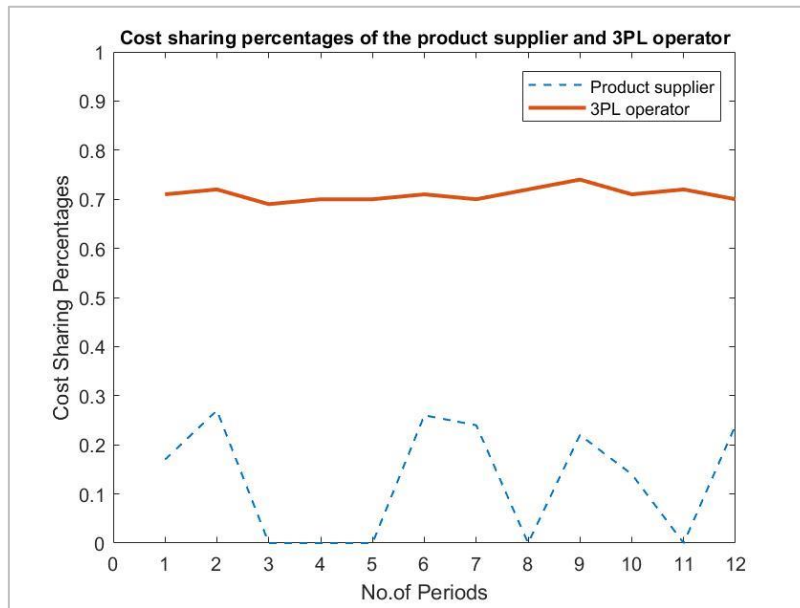


Figure 3.6 Analysis of $k_{i,1}^{\%}$ and $k_{i,3}^{\%}$

In Figure 3.6, it is observed that $k_{i,1}^{\%} \leq k_{i,3}^{\%}$, and in some periods $k_{i,1}^{\%} = 0$. In contrast, $k_{i,3}^{\%}$ has more stable percentage levels throughout the contract period, which is also emphasised by the numerical outcomes. The sharing percentage of the product supplier ($k_{i,1}^{\%}$) varies between 14% and 27%, while the sharing percentage of the 3PL operator ($k_{i,3}^{\%}$) varies between 69% and 72%. Therefore, the contract delivers the optimal cost-sharing levels that the e-tailer should adopt to obtain the minimum supply chain costs (z) in each period of operation.

Since the optimal solution presented in Table 3.5 is based on a single set of parameters given to θ, γ and W_j , this study conducted a sensitivity analysis (discussed in Section 3.8.5) to analyse the impact of probability (θ, γ) and weight allocation (W_j) on the outcomes of the cost-sharing contract.

3.8.4 Benchmark Model (No Contract)

The operational outcomes in the decentralised setting were tested without a contract model to compare the supply chain costs with the results of the proposed cost-sharing contract. In this setting, the players operated as individual organisations, and no binding agreement was available to work towards a common objective. This operational scenario may generate optimal solutions, but it is necessary to identify whether it provides better outcomes for resolving the information asymmetry and conflict of interest issues. Hence, the results of the cost-sharing contract model were compared with the decentralised operational setting. Three operational scenarios were considered for decentralised operations to conduct this analysis: no contract with asymmetric information, no contract with higher operational costs; and no contract with lower operational costs.

Although the operation in this setting is decentralised, inventory management and distribution operations are linked with other players. Hence, inventory levels, order and production quantities affect the costs of each other. However, when the operation is carried out, none of these players considers the impact of their actions on the outcomes of another party, or on the overall outcomes of the e-commerce supply chain. Based on that, the outcomes were tested with an optimisation model, with each player's objective separately optimised subject to the operational constraints of the system.

The objective functions of each player in a no-contract scenario, with asymmetric information, are as follows:

$$c_1 = \sum_{\forall_i} \left[\left(\theta(\overline{UC_i}) + (1-\theta)(\underline{UC_i}) \right) \cdot \left(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2 \right) - \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \right] \quad [3.19]$$

$$c_2 = \sum_{\forall_i} \left[HC_i(s_{i,2} + s_{i-1,2}) / 2 + \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) + \left((\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}})) \cdot D_i \right) \right] \quad [3.20]$$

$$c_3 = \sum_{\forall_i} \left[\left(\gamma(\overline{DC_i}) + (1-\gamma)(\underline{DC_i}) \right) \cdot D_i - \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \right] \quad [3.21]$$

The objective functions of the product supplier, e-tailer and 3PL operator are formulated for both higher and lower cost scenarios.

Individual cost objectives (higher costs)

$$c_{1H} = \sum_{\forall_i} \left[\left(\theta \cdot (\overline{UC_i}) \right) \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) - \left(\theta(\overline{P_{i,1}}) \cdot d_i \right) \right] \quad [3.22]$$

$$c_{2H} = \sum_{\forall_i} \left[HC_i(s_{i,2} + s_{i-1,2}) / 2 + \theta(\overline{P_{i,1}}) \cdot d_i + \gamma(\overline{P_{i,3}}) \cdot D_i \right] \quad [3.23]$$

$$c_{3H} = \sum_{\forall_i} \left[\left(\gamma(\overline{DC_i}) \right) - \left(\gamma(\overline{P_{i,3}}) \cdot D_i \right) \right] \quad [3.24]$$

Individual cost objectives (lower costs)

$$c_{1L} = \sum_{\forall_i} \left[\left((1 - \theta)(\underline{UC_i}) \right) \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) - \left((1 - \theta)(\underline{P_{i,1}}) \cdot d_i \right) \right] \quad [3.25]$$

$$c_{2L} = \sum_{\forall_i} \left[HC_i(s_{i,2} + s_{i-1,2}) / 2 + \left((1 - \theta)(\underline{P_{i,1}}) \cdot d_i \right) + \left((1 - \gamma)(\underline{P_{i,3}}) \cdot D_i \right) \right] \quad [3.26]$$

$$c_{3L} = \sum_{\forall_i} \left[\left((1 - \gamma)(\underline{DC_i}) \cdot D_i \right) - \left((1 - \gamma)(\underline{P_{i,3}}) \cdot D_i \right) \right] \quad [3.27]$$

Eq. (3.22) to Eq. (3.24) represent the cost objectives of the individual players for the higher operational cost scenario. Eq. (3.25) to (3.27) express the total individual costs of each player for the lower cost scenario. Eq. (3.22) and (3.25) explain the total operational cost of the product supplier, which comprises the total production and inventory costs. As the fixed unit price paid by the e-tailer is applicable in this scenario as well, the objective functions of each player include the total fixed price. Eq. (3.23) and (3.26) denote the total inventory handling costs of the e-tailer along with the price he pays to the product supplier and the 3PL operator. Finally, Eq. (3.24) and (3.27) denote the total cost of the 3PL operator, which comprises the total distribution cost with the cost reduction generated by the price received from the e-tailer. The decentralised model includes the operational constraints represented by Eq. (3.12) to Eq. (3.18) and described in Section 5.4.3, in addition to the above individual total cost constraints.

The numerical analysis was conducted using the same data set in Table 3.4 to compare the results. First, no contract setting (with asymmetric information) was tested, and total individual costs of the players are compared with the results of the contract model in Figure 3.7. The results indicate that the proposed cost-sharing contract delivers improved outcomes in terms of optimising supply chain operational costs. The individual total costs of the product supplier

and the 3PL operator are also reduced in the cost-sharing contract compared to the scenario of no-contract with asymmetric information. The e-tailer's cost is increased in the cost-sharing contract (see Figure 3.7). The results show that with the cost-sharing contract, the product supplier's cost reduced by 7%, the 3PL operator's costs reduced by 27%, while the e-tailer's costs increased by 13%.

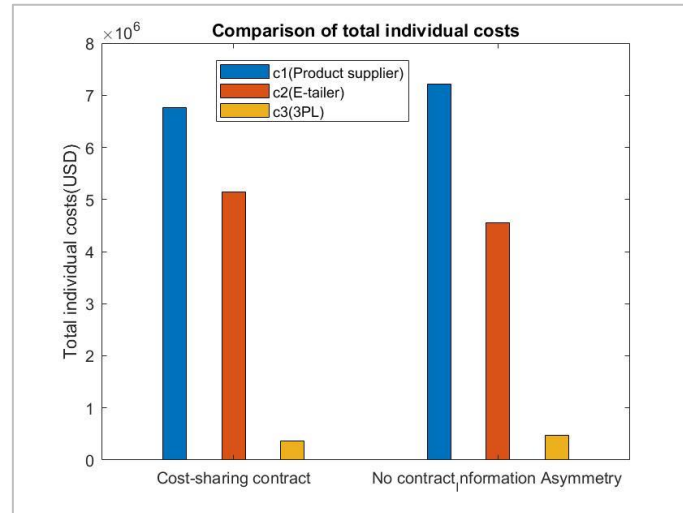


Figure 3.7 Comparison of total individual costs between cost-sharing contract and no contract with asymmetric information

The overall supply chain cost (z) was reduced by more than 50% compared to the no-contract (information asymmetry) setting. Therefore, being in a cooperative coalition generates better supply chain costs for the overall supply chain.

The results generated from the no-contract model with symmetric information scenarios show that individual total costs are low compared to the costs of the cost-sharing contract (see Figure 3.8).

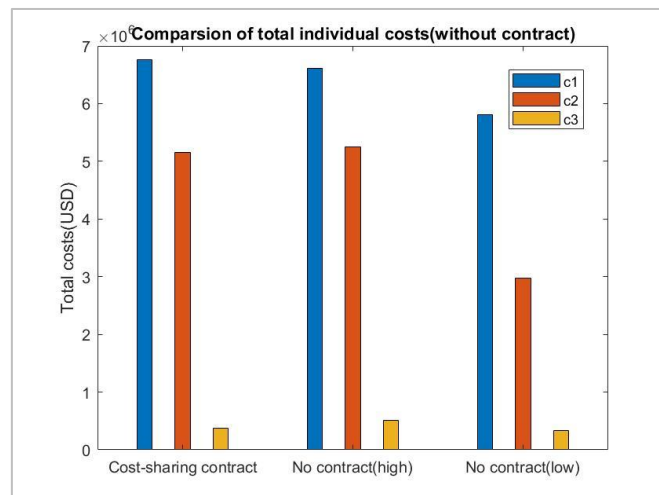


Figure 3.8 Comparison of individual total costs between contract and no-contract (high and low operational costs) scenarios

The no-contract setting with low operational costs has the lowest total costs, which is the best solution any supply chain can be obtained. However, it is not a universal option. The comparison between the cost-sharing contract and the no-contract with higher operational costs indicates a different outcome, even with the symmetric information. The e-tailer's and 3PL operator's costs are 2% and 28% higher in the no-contract setting, with high operational costs than in the cost-sharing contract. However, the product supplier's costs are 2% higher in the cost-sharing contract than in the no-contract setting with higher operational costs. Therefore, it is evident that having higher operational costs negatively affects supply chain performance, even with symmetric information, whereas the cost-sharing contract delivers better outcomes for individual players.

Next, overall supply chain costs in each scenario were analysed to see how the proposed cost-sharing contract affects supply chain performance (see Figure 3.9).

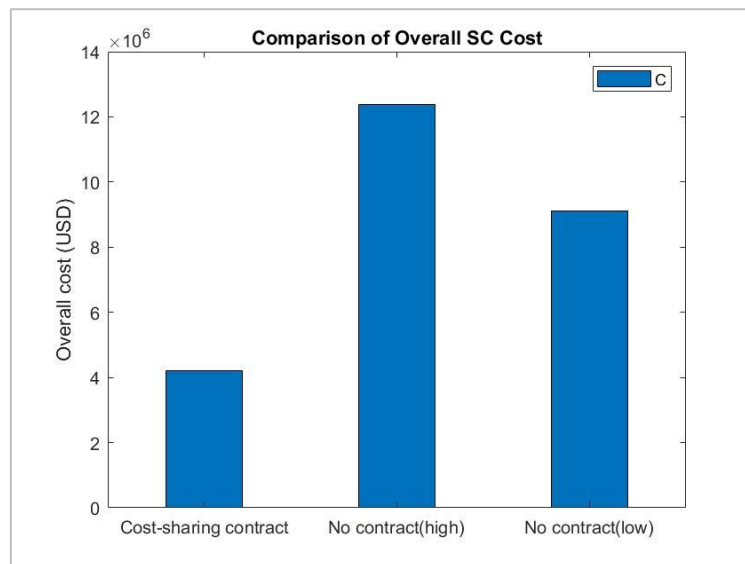


Figure 3.9 Comparison of overall supply chain costs between cost-sharing contract and no-contract with high and low operational costs

The overall supply chain cost (z) is lowest in the cost-sharing contract compared to the no-contract setting with higher and lower costs. This result highlights that implementing the proposed cost-sharing contract brings significant benefits to e-tailer supply chains. Especially small-scale and start-up e-tailers receive the opportunity to reduce their product prices.

Therefore, formulating a cost-sharing contract delivers better supply chain costs when asymmetric information exists. These findings create a platform to motivate individual players to achieve benefits from the common objective rather than focusing only on individual benefits. Hence, the outcomes of this cost-sharing contract highlight that conflicts of interests among

different players can be resolved through a cost-sharing contract, as discussed throughout this study. The findings very clearly emphasise that without the cost-sharing contract, the supply chain will not improve on performance as the overall supply chain costs are higher without the contract elements.

3.8.5 Sensitivity Analysis

3.8.5.1 Impact of Asymmetric Costs Probabilities θ and γ on Supply Chain Costs

First, a sensitivity analysis was conducted to analyse how the information asymmetry issues affect the outcomes of the contract. As the probability function varies between $0 < \theta < 1$ and $0 < \gamma < 1$, probability values were changed within those boundaries to identify the impact on the objective function and individual cost functions. The results of the sensitivity analysis are demonstrated in Appendix G. Based on the results, Figure 3.10 and Figure 3.11 were created to interpret the results.

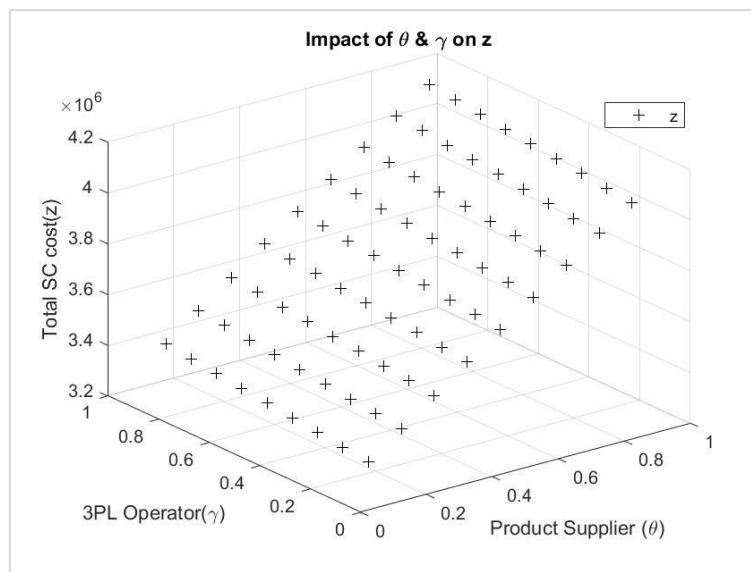


Figure 3.10 Impact of θ and γ on overall supply chain cost

When θ and γ takes the lowest probability levels, which is 0.1, the overall supply chain cost always takes minimum values. This result emphasises that the cost-sharing contract provides the highest effective outcomes when the asymmetric costs have the lowest probabilities. Furthermore, it indicates that the upstream and downstream of the e-commerce supply chain must maintain lower costs to gain the lowest costs for the supply chain operation, which can ultimately transfer to the consumer. The results are further illustrated in Figure 3.11, which

displays how the probabilities of θ and γ affect the total individual costs of the product supplier, e-tailer and 3PL operator.

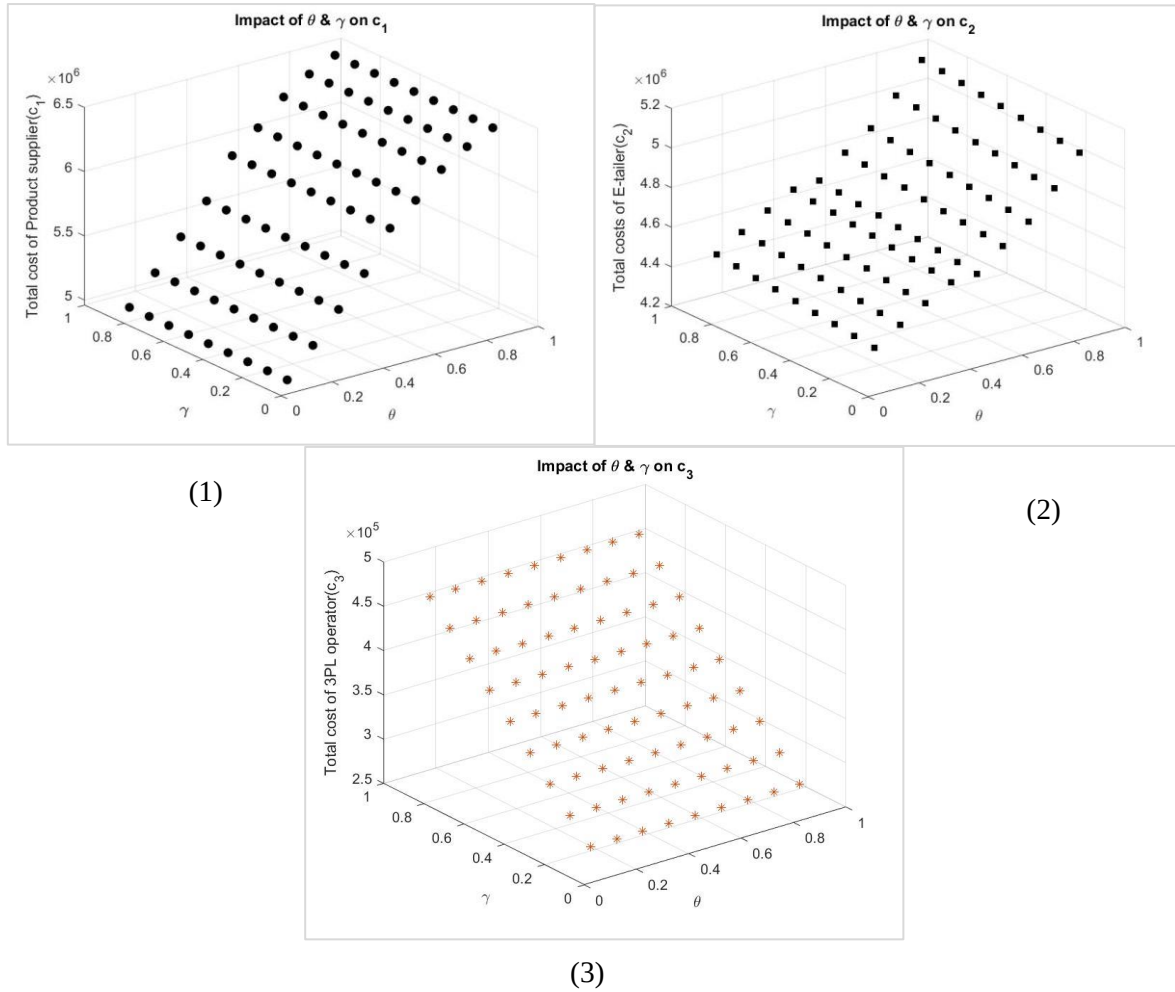


Figure 3.11 Impact of θ and γ on total individual costs of the product supplier (1), e-tailer (2) and 3PL operator (3)

As illustrated in Figure 3.11, both the product supplier and the e-tailer's total costs have a similar trend. However, all three players have lower costs when $\theta = 0.1$ and $\gamma = 0.1$ similar to the total supply chain cost. Therefore, when the asymmetric information is lowest, the group rationality of the cost-sharing contract is achieved with cost minimisation.

3.8.5.2 Impact of Weight Allocation on Supply Chain Costs

As the proposed contract model was solved as a MOO problem, using the weighted sum method, it is necessary to define the weight allocation that derives Pareto-optimal or Pareto-improvement of the cost-sharing contract. Therefore, a sensitivity analysis was conducted by exploring possible weight allocations for each player. The e-tailer is the party who decides the weights for each supply chain member, as per the solution approach of cooperative games (Matsumoto & Szidarovszky 2016). The results of this sensitivity analysis could further assess the best possible operational combination to generate minimal supply chain costs for the e-commerce operation. In this analysis, none of the players was allocated zero probability of weights, as this operation could not be carried out without any supply chain member. Therefore, the minimum possible value assigned for a player is 0.1. The weighted individual total costs for different possible weight allocations were analysed and interpreted using linear interpolation (see Figure 3.12).

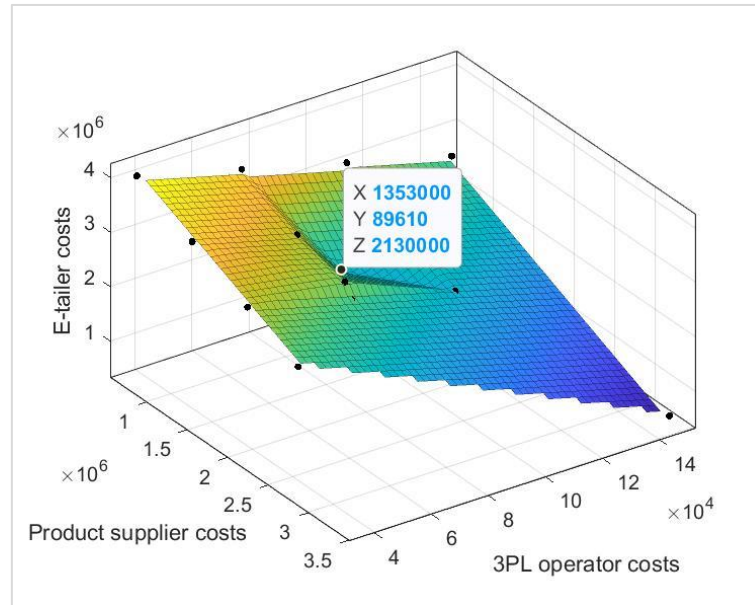


Figure 3.12 Impact of weight allocations on total individual costs of the product supplier, e-tailer and 3PL operator

The interpolation demonstrates the relationship between the total individual costs (c_1, c_2, c_3) of three players. Accordingly, the lowest point shown in Figure 3.12 generates the values of $c_1 = 1353000$; $c_2 = 2130000$; $c_3 = 89610$. These values are generated from the weight allocations in between $w_1 = 0.1, w_2 = 0.5, w_3 = 0.4$ and $w_1 = 0.2, w_2 = 0.4, w_3 = 0.4$ (see Table 3.6). As sensitivity analysis was conducted for discrete weight allocations varying from 0.1 to 0.9, the weight allocation $w_1 = 0.1, w_2 = 0.5, w_3 = 0.4$ generates the lowest z (see Table 3.6). By comparing the

discrete values of sensitivity analysis with the lowest point of linear interpolation, it can be identified that the product supplier's costs are increased, while the e-tailer's costs and the 3PL operator's costs are reduced. Therefore, it is evident that linear interpolation shows the lowest z for this supply chain operation, which is beneficial and derives Pareto-improvement for the players.

Table 3.6 Sensitivity analysis based on weight allocations

W1	W2	W3	c_1	c_2	c_3	z
0.1	0.5	0.4	685090	2545095	147258	3377440
0.2	0.4	0.4	1370050	2093460	89958	3553470
0.1	0.6	0.3	685090	3054114	110443.5	3849640
0.2	0.5	0.3	1370180	2545095	110443.5	4025690
0.3	0.4	0.3	2027127	2060144	110443.5	4197710
0.1	0.7	0.2	685090	3563133	73629	4321850
0.2	0.6	0.2	1370180	3054114	73629	4497920
0.3	0.5	0.2	2046774	2552970	73629	4673370
0.1	0.8	0.1	685090	4072152	36814.5	4794050
0.4	0.4	0.2	1960536	2790336	73629	4824500
0.2	0.7	0.1	1370180	3563133	36814.5	4970120
0.3	0.6	0.1	2055075	3054240	36814.5	5146130
0.4	0.5	0.1	2681244	2596435	36814.5	5314490

3.9 Discussion of Key Findings

This chapter investigated the first research question: whether an effective cost-sharing contract can address the issues of ineffective coordination, asymmetric information and integration of an e-tailer supply chain and derive a cost-optimisation strategy. The findings of this chapter clarify that the cost-sharing contract significantly reduces the overall supply chain cost (z) when compared with the no-contract setting (both with asymmetric information and with symmetric information), which was tested for high and low cost scenarios. Therefore, the proposed cost-sharing design reinforces the findings of the contract modelling literature related to supply chain management, specifically that an effective contract design can deliver optimal supply chain outcomes. In addition, the findings of this study highlight that even when asymmetric information exists in upstream and downstream, the e-tailer supply chain can obtain optimal supply chain costs through effective cost-sharing. This finding represents an important contribution to the literature, as no clear evidence is found from previous studies that investigated this issue related to e-commerce supply chains. The findings further underline that when the asymmetric information exists in both upstream and downstream, the cost-sharing

contract delivers Pareto-improved outcomes for the overall supply chain and individual players.

This study derived the optimal cost-sharing percentages that the e-tailer shares with each player in each period. The analysis of Kaya and Caner (2018) within asymmetric information indicated that cost-sharing is effective for deriving supply chain coordination. However, these authors did not derive the optimal cost-sharing percentages, which is important for effective decision-making. Raj, Biswas and Srivastava (2018) determined the optimal cost-sharing percentage of greening cost-sharing for a single period model. However, these authors did not consider asymmetric information, multi-periods or three-stage supply chains. Therefore, the findings of this current study are once again significant for supply chain literature as well as for e-tailer supply chain operations.

The findings of the study by Ghosh and Shah (2015) emphasised that when players have higher greening costs, having a lower level of cost-sharing is effective. This research delivered similar results to those of Ghosh and Shah (2015), however, with the menu of contract presented with inversely proportionate cost-sharing. This finding further showed that it not only supports the cost-sharing levels but also contributes to the substantial reduction of overall supply chain costs and motivates the players to reduce their individual costs.

The findings of the sensitivity analysis revealed that when asymmetric information is less, the cost-sharing contract delivers minimal supply chain costs z, c_1, c_2 and c_3 . This finding indicates the importance of accurate cost-sharing for e-tailer supply chain operations as it mainly depends on accurate information and also emphasise the findings of Cao et al. (2013), Zissis, Ioannou and Burnetas (2015) and Chen et al. (2017). In addition, the proposed cooperative decision-making approach obtained Pareto-improved outcomes for all supply chain members to work towards a common objective. This finding is beneficial for successful integration in multi-period operations, helping to increase the customer base in the long-term and, consequently, creating a loyal customer base. Hence, this outcome would be of significant benefit to small/medium scale and start-up e-tailer supply chains.

3.10 Conclusion

Since e-commerce supply chains are operated in a highly competitive business environment, small/medium scale e-tailers require cost-effective strategies to improve their operational effectiveness. As members of the online retailing supply chains are external organisations,

asymmetric information exists among its members, inhibiting productive information sharing. This chapter focused on resolving issues pertaining to conflicts of interest among the parties and information asymmetry, which could impede optimal operational performance. Hence, this chapter presented a cost-sharing contract designed to obtain optimal supply chain costs and effectively manage the operations while encouraging accurate information sharing in a small-scale e-tailer supply chain. The contract model considered the cooperative behaviour of the players, with a common payoff defined through cost-sharing to minimise the supply chain costs.

The proposed contract model was designed to include both operational and contract related constraints. In online retailing operations, developing a competitive pricing strategy for the end customer is essential for small-scale e-tailers if they are to attract new customers and retain existing customers. The main objective of the proposed contract model was to achieve minimal supply chain costs without generating losses. Ultimately, this would create significant benefits for the customers of the supply chain as they receive lower cost products. Therefore, the cost-sharing contract encourages members of the e-tailer supply chain to work towards achieving a higher market share in the long-term, while obtaining a competitive edge in the market.

The cost-sharing contract designed in this study has derived optimal solutions to generate minimum costs for the overall e-commerce supply chain operation. The results suggest that cost-sharing contract encourage maintaining lower operational costs and revealing the true costs of players in the upstream and downstream, thereby eliminating information asymmetry issues. The results also provide suitable contract parameters that could be used to create the lowest supply chain costs. These parameters have been analysed in this study by considering cost-sharing percentages, probabilities, and weights allocation.

In the next chapter, the second research objective will be addressed. This is to consider the long-term integration of the e-tailer's upstream and downstream players. Strategies are presented to extend the base cost-sharing contract model into a dynamic contract model.

CHAPTER 4 : DYNAMIC COST-SHARING CONTRACT MODEL FOR LONG-TERM INTEGRATION

4.1 Introduction

In the previous chapter, the base contract model was developed for the e-tailer supply chain to share operational costs among the players and create a cooperative decision-making approach to optimise supply chain costs and enable true cost revelation. The analysis of the proposed contract design revealed that cost-sharing derives cost optimisation for the overall supply chain and eliminates asymmetric information with the revelation principle. This chapter investigates whether extending the proposed base cost-sharing contract by considering dynamic contract aspects can achieve long-term integration among partners in e-tailer supply chains while eliminating issues of asymmetric information and cost optimisation. As with the model discussed in the previous chapter, the cooperative decision-making approach is considered in this scenario, with the dynamic contract related aspects discussed in the literature review chapter included in the model.

4.2 Previous Dynamic Contract Models

In Chapter 2, dynamic contract aspects were discussed in detail, while identifying the limitations of the previous literature. Researchers have paid little attention to the impact of dynamic stability and re-negotiation on achieving long-term integration based on dynamic contracts in supply chain management. More studies are also required to analyse the impact of asymmetric information on long-term contracts, which is the focal point of this chapter. In this section, several important dynamic contracts related to the model extension discussed in this chapter are analysed comprehensively.

4.2.1 Dynamic Contracts with Information Asymmetry Issues and Re-negotiation

As the operational scenario in this research includes asymmetric cost information in both upstream and downstream of the supply chain, the dynamic contracts that explored asymmetric information were analysed first in detail. This was followed by an analysis of the impact of re-negotiation.

An optimal multi-period contract could be a repetition of a single period optimal contract when the utility functions do not involve time preferences (Mueller & Trost 2018). As discussed by Deb and Said (2015), when a contract is created at an early stage of a principal-agent relationship, when less informational disadvantage exists, the principal can create effective outcomes with price discrimination and informational rent. When a contract is generated within an adverse selection environment, the parties have the advantage of using the information revealed within the first period of contract for the later periods. This is distinct from a moral hazard problem, which does not reveal the information with repetition (Macho-Stadler & Pérez-Castrillo 2001). Intertemporal moral hazard has more complexity, as it is caused by the increasing private information with repetition and the uncontrollable effect generated based on the agent's effort (Salanié 2005). Therefore, creating incentives in a dynamic contract is a crucial but complex task (Williams 2015).

Mobini, van den Heuvel and Wagelmans (2019) discussed a multi-period contract in a two-echelon supply chain in which the retailer's cost and demand were taken as asymmetric information. The asymmetric information setting was addressed using a screening contract approach in which a menu of contract was presented to the retailer, assuming that the retailer has N types of probabilities. These authors designed a bi-level optimisation problem and solved it as a mixed integer programming (MIP) problem, converting it to a single-level variant. The findings of this study derive the optimal side payment levels that could achieve optimal lot-sizing and supply chain coordination. However, Mobini, van den Heuvel and Wagelmans (2019) did not consider how long-term integration can be achieved through designing multi-period contracts, although they did consider inventory related constraints in their models.

De Giovanni (2017) designed a dynamic game between a manufacturer and retailer in a closed-loop supply chain, considering an infinite planning horizon and the greening effort of the players in achieving supply chain coordination. This author analysed both symmetric and asymmetric scenarios in a profit-sharing contract based on two settings, endogenous and exogenous incentive levels, in a Stackelberg game. In the endogenous incentive scenario, the asymmetric information was considered as the profit-sharing level. The findings revealed that both players preferred no incentives in the endogenous incentive setting, as the manufacturer gains an information advantage, and it de-motivates the retailer from investing more in greening efforts. In contrast, both players prefer profit-sharing contract implementation when the incentive levels are common knowledge. Therefore, the findings of this study emphasise

that having symmetric information in multi-period contracts can lead to improved outcomes for supply chain members.

Gao (2015) designed an optimal revenue-sharing contract in which the retailer's private cost information evolved over time and was subject to disruption shocks. This study focused on designing dynamic contracts when supply chain risks are involved. Sequential incentive compatibility and individual rationality were considered in formulating the optimal contract between the buyer and supplier, with variable terms and fixed costs used in the contract. Gao (2015) concluded that asymmetric information only negatively affects in the initial period and, therefore, committing to a long-term contract can help mitigate the impact of hidden information in the next periods. However, when the asymmetric information changes in each period, unlike evolving, as discussed by Gao (2015), further examination is needed to determine how a dynamic contract can be proposed.

Taylor and Plambeck (2007) proposed a relational contract to encourage the supplier to invest in their capacity to achieve supply chain coordination. In this context, the demand is observed privately by the buyer, and the capacity is known privately by the supplier, and a repeated newsvendor model is developed. This study assumed the production costs are negligible, with only the capacity investment costs considered. The repeated contract induces players to formulate an informal contract. The paper concludes that having properly structured informal contracts can prevent the buyer from monitoring the supplier's capacity development.

In the study of Brusset and Agrell (2015), a two-period contract was developed considering the investment costs of a two-echelon supply chain to derive coordination. The manufacturer and supplier in this model invest in relationship specific assets (RSA) when the contract starts in each period. If the manufacturer rejects the contract, supplier has the capacity to trade it with a third party and then re-negotiation for the next period starts. This analysis elaborates on how the supplier and manufacturer can gain from hiding truthful information and how this affects the overall performance of the supply chain. Bondareva and Pinker (2018) studied the quality enforcement levels using a cost-sharing contract in which a buyer commits to the contract while the supplier may not do the same. The effort level of the supplier is taken as a key determinant, with financial penalties used to evaluate the re-negotiation. Through the financial penalties, supplier achieved compliance at the contract termination. In both these studies, re-negotiation is considered possible at contract termination at the end of each period. While Bondareva and Pinker (2018) studied re-negotiation based on financial penalties, which also enable high

quality levels, Brusset and Agrell (2015) examined the impact of re-negotiation with a new business partner.

Mobini, van den Heuvel and Wagelmans (2019) studied the multi-period contract model with an approach to the method that has also been applied in this study. The main aim of this chapter is to outline the development of the multi-period contract. It was designed to enable long-term integration and eliminate the potential of re-negotiation in the interim periods of the contract, thus also eliminating re-negotiation costs to the e-tailer and the extra effort of finding more supply chain partners to continue successful operations. Accordingly, the formulation of the dynamic contract model is discussed as follows.

4.3 Problem Description and Model Formulation

4.3.1 Dynamic Operational Setting of the Model

The same operational model illustrated in Figure 3.1 was applied in developing the dynamic contract model. As the focus is on dynamic operational aspects, the multi-period operational setting of the e-tailer supply chain operation is considered, as illustrated in Figure 4.1.

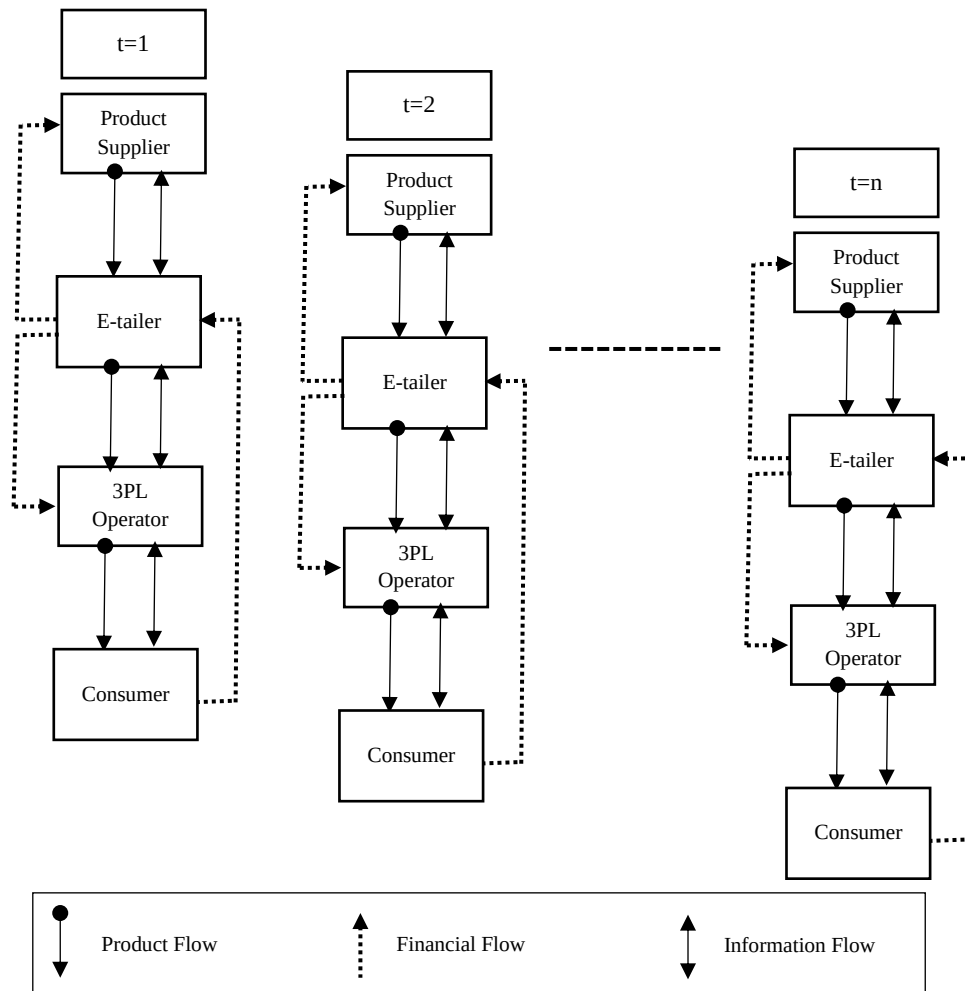


Figure 4.1 E-commerce supply chain flows and links in multi-period operations

This chapter discusses the three-player integration of the above e-tailer supply chain by minimising overall supply chain costs. This creates a better competitive strategy for expanding the customer base and market share in the long-term. The group rationality of this contract is achieved by minimising the overall supply chain cost, and the individual rationality is achieved by minimising the total individual costs of the players over time.

4.3.2 Assumptions and Notations of the Proposed Model

The model assumptions applied in this chapter are similar to those presented in Chapter 3. For easy reference, the notations of the model and all constraints are repeated in this chapter, along with the newly added constraints and modifications.

4.3.2.1 Notations for the Proposed Model

Table 4.1 Notations of the dynamic contract model

Notation	Description
Sets and indexes	
i	Time period (1,2,3.....n)
j	Players (1: product supplier, 2: e-tailer, 3: 3PL operator)
Parameters	
UC_i	The unit cost of production of supplier for the period i
α_i	Percentage increment/decrement of inventory holding cost of product supplier in the period i
HC_i	The unit cost of holding inventory at the e-tailer in period i
DC_i	The unit cost of distribution at the 3PL operator in period i
D_i	Customer demand in the period i
II_j	Initial Inventory of player j
W_{capj}	Maximum capacity of the warehouse of player j
M_{cap}	Maximum capacity of manufacturing of the product supplier
θ	Probability of occurring higher operational costs with the product supplier
γ	Probability of occurring higher operational costs with the 3PL operator
W_j	Weight allocation of player j
$P_{i,j}$	The fixed unit price paid by the e-tailer to the player j ; $j \neq 2$ in each period i
δ_j	Discount rate of player j
Decision variables	
q_i	Unit quantity produced by the supplier in the period i
d_i	Units demanded by the e-tailer from the supplier in the period i
$s_{i,j}$	Inventory level of each period i of the player j
$k_{i,j}^{\%}$	The fraction of cost-sharing in % for player j ; ($j \neq 2$)
$SC_{i,j}$	Shared costs by the e-tailer of the other players j
Other variables	
c_j	Individual total costs of the player j

4.3.3 Dynamic Cost-Sharing Contract

The main aim of this model is to enable long-term integration while optimising supply chain costs and asymmetric information. To achieve this outcome, maintaining dynamic stability of the contract is essential. Therefore, dynamically consistent incentive constraints are introduced into the model. These constraints are developed to ensure that players remain across the entire contract period, as discussed by Yeung and Petrosyan (2006), and Yeung et al. (2019). In order to achieve effective long-term integration among the supply chain players, the discounting approach is also incorporated into the contract model, considering that the supply chain members have the opportunity to make decisions based on future values of the operations (Zhao et al. 2014). To resolve information asymmetry issues, the screening contract approach with the revelation principle, as discussed in Chapter 3 is incorporated into this model as the e-tailer must be aware of the actual operational costs of his upstream and downstream to create a competitive pricing strategy for consumers.

A similar approach, as discussed in Chapter 3, was used to design the menu of contracts, sharing a fraction of the operational costs and the fixed unit costs for each period of the contract. Cost-sharing with fixed unit costs has been little discussed in the literature. However, Jørgensen (2011) did adopt this approach in a dynamic contract model. Then, dynamic consistency was combined into the proposed dynamic contract model in this study by creating consistent cost-sharing in each period of the contract to establish the dynamic stability of the contract model. The sequence of the game when the contract is offered to the product supplier is shown in Figure 4.2.

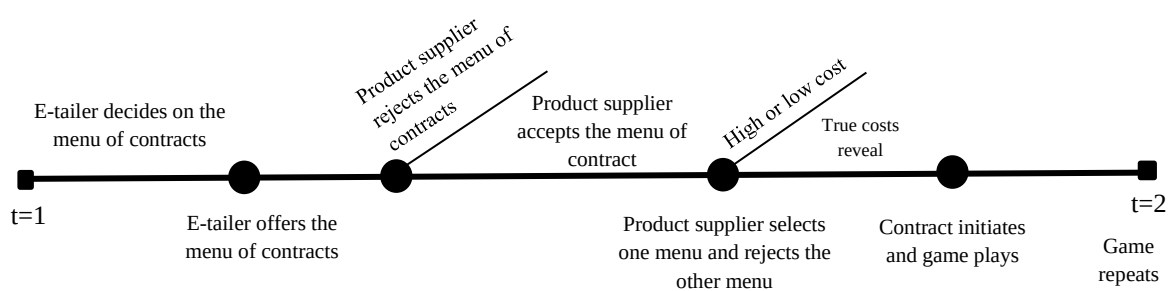


Figure 4.2 Sequence of the game with the product supplier

The order of play illustrated in Figure 4.2 follows the general rules set under screening contracts in game theory (Cachon & Netessine 2006; Rasmusen 2007). The cost-sharing contract is initiated by the e-tailer, as the dominant and less-informed party. The e-tailer initiates the game at period $t=1$ by offering a cost-sharing contract to the product supplier and the 3PL operator. The e-tailer does not observe the actual operational costs of either player. The contract is

offered in the form of $(sc_{i,j}, P_{i,j})$; where $sc_{i,j}$ is the cost shared by the e-tailer with either the product supplier or the 3PL operator and $P_{i,j}$ is the fixed ordering cost or the service fee paid by the e-tailer to the product supplier or the 3PL operator, respectively. The product supplier/3PL operator either accepts or rejects the contract. If the product supplier/3PL operator rejects the contract, the game ends. If the product supplier/3PL operator accepts the contract, they select the relevant menu of contract according to their actual operational costs, denoted as $\{\overline{sc_{i,j}}, \underline{P_{i,j}}\}, \{\underline{sc_{i,j}}, \overline{P_{i,j}}\}$. The game ends for $t=1$ and then starts again in $t=2$. The process is repeated until the end of the contract period $t=n$.

4.3.4 Modelling the Objective Function

The objective of the dynamic contract is also to minimise the total cost of the e-commerce supply chain, which consists of the cost of the product supplier, e-tailer and the 3PL operator, where z is the total supply chain cost and c_j is the individual costs of the player for all players j .

$$\text{Minimize } z = \sum_{\forall j} W_j \cdot (c_j) : \forall j \quad [4.1]$$

(i) The individual cost objectives

$$c_1 = \sum_{\forall i} \left[\frac{1}{(1+\delta_1)^i} \left\{ \left(\theta(\overline{UC_i}) + (1-\theta)(\underline{UC_i}) \right) \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) - \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) \right. \right. \\ \left. \left. - \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \right\} \right] \quad [4.2]$$

$$c_2 = \sum_{\forall i} \left[\frac{1}{(1+\delta_2)^i} \left\{ HC_i(s_{i,2} + s_{i-1,2}) / 2 + \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) + \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \right. \right. \\ \left. \left. + \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) + \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \right\} \right] \quad [4.3]$$

$$c_3 = \sum_{\forall i} \left[\frac{1}{(1+\delta_3)^i} \left\{ \left(\gamma(\overline{DC_i}) + (1-\gamma)(\underline{DC_i}) \right) \cdot D_i - \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) \right. \right. \\ \left. \left. - \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \right\} \right] \quad [4.4]$$

The total cost of the supplier (c_1) consists of the discounted summation of production and inventory holding cost of each period i , with the sharing cost received from the e-tailer and the total fixed price paid by the e-tailer. The cost of the e-tailer (c_2) consists of the discounted total inventory holding costs at his warehouse, along with the cost-sharing and total fixed price paid to the product supplier and 3PL operator. The cost of the 3PL operator (c_3) includes the discounted total distribution cost of the units demanded by the customer in each period i with the benefit received from the contract through sharing cost and with the total fixed price for the

units paid by the e-tailer. In all these total cost functions, the index i (i.e., time periods) is employed to represent the long-term effect of the operation. By including the discounted summation, the dynamic aspect is determined for long-term multi-period operations.

4.3.5 Constraints of the Model

The following constraints are developed in the model.

(ii) Incentive compatibility constraints

$$\overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \overline{P}_{i,1} \cdot d_i \geq \underline{UC} \cdot q_i + \alpha_i \cdot \underline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \underline{P}_{i,1} \cdot d_i; \forall_i, i < n \quad [4.5]$$

$$\underline{UC}_i \cdot q_i + \alpha_i \cdot \underline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \underline{P}_{i,1} \cdot d_i \geq \overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \overline{P}_{i,1} \cdot d_i; \forall_i, i < n \quad [4.6]$$

$$\overline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \overline{P}_{i,3} \cdot D_i \geq \underline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i; \forall_i \quad [4.7]$$

$$\underline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \geq \overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \overline{P}_{i,3} \cdot D_i; \forall_i \quad [4.8]$$

(iii) Individual rationality constraints

$$\overline{sc}_{i,1} \leq k_{i,1}^{\%} (\theta \cdot (\overline{UC}_i (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2)) + (1 - \theta) \cdot (\underline{UC}_i (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2))) \quad [4.9]$$

$$\overline{sc}_{i,3} \leq k_{i,3}^{\%} \cdot \{\gamma \cdot (\overline{DC}_i \cdot D_i) + (1 - \gamma) (\underline{DC}_i \cdot D_i)\} \quad [4.10]$$

$$\overline{sc}_{i,j} \geq \underline{sc}_{i,j} \geq 0; j \neq 2 \quad [4.11]$$

(iv) Consistency constraints

$$\frac{(\overline{sc}_{i,1})}{\left(\underline{UC}_i (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \right)} \leq \frac{(\overline{sc}_{i+1,1})}{\left(\underline{UC}_{i+1} (q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2) \right)}; i < n \quad [4.12]$$

$$\frac{(\overline{sc}_{i,1})}{\left(\underline{UC}_i (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \right)} \leq \frac{(\overline{sc}_{i+1,1})}{\left(\underline{UC}_{i+1} (q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2) \right)}; i < n \quad [4.13]$$

$$\frac{(\overline{sc}_{i,3})}{\left(\underline{DC}_i \cdot D_i \right)} \leq \frac{(\overline{sc}_{i+1,3})}{\left(\underline{DC}_{i+1} \cdot D_{i+1} \right)}; i < n \quad [4.14]$$

$$\frac{(\overline{sc}_{i,3})}{\left(\underline{DC}_i \cdot D_i \right)} \leq \frac{(\overline{sc}_{i+1,3})}{\left(\underline{DC}_{i+1} \cdot D_{i+1} \right)}; i < n \quad [4.15]$$

(v) Operational constraints

$$s_{1,1} = q_1 - d_1 + II_1 \quad [4.16]$$

$$s_{1,2} = d_1 - D_i + II_2 \quad [4.17]$$

$$s_{i,1} = q_i - d_i + s_{i-1,1} : t > i > 1 \quad [4.18]$$

$$s_{i,2} = d_i - D_i + s_{i-1,2} : t > i > 1 \quad [4.19]$$

$$SS_j \leq s_{i+1,j} : \forall_i, \forall_j; t > i > 1 \quad [4.20]$$

$$s_{i+1,j} \leq W_{capj} : \forall_i, \forall_j \quad [4.21]$$

$$q_i \leq M_{cap} : \forall_i \quad [4.22]$$

(vi) Non-negativity constraints

$$q_i \geq 0; d_i \geq 0; s_{i,j} \geq 0; sc_{i,j} \geq 0, c_j \geq 0 \quad [4.23]$$

The constraints denoted by Eq. (4.5), Eq. (4.6), Eq. (4.7) and Eq. (4.8) represent the incentive compatibility constraints. The individual rationality constraints of the product supplier and the 3PL operator are represented by Eq. (4.9) and Eq. (4.10). Eq. (4.11) ensures that the sharing cost of the lower cost status of the product supplier or the 3PL operator does not exceed the sharing cost offered in the higher cost state. This generates the maximum margin that the sharing cost could reach and, therefore, ensures that a higher benefit is received with a higher cost share.

Eq. (4.12), Eq. (4.13), Eq. (4.14) and Eq. (4.15) represent the newly added consistency constraints of the dynamic contract for the product supplier and the 3PL operator. These constraints explain that the shared cost proportion received in the current period must be equivalent or higher than the shared cost proportion received in the previous period. This ensures that both the product supplier and the 3PL operator have consistent incentives to remain in the contract until the end of the time period being considered. These constraints are proposed to ensure that neither the product supplier nor the 3PL operator has any incentive to re-negotiate the contract terms until the end of the contract period. Hence, these constraints have the potential to maintain re-negotiation proofness in the contract model.

The operational constraints that include inventory and capacity levels are denoted by Eq. (4.16) to Eq. (4.22), similar to those applied in the base contract model discussed in Chapter 3. Eq. (4.23) describes the non-negativity constraints of the decision variables. The operational

constraints that include inventory and capacity levels are denoted by Eq. (4.16) to Eq. (4.22) as similar to the base contract model in Chapter 3. Eq. (4.23) describes the non-negativity constraints of the decision variables.

The model objective is linear, and the model constraints include non-linear constraints. Therefore, the overall model is an NLP problem. To derive some analytical solutions, the following propositions were developed based on the optimality conditions of the model, derived based on Karush-Kuhn-Tucker (KKT) necessary conditions (see Appendix E).

Proposition 1: *The optimal inventory levels of the product supplier and the e-tailer depend on the warehouse capacity level (W_{capj}), and the manufacturing capacity (M_{cap}) levels when the q_i and $s_{i+1,j}$ have optimal values with binding solutions: ($q_i = M_{cap}, s_{i+1,j} = W_{capj}$).*

(a) When the warehouse capacity and the manufacturing capacity increases, it will increase the inventory levels of the product supplier. The optimal inventory of the product supplier is given below in Eq. (4.24).

$$s_{i,1} = \frac{(\underline{UC}_i - \overline{UC}_i) \{2M_{cap} + W_{cap}\} + 2(\overline{P}_i - \underline{P}_i) \{M_{cap} + W_{cap}\}}{(\underline{UC}_i - \overline{UC}_i) + 2(\overline{P}_i - \underline{P}_i)} \quad [4.24]$$

(b) Even though demand is known, it is evident that when the demand and the warehouse capacity of the e-tailer increases, the e-tailer's inventory level increases. However, it decreases when the manufacturing capacity increases. The optimal inventory of the e-tailer is given by Eq. (4.25):

$$s_{i,2} = D_i + W_{cap,2} - \frac{M_{cap} \{3(\underline{UC}_i - \overline{UC}_i) + 4(\overline{P}_{i,1} - \underline{P}_{i,1})\}}{(\underline{UC}_i - \overline{UC}_i) + 2(\overline{P}_{i,1} - \underline{P}_{i,1})} \quad [4.25]$$

The e-tailer's optimal inventory level also depends on the product demand.

For the proof of Proposition 1, see Appendix E.

Proposition 2: As $\overline{SC_{i,j}} \geq \underline{SC_{i,j}}$ and is not binding, the cost-sharing percentage($k_{i,j}^{\%}$) is the determining factor between the limits of the higher and lower sharing cost of the players. (See Appendix E):

(a) For the product supplier's sharing costs:

$$\overline{SC_{i,1}} \geq \underline{SC_{i,1}};$$

$$\underline{SC_{i,1}} = \frac{k_{i,1}^{\%} \left\{ (1 + \alpha_i) (\underline{UC_i} - \overline{UC_i}) (W_{cap,1} + 2M_{cap}) + (4 + \alpha_i) (\overline{P_{i,1}} - \underline{P_{i,1}}) \right\} (\theta \cdot \overline{UC_i} + (1 - \theta) \underline{UC_i})}{2(\underline{UC_i} - \overline{UC_i}) + 4(\overline{P_{i,1}} - \underline{P_{i,1}})} \quad [4.26]$$

$$\overline{SC_{i,1}} = \frac{\left(\underline{UC_i} - \overline{UC_i} \right) \left\{ 2M_{cap} (4 + \alpha_i) + W_{cap,1} (2 + \alpha_i) \right\} + 4(\overline{P_{i,1}} - \underline{P_{i,1}}) (3M_{cap} + W_{cap,1}) + k_{i,1}^{\%} (\theta \cdot \overline{UC_i} + (1 - \theta) \underline{UC_i}) \left\{ (\underline{UC_i} - \overline{UC_i}) (1 + \alpha_i) (W_{cap,1} + 2M_{cap}) + (\overline{P_{i,1}} - \underline{P_{i,1}}) (4 + \alpha_i) \right\}}{2(\underline{UC_i} - \overline{UC_i}) + 4(\overline{P_{i,1}} - \underline{P_{i,1}})} \quad [4.27]$$

(b) For the 3PL operator's sharing costs:

$$\overline{SC_{i,3}} \geq \underline{SC_{i,3}};$$

$$\underline{SC_{i,3}} = k_{i,3}^{\%} \left\{ \gamma \cdot \overline{DC_i} + (1 - \gamma) \underline{DC_i} \right\} D_i \quad [4.28]$$

$$\overline{SC_{i,3}} = D_i \left\{ (\overline{DC_i} - \underline{DC_i}) - (\overline{P_{i,3}} - \underline{P_{i,3}}) + K_{\%,3} \left\{ \gamma \cdot \overline{DC_i} + (1 - \gamma) \underline{DC_i} \right\} \right\} \quad [4.29]$$

Even though the sharing costs depend on the manufacturing capacity, warehousing capacity, unit operational costs and price, in both these scenarios, $k_{i,j}^{\%}$ associated with the cost-sharing determines the sharing value received by each supply chain member.

4.4 Solution Approach

As with the previous model solving approach, the dynamic contract model was solved as a MOO problem with a weighted sum method. This method is the most well-known strategy of MOO in deriving Pareto outcomes (Margolis et al. 2018) and also the approach used based on cooperative decision-making. To further elaborate on the solution approach of the model, a step-by-step solution approach of this model is given as follows:

Step 1: Input model parameters $UC_i, HC_i, DC_i, \Pi_j, W_{capj}, M_{cap}, D_i, P_{i,j}, \delta_j, W_j, \theta, \gamma$ and α_i .

For UC_i and DC_i , lower and upper bound parameters are defined as $\overline{UC_i}, \underline{UC_i}, \overline{DC_i}$ and $\underline{DC_i}$.

Similarly, for $P_{i,j}$ lower and upper bound are defined for each player as $\overline{P_{i,1}}, \underline{P_{i,1}}, \overline{P_{i,3}}$ and $\underline{P_{i,3}}$

Step 2: Objective functions and the constraints from [4.5] to [4.23] are included in the model, and it is solved for $t=1$.

As indicated in Proposition 2, $k_{i,j}^{\%}$ is one of the critical decision variables, which defines the values of $sc_{i,j}$ and, therefore, supports the derivation of minimal values of the objective functions of each player, as well as the overall supply chain. This is verified as $sc_{i,j}$ is associated with a negative sign in the objective functions of the product supplier and 3PL operator. However, it is associated with a positive sign for the e-tailer. Therefore, a win-win trade-off solution needs to be found to generate a minimal outcome for z . The constraints of incentive compatibility, participation and consistency relate to $sc_{i,j}$, and operational constraints determine the optimal $q_i, d_i, s_{i,j}$.

Step 3: Step 2 is repeated for all periods of the model ($t=n$)

Step 4: The solution outcomes derived after step 4 are amalgamated into C_j , and the weighted sum is calculated with W_j and C_j .

Step 5: The optimal values for decision variables, $q_i, d_i, s_{i,j}, sc_{i,j}, k_{i,j}^{\%}$ are obtained and, accordingly, optimal supply chain costs z and C_j are derived.

The optimisation solver tool, BARON, was used to carry out this solution process.

4.5 Numerical Analysis and Result Discussion

4.5.1 Numerical Data

The model outcomes were illustrated through numerical experiments. The same data set from Ragsdale (2017) was used in this model to indicate the product supplier's manufacturing and inventory costs as this data relates to a supply chain operational model in a similar operational context to the model proposed in this study. The additionally required data, which is not

available in Ragsdale (2017), was randomly generated using spreadsheet simulation considering discrete and normal distributions. In this model analysis, the demand data was changed to a normally distributed data set to analyse the impact of demand as well as the robustness of the model results. This would further validate the model. The AMPL model code, data file and run code of the dynamic cost-sharing model are presented in Appendix B.

The following assumptions were considered in this numerical illustration. Some of these assumptions have already used for the numerical analysis in Chapter 3. The probability of the e-tailer assuming that the product supplier and the 3PL operator have higher operational costs is considered as $\theta = 0.5$; $\gamma = 0.5$. The weights are allocated as: $W_1 = 0.3$; $W_2 = 0.4$; $W_3 = 0.3$, with a higher weight for the e-tailer as the initiator of the contract. Discount rate values are taken as 10%, where $\delta_1 = 0.1$; $\delta_2 = 0.1$; $\delta_3 = 0.1$ assuming all players have similar financial situations. The warehouse capacity of both the product supplier and the e-tailer is assumed to be equal and, hence, $MCAP = 10000$ and $WCAP_j = 6000$ are considered for all 12 periods of the contract and $II_1 = 2750$ and $II_2 = 2500$ for the initial inventory levels of this operational scenario.

Table 4.2 Data used for the numerical analysis of the dynamic contract model

Parameter	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12
$\overline{UC}_i$	240	250	260	280	280	260	260	280	250	240	280	260
$\underline{UC}_i$	200	190	200	190	200	200	200	180	190	200	190	190
α_i	0.005	0.015	0.005	0.010	0.015	0.020	0.005	0.010	0.015	0.005	0.010	0.015
D_i	5329	4991	4251	6070	8044	6310	6274	4257	3017	5016	4482	6960
HC_i	5.98	5.87	6.04	5.58	2.92	4.37	4.68	4.52	5.46	5.91	5.91	4.82
$\overline{DC}_i$	19.65	20.22	18.90	19.85	19.59	20.65	19.56	18.94	21.45	20.07	19.26	18.99
$\underline{DC}_i$	11.21	14.16	12.49	11.34	13.15	11.97	13.08	12.75	12.21	12.39	11.47	12.07
$\overline{P}_1$	85	100	105	110	110	95	95	110	90	85	110	95
$\underline{P}_1$	60	55	60	55	60	60	60	50	55	60	55	55
$\overline{P}_3$	10	9	10	10	10	10	10	8	9	10	9	9
$\underline{P}_3$	5	7	6	5	6	5	6	6	6	6	5	5

4.5.2 Computer Experiments

Computer experiments were conducted to derive model implications and test the validity of the model results. All experiments were performed in the NEOS server. As the proposed model is an NLP problem, it was executed in the optimisation solver tool BARON (4.14 version 2020), similar to the process conducted in the model execution described in Chapter 3 (Section 3.8).

4.5.3 Results Analysis

The BARON solver generated an optimal solution for the numerical data shown in Table 4.2. The cost-sharing contract ensures that making cooperative decisions generates optimal payoff in terms of cost minimisation in the long-term. One of the significant observations shown in Table 4.3 is that the lower sharing costs received by both the product supplier (i.e. $\underline{sc}_{i,1}$) and the 3PL operator (i.e. $\underline{sc}_{i,3}$) have comparatively low values in the optimal solution. This emphasises that neither the product supplier nor the 3PL operator would benefit from the cost-sharing contract if they have higher operational costs. This result encourages both of these players to maintain lower operational costs as it affects the costs of the overall supply chain operation. This outcome ensures the validity of the revelation principle, as neither player is motivated to declare false costs. Similar results were generated in the analysis discussed in Chapter 3, with both $\underline{sc}_{i,1}$ and $\underline{sc}_{i,3}$ receiving zero values. Therefore, this result reinforces the model outcomes and verifies the model validity for long-term operations.

Table 4.3 The optimal solution of the dynamic cost-sharing contract

Variables	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12
q_i	264	4806	5926	5568	6872	6310	6274	4257	3017	5016	4482	6960
d_i	2829	4992	4251	6070	8044	6310	6274	4257	3017	5016	4482	6960
$s_{i,1}$	185	0	1675	1173	0	0	0	0	0	0	0	0
$s_{i,2}$	0	0	0	0	0	0	0	0	0	0	0	0
$\overline{sc}_{i,1}$	59849	63865	164768	169055	148240	158679	159535	206697	311456	198076	208753	208800
$\overline{sc}_{i,3}$	18333	24700	25574	21316	19666	23233	25530	36593	49411	30218	31284	21239
$\underline{sc}_{i,1}$	0	10	5	0	0	15	0	0	20	25	0	0
$\underline{sc}_{i,3}$	0	24	0	10	37	11	25	0	0	30	11	29
$k_{i,1}^{\%}$	68%	69%	74%	70%	67%	70%	70%	72%	78%	71%	72%	71%
$k_{i,3}^{\%}$	75%	77%	80%	75%	73%	75%	76%	85%	99%	80%	83%	74%
c_1	4191160											
c_2	3656080											
c_3	223540											
z	2786840											

The optimal values of the cost-sharing fraction in each period of the contract are provided in Table 4.3. The cost-sharing percentage of the product supplier is $k_{i,1}^{\%} \geq 68\%$, whereas, for the 3PL operator, it is $k_{i,3}^{\%} \geq 73\%$ for all periods of the contract. $k_{i,1}^{\%}$ and $k_{i,3}^{\%}$ determine the optimal cost-sharing percentages in each period of the proposed cost-sharing contract, which is an important determinant, as stated in Proposition 2. In this current study, the optimal cost-sharing

percentages were determined with asymmetric information, along with the consistency constraints, to assess the consistent incentives throughout the contract period.

The operational decisions were also analysed based on the results shown in Table 4.3. This shows that the e-tailer's inventory levels do not have a significant impact as the e-tailer has zero inventory levels. Therefore, the e-tailer has the potential to work with a zero-inventory policy when the e-tailer knows the demand before initiating the contract.

4.5.4 Comparison of the Dynamic Cost-Sharing Contract with and without Consistency Constraints

4.5.4.1 Numerical Results of the Base Cost-sharing Contract (Discounted Model – No Consistency Constraints)

To evaluate the effectiveness of consistency constraints, the dynamic consistency constraints were excluded from the dynamic cost-sharing contract model, and computer experiments were performed. The same data set (see Section 4.5.1) was used for this analysis. Table 4.4 illustrates the optimal solution for the base cost-sharing contract (discounted model without consistency constraints).

Table 4.4 The optimal solution of the base cost-sharing contract

Variables	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8	Period 9	Period 10	Period 11	Period 12
q_i	264	4806	4251	6070	8044	6310	6274	4257	3017	5016	4482	6960
d_i	2829	4991	4251	6070	8044	6310	6274	4257	3017	5016	4482	0
$s_{i,1}$	185	0	0	0	0	0	0	0	0	0	0	0
$s_{i,2}$	0	0	0	0	0	0	0	0	0	0	0	0
$\overline{SC}_{i,1}$	59849	63855	63767	212465	241333	157754	156868	170291	75440	75247	156871	208800
$\overline{SC}_{i,3}$	18332	20266	10245	21307	19628	23221	15561	17838	18830	18461	16987	20323
$\underline{SC}_{i,1}$	0	0	0	0	0	0	0	0	0	0	0	0
$\underline{SC}_{i,3}$	0	0	0	0	0	0	0	0	0	0	0	0
$k_{i,1}^{\%}$	68%	68%	68%	69%	69%	69%	69%	68%	69%	69%	71%	69%
$k_{i,3}^{\%}$	70%	74%	72%	75%	72%	76%	73%	47%	68%	58%	76%	71%
c_1	4237620											
c_2	3543600											
c_3	249530											
z	2763580											

The sharing costs and the cost-sharing percentage values have changed in the base cost-sharing contract (discounted model - no consistency constraints) compared to the results of the dynamic cost-sharing contract (with consistency constraints). However, the lower shared values received by both the product supplier and the 3PL operator indicate zero values throughout the contract period in this scenario, showing similar results to those previously generated in this study. To analyse the impact of the consistency constraints, the optimal solutions of both contracts were analysed further, as discussed below.

4.5.4.2 Dynamic Consistency of the Incentives

As discussed, in dynamic contracts, the optimal payoff received in the cost-sharing contract must remain optimal throughout the total contract period to ensure that none of the players deviates from the original contract. If none of the players has sufficient incentives in future periods of the contract, there is no assurance that these players will continue to remain in the contract. The results of $k_{i,1}^{\%}$ and $k_{i,3}^{\%}$ with the dynamic contract (with consistency constraints) and the base-cost sharing contract (discounted model - no consistency constraints) were compared to derive the impact of consistency constraints in the multi-period contract (see Figure 4.3 and Figure 4.4).

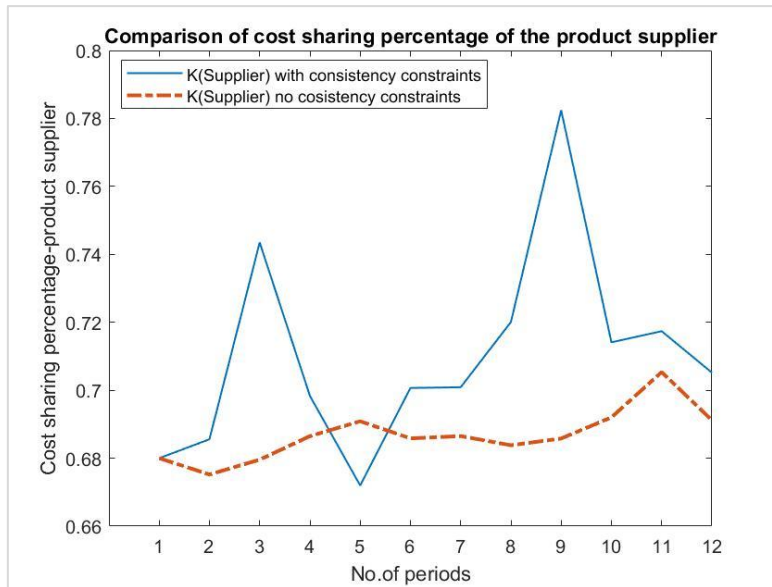


Figure 4.3 Comparison of the cost-sharing percentage (%) of the product supplier (with and without consistency constraints)

In the case of the product supplier, consistency constraints deliver higher cost-sharing levels except in period 5, compared to the base cost-sharing contract without the consistency constraints. This period has the highest demand and the highest number of productions, which

derives the highest operational costs and, therefore, it affects the portion of sharing costs. The results of the $k_{i,3}^{\%}$ also emphasise that the 3PL operator receives a higher cost-sharing percentage in all periods compared to the base cost-sharing contract with no consistency constraints (see Figure 4.4).

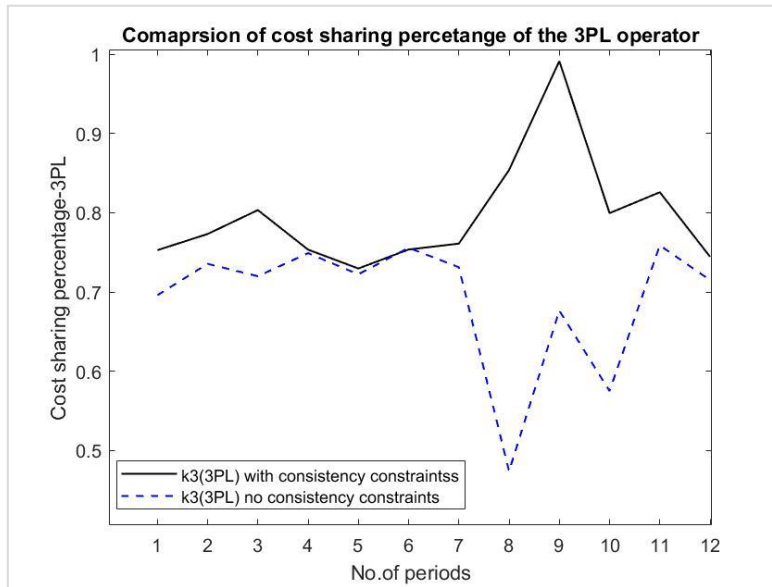


Figure 4.4 Comparison of the cost-sharing percentage (%) of the 3PL operator (with and without consistency constraints)

The results indicate that the 3PL operator receives a higher incentive in terms of shared costs with the consistency constraints than in the contract scenario without the consistency constraints.

The outcomes shown in both Figure 4.3 and 4.4 ensure that the consistency constraints motivate the players to engage in the contract for the long-term. As a result, the players will not consider re-negotiation within the interim periods of the contract. Hence, the proposed dynamic cost-sharing contract enables re-negotiation proofness within a long-term operation.

4.5.4.3 Overall Cost Comparison of the Dynamic Contracts (Including and Excluding Consistency Constraints)

The costs of individual players and the overall supply chain with the dynamic contract with and without consistency constraints were analysed to identify how consistency constraints affect the costs of this operation.

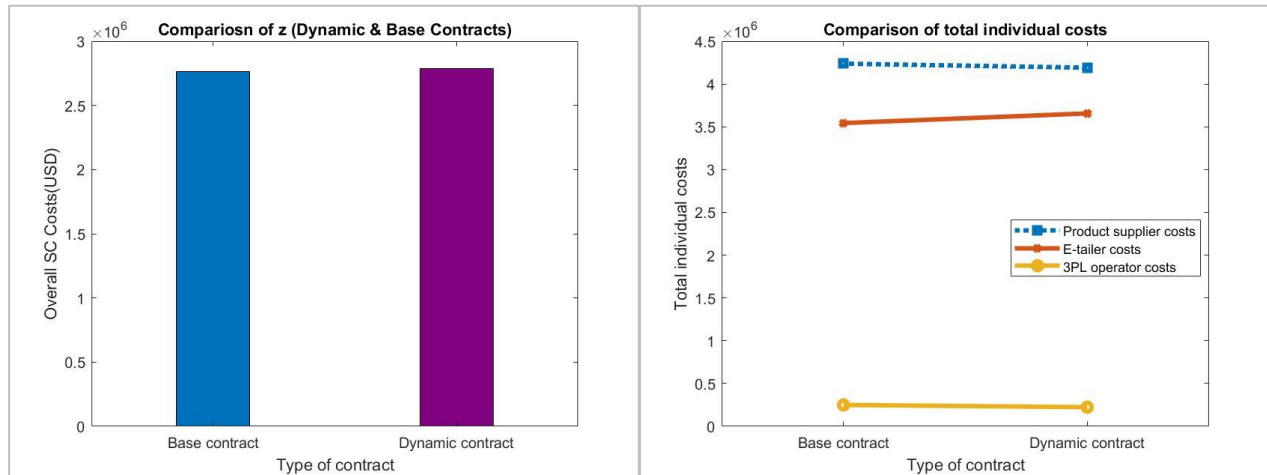


Figure 4.5 Comparison of the supply chain costs with and without the consistency constraints

The dynamic cost-sharing contract delivers reduced costs for the product supplier and 3PL operators by 1% and 12% respectively. However, the overall supply chain costs (z) increased by 1% (see Figure 4.5). This outcome is generated due to the increased level of incentives delivered through consistency constraints. As the main objective of the proposed dynamic contract is to maintain long-term integration among the players, it is fulfilled as the incentive portions are increased, and the individual costs are reduced compared to the base cost-sharing contract (discounted model - no consistency constraints).

Therefore, ensuring that the players receive consistent incentives over time is imperative when a dynamic contract is designed for the time-dependent e-commerce supply chain operational scenario. It ensures that all parties remain within the contract over time.

4.5.5 Comparison of the Dynamic Contract with the No Contract Operational Model (Benchmark Model)

To further test the validity of the dynamic cost-sharing contract, the contract outcomes were compared with the de-centralised operation without any contract elements. The fixed price paid by the e-tailer was taken into the no-contract operational model as the e-tailer has to pay for the services of the product supplier and the 3PL operator in a typical operational setting. Furthermore, as the contract is designed for 12 periods in both scenarios, the discount rate was

incorporated into the benchmark model without any cost-sharing contract elements. The objective function of the operational model is as follows:

$$\text{Minimize } z' = \sum_{\forall_j} (c_j) : \forall_j \quad [4.30]$$

(i) *The individual cost objectives with higher costs scenario*

$$c'_{1h} = \sum_{\forall_i} \left[1/(1+\delta_1)^i \left\{ (\overline{UC}_i) (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1})/2) - (\overline{P}_{i,1}) \cdot d_i \right\} \right] \quad [4.31]$$

$$c'_{2h} = \sum_{\forall_i} \left[(1/(1+\delta_2))^i \left\{ HC_i(s_{i,2} + s_{i-1,2})/2 + (\overline{P}_{i,1}) \cdot d_i + (\overline{P}_{i,3}) \cdot D_i \right\} \right] \quad [4.32]$$

$$c'_{3h} = \sum_{\forall_i} \left[1/(1+\delta_3)^i \left\{ (\overline{DC}_i \cdot D_i) - (\overline{P}_{i,3}) \cdot D_i \right\} \right] \quad [4.33]$$

(ii) *The individual cost objectives with lower costs scenario*

$$c'_{1L} = \sum_{\forall_i} \left[1/(1+\delta_1)^i \left\{ (\underline{UC}_i) \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1})/2) - (\underline{P}_{i,1}) \cdot d_i \right\} \right] \quad [4.34]$$

$$c'_{2L} = \sum_{\forall_i} \left[(1/(1+\delta_2))^i \left\{ HC_i(s_{i,2} + s_{i-1,2})/2 + (\underline{P}_{i,1}) \cdot d_i + (\underline{P}_{i,3}) \cdot D_i \right\} \right] \quad [4.35]$$

$$c'_{3L} = \sum_{\forall_i} \left[1/(1+\delta_3)^i \left\{ (\underline{DC}_i) \cdot D_i - (\underline{P}_{i,3}) \cdot D_i \right\} \right] \quad [4.36]$$

The operational models were tested for lower operational cost and higher operational cost scenarios separately. The operational constraints denoted by Eq. (4.16) to (4.23) were included in each model testing of the numerical illustration. Eq (4.30) – (4.36) explain the total individual costs of the product supplier, 3PL operator and the e-tailer, similar to the decentralised model described in Chapter 3.

Figure 4.6 depicts the comparison of overall supply chain costs without the contract elements and with the contract elements.

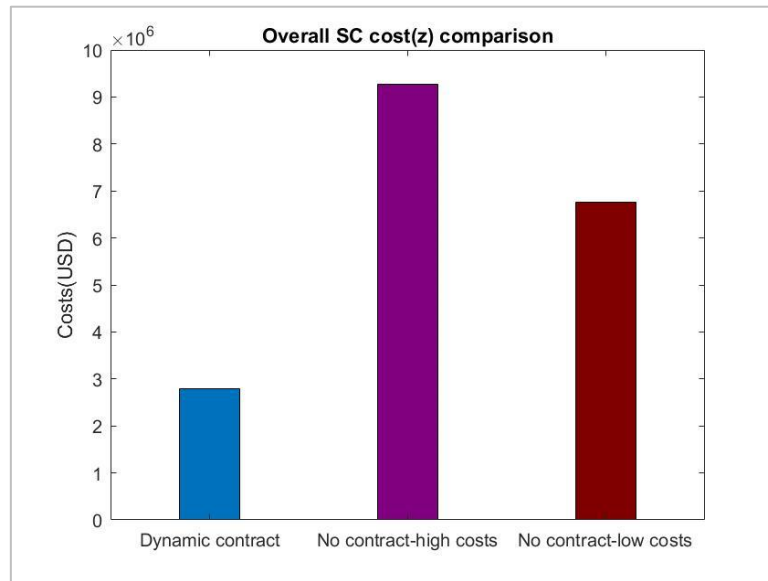


Figure 4.6 Overall supply chain cost comparison between contract and no-contract scenarios

The results indicate that the overall supply chain cost reduces significantly with the dynamic cost-sharing contract. This finding emphasises that dynamic cost-sharing delivers improved performance levels for the overall supply chain, as the members of this supply chain can derive competitive pricing for the customers based on the reduced supply chain costs. The individual supply chain costs of each player were also compared, as shown in Figure 4.7. These results also highlight that the dynamic cost-sharing contract derives significantly reduced supply chain costs for the product supplier and the 3PL operator.

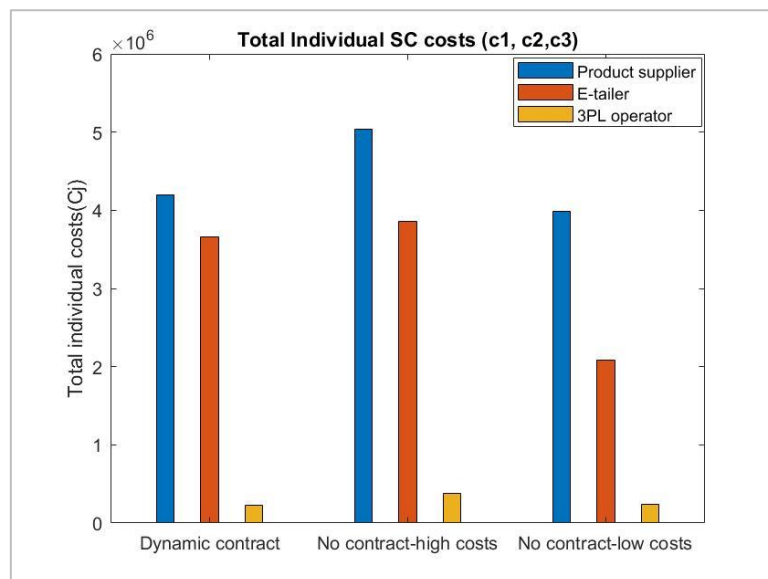


Figure 4.7 Individual total costs comparison between contract and no-contract scenarios

The individual total costs of the 3PL operator (c_3) reduced significantly, whereas the total costs of the product supplier (c_1) reduced by 20% compared to the higher costs and increased by 5% compared to the lower costs. E-tailer's costs reduced by 13% with the contract, compared to the higher cost level; but increased by 75% compared with the lower cost level with no contract. Nevertheless, lower operational costs cannot be expected in all periods of the operation. To further verify this outcome, in the next section, the further testing of the decentralised operation with the asymmetric information is discussed.

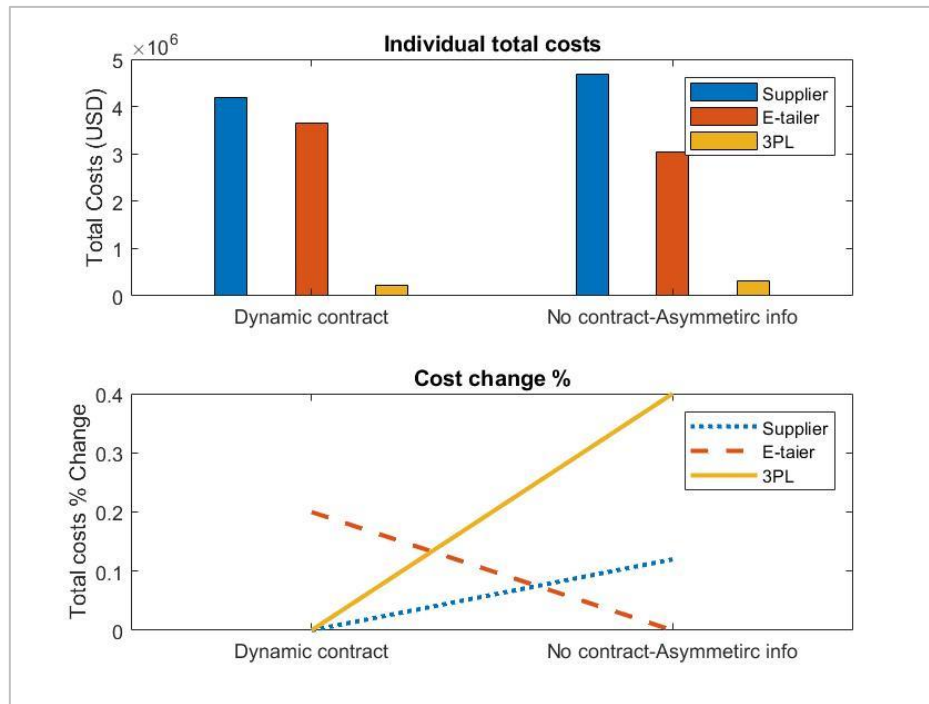


Figure 4.8 Comparison of total costs between dynamic contract and no-contract (asymmetric information)

The results shown in Figure 4.8 emphasise the impact of asymmetric information in the no-contract scenario, in which the individual total costs have changed. The product supplier's costs reduced by 12%, and the 3PL operator's costs reduced by 40% with the dynamic cost-sharing contract. Simultaneously, the dynamic contract increases the e-tailer's costs by 20% more than the no-contract operation with asymmetric information. The results also reveal that when the operational costs of the players are higher, the impact of asymmetric information is lower. For example, product supplier's costs are higher in this numerical illustration, and hence, the effect of asymmetric information is lower compared to that of the 3PL operator, whose operational costs are lower than the product supplier.

As the party who initiates the contract, the e-tailer has the opportunity to assess his decisions within this contract setting and opt for obtaining the group benefit of the contract rather than

the individual benefit, based on the cooperative game concepts. This decision creates significant improvements in long-term operations.

4.5.6 Sensitivity Analysis

In this section, the impact of contract parameters on the proposed cost-sharing contract is evaluated. The parameters θ, γ, W_j and D_i are considered in this analysis.

4.5.6.1 Impact of Parameter θ and γ on Supply Chain Costs

The curve fitting derived from linear interpolation indicates a proper fit of the results for parameters θ and γ . Accordingly, the overall supply chain cost (z) is at a minimum when the e-tailer assumes that both the product supplier and the 3PL operator have the lowest probability of having higher operational costs (i.e. $\theta = 0.1$ and $\gamma = 0.5$) (see Figure 4.9).

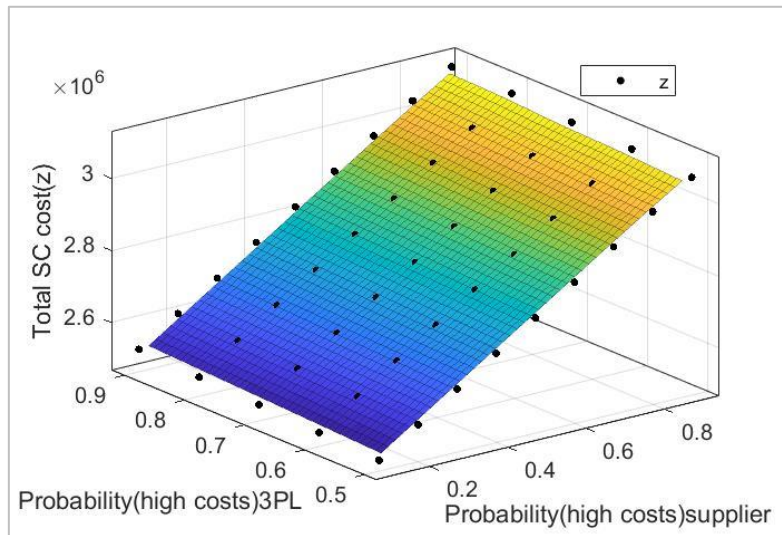


Figure 4.9 Impact of asymmetric costs on the overall supply chain cost (z)

The results of the sensitivity analysis are demonstrated in Table 4.5. The contract does not derive feasible solutions for $\gamma < 0.5$ scenarios for the given data set (See Table 4.5). However, the above result underlines the importance of maintaining lower operational costs in the upstream and downstream of the selected e-commerce supply chain. The results further emphasise that when the asymmetric information increases, the supply chain cost increases and the contract derives its lowest z when the probability associated with the asymmetric information of the product supplier and the 3PL operator are at their lowest levels. Similar results were generated from the base cost-sharing contract discussed in Chapter 3.

Table 4.5 Results of the sensitivity analysis between asymmetric information (θ and γ) and supply chain costs

θ	γ	c_1	c_2	c_3	z
0.1	0.5	3587510	3385830	223540	2497640
0.1	0.6	3587510	3382900	253679	2505520
0.1	0.7	3587510	3379980	283819	2513390
0.1	0.8	3587510	3377050	313958	2521260
0.1	0.9	3587510	3374130	344097	2529130
0.2	0.5	3669820	3505580	223540	2570240
0.2	0.6	3669820	3502660	253679	2578110
0.2	0.7	3669820	3499730	283819	2585980
0.2	0.8	3669820	3496810	313958	2593860
0.2	0.9	3669820	3493890	344097	2601730
0.3	0.5	3831700	3564950	223540	2642550
0.3	0.6	3831700	3562030	253679	2650420
0.3	0.7	3831700	3559100	283819	2658300
0.3	0.8	3831700	3556180	313958	2666170
0.3	0.9	3831700	3553250	344097	2674040
0.4	0.5	4009910	3611690	223540	2714710
0.4	0.6	4009910	3608760	253679	2722580
0.4	0.7	4009910	3605840	283819	2730460
0.4	0.8	4009910	3602920	313958	2738330
0.4	0.9	4009910	3599990	344097	2746200
0.5	0.5	4191160	3656080	223540	2786840
0.5	0.6	4191160	3653160	253679	2794720
0.5	0.7	4191160	3650230	283819	2802590
0.5	0.8	4191160	3647310	313958	2810460
0.5	0.9	4191160	3644390	344097	2818330
0.6	0.5	4372510	3700400	223540	2858970
0.6	0.6	4372510	3697480	253679	2866850
0.6	0.7	4372510	3694550	283819	2874720
0.6	0.8	4372510	3691630	313958	2882590
0.6	0.9	4372510	3688700	344097	2890460
0.7	0.5	4553940	3744640	223540	2931100
0.7	0.6	4553940	3741720	253679	2938970
0.7	0.7	4553940	3738800	283819	2946850
0.7	0.8	4553940	3735870	313958	2954720
0.7	0.9	4553940	3732950	344097	2962590
0.8	0.5	4636760	3858740	223540	3001590
0.8	0.6	4636760	3855820	253679	3009460
0.8	0.7	4636760	3852890	283819	3017330
0.8	0.8	4636760	3849970	313958	3025200
0.8	0.9	4636760	3847040	344097	3033080
0.9	0.5	4822090	3891930	223540	3070460
0.9	0.6	4822090	3879260	253679	3079930
0.9	0.7	4822090	3889040	283819	3085280
0.9	0.8	4822090	3871820	313958	3096020
0.9	0.9	4822090	3884080	344097	3100790

Therefore, the results of the dynamic contract also reinforce the findings generated by Cachon (2003), Kaya and Caner (2018), and Cao et al. (2013), where asymmetric information adversely affects the supply chain outcomes. Hence, it is evident that minimising asymmetric information is beneficial for long-term contracts.

4.5.6.2 Impact of Weight Allocation on Supply Chain Costs

Initially, weights were allocated arbitrarily, considering a higher weight for the e-tailer, as the initiator of the contract ($W_1 = 0.3, W_2 = 0.4, W_3 = 0.3$). To identify the impact of weight allocation on the supply chain costs, a sensitivity analysis was conducted by changing the weight allocations of each supply chain member (See Table 4.6).

Table 4.6 Results of the sensitivity analysis between weight allocation and supply chain costs

W_1	W_2	W_3	C_1	C_2	C_3
0.1	0.1	0.8	314222	476254	105515.2
0.1	0.2	0.7	413316	774992	92325.8
0.1	0.3	0.6	416567	1155594	79136.4
0.1	0.5	0.4	425811	1868800	88735.2
0.1	0.6	0.3	426388	2241936	66551.4
0.1	0.7	0.2	440217	2600647	44367.6
0.1	0.8	0.1	447666	2964064	22183.8
0.1	0.4	0.5	483145	1562764	65947
0.2	0.2	0.6	633470	947482	79136.4
0.2	0.3	0.5	810768	1173126	65947
0.2	0.4	0.4	827040	1517384	80898
0.2	0.5	0.3	827978	1885870	66551.4
0.2	0.6	0.2	833134	2257224	44367.6
0.2	0.7	0.1	833502	2633029	22183.8
0.3	0.3	0.4	1052028	1319400	52757.6
0.3	0.4	0.3	1257549	1462736	67303.8
0.3	0.5	0.2	1279305	1804280	44869.2
0.3	0.6	0.1	1300032	2141670	22434.6
0.4	0.4	0.2	1430048	1693404	44869.2
0.4	0.5	0.1	1676732	1828420	22434.6

The sensitivity analysis did not result in an exact weight allocation point for Pareto-optimality for all three players as they deploy discrete data values. Instead, it has identified a Pareto improvement point for the e-tailer and the product supplier. Therefore, linear interpolation is used to create the Pareto-optimality solution as indicated in Figure 4.10.

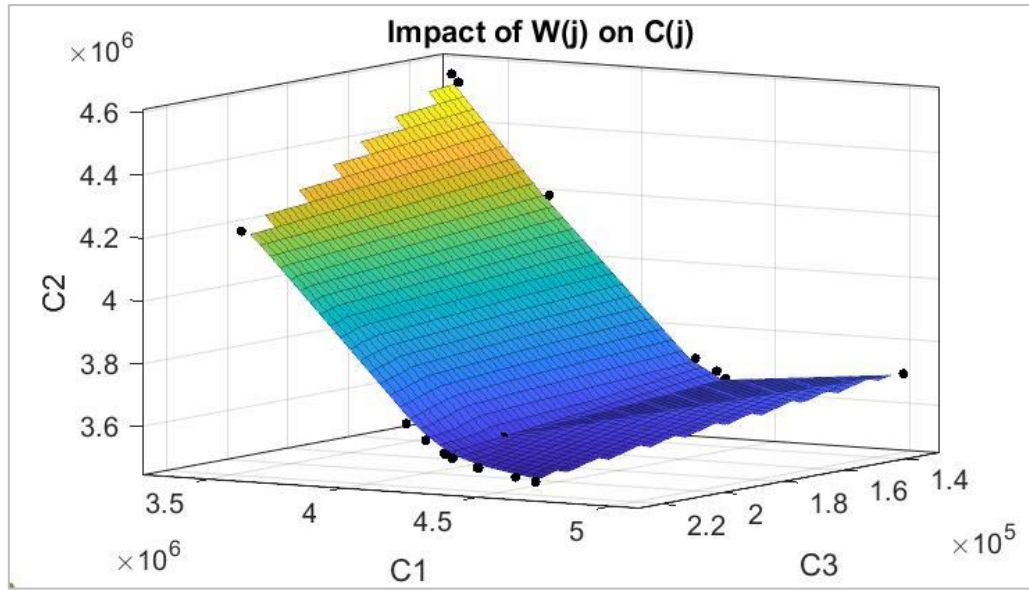


Figure 4.10 Impact of weight allocation on individual total costs

According to the results of the sensitivity analysis, the supply chain receives the lowest costs for z , c_1 and c_2 when the weight allocation is $w_1 = 0.1, w_2 = 0.1, w_3 = 0.8$. This allocation is the best solution for the product supplier and e-tailer. However, it is not optimal for the 3PL operator. The curve fitting graph based on linear interpolation produced a Pareto-optimal solution, which represents benefits for all three players (see Figure 4.10), and a better solution than the base cost-sharing contract (see Figure 3.12). Therefore, the dynamic contract model derives improved supply chain outcomes in terms of cooperative decision-making.

4.5.6.3 Impact of Demand on Supply Chain Costs

In this section, the impact of an increasing or decreasing trend of demand over 12 periods on total costs, c_j and z is analysed. In the first numerical illustration, a fluctuating demand pattern was taken for the analysis, considering demand in each period is independent. For the sensitivity analysis, D_i values were taken with increasing and decreasing trends up to 3%.

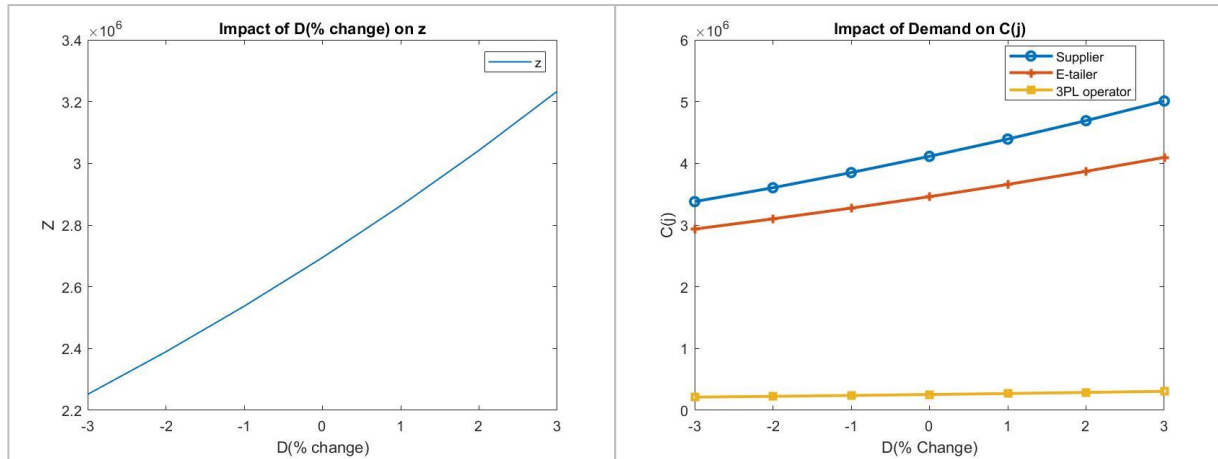


Figure 4.11 Impact of demand on supply chain costs

The demand has a positive linear relationship with C_j and z (see Figure 4.11). The highest impact of the demand is generated on the product supplier's costs, and the lowest impact is on the 3PL operator's costs. This result is generated due to the higher operational costs of the product supplier. The cost-sharing percentages ($k_{i,1}^{\%}$ and $k_{i,3}^{\%}$) were also analysed, which however, did not indicate significant changes according to the change in demand (see Figure 4.12 and Figure 4.13).

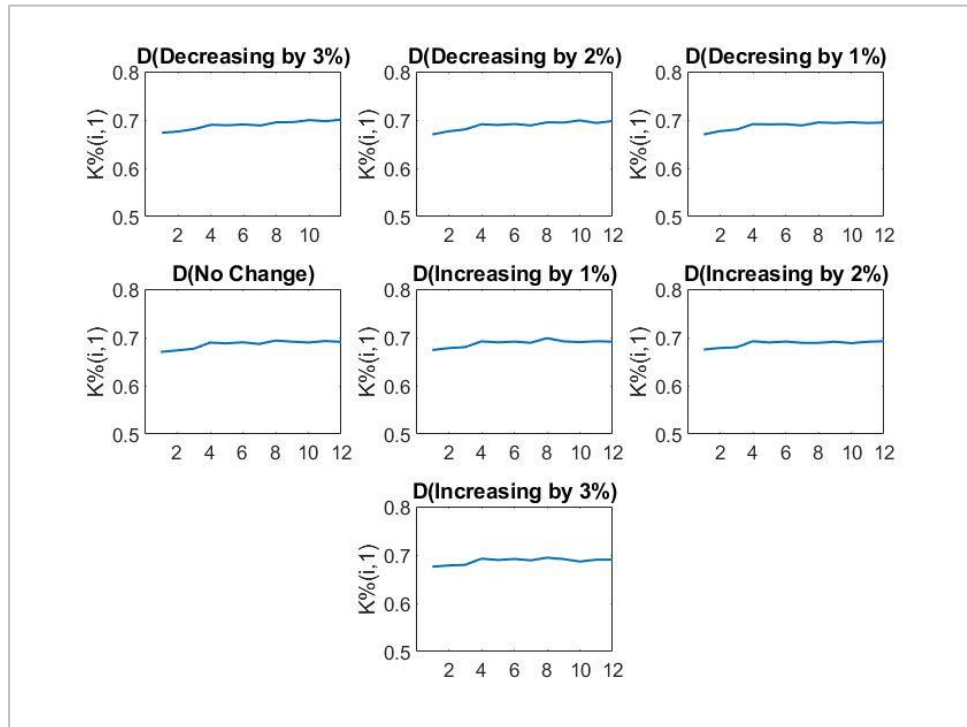


Figure 4.12 Impact of demand on the cost-sharing percentage of the product supplier

The cost-sharing fraction $k_{i,1}^{\%}$ follows similar sharing levels with slight changes over 12 periods, even when the demand has increasing or decreasing trends. Similar results were observed for $k_{i,3}^{\%}$, as shown in Figure 4.13.

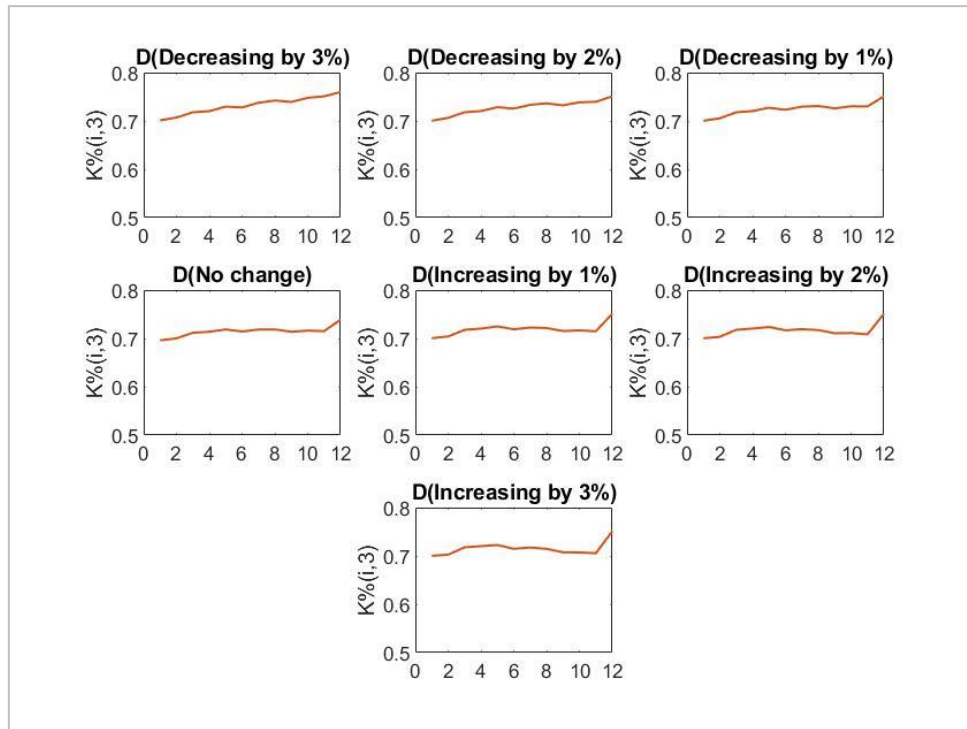


Figure 4.13 Impact of demand on the cost-sharing percentage of the 3PL operator

The results further verify that demand does not have a significant impact on the cost-sharing fractions that coordinate the supply chain in terms of cost optimisation.

4.6 Discussion of Key Findings

The dynamic contract model discussed in this chapter represents an important contribution to the literature, as well to e-tailer practitioners. The proposed contract design introduced consistency constraints under cooperative game concepts to enable the dynamic stability of the contract as described by Yeung et al. (2019). The consistency constraints were designed in such a manner that the product supplier and the 3PL operator receives the cost-sharing fractions proportionate to their total costs and in an increasing way. The numerical analysis shows that both these players receive an increased level of incentives within the total contract period, thereby motivating these players to remain in the contract. To complement this finding, the overall supply chain cost is only increased by 1% compared to the base cost-sharing contract with no-consistent constraints. Therefore, implementing consistent incentive terms into the contract generates positive benefits and reduces the possibility of re-negotiation in the interim periods. As discussed by Bondareva and Pinker (2018), re-negotiation can be eliminated by giving proper motivation. Rather than instigating financial penalties aimed at threatening players, this study proposed consistent incentives, which have a more positive impact on motivating players. Therefore, as indicated above, proposing consistency incentives enhances

the contribution to the literature as well as providing opportunities for e-tailer organisations in achieving long-term integration. Moreover, the analysis of the proposed consistency constraints in this study reinforces the findings of Yeung and Petrosyan (2006), and Yeung et al. (2019). These findings highlight the importance of achieving dynamic contract stability, which can enable the re-negotiation proofness of the contract models.

The optimal cost-sharing fractions in a multi-period setting have also been identified through the analysis in this study. Zhao et al. (2014) also determined optimal cost-sharing levels; however, these authors did not consider asymmetric information in the contract. The optimal cost-sharing levels derived in this current study indicate a consistent level of incentives without significant fluctuations for any player, supported by the consistent constraints. This finding further highlights the importance of formulating consistent incentives in long-term contracts.

The proposed dynamic cost-sharing contract does not include the evolving nature of the information as applied by Gao (2015). However, the results indicate that asymmetric information needs to be eliminated not only in the first period of the contract but in all other periods when they change in each period. These findings align with those of Mobini, van den Heuvel and Wagelmans (2019). The sensitivity analysis has also reinforced the findings that when information asymmetric is lowest, the contract delivers better outcomes, which is aligned with the findings of Brusset and Agrell (2015). This finding is applicable not only for dynamic contracts but also for static contracts.

4.7 Conclusion

To gain a competitive edge within a highly competitive e-commerce business environment, players must integrate while eliminating strategic decision-making issues. This chapter has discussed the extension of the base cost-sharing contract model, presented in Chapter 3, and the formulation of a dynamic cost-sharing contract model for a three-player e-commerce supply chain. The main aim of the dynamic contract was to achieve optimal outcomes for the overall supply chain as well as the individual players, using a cooperative approach for long-term operation. As supply chain operations depend on time, the implications of cost-sharing in a dynamic operational setting with multi-periods was analysed in this chapter. It is necessary to ensure that players remain throughout the total contract period when a multi-period contract is executed. This issue was addressed by defining consistency constraints to enable sufficient incentives over time that would ultimately guarantee re-negotiation proofness.

The results of the analysis revealed that consistency constraints could ensure improved incentives, thereby guaranteeing that the players have sufficient incentives to be in the contract for the long-term. Comparison results with the base cost-sharing contract model (no-consistent constraints) scenario further disclosed that having consistent incentives reduces the individual player's costs by 2% and 12% for the product supplier and the 3PL operator, respectively, while only increasing the overall supply chain cost by 1%. This is due to the increased portion of incentives associated with the consistency constraints.

Furthermore, the dynamic cost-sharing is highly beneficial for this e-tailer supply chain as it significantly reduces the overall supply chain cost and the individual costs, when compared with the operational scenario with no-contract elements. Through cooperative behaviour, the contract delivers substantial cost minimisation for the overall supply chain. This outcome can be transferred to the pricing of goods, thus benefiting customers and, in the long-term, helping to expand the customer base and market share. Therefore, the findings of this study emphasise that the proposed dynamic cost-sharing contract can derive optimal supply chain costs for the small-scale e-commerce supply chain operation and enable effective long-term integration.

Thus far, this study has discussed how effective contract models derive optimal e-commerce supply chain outcomes in terms of minimising costs, eliminating asymmetric information, and enabling successful integration. Primarily, all these contract models include the operational costs of supply chain members, with cost information playing a vital role. Therefore, in the next chapter, the importance of cost measurement techniques and their impact on optimal supply chain costs and contracts are discussed, as accurate information is a crucial asset of online supply chain operations.

CHAPTER 5 : IMPACT OF ACCOUNTING METHODS ON SUPPLY CHAIN COSTS AND CONTRACTS

5.1 Introduction

As discussed in the previous chapter, a dynamic cost-sharing contract model was developed to enable long-term integration while eliminating asymmetric information. In this contract model, the importance of cost-sharing and cost optimisation was discussed extensively. As previously identified, knowing the actual cost structure is crucial for online supply chains, as it has significant implications for overall supply chain costs. As cost measurement techniques define the values of costs, these techniques can directly impact the outcomes of supply chain contracts. Therefore, this chapter explores how the cost measurement techniques adopted by different supply chain members affect the supply chain performance through the proposed dynamic contract model.

The rest of the chapter is structured as follows. First, previous literature is discussed on costs, relationships of costs to the supply chain outcomes, different cost measurement techniques based on accounting methods, and the application of accounting methods related to supply chain contract implications. In Section 5.3, the theoretical framework is outlined, integrating accounting methods with the cost measurement aspects associated with managing supply chain costs. In order to explore how these cost measurement aspects relate to supply chain contract outcomes, propositions were developed based on the theoretical framework. These propositions were tested by numerical analysis, discussed in Section 5.4, using the proposed dynamic cost-sharing contract model developed in this study. Based on the results of the numerical analysis, key findings are discussed in Section 5.6, and the final section concludes the chapter.

5.2 Previous Literature on Cost Measurement and Accounting Methods

5.2.1 The Relationship between Cost Management and Supply Chain Operations

According to Horngren et al. (2014), cost is defined by accountants as a resource that sacrifice to achieve a specific objective, which can be measured in terms of monetary values, and can be used to acquire goods or service. McGuigan, Moyer and Harris (2014) argue that cost is the sacrifice made when a conversion or exchange of resources happens. Cost management in supply chain operations takes a strategic perspective, since supply chain members must

consider not only their internal costs but also total supply chain costs, including the costs of integrating the upstream and downstream of the chain (Nagarajan & Sošić 2008). A firm follows a two-step procedure in deciding how to obtain a certain level of output, which consists of technology efficiency and economic efficiency. Economic efficiency focuses on cost minimisation in deriving a specific output or product (Perloff 2014). Therefore, supply chain members must have a better understanding of the costs that are involved in supply chain operations to manage, and ultimately minimise their costs effectively. To analyse this relationship between cost management and supply chain management, different concepts of costs and measurement of costs are discussed below.

5.2.2 Cost Concepts and Cost Structures

Kaplan and Atkinson (1998) argued that cost information is one of the critical aspects of management accounting. As these authors further explain, the cost behaviour of an organisation affects decision-making aspects such as product features and product-mix, competitive strategies development, operations improvement and performance evaluation. Economists segregate the firm's cost structure into two main sub-classes: fixed costs and variable costs. The total cost of the firm is a summation of fixed and variable costs ($TC=FC+VC$; TC-total cost; FC-fixed cost; VC-variable cost). Perloff (2014) described these costs as the short-run costs of a firm. The behaviour of FC and VC is important to know when supply chain organisations are making strategic decisions about managing costs. As also elaborated by Shapiro (2007), VCs vary with the output of the firm, whereas FCs remain unchanged within a total given period. McGuigan, Moyer and Harris (2014) defined costs based on accounting and economic terms, where accountants measure costs for financial reporting purposes, while economists measure costs for decision-making processes. According to this explanation of cost measurement, the exact costs included in a product are identified as labour, raw materials, suppliers, rent, interest, utilities and opportunity costs.

Horngren et al. (2014) described costs included in production as research and development costs, product design costs, manufacturing costs, marketing costs, distribution costs and customer service costs. Further, the author segregated costs involved in production into two sub-sections: direct and indirect costs. Shapiro (2007) argued that in supply chain decision-making, costs should be represented as a relationship, in which cost functions or activities are included to describe how costs are incurred. The author further stated that the cost relationship in an optimisation model is defined based on the relationship between direct and indirect cost

factors and the model objective, identified as cost drivers. However, this study elaborated that selecting cost drivers from a direct cost relationship is less complicated than choosing cost drivers from indirect cost relationships. When considering indirect cost relationships, more in-depth analysis is required, with the support of the organisation's management accountants. Hobbs (1996) investigated the transaction costs within a supply chain framework. The transaction costs were categorised into three main sub-categories: information costs, negotiation costs, and monitoring costs. Perloff (2014) explained that firms need to consider opportunity costs as well, as this helps identify the costs for the best alternative available. Further, this author argued that sunk costs are necessary for identifying the nature of costs, as these costs belong to past expenditure, which cannot be recovered in the present. Costs in an operational facility are described using cost taxonomy, which includes five cost types: product costs, process costs, inventory costs, facility resource costs, and facility overhead costs (Shapiro 2007). Pettersson and Segerstedt (2013) also defined a model for supply chain costs with six cost categories: manufacturing, administration, warehousing, distribution, capital, and installation cost.

According to Nagarajan and Sošić (2008), when supply chain members manage costs focused on upstream and downstream, their strategies include global supplier development, sharing of cost savings, effective customer relationship management, sharing technology and engineering controls, and target pricing. This current study also focused on these issues in cases where the cost-sharing contract enables sharing operational costs among the supply chain members to minimise the overall costs of the e-commerce supply chain. Therefore, it is necessary to identify how these costs are measured by different supply chain members of the e-tailer supply chain considered in this study. Hence, the cost measurement techniques used by organisations are discussed in the next section.

5.2.3 Accounting Methods and Measurement Techniques

5.2.3.1 Historical Cost Accounting (HCA) and Fair Value Cost Accounting (FVA)

In accounting terms, cost measurement is extremely important. Generally, accounting methods are segregated into HCA or FVA. There is a never-ending debate about adopting either HCA or FVA/current cost accounting (CCA). Many scholars have argued the pros and cons of both these accounting methods, which have different implications for profit generation, capital and assets, earning management and operating costs (Godfrey et al. 2010; Marra 2016). HCA uses historical data to measure costs, while FVA/CCA measure costs based on the current market

prices (Godfrey et al. 2010). Due to these different measurement approaches, diverse implications are generated for the organisations.

FVA generates forward-looking information while it violates the reliability of information as these values can be manipulated. In contrast, HCA data cannot be manipulated, but the information is not so forward-looking and relevant. This scenario is identified as the most significant trade-off between these two accounting measurement types (Blecher 2019; McDonough & Shakespeare 2015).

In HCA, accountants track the flow of costs to match them against the revenue earned (Godfrey et al. 2010). However, they do not take into account the residual net value of an organisation's assets when the income statements are prepared. Moreover, HCA incorporates the conservative contractual relationship between an organisation and the parties who provide the necessary resources. Godfrey et al. (2010) further argued that HCA is applicable when the economic decisions are made in a company at the time at which a transaction occurs, not when it is merely possible. These factors can be identified as the benefits of adopting the HCA approach.

On the other hand, HCA could negatively affect the efficiency levels of companies because it illustrates past behavioural efficiency of managers and uses lower depreciation levels for assets. Ultimately, this practice results in the display of improved efficiency levels in financial information (Godfrey et al. 2010), which however is not the actual level of efficiency of that particular organisation. Tkachuk (2019) brings a compelling argument about adopting HCA in determining the costs of finished goods. There are direct and indirect costs involved in determining the actual cost involvement of a finished good, and hence, if a firm uses historical costs to do the valuation of the product cost when a substantial amount of indirect costs are involved, it affects the objectivity of the historical costs. Furthermore, recent literature suggests that investors do not look for financial statements based on historical data; instead, they are interested in obtaining up-to-date information (Marra 2016; Tkachuk 2019).

The FVA method has evolved over the years and has been subjected to a number of changes within International Financial Reporting Standards (IFRS) and GAAP (Generally Accepted Accounting Principles). According to FASB (Financial Accounting Standard Board), fair value inputs are segregated into a three-level hierarchy, which is based on reliability (Liao et al. 2013). Level 1 inputs are determined based on quoted prices that can be identified from the market; level 2 inputs are not quoted from market prices but can be determined based on public information, which requires a certain level of subjectivity. Finally, level 3 inputs are

unobservable data, which depend on the valuation made by the particular organisation. This is not visible to outside parties (Liao et al. 2013; Tkachuk 2019). Therefore, in fair value measurement, level 1 inputs are least affected by subjectivity, while level 3 inputs are the most affected by subjectivity (Sellhorn & Stier 2019). Thus, organisations must be vigilant when they decide to apply fair value measurement to their assets or liabilities (Fargher & Zhang 2014). Hence, the terms of fair value measurement need to be taken into consideration if they are adopted within supply chain organisations. Several recent works in the literature related to FVA are focused on measuring non-financial assets in the organisation. Sellhorn and Stier (2019) tested the suitability of fair value measurement for long-lived operating assets, defined as non-financial assets. Blecher (2019) also argued that FVA is appropriate for measuring non-financial assets, such as the goodwill of a firm.

The issues associated with FVA are identified as recognition principle and objectivity, which are described as the acknowledgement of actual information and using solid evidence for accounting statements (Scott 2015). There is a huge debate going on regarding the reliability of adopting FVA to determine the financial position of organisations (Tkachuk 2019). FVA/CCA violates the conservatism principle of HCA as it records non-monetary assets in the current market price, thereby, including unrealised gains in the financial records. The holding gains of company profit are calculated as cost savings in FVA when these cost savings are actually not realised. Therefore, the costs are recorded without the actual transaction occurring within that firm. However, the theorists in the accounting field argue that when the market prices of items can be easily determined, the accountant can use current costs to value those items. One such item is identified as the inventories of a firm (Godfrey et al. 2010). For e-commerce supply chain organisations, the cost of holding inventory is a crucial component, and hence, determining which cost measurement system should be adopted is an important decision.

Marra (2016) stated that the best argument for FVA is that it fulfils the requirement for having decision-useful information within the current globalised, innovative and complex business world. However, when the market conditions are changed, the input values for the accounting data under fair value measurement require changes according to changes in the market (Du, Li & Xu 2014). These authors also emphasise that when the market is excessively volatile such as a financial crisis, it is difficult to obtain correct values for the inputs based on fair value measurement.

5.2.3.2 Mixed Methods of Accounting

The mixed methods of accounting are also identified as important, mainly due to the trade-offs of HCA and FVA when considered individually. As described by Blecher (2019), the decision to use either FVA or HCA depends on the decision of the standard-setter. In that case, there is a possibility to manipulate the valuation process, and hence, HCA method is more suited. Therefore, Blecher (2019) emphasised that the level of uncertainty in decision-making has an impact on whether to use the fair value method or the historical cost method. Godfrey et al. (2010) also described that there is a wide acceptance of mixed measurement methods due to several changes made by the IFRS over the years. However, the author explains that the majority of enterprises commonly use the historical cost measurement approach, combined with other measurement practices. However, mixed method approach can also create a variety of risks such as the difficulty of elaborating the methods used to measure different items, difficulty of aggregating data and estimation risks (Dvorakova 2011).

The above discussion of HCA, FVA and mixed methods of accounting reveals that the cost measurement type adopted by different supply chain members have a significant impact on how they interpret their cost data and provide information to outside stakeholders or collaborators.

5.2.3.3 Creative Accounting

Creative accounting is defined as a changing method used to present a company's financial outcomes to attract more investors (Fizza & Qaisar 2015). It is questionable in nature in terms of ethical practice, since it does not present the actual situation of the business (Fizza & Qaisar 2015; Remenarić, Kenfelja & Mijoč 2018). As stated by Bhasin (2016), adopting creative accounting principles means ignoring some rules and choosing only those rules that are advantageous to the organisation. This author also emphasised that creative accounting is a crime and that accounting bodies should take necessary actions to stop these unethical practices. Fizza and Qaisar (2015) analysed the causes of using creative accounting in organisations through empirical investigations. The main reason was identified as extreme competition in businesses, followed by the benefits of manipulation, obtaining more investments and materialising accounting statement-making art. Shahid and Ali (2016) pointed out that using creative accounting is a short term rather than a long-term gain, and the organisations generally become interested in such practices when they are in financial distress.

Several aspects of creative accounting practices have been identified as used for manipulating information. Tangible assets related to depreciation, company goodwill calculations, inventory levels, provisions allowed for liabilities, and the creating of contracts are some of the main areas identified (Yadav, Kumar & Bhatia 2014). This illustrates that some supply chain organisations may be motivated to adopt creative accounting practices. One famous real-world example of using creative accounting to manipulate earnings management was analysed by Dugar and Gujarathi (2018), which was related to Toshiba Corporation. In this case, the Toshiba Corporation stated in their 2015 Annual Report that the main cause of their financial distress was the economic crisis of 2008. However, they were discovered to be using creative accounting methods and had to readjust their company earnings later for a seven-year period, thereby reducing their profit levels by USD 1.86 billion. Hence, adopting creative accounting is a risky practice, which can have an adverse impact on the overall profits and the reputation of an organisation.

The extant literature provides evidence that creative accounting practices are primarily linked to agency problems (Diana & Beatrice 2010; Fizza & Qaisar 2015; Shahid & Ali 2016; Umobong & Ironkwe 2017). Creative accounting practices are often used to address conflicts of interest in accounting information among different players (Diana & Beatrice 2010). Shahid and Ali (2016) tested a hypothesis to identify the relationship between agency problems and creative accounting, proving that these two aspects are significantly related. Therefore, the impact of creative accounting practices on contractual agreements is critical and needs to be explored further.

When considering the pros and cons of these accounting methods, it is evident that the selection of a suitable accounting method has implications for decisions related to valuation and in determining the actual earnings and expenses of firms. More importantly, there is the potential for manipulation, depending on the accounting techniques used by different organisations, which affects the operational outcomes of supply chain organisations. E-commerce supply chain organisations depend heavily on accurate information sharing among different supply chain partners and, therefore, supply chain members must be aware of the financial information and measurement terms that will affect decision-making in their operations. Since this study considers small-scale e-tailers as its operational context and cost-effective strategies to meet customer expectations as its focus, the accounting methods adopted by different supply chain members needed to be explored to determine their impact on the proposed cost-sharing

contract. Thus, previous studies that investigated the impact of accounting methods on contracting were analysed in the next section.

5.2.4 Impact of Cost Measurement and Accounting Methods on Contracting

Scott (2015) stated that the chosen accounting method has a direct impact on efficient contracting. Sellhorn and Stier (2019) also argued that the financial reporting method serves the purpose of providing pertinent information and measures that can be used to arrange contractual terms. When a firm adopts a high-quality financial reporting system, it enables all parties to act with integrity and trust when they form a contractual agreement (Scott 2015). The study of Fargher and Zhang (2014) also clarified that providing additional discretion to use FVA within organisations, creates an environment for managers to act opportunistically, thereby generating less informative financial outcomes. These authors further emphasised that this negatively affects the reliability of financial reporting and ultimately affects the earning management of a firm.

Scott (2015) exclusively discussed the relationship between accounting policies for efficient contracting. The main factors that this author discussed were reliability, conservatism, and contract rigidity in creating efficient contracts. Scott (2015) argued that accounting policy differences are created by the measurement type adopted by an organisation. The author added that efficient contracting leads to the establishment of trust at the lowest cost. This argument is supported by the fact that contracting terms are focused on minimising agency costs in the analysis within a principal-agent framework (Christensen, Nikolaev & Wittenberg-Moerman 2016). However, if a firm is using FVA, there is an opportunity to manipulate accounting information when the contract is signed, which leads to creating un-trustful scenario among the parties who engage in the contract (Scott 2015). When information is assessed according to the historical cost and fair value, it is evident that historical cost maintains the reliability of information while fair value maintains the relevance of information (Blecher 2019). Christensen, Nikolaev and Wittenberg-Moerman (2016) also explained that when a firm is more focused on scoring high on relevance in accounting measurement, FVA methods are applied, but reliability levels decrease as verifying information is difficult. This argument corroborated that of Scott (2015), who sought to determine the impact of accounting measurement reliability on the outcomes of efficient contracting. The findings of Christensen, Nikolaev and Wittenberg-Moerman (2016), and Scott (2015) are important to consider, especially in the context of e-commerce supply chains, as information is a driving factor in

creating efficient operations. Therefore, supply chain members must identify the most appropriate accounting method within their respective organisations to manage the trade-off between reliability and relevance.

Chen, Hemmer and Zhang (2007), and Gao (2013) argued that having a conservative accounting approach reduces the possibility of manipulating earnings management and thus benefits efficient contracting. Gao (2013) argued that such an approach was most applicable when information asymmetry exists within an organisation. Therefore, knowing the cost measurement in organisations is essential for decision-making and in designing efficient contract models.

Liao et al. (2013) extensively analysed how fair value measurement affects information asymmetry within organisations. The authors tested their arguments in the banking industry, considering net assets measurement. According to their findings, information asymmetry is positively correlated with fair value measurement for all three levels of the fair value input hierarchy. Further, they argued that investors are suspicious of financial statements when an organisation uses fair value measurements. These findings provide a critical insight, which can be applied to supply chain operations. However, no studies can be found within the supply chain literature that identifies how accounting measurement information, whether FVA, HCA, or creative accounting, can affect supply chain cost and contractual outcomes.

It is important to state that Activity-Based Cost (ABC) accounting, which relates to the different activities of an organisation, also plays a vital role in firms. ABC is identified as a better costing method than the direct cost of profitability since it incorporates indirect costs for supply chain activities while the direct cost of profitability includes only traditional direct costs (LaLonde & Pohlen 1996; Pettersson & Segerstedt 2013). However, even if a company adopts ABC as its cost accounting method, a question remains as to whether they are using HCA or FVA methods in measuring their assets and costs.

All the previously mentioned studies that have explored contracting and accounting information are focused on a single organisation in which principal-agent relationships are considered in developing compensation contracts and debt contracts. No clear evidence is found for testing this argument for supply chain operations specifically in e-commerce supply chains, in which different external supply chain members interact through an efficient contract to derive better operational and economic outcomes. Hence, this chapter has analysed how the different cost measurement techniques might impact the contracts and costs of the e-tailer

supply chain. To further verify the use of cost measurement in supply chain studies, the next section explores the extant literature related to applications of cost measurement in supply chains.

5.2.5 Applications of Cost Measurement in Supply Chain Management Studies

One of the significant issues in cost management in supply chain operations is cost measurement (Nagarajan & Sošić 2008). Supply chain costs can be estimated in different ways, including data from budgets and cost accounting methods, types of standard costs and actual costs (Pettersson & Segerstedt 2013). Primarily, supply chain studies have analysed cost measurement approaches such as ABC, the direct cost of profitability and total cost of ownership (TCO) (LaLonde & Pohlen 1996).

ABC costing method has been the focus of numerous studies in the field of supply chain management. Lin, Collins and Su (2001) analysed logistics costs and their impact on corporate decision-making based on the ABC approach. Dekker and Van Goor (2000) developed an ABC model to measure supply chain integration based on a management accounting approach. Schulze, Seuring and Ewering (2012) developed an ABC costing model for supply chain management considering a two-steps approach, taking into account activity-based supply chain configuration and activity-based supply chain operations. Almeida and Cunha (2017) developed an ABC model for a manufacturing company, based on a case study of a coffee production company, to establish proper cost estimation strategies to improve the productivity of outputs. Shigaev (2015) also developed an ABC costing model for a distribution company in which three departments were defined (general administration, warehouse and fleet of trucks) to allocate costs based on their activities. Askarany, Yazdifar and Askary (2010) found that manufacturing companies were adopting the ABC approach more than non-manufacturing companies. These authors also argued that the ABC approach derives more benefits in terms of understanding the cause and effect relationship between cost and demand activities, in identifying value-adding and non-value-adding activities, and in improving the accuracy of organisational cost data.

The TCO in supply chain management requires measuring costs beyond the traditional cost incorporated in unit price, transportation and supply and distribution (Nagarajan & Sošić 2008). Furthermore, Nagarajan and Sošić (2008) argued that traditional accounting measures could not measure the actual values related to the TCO in a company. When a supply chain firm analyses the TCO, these data can be used in strategic decision-making activities. Also, the firm

can use this approach in selecting suppliers and distributors, and to improve supplier and distributor performance, identify the performance objectives, increase supply chain member accountability and control, and establish an evaluation tool with the proper cost measurement system. However, TCO does not have the capability to acquire costs from the upstream players of a supply chain. This affects the inter-relationships among supply chain members since they cannot identify the trade-offs or the impact on the integrated supply chain performance (LaLonde & Pohlen 1996). Therefore, TCO is not capable of providing effective outcomes in designing contracts among different supply chain members.

Efficient contracting models have been studied extensively in the supply chain literature. However, no attention has been given to exploring how accurate accounting information can affect the outcomes of the contract models formulated to create effective supply chain coordination and optimal outcomes. This study addresses this literature gap by developing a theoretical framework to identify the effect of using different accounting methods on the accurate cost measurement and effective contract formation of e-commerce supply chain operations.

5.3 Theoretical Framework

This study presents the following theoretical framework to address the issues raised in the previous discussion:

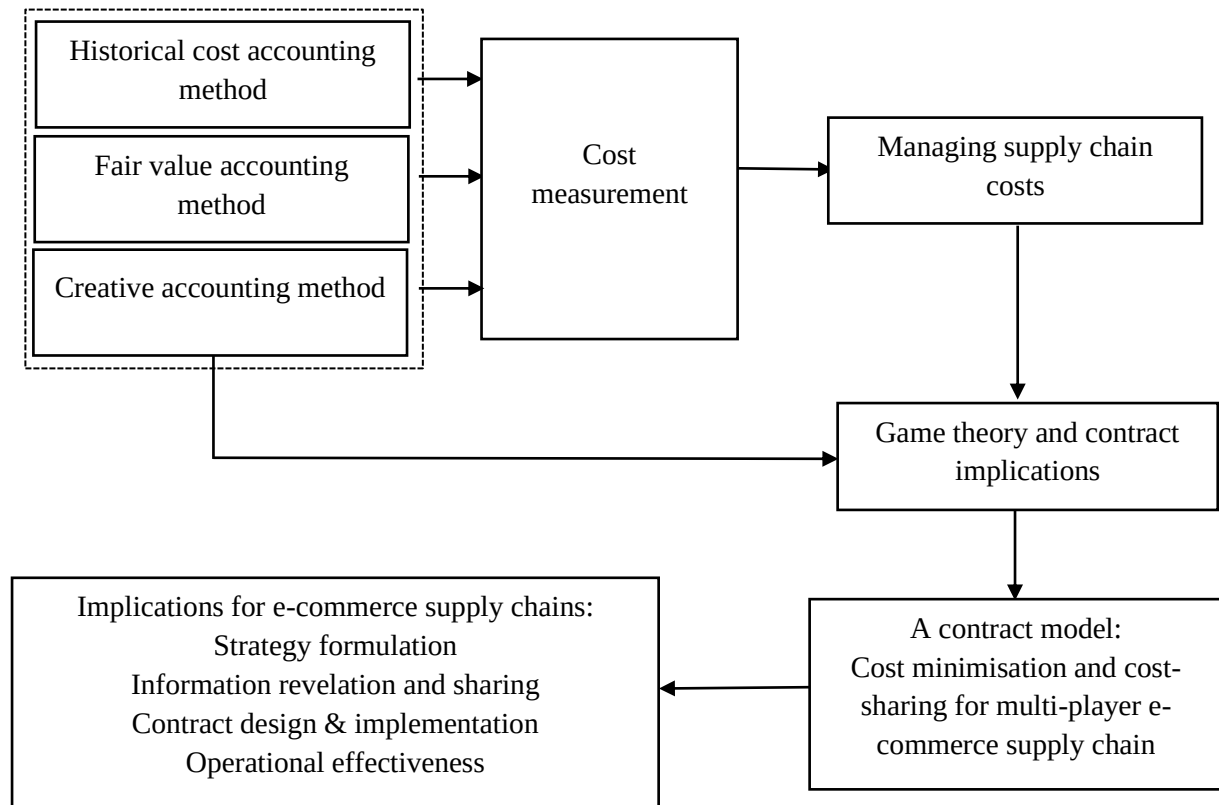


Figure 5.1 Theoretical framework

Members of e-tailer supply chains could adopt one or both of the key accounting methods discussed: HCA or FVA. They could also potentially use creative accounting. As cost information in e-commerce supply chains can be derived from one of these accounting methods, it is necessary to identify which method is the most appropriate for producing accurate cost information. Cost measurement can influence the management of supply chain costs, such as inventory, distribution, logistics, and manufacturing costs. As accounting data affects strategic decision-making within and across firms, the strategic interactions among different agents become imperative (Migdalas 2002). Therefore, game-theoretical implications have been generated from the accounting methods, mainly focused on efficient contracting, incentive setting, and ex-ante and ex-post data recording (Migdalas 2002; Scott 2015). Hence, accounting methods have a direct relationship with game theory-based contract models.

This study examines the impact of supply chain cost information on the contractual framework among three supply chain members of an e-tailer supply chain. These supply chain members

operate in a decentralised and asymmetric information scenario. Hence, the contract model outcomes can differ according to the accounting method employed by these players. To identify the relationships within the theoretical framework presented in Figure 5.1, numerical analysis was conducted using the dynamic cost-sharing contract to consider the effect of each of these accounting methods on strategy formulation, information revelation and sharing, contract design, and implementation and operational effectiveness.

Based on the above theoretical framework, the following propositions were developed:

Proposition 1 - *FVA has a positive/negative impact on supply chain costs when integrated through a dynamic cost-sharing contract in an e-tailer supply chain.*

Proposition 2 – *The HCA method has a positive/negative impact on supply chain costs when integrated through a dynamic cost-sharing contract in an e-tailer supply chain.*

Proposition 3 – *Creative accounting can manipulate the contractual outcomes in an asymmetric information environment without revelation principle-based compatible incentives in an e-tailer supply chain.*

5.4 Model Description

5.4.1 E-commerce Operational Setting and Cost Information

To test the impact of the different accounting methods on cost information in e-commerce supply chain organisations, the contract model presented in Chapter 4 was used.

5.4.2 Dynamic Cost-Sharing Contract Model

As the model described in Chapter 4 was used to test the propositions, all model constraints presented here are similar to those presented in Chapter 4, except the individual objective functions of the supply chain members. The model objectives were changed to obtain cost data for each period of the contract without the discounting approach. Therefore, the model objectives are indicated in the model formulation as below. For easy reference, the model notations, which required for the model testing in this chapter, are repeated as follows:

Table 5.1 Notations of the dynamic cost-sharing contract model as in Chapter 4

Notation	Description
Sets and indexes	
i	Time period (1,2,3.....n)
j	Players (1: product supplier, 2: e-tailer, 3: 3PL operator)
Parameters	
UC_i	The unit cost of production of supplier for the period i
α_i	Percentage increment/decrement of inventory holding cost of product supplier in the period i
HC_i	The unit cost of holding inventory at the e-tailer in the period i
DC_i	The unit cost of distribution at the 3PL operator in the period i
D_i	Customer demand in period i
II_j	Initial Inventory of player j
W_{capj}	Maximum capacity of the warehouse of player j
M_{cap}	Maximum capacity of manufacturing of the product supplier
θ	Probability of occurring higher operational costs with the product supplier
γ	Probability of occurring higher operational costs with the 3PL operator
W_j	Weight allocation of player j
$P_{i,j}$	The fixed unit price paid by the e-tailer to player j ; $j \neq 2$ in each period i
Decision variables	
q_i	Unit quantity produced by the supplier in the period i
d_i	Units demanded by the e-tailer from the supplier in the period i
$s_{i,j}$	Inventory level of each period i of the player j
$k_{i,j}^{\%}$	Fraction of cost-sharing in % for player j ; ($j \neq 2$)
$SC_{i,j}$	Shared costs by the e-tailer of the other players j
Other variables	
c_j	Individual total costs of the player j

Objective Function and Individual Cost Objectives

$$\text{Minimize } z = \sum_{\forall_i \forall_j} W_j \cdot (c_{i,j}) : \forall_j \quad [5.1]$$

(i) The individual cost objectives

$$c_{i,1} = \left\{ \begin{aligned} & \left(\theta(\overline{UC_i}) + (1-\theta)(\underline{UC_i}) \right) \cdot (q_i + \alpha_i \cdot (s_{i,1} + s_{i+1,1}) / 2) - \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) \\ & - \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \end{aligned} \right\} \quad [5.2]$$

$$c_{i,2} = \left\{ \begin{aligned} & HC_i(s_{i,2} + s_{i+1,2}) / 2 + \left(\theta(\underline{sc_{i,1}}) + (1-\theta)(\overline{sc_{i,1}}) \right) + \left(\theta(\overline{P_{i,1}}) \cdot d_i + (1-\theta)(\underline{P_{i,1}}) \cdot d_i \right) \\ & + \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) + \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \end{aligned} \right\} \quad [5.3]$$

$$c_{i,3} = \left\{ \begin{aligned} & \left(\gamma(\overline{DC_i}) + (1-\gamma)(\underline{DC_i}) \right) \cdot D_i - \left(\gamma(\underline{sc_{i,3}}) + (1-\gamma)(\overline{sc_{i,3}}) \right) \\ & - \left(\gamma(\overline{P_{i,3}}) + (1-\gamma)(\underline{P_{i,3}}) \right) \cdot D_i \end{aligned} \right\} \quad [5.4]$$

The constraints of the model discussed in Chapter 4, from Eq. (4.5) to (4.23), were taken into consideration to analyse the impact of cost information on the e-tailer supply chain contract and costs as described in this study.

5.4.3 Analysis of Propositions

As indicated, the propositions were tested using numerical analysis of the model described in Chapter 4. The same operational context and data were used to conduct the testing. Several operational scenarios and assumptions were considered in the analysis, as follows.

5.4.3.1 Propositions 1 and 2

To test propositions 1 and 2, the accounting methods adopted by the product supplier, e-tailer and 3PL operator needed to be considered based on the following scenarios.

1. Numerical test 1 - All players of the supply chain adopt HCA.
2. Numerical test 2 – The e-tailer and 3PL operator both use HCA while the product supplier uses FVA.
3. Numerical test 3 – The e-tailer uses HCA while the product supplier and the 3PL operator both use FVA.

When each supply chain member adopts different accounting methods in their organisation, the operational costs will have different numerical outcomes. This will affect the total costs of each supply chain organisation, as well as the overall supply chain cost.

Operational Scenarios

To conduct numerical tests 1,2 and 3, the following operational scenarios were tested.

To embed FVA and HCA methods, re-valuation was considered. An operational scenario in which the market value of the products is reduced was considered. This scenario can be caused by several factors, such as a pandemic, the introduction of new technology, or an increased level of competition from other e-tailers.

- In testing scenario 1, in which all members adopt HCA, even if the market value is reduced, no asset is re-valued, and the costs are calculated based on previously incurred values (historical data).
- In testing scenario 2, only the product supplier re-values its assets according to the changed market value, resulting from changes in the product supplier's operational costs.
- In testing scenario 3, both the product supplier and the 3PL operator re-evaluate their assets based on the current market value. Therefore, the operational costs of the product supplier and the 3PL operator are changed.

According to the categorisation of assets under FVA, three asset levels are identified. This is important for the re-valuation of the assets. In these operational scenarios, the finished goods and inventories are the main assets, as these assets can produce an income through the sale of goods in future. The operational costs are inherent for each organisation but are unobservable to the market. However, the sales prices of the finished goods are matched according to the market values. According to FVA rules, the assets in this operation relate to level 3, as the operational costs are unobservable for each organisation. Based on these facts, asset re-valuation was considered in this study under FVA rules.

5.4.3.2 Proposition 3

If any organisation adopts creative accounting methods, it allows the accountant to manipulate and change the information to showcase better financial information. Within an information asymmetry scenario in an e-commerce supply chain, creative accounting motivates organisations to report false costs to obtain extra benefits from their contracts. To eliminate the cost information asymmetry, the revelation principle was adopted in the cost-sharing contracts developed in this study. Therefore, the contract model incorporates incentive compatibility constraints to ensure that all players reveal accurate information when engaged in the contract.

These incentive compatibility constraints were developed to ensure that the supply chain members do not have an opportunity to manipulate the cost data in the proposed contract. Therefore, incentive compatibility constraints may affect the decision to use creative accounting in the product supplier and 3PL operator's organisations. Based on this argument, proposition 3 was tested to identify the impact of creative accounting on contractual outcomes.

The incentive compatibility constraints developed for the cost-sharing contract are taken directly from Chapter 4, as indicated below.

(ii) Incentive compatibility constraints

$$\overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \overline{P}_{i,1} \cdot d_i \geq \underline{UC} \cdot q_i + \alpha_i \cdot \underline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \underline{P}_{i,1} \cdot d_i; \forall_i, i < n \quad [4.5]$$

$$\underline{UC}_i \cdot q_i + \alpha_i \cdot \underline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \underline{sc}_{1,i} - \underline{P}_{i,1} \cdot d_i \geq \overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \overline{P}_{i,1} \cdot d_i; \forall_i, i < n \quad [4.6]$$

$$\overline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \overline{P}_{i,3} \cdot D_i \geq \underline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i; \forall_i \quad [4.7]$$

$$\underline{DC}_i \cdot D_i - \underline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \geq \overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \overline{P}_{i,3} \cdot D_i; \forall_i \quad [4.8]$$

Eq. [4.5] and [4.6] apply to the product supplier, and Eq. [4.7] and [4.8] apply to the 3PL operator. All these equations indicate the incentive level received in the proposed cost-sharing contract. Accordingly, when either the product supplier or the 3PL operator have higher operational costs, the sharing fraction is lower. The total costs of the product supplier under the higher operational costs scenario are equal or greater than the total costs under the lower operational costs (Eq. [4.5]). Similarly, the total costs under the higher operational costs of the 3PL operator are also equal or greater than the total costs under the lower operational costs, as denoted by Eq. [4.7]. The total costs are determined after deducting the sharing fraction and the fixed payment received by the product supplier and the 3PL operator in each period. Constraints denoted by Eq. [4.6] and [4.8] ensure the true cost revelation by selecting the correct menu of contracts for these supply chain members. The total operational costs of the product supplier under lower costs, when he receives a lower sharing fraction ($\underline{sc}_{i,1}$) and lower payment ($\underline{P}_{i,1} \cdot d_i$), are equal or greater than the total operational costs under higher costs, when the product supplier receives a higher sharing fraction ($\overline{sc}_{i,1}$) and a higher payment ($\overline{P}_{i,1} \cdot d_i$).

Similarly, the 3PL operator's total costs under lower operational costs, when he receives a lower sharing fraction ($\underline{sc}_{i,3}$) and the lower payment, are equal or greater than the total operational costs under higher costs, with a higher cost-sharing fraction ($\overline{sc}_{i,3}$) and higher payment ($\overline{P}_{i,3} \cdot D_i$). Therefore, neither the product supplier nor the 3PL operator receives extra benefits from reporting lower costs, when they have higher operational costs. Hence, Eq. [4.6] and [4.8] compel these players to select the correct contract menu according to their operational costs.

However, when the Eq. [4.6] and [4.8] are not included in the contract, and only Eq. [4.5] and [4.7] are included, there is no guarantee that either player will report the correct costs. They may under-report the costs to gain a higher sharing fraction from the e-tailer, which allows the manipulation of information within these organisations. Therefore, proposition 3 was tested in the numerical analysis by comparing the incentive levels with the inclusion and exclusion of incentive compatibility constraints. This would determine whether effective contract outcomes can be generated through incentive compatibility constraints without the possibility of adopting creative accounting methods.

5.5 Numerical Analysis

Propositions 1, 2 and 3 were tested using numerical analysis. Again, the BARON solver was used to conduct the numerical experiments through the NEOS server, since the contract model is an NLP model.

5.5.1 Results Analysis of Propositions 1 and 2

As mentioned in Section 5.4.3, three operational scenarios were analysed in this numerical illustration. The model data from Ragsdale (2017), which were included in Chapter 4, were also considered for the analysis of this model. The additionally derived data required for each numerical testing are presented in Appendix H.

The following assumptions were taken into account for the numerical testing:

1. The unit cost values change according to the accounting method adopted by the supply chain member.
2. The demand drop is assumed to be 30%, which occurs from the third period of the model.

Operational Scenario 1

In the operational scenario 1, no asset re-valuation occurs as all players maintain HCA in their organisations. Therefore, the unit operational costs of the dynamic contract model do not change. However, as the demand drops, the supply chain costs are affected, due to fluctuations in manufacturing, order quantities and the inventory levels. The results indicate a 56% overall supply chain cost reduction when the demand drops by 30%, without any changes to the operational costs. The impact of the decreased market demand on the total individual costs also indicates significant cost reductions in all periods of the model and is illustrated in Figure 5.2.

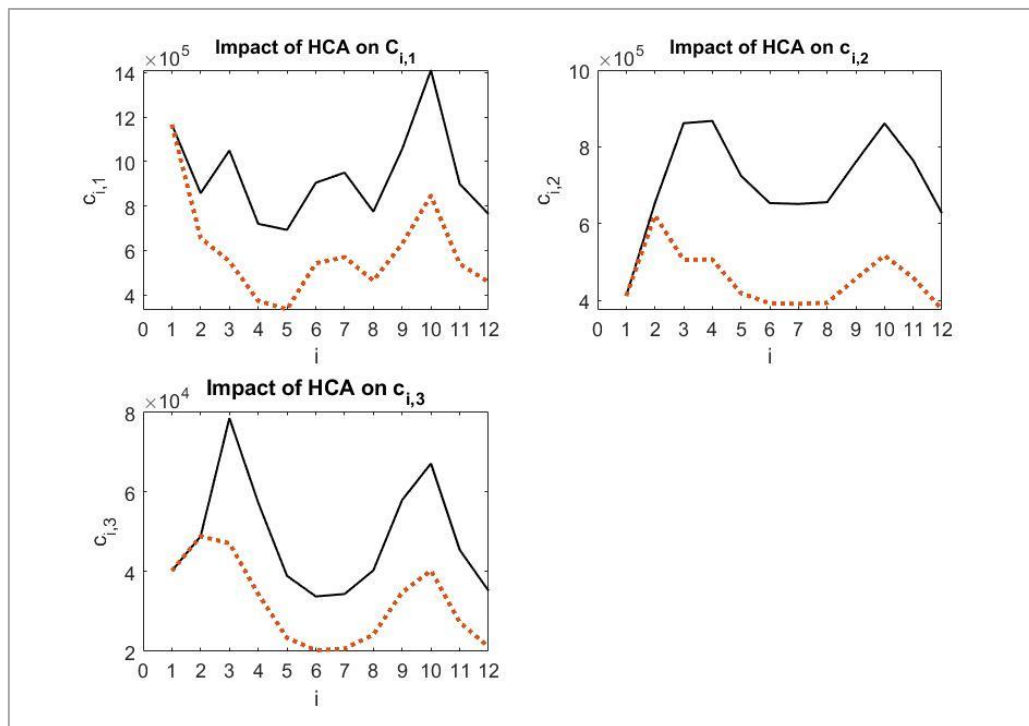


Figure 5.2 Impact of demand drop on the individual total costs of the players under HCA

The results emphasise that the decrease in demand affects the operational outcomes of the supply chain and, accordingly, the total individual costs of each period are reduced. The incentives given to the product supplier and 3PL operator, based on sharing costs, also indicate a similar trend as the sharing costs are reduced based on the reduction of the manufacturing and inventory holding levels. This is illustrated in Figure 5.3.

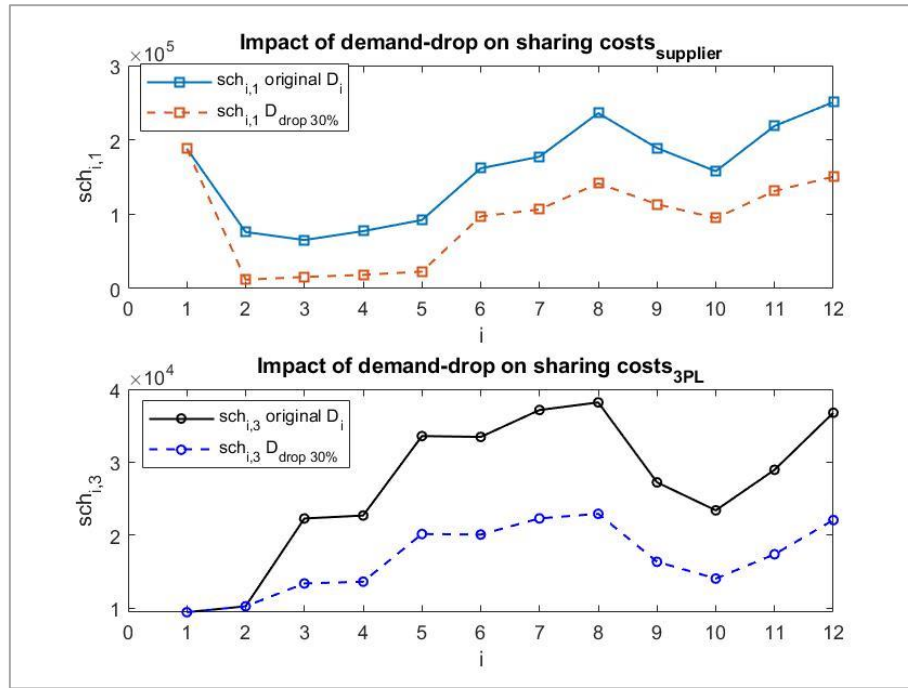


Figure 5.3 Impact of demand drop with HCA on sharing costs of the product supplier and 3PL operator

Therefore, when the market conditions change, which is reflected through a decrease in demand, supply chain costs and the incentives of the cost-sharing contract are reduced even when the players used HCA in their organisations. However, this is not due to changes in the operational costs of the organisation, but to the external conditions of the market.

Operational Scenario 2

In the operational scenario 2, the product supplier re-values its organisation's assets according to the current market value, whereas the e-tailer's costs and the 3PL operator's costs remain unchanged. The asset re-valuation results in changing the unit costs within the product supplier's organisation. A sensitivity analysis was conducted assuming that due to the FVA, the assets re-valuation results in reducing the unit cost of production (UC_i) by 5%, 10%, 15% and 20%. When the UC_i change, the inventory holding costs also change accordingly.

Figure 5.4 illustrates the impact of FVA on the overall supply chain costs. The results are compared with the overall supply chain costs when HCA is adopted.

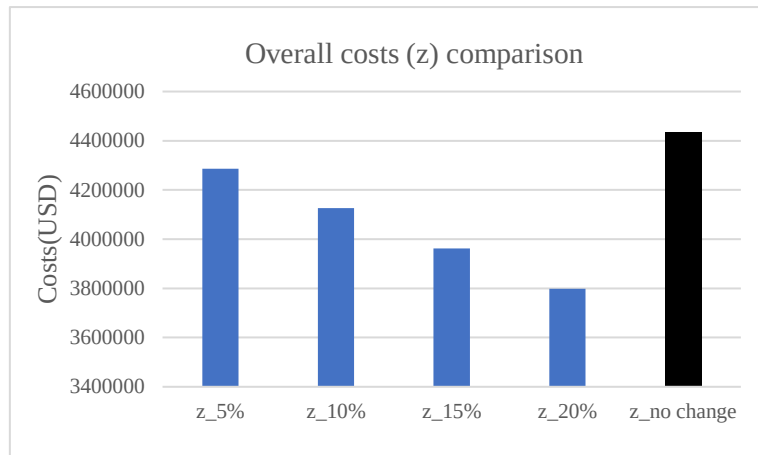


Figure 5.4 Impact of FVA and HCA on the overall supply chain costs

The results show that when one player adopts FVA in the contract, in this case, product supplier, it has more of an impact on reducing the overall supply chain costs (z) than if using the HCA method (see Figure 5.4). The z has decreased by 3% when the unit costs are reduced by 5%, compared to the z with HCA (indicated as $z\_no\ change$) and further reduced when the unit cost of production is reduced by 10%, 15% and 20%.

The impact of the FCA on the product supplier's individual total costs are indicated in Figure 5.5, which shows that the total costs ($c_{i,1}$) reduce according to the changes of unit cost reduction.

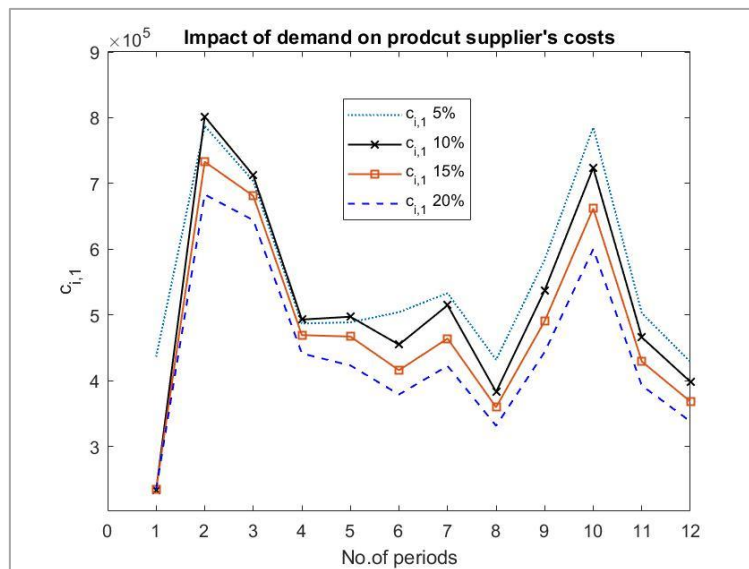


Figure 5.5 Impact of FVA on the product supplier's costs

This can be further elaborated based on the sharing costs received by the product supplier and the 3PL operator. The sharing costs received by the 3PL operator remain unchanged while the product supplier's sharing costs change (see Table 5.2).

Table 5.2 Impact of FVA adoption by the product supplier on the sharing costs

Variable	1	2	3	4	5	6	7	8	9	10	11	12
$SC_{i,1(5\%)}$	40839	54222	61362	72945	84859	85444	95280	123152	98694	82400	113697	130686
$SC_{i,1(10\%)}$	0	58999	63934	76141	88459	95237	89725	95930	83962	70081	96231	110932
$SC_{i,1(15\%)}$	0	37161	54580	65043	76428	83659	79582	82988	69193	57735	78824	91179
$SC_{i,1(20\%)}$	0	21389	43516	51884	62446	68354	65175	67327	54377	45354	61496	71427
$SC_{i,3(5\%)}$	9419	10237	13363	13607	20145	20072	22284	22916	16335	14033	17367	22060
$SC_{i,3(10\%)}$	9419	10237	13363	13607	20145	20072	22284	22916	16335	14033	17367	22060
$SC_{i,3(15\%)}$	9419	10237	13363	13607	20145	20072	22284	22916	16335	14033	17367	22060
$SC_{i,3(20\%)}$	9419	10237	13363	13607	20145	20072	22284	22916	16335	14033	17367	22060

Next, the results of the sharing costs with HCA and FVA were compared to see the impact these accounting methods create for the incentives of the contract (see Figure 5.6).

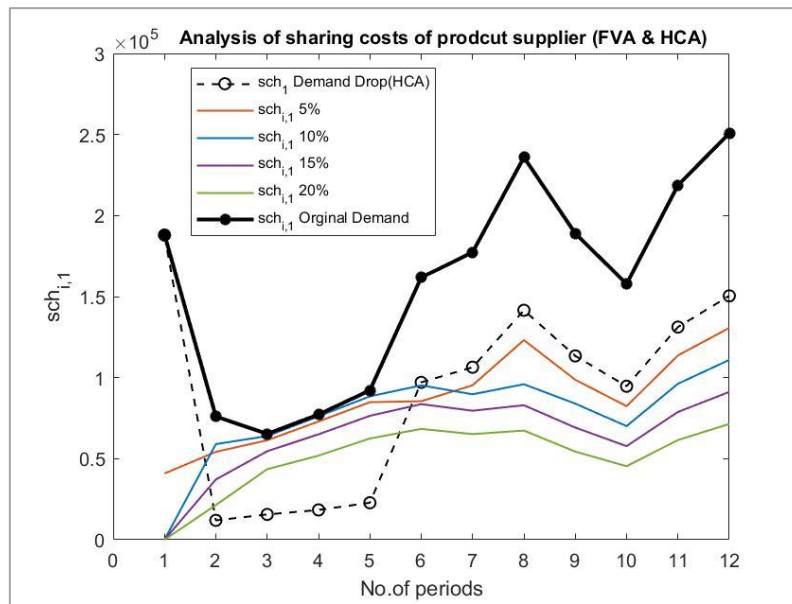


Figure 5.6 Comparison of the sharing costs of the product supplier between HCA and FVA

According to the results, the sharing costs are reduced when the demand drops in both HCA and FVA scenarios. However, the sharing costs received up to period 5 are less in the HCA scenario than in all FVA scenarios. The costs then increase after period 6. The main reason for this outcome is that the operational costs of the product supplier in these periods do not change with HCA but do change with FVA.

Operational Scenario 3

In operational scenario 3, both the product supplier and the 3PL operator's operational costs change with the change in market demand. Therefore, a sensitivity analysis was conducted for the change of unit costs (UC_i, DC_i) by 5%, 10%, 15% and 20% to derive the impact of FVA on the supply chain costs and the incentive levels of the cost-sharing contract. The operational scenarios of the sensitivity analysis are indicated in Appendix I. The impact of FVA adoption at both upstream and downstream of the e-tailer supply chain is illustrated in Figure 5.7. z values are associated with all possible operational cost scenarios and, for example, $z(S5\%, D5\%)$ indicates the change of unit operational costs of the product supplier and the 3PL operator by 5%, in which S denotes the product supplier and D denotes the 3PL operator.

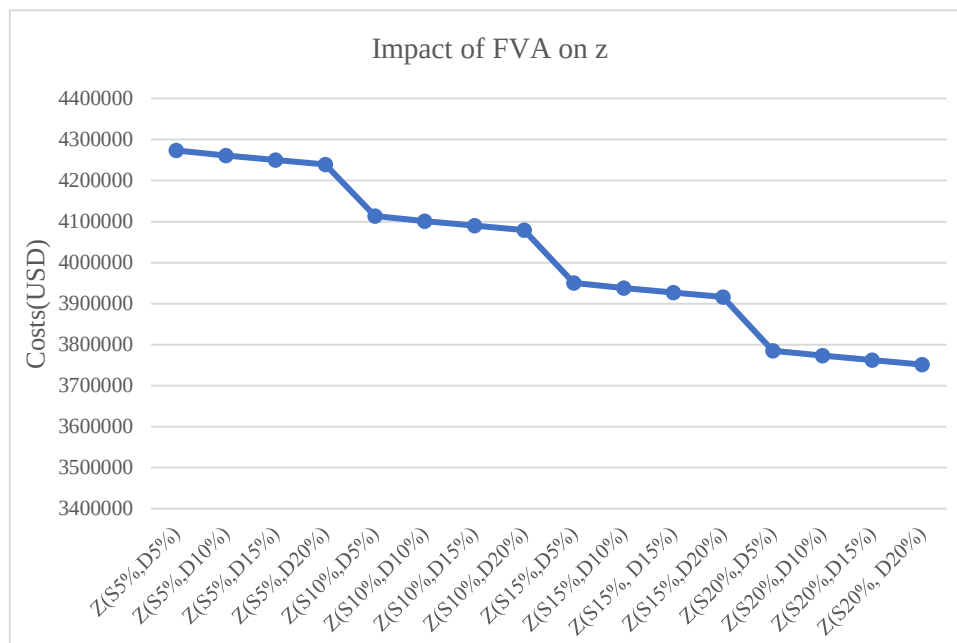


Figure 5.7 Impact of FVA on overall supply chain costs

The results indicate that the z reduces when the unit costs (UC_i, DC_i) are reduced based on the asset re-valuation of FVA. As the manufacturing costs are higher in the numerical analysis, the higher impact is observed when the operational costs of the product supplier are changed than the unit distribution costs of the 3PL operator. Therefore, it is evident that the FVA adoption affects the supply chain costs, and when the asset re-valuation generates lower output for unit costs, the overall supply chain costs achieve a lower cost reduction (see Figure 5.7). Hence, FVA method allows supply chain members to modify their costs and provides opportunities for manipulating costs.

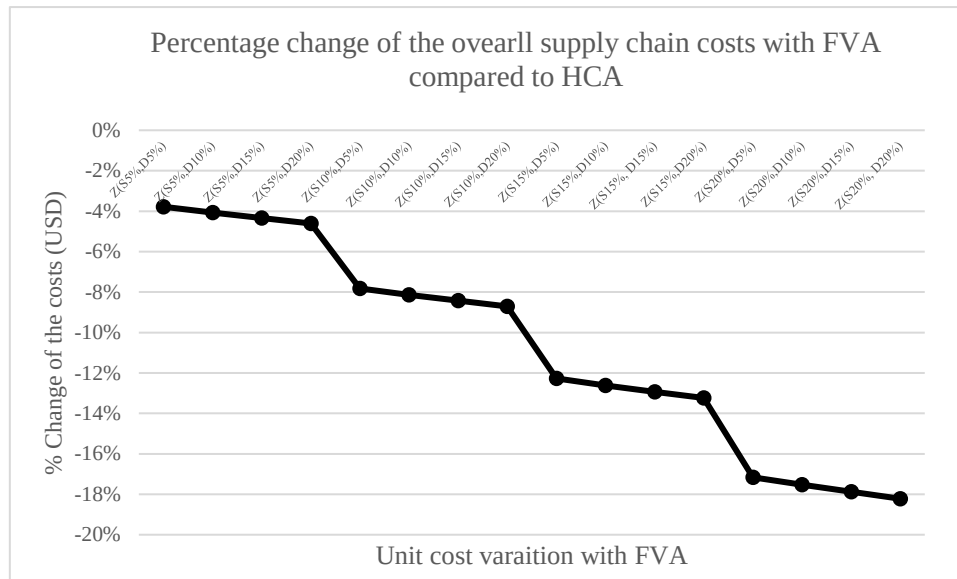


Figure 5.8 Percentage change of the overall supply chain costs with FVA compared to HCA

The results obtained from the sensitivity analysis of operational scenario 3 were compared with those of operational scenario 1, in which the HCA method was adopted by all supply chain members. This comparison was intended to identify the impact of using FVA methods at both upstream and downstream of the supply chain on the overall supply chain costs (see Figure 5.8). The overall supply chain costs are reduced from 4% to 18% when both the product supplier and the 3PL operator adopted FVA in their organisation compared to the costs when HCA is adopted. Hence, the results emphasise that FVA has a substantial impact on supply chain costs when compared with HCA.

Based on the results obtained from propositions 1 and 2, it is clear that the accounting method adopted by the different supply chain members has a significant impact on the supply chain costs as well as the incentive levels of the contracts. The results emphasise that adopting FVA within supply chain organisations changes the supply chain outcomes. This outcome depends on the outcomes of the asset re-valuation of these organisations. Using FVA affects both the supply chain costs as well as the contract outcomes. In contrast, adopting HCA affects the supply chain costs without altering the operational costs of the organisations. This can create lower sharing costs for the contract when the unit operational costs are higher.

Therefore, the findings generated through testing operational scenarios prove that both HCA and the FVA have a positive relationship with supply chain outcomes and contractual incentives. A higher impact is evidenced through FVA. However, FVA also creates opportunities for manipulating costs as asymmetric information exists in e-commerce supply chain operations, and these operations depend on accurate information. Therefore, both

Propositions 1 and 2 show positive relationships with the supply chain costs, but proposition 1 does not indicate a significant relationship with the incentive levels of a supply contract.

5.5.2 Results Analysis of Proposition 3

Proposition 3, which examined whether the revelation principle derived through incentive compatibility eliminates the possibility of manipulating information through creative accounting, was tested by incorporating two numerical illustrations. In the first instance, all constraints of the model were included in the contract model; in the second instance, constraints denoted by Eq. [4.5] and [4.8] were excluded. The numerical analysis was conducted with the same computer programme and the same data set.

The results of the contract model differed when Eq. [4.6] and [4.8] were removed from the model. The main observation from the results is the change in sharing costs. The sharing costs received by the 3PL operator are reduced, while for the product supplier, they become zero. To further highlight this result, a comparison was made between the sharing costs with the compatibility constraints and without the compatibility constraints, as illustrated in Figure 5.9.

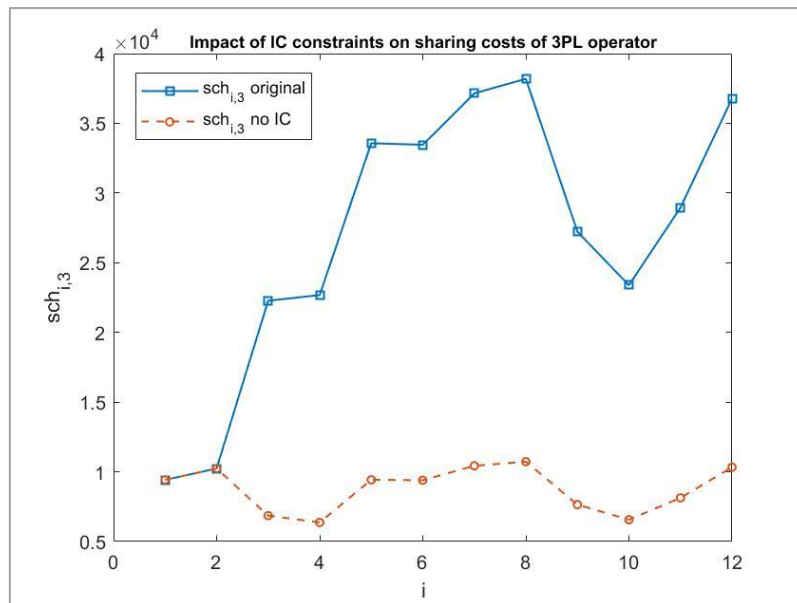


Figure 5.9 Comparison of sharing costs with and without incentive compatibility constraints for the 3PL operator

The reduction in incentives verifies that reporting false or modified costs does not provide benefits from the contract. The cost-sharing incentive received by the 3PL operator significantly reduces, and the product supplier gets zero benefits. This ensures that the revelation principle-based incentive compatibility motivates players to reveal true costs. As a result, it eliminates the possibility of adopting the creative accounting method to enhance the

financial picture. Removing compatibility constraints affects not only the incentives but also the supply chain costs. Figure 5.10 illustrates the impact of incentive compatibility constraints on the total individual costs when those constraints are removed from the cost-sharing contract.

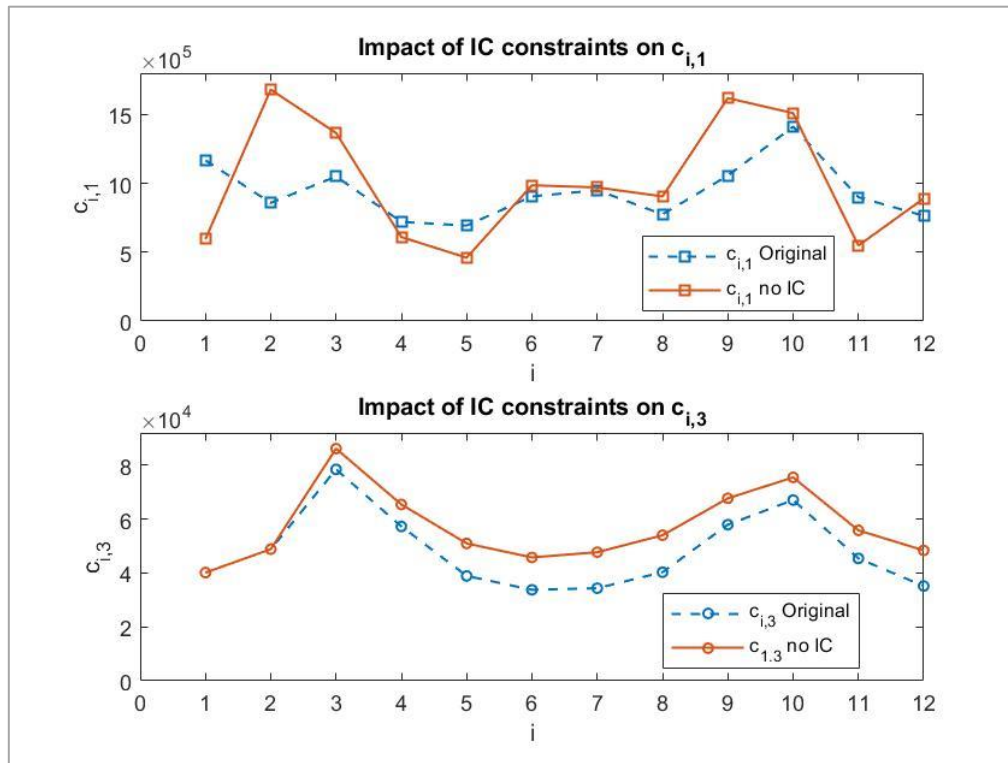


Figure 5.10 Comparison of the total individual costs with and without compatibility constraints

The total costs of the product supplier and 3PL operator increase without the incentive compatibility constraints. The product supplier's costs with compatibility constraints are higher in periods 4, 5 and 11. This is due to the increased level of manufacturing in those periods, as manufacturing cost is significantly higher in the numerical illustration considered in this study. In all other periods, the total costs are higher without incentive compatibility constraints. Therefore, the results further underline that incorporating incentive compatibility constraints ensures better cost optimisation for the product supplier as well as the 3PL operator. It also delivers better incentives, thus eliminating the possibility of adopting creative accounting practices. Therefore, the results of the numerical analysis show that proposition 3 is accurate.

5.6 Discussion of Key Findings

Throughout this chapter, the importance of cost measurement has been discussed in relation to the accounting information provided by supply chain organisations. Three propositions were tested to analyse the impact of different accounting information on supply chain and contractual outcomes. The findings highlight that both HCA and FVA methods affect the supply chain

costs, proving that propositions 1 and 2 have a positive relationship to the supply chain costs when the supply chain members are integrated through a contract model.

The findings of Horngren et al. (2014), and McGuigan, Moyer and Harris (2014) indicated that cost information changes according to the accounting method adopted by the supply chain organisation. This is reinforced by the results of the numerical analysis conducted in this study with the testing of propositions 1 and 2. The findings of this analysis emphasise further that FVA has more impact on supply chain costs than the HCA method. Migdalas (2002) and Scott (2015) discussed the impact of accounting methods on efficient contracting and the strategic interactions in a game or contract. According to the findings generated from propositions 1 and 2, HCA and FVA change the incentive levels of the proposed costs-sharing contract, thereby affecting the contractual outcomes and the motivation of the supply chain members to remain within the contract in the long-term. The findings of the numerical analysis presented in this chapter validate the argument of Gao (2013) that HCA supports better contractual conditions when asymmetric information exists. The results of this study clearly indicate that the outcomes of the supply chain costs under HCA are due to changes in market value but not changes in operational costs. In contrast, supply chain costs change due to changes in the market value as well as operational costs in the FVA method. Therefore, supply chain members have an opportunity to manipulate cost information, which is more pertinent for the operational setting of an e-tailer supply chain discussed in this study. This finding also corroborates the findings of Liao et al. (2013) in which the authors found that the FVA is positively correlated with the asymmetric information of the organisation.

The findings derived through proposition 3 prove that incentive compatibility constraints ensure that supply chain members cannot report false or modified cost information in the contract to gain extra benefits from cost-sharing. Instead, the players receive reduced levels of incentives or zero incentives without the incentive compatibility constraints, based on the revelation principle. Therefore, designing contracts with incentive compatibility constraints when asymmetric information is included eliminates the possibility of altering or modifying accounting information. Several studies in the literature related to creative accounting elaborate on the impact that this method can have on financial information; however, no findings are available on the impact of creative accounting adoption on supply chain outcomes and contract theory outcomes. The findings from proposition 3 verify that creative accounting affects supply chain contracts and incentive levels and, therefore, it is necessary to design and formulate

contracts with incentive compatibility conditions to avoid the use of creative accounting when asymmetric information exists.

Thus, the findings of this research verify the relationships and implications discussed in the theoretical framework of this chapter. Accounting information has a significant impact on the strategic interactions within supply chain operations, contractual outcomes, decision-making and supply chain costs.

5.7 Conclusion

This chapter analysed the impact of cost measurement on the outcomes of supply chain contracts. Cost measurement in supply chain organisations depends on the accounting methods adopted. Extant literature related to accounting information and contracts has indicated the importance of accounting information and its impact on contractual outcomes. However, there is no clear evidence on accounting information and its impact on supply chain contracts and costs, despite the fact that cost minimisation is a critical objective for any supply chain operation. This chapter has addressed this literature gap and provided evidence of the effects that different accounting methods have on supply chain costs and contracts. This study has used an e-commerce supply chain operation with a three-player scenario, led by an e-tailer, to test the gaps in the literature, particularly as e-commerce supply chains depend greatly on accurate information.

A theoretical framework was created to define the relationships between different accounting methods and supply chain costs, strategic decision-making and contractual outcomes. Based on that, three propositions were developed and tested using the dynamic cost-sharing contract model developed in this thesis. A numerical analysis was conducted for different operational scenarios, and the results were interpreted in relation to the developed model.

Both HCA and FVA affect supply chain costs. However, HCA does not create the opportunity for manipulating information as supply chain costs are affected by changes in external operational conditions, not by changes in accounting information. In contrast, FVA has a higher impact on changing cost information. Therefore, HCA is more appropriate for contracts than FVA, especially when asymmetric information is present. On the other hand, FVA derives better cost minimisation than HCA, as it uses current data to generate up-to-date information. Finally, the results of this study reveal that incentive compatibility adopted contracts ensure

that supply chain members have no opportunity to adopt creative accounting or manipulate contractual outcomes and supply chain costs.

So far, this study has discussed how effective contracts can be used to optimising e-tailer supply chain operations. In the next chapter, the importance of implementing a disruptive technology in eliminating the strategic issues discussed in this thesis are explored based on blockchain technology implementation in e-tailer supply chains.

CHAPTER 6 : BLOCKCHAIN IMPLEMENTATION FOR OPTIMISING E-COMMERCE SUPPLY CHAIN OPERATIONS

6.1 Introduction

Hitherto, supply chain contract modelling has been employed as a mechanism for addressing the issues of ineffective integration, information asymmetry and sub-optimal costs that arise in e-tailer supply chains. Both the extant literature and supply chain practitioners indicate that disruptive technology adaptation is being given increasing attention in addressing the strategic issues described in this study to improve supply chain performance. As discussed in Chapter 2, blockchain technology inherently eliminates some of the strategic issues related to information sharing, trust and even ineffective costs. In this chapter, the final research objective is investigated to determine how effectively blockchain system implementation can improve e-tailer supply chain operations.

The main characteristics that a blockchain system offers are distributed storage and listing, transactional validity, anonymity, improved levels of privacy, traceability and immediacy (Subramanian 2017). These factors are incredibly useful for electronic marketplaces as in online retailing, external supply chain partners collaborate virtually. The decentralisation aspect of the blockchain enables small and medium scale e-commerce operators to improve their operational trustworthiness. A blockchain also generates secure and transparent payment schemes with digital currencies while eliminating consumer disputes in online purchases (Fuzamei 2018). Therefore, e-commerce operations can gain significant benefits from implementing blockchain technology in their supply chains.

Integrating an emerging technology into an existing operation is a challenging task, as all parties need to agree and fulfil the basic requirements of the system. This can be complex in the case of a blockchain system implementation (Bai & Sarkis 2020). Hence, the feasibility of implementing a blockchain system into an existing e-commerce supply chain is an important issue to explore.

Accordingly, this chapter focuses on the following sub-objectives that are linked directly to the final research objective of this study:

1. How does the implementation of a blockchain system reduce information asymmetry issues and improve the transparency of the e-commerce supply chain?
2. What type of blockchain framework should be adopted by the e-commerce supply chain organisations?
3. How can blockchain implementation improve e-commerce supply chain operations in terms of cost minimisation?

Focusing on the above sub-objectives, first, the operational scenarios of different blockchain systems currently being utilised in the supply chains were identified. The attributes of the relevant blockchain systems were determined first. Accordingly, a suitable blockchain framework for e-commerce supply chain operations was developed. Based on the blockchain framework, information-sharing methods are discussed in terms of reducing information asymmetry issues among the e-commerce supply chain members.

The first two sub-objectives were addressed using conceptual analysis. Subsequently, the blockchain-related costs and e-commerce operational costs were identified, and the operational efficiency based on cost minimisation of the overall supply chain operations was analysed. Finally, the traditional e-commerce supply chain operation, which includes information asymmetry issues, was compared with the blockchain adopted e-commerce supply chain to examine whether a blockchain can derive operational efficiency and improve information sharing and transparency of operations. Optimisation models were formulated to analyse the operational feasibility of the blockchain system and to determine the level of improvements that can be obtained in e-commerce supply chain operations.

The rest of this chapter is organised as follows. Section 6.2 describes the key features and attributes of blockchain system implementation that are crucial in determining what type of blockchain system should be implemented. Section 6.3 describes the operational context, and Section 6.4 identifies the appropriate blockchain framework of the e-tailer supply chain. Then, in Section 6.5, an optimisation model is presented incorporating blockchain implementation parameters and costs in the decentralised operational model described in Chapter 3. The model was tested using industrial and hypothetical data, and a comparison was made between the traditional operation and the blockchain technology adopted operation. Based on the numerical analysis, the feasibility of blockchain implementation and cost optimisation is discussed in Section 6.6. Lastly, Section 6.7 discusses the key findings of this chapter, and the final section draws conclusions.

6.2 Blockchain System Implementation- Characteristics and Operational Features

6.2.1 Main Features of the Blockchain System

There are critical attributes that define the uniqueness of blockchain architecture. These are summarised in Table 6.1.

Table 6.1 Main attributes of the blockchain system

Attribute	Description	Reference
Decentralisation	Peer to peer network with data shared through all participants of the system and validated without a central authority. Therefore, the blockchain acts as a distributed ledger.	Perboli, Musso and Rosano (2018); Zheng et al. (2017)
Anonymity	Identity of the user remains anonymous.	Zheng et al. (2017)
Immutability	Data stored in the blockchain is verified and validated through the cryptographic mechanism, and therefore, data cannot be tampered with or altered.	Perboli, Musso and Rosano (2018)
Persistency	The capability of quick validation of transactions and admitted transactions into the system cannot be deleted.	Zheng et al. (2017)
Auditability	Easily verifiable transactions and the capability to track the transaction from inception.	Zheng et al. (2017)

Blockchains are differentiated according to their operational setting, which has evolved from the general Bitcoin based system. In that context, three central systems are widely defined in blockchain operations as public, private and consortium blockchains (Dib et al. 2018). The main features of these blockchains are summarised in Table 6.2. These features are essential for identifying what type of blockchain should be implemented by the e-tailer supply chain considered in this study.

The resources needed for a public blockchain are comparatively high compared with private or consortium blockchains, as it requires a substantial amount of physical and technological infrastructure (Zheng et al. 2020). In practice, some organisations are reluctant to enter into a public blockchain system as it shares all sensitive and confidential information, which competitors can exploit (O'Leary 2017). Chang, Chen and Lu (2019) found that using private blockchain is suitable for B2B operations as the privacy and confidentiality of data is preserved.

Table 6.2 Comparison of public, private and consortium blockchains

Description	Public blockchain	Private blockchain	Consortium blockchain
Operational setting	Fully decentralised	Centralised	Partially decentralised
Transaction validation	Anyone or a miner	Authorised participants or validators	
Ownership	Nobody	Single entity	Multiple entities
Governance	Public	Single organisation	Multiple organisations
Consensus mechanism	Proof of Work (PoW), Proof of Stake (PoS),	Proof of Authority (PoA), Practical Byzantine Fault Tolerance (PBFT), Tendermint	
Transaction speed	Slow	Fast	Fast
Immutability of the system	Almost impossible to tamper with the system	Possibility of tampering with the data	
Operating technologies	Bitcoin, Ethereum, Ripple, etc.	MultiChain, Quorum, Hyperledger, Ethermint, Tendermint, etc.	

Source: (Dib et al. 2018; O'Leary 2017; Zheng et al. 2017)

The world's largest e-tailer, Amazon, is currently managing blockchain systems supported for Ethereum and Hyperledger, enabling both public and private/consortium blockchain systems (Amazon Web Services Inc 2020). Therefore, it is clear that e-commerce giants such as Amazon also create platforms for a consortium blockchain, which is also known as the permissioned blockchain system, based on Hyperledger. Maersk, the largest shipping line in the world, has already implemented a consortium blockchain system in its supply chain system. The collaboration between Maersk and IBM is one of the best industry examples of consortium blockchain implementation, with the main focus being to fully digitalise container document transfer and improve container tracking (O'Leary 2017).

Blockchain has obtained these unique attributes because of its inimitable design architecture and characteristics. The consensus mechanism and smart contracts are critical aspects of a blockchain system. These aspects needed to be investigated further to determine the suitability of the blockchain operational framework of this study.

6.2.1.1 Consensus Mechanism

The consensus mechanism is one of the main characteristics that determine the immutability of the blockchain system. Several different consensus mechanisms generate different operational settings in the blockchain. These consensus mechanisms must showcase liveliness and safety, where liveliness ensures that if an honest user wants to include their transactions in the blockchain, it will eventually get accepted. Safety ensures that the transactions included in the system cannot be altered later (Dib et al. 2018).

Numerous consensus algorithms are available in the current market, and the most popular mechanisms are Proof of Work (PoW), Proof of Authority (PoA), Proof of Stake (PoS), Practical Byzantine Fault Tolerance (PBFT), Delegated Proof of Stake (DPoS) and Tendermint (Zheng et al. 2017). These consensus mechanisms have different impacts on blockchain operations, as summarised in Table 6.3.

Table 6.3 Comparison of the consensus mechanisms adopted in the blockchain system

Consensus mechanism	Type of blockchain system	Validation process	Resource Consumption levels	Security levels
PoW	Public	Validation through miners, where miners change the hash value of the block header frequently until the target value is reached and accepted by all nodes	High resources and energy levels	High
PoS	Public	Validation through “Forgers” based on the level of stake of the miners	Less resources and energy levels than PoW	Less than PoW
PoA	Private	Pre-approved validators carryout consensus based on the level of stake. No communication among validators to derive genuine nodes as all are pre-evaluated and approved.	Less energy and resources	High
PBFT	Private and consortium	Sends multiple messages/ performs coordinated attacks with the replication algorithm to determine the validity via identifying fault tolerance of the transactions. 2/3 votes from all nodes are required to accept the transaction and move to the next block.	Less resources and energy levels than PoS, DPoS	High
DPoS	Private	Stakeholders of the system select the validators, and it uses voting and selecting processes.	Less resources and energy than PoW, PoS	High
Tendermint	Consortium	Disseminates the transaction process to validators (quite similar to PBFT), and a leader is selected in a round-robin manner to commit the data to a block.	Less resources and energy levels than PoS, DPoS	Higher security than PBFT

Source: (Dib et al. 2018; He et al. 2019; Jalalzai, Richard & Busch 2019; Mao et al. 2019)

6.2.1.2 Smart Contracts

The smart contract is automatically executed when the contract clauses, terms and conditions are met, where these conditions and clauses are pre-written into the computer program (Dolgui et al. 2019; Mao et al. 2019; Zheng et al. 2020). These contracts work within blockchain systems. They consist of system transactions and do not need to be financial in nature (Laurence 2017). The smart contract eliminates the “trusted third party”, who manages the conventional

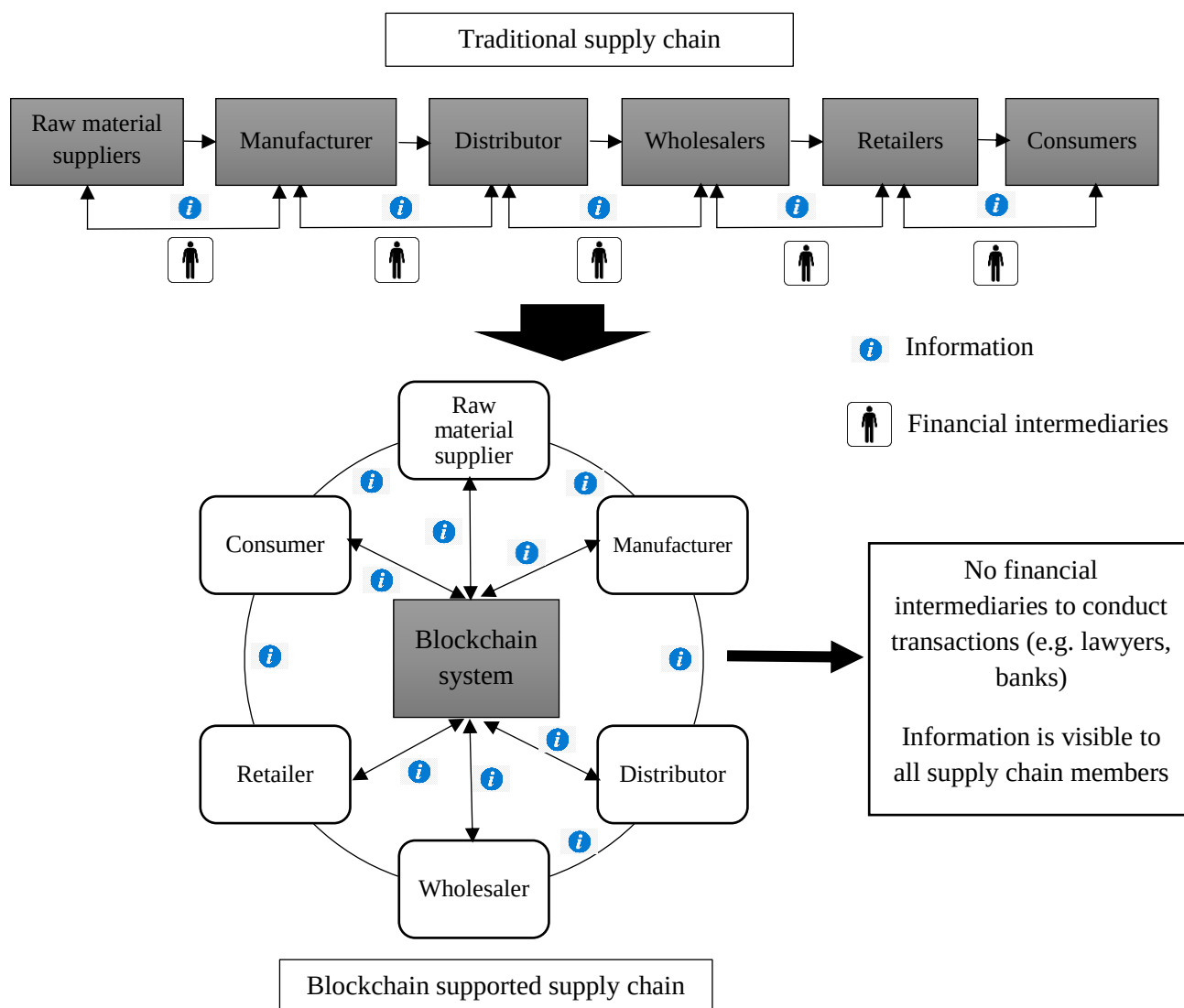
contract and, therefore, allows cost reduction and peer-to-peer operation within the blockchain system (Hu, Fan & Gao 2019; Zheng et al. 2020). The smart contract thus enables the transactions included in the blockchain to be traceable and permanent (Hu, Fan & Gao 2019). When the smart contract is executed, the blockchain system acts as the trusted third party and enforcer (Laurence 2017). According to Zheng et al. (2020), the main advantages of smart contracts compared to traditional contracts are reduction of risk levels, elimination of administration and service costs, and efficiency improvement in the business processes of organisations.

The smart contract has a lifecycle that consists of creation, deployment, execution and completion within the blockchain framework. Firstly, the parties who are involved in the blockchain negotiate the terms and conditions for the contracts. These terms and conditions are then written into the blockchain system and stored under deployment. Then the contract is automatically executed when the contract clauses are met in the execution step. Finally, the digital assets are transferred, such as money, and the data is updated to the blockchain system in the completion step (Zheng et al. 2020).

6.2.2 Blockchain Integration in Supply Chain Operations

When a blockchain system is integrated into supply chain operations, its operational nature changes. A comparison between the traditional supply chain setting and a blockchain implemented supply chain is illustrated in Figure 6.1, adapted from the work of Saberi, S et al. (2019).

As clearly depicted in Figure 6.1, the main changes of the blockchain system are generated by eliminating financial intermediaries such as financial institutions, law firms, and other payment platforms. This improves supply chain efficiency (Tapscott & Tapscott 2016). It also creates a platform for better information sharing among the supply chain partners, which is crucial for effective supply chain management. Blockchain systems can also safeguard the players, who share their sensitive information, thus enabling a trusted and secure operational setting for supply chain operations. Therefore, asymmetric information among supply chain members is reduced (Nakasumi 2017).



Source: Saberi, S et al. (2019)

Figure 6.1 Transformation of the supply chain with blockchain system implementation

The extant literature provides few studies that have incorporated blockchain adopted modelling to improve supply chain effectiveness. Bai and Sarkis (2020) investigated blockchain adaptation in resolving transparency issues in sustainable supply chain operations. The findings illustrate a framework for supply chain decision-makers to derive an appraisal model based on blockchain implementation. Wamba, Queiroz and Trinchera (2020) analysed the determinants of blockchain adoption on supply chain outcomes through empirical data gathered in India and the USA. The findings of this study disclose that the blockchain improves supply chain performance, and the main determinants are knowledge sharing and trading partner pressure. The relationship between blockchain enablers and the agricultural supply chain was discussed by Kamble, Gunasekaran and Sharma (2020), based on an empirical analysis. These authors identified 20 blockchain enablers and found that traceability is the most significant blockchain

enabler for agricultural supply chain operations. Longo et al. (2019) analysed how to improve trust and information sharing by deploying a public blockchain system, focused on an Ethereum like the UnicalCoin blockchain system. Within the simulation analysis of their study, transaction fees were considered as an important factor of blockchain operations and the study used algorithm-based models to derive the implications.

Several studies have incorporated smart contract development to improve supply chain operations. Wang, Z et al. (2020) designed a smart contract to enhance the traceability and information sharing of precast construction supply chains, considering ordering, delivery, and production costs. The smart contract conditions were analysed through algorithms by these authors. Dolgui et al. (2019) designed a smart contract to improve flow shop scheduling of supply chain operations using optimal control-based algorithms. Manupati et al. (2020) designed a smart contract within a consortium blockchain framework for a sustainable supply chain operation in effectively managing emission costs. However, these authors did not consider the implementation and management costs of blockchain in their model.

Nevertheless, no evidence is found in the literature that has investigated the blockchain costs and its impact on operational outcomes, such as cost optimisation, in e-commerce supply chains. Furthermore, no study has been found in the literature related to the comparison of blockchain costs between public and consortium blockchain operations. This is an important area to investigate as these blockchain systems have different implications. Therefore, this chapter explores how the blockchain system implementation improves the efficiency of e-tailer supply chains and derive some significant contributions to the literature as well as practice.

6.3 Problem Description

As discussed previously, e-commerce supply chains rely heavily on accurate information sharing and handle a significant volume of information within their systems. In the traditional e-tailer operational setting, each player maintains centralised databases in their organisations, with no guarantee of the accuracy of the information shared. This has been discussed as cost information asymmetry in previous chapters. Furthermore, the transactions occurring via the supply chain are always processed through a third-party intermediary, such as online payment platforms or banks, which cause additional expenses in operations (see Figure 6.2). It also leads to ineffective supply chain integration. Online supply chains need a transparent system among their supply chain partners to improve efficiency while optimising the operational costs of the system. Hence, a blockchain system is proposed in this study to optimise costs while

eliminating information asymmetry issues and improving transparency among supply chain members.

6.3.1 Integration of Traditional Supply Chain Data through a Blockchain System

Figure 6.2 illustrates how cyber supply chain information is integrated with the physical supply chain through blockchain implementation. The existing players of this supply chain have their centralised databases (e.g., ERP), which store the data required for the e-commerce supply chain operations. These databases are not accessible to other supply chain members. Data is incorporated into the blockchain system, and it is recorded in the distributed ledger operated within that system.

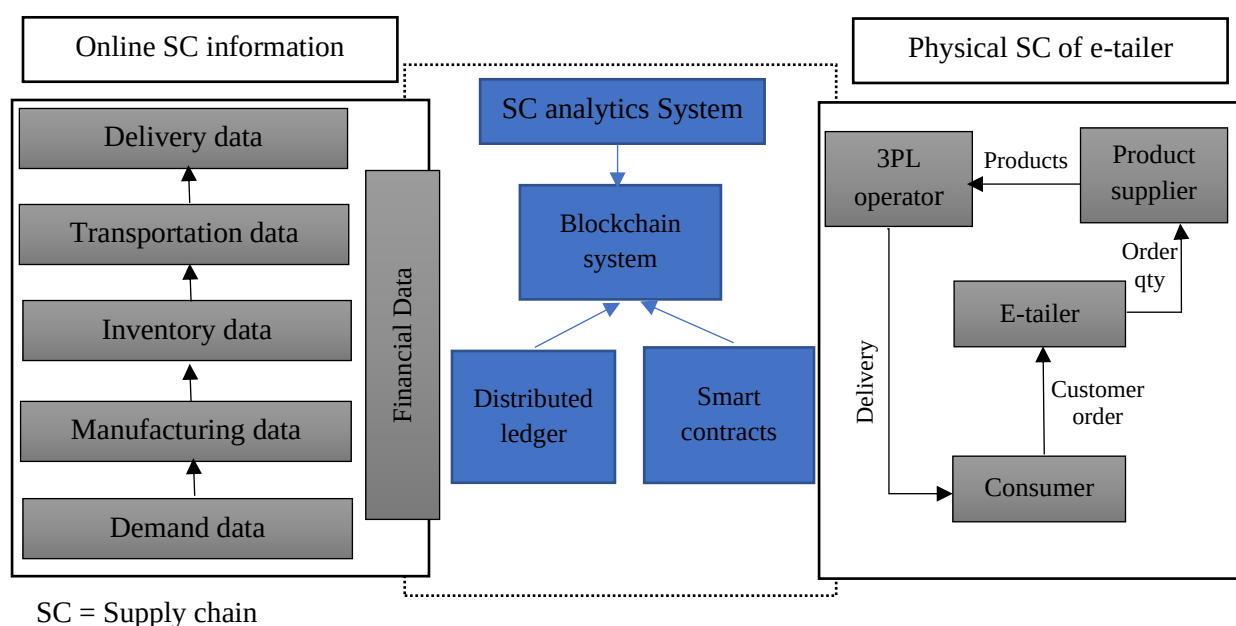


Figure 6.2 Integration of the cyber supply chain information with the physical supply chain

6.3.2 Blockchain System Based E-commerce Supply Chain Operation

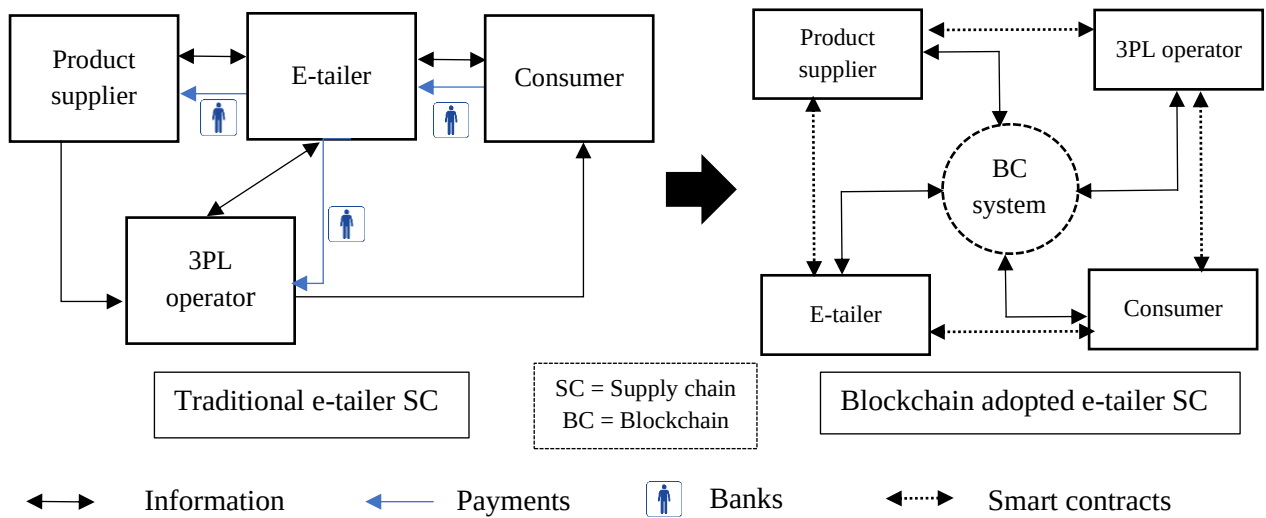


Figure 6.3 Comparison of the information and financial flow between the traditional e-commerce supply chain and blockchain adopted supply chain

In a traditional e-tailer supply chain, information sharing happens only between two players at a given time. In the blockchain adopted supply chain, all information is recorded in the blockchain system, and all members can see the information within the chain. For example, the consumer and other players can view the product details. This ensures security and trust for the purchase of goods (Saber, S et al. 2019). Furthermore, in blockchain adopted supply chains, all payments are made via cryptocurrencies or digital currencies such as Bitcoin, which eliminates the requirement of third-party payments (e.g., to banks), unlike in the traditional supply chain. Transactions occur via smart contracts in blockchain adopted supply chains, enabling all information to be validated before including it in the system and revealing accurate information to all players in the blockchain. Therefore, adopting the blockchain system in an e-commerce supply chain eliminates information asymmetry among different supply chain members and improves transparency in information sharing within the supply chain. In long-term operations, this enhances trust among the supply chain partners and supports successful long-term integration.

Next, the proposed blockchain framework for the e-tailer supply chain is discussed in detail.

6.4 Proposed Blockchain Framework

In the operational setting established in this study, it is assumed that the e-tailer proposes to implement the blockchain system for effectively collaborating with the supply chain partners with the expectation of minimising supply chain costs, improving information sharing and transparency of operations. In this chapter, the multi-players in each supply chain level are considered, relating to real-world operations. Therefore, the assumption of considering a single player in each supply chain level (as discussed in previous models) is relaxed. Still, a small/medium-scale operation is considered as the operational context.

As this setup has multiple organisations, which operate within a competitive market, designing a private blockchain is appropriate to ensure the confidentiality of the data and security for the supply chain members (Chang, Chen & Lu 2019; Manupati et al. 2020). Therefore, a consortium blockchain system was selected as the most appropriate as it gives decision-making authority not only to a single organisation but to pre-selected and approved members in the supply chain. Therefore, product suppliers and 3PL operators will both have decision-making authority. The PBFT consensus mechanism was incorporated into this framework. This has been identified as one of the best practical consensus mechanisms in permissioned blockchain systems as it utilises fewer resources, reduces energy consumption, and creates a higher level of security (see Table 6.3). This system adopts multiple smart contracts for carrying out all transactions, thereby eliminating financial intermediaries and manual operating costs.

The blockchain framework illustrated in Figure 6.4 has a private layer and public layer. The public layer is developed to give access to consumers, and the private layer consists of the designed consortium blockchain system. Each supply chain member must be equipped with the necessary IoT facilities and ERP systems to integrate the blockchain system into their operations. For example, the product supplier may require Radio Frequency Identification (RFID) tags, Hand-Held Terminals (HHT) for data entries and GPS tracking systems to feed the data into their systems. When the blockchain system integrates with the ERP, it improves the capabilities of the ERP system as it absorbs the unique features of the blockchain (Kulkarani 2018; Mearian 2017). The transformation towards a blockchain system will require a considerable initial investment cost. Then, the operational and maintenance cost of the blockchain system is shared by all members of the supply chain, allowing the marginal costs of the blockchain system to be reduced (Dib et al. 2018). The transaction data is recorded in the system after being validated through the PBFT consensus mechanism. Using such a

mechanism allows pre-authorised validators to verify and approve transactions with 2/3 consensus from all nodes. Hence, there is less chance of corruption, such as in public blockchains with miners. New blocks are created for the system once the transactions are approved and recorded. These transactions happen via smart contracts. In the next section, the incorporation of smart contracts in this blockchain framework is explained in detail.

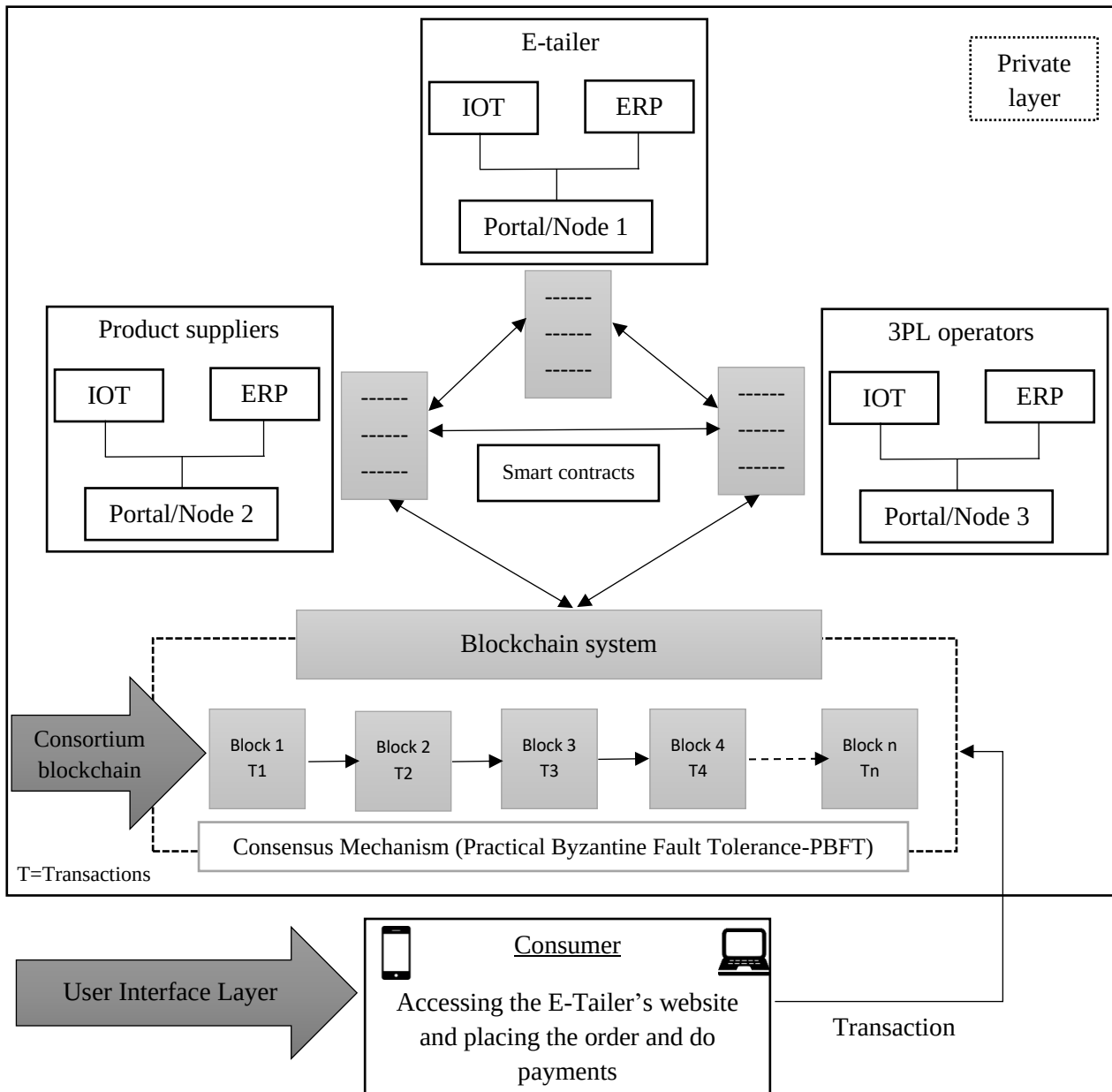


Figure 6.4 Proposed blockchain framework for an e-commerce supply chain

6.4.1 Smart Contracts Adopted within the Proposed E-commerce Supply Chain Operation

As illustrated in Figure 6.4, the proposed blockchain framework adopts multiple smart contracts in conducting the transactions of this system. The smart contracts are developed for transactions between product suppliers and the e-tailer, 3PL operators and the e-tailer, and product suppliers and 3PL operators.

Smart contract 1 (Product suppliers and e-tailer)

When the e-tailer receives consumer demand into the blockchain, he sends the order quantity levels to all the product suppliers included in the consortium, with the clauses of minimum order quantity levels. Then the product suppliers submit their quotations to the system, and the product supplier/s are matched with the minimum order quantity levels, and the lower costs are selected to provide the goods for the supply chain.

Smart contract 2 (E-tailer and 3PL operators)

When the e-tailer decides the order quantity, he sends the delivery quantity levels with the clause of minimum delivery quantity to the 3PL operators in the consortium. The 3PL operators submit their quotations to the system, and suitable 3PL operator/s are selected to deliver the products to the consumer. The e-tailer makes the payment when the 3PL operator/s deliver the products to the consumer.

Smart contract 3 (Product suppliers and 3PL operators)

When products suppliers are selected, they contact the selected 3PL operator/s to pick up the goods from their warehouses and deliver to the consumer.

Payments for the transactions also occur via smart contracts. The e-tailer's payments for product suppliers and 3PL operators, as well as consumer payments, also occur through smart contracts.

6.5 Model Formulation

The notations and assumptions for the proposed blockchain model are given as follows. As this model includes additional indexes, the model notations are newly interpreted in Table 6.4 for this chapter.

Table 6.4 Notations for the proposed blockchain model

Notation	Description
Sets and Indexes	
i	Time period (1, 2, 3, ..., t)
j	Type of supply chain members (1: Product supplier, 2: E-tailer, 3: 3PL operator)
n	Number of product suppliers (1, 2, ..., r)
m	Number of 3PL operators (1, 2, ..., z)
Parameters	
$UC_{i,n}$	The unit production cost of the product supplier n in period i
$HC_{i,n}$	The unit cost of storage of the product supplier n in period i
$DC_{i,m}$	Unit distribution cost of the 3PL operator m in period i
Π_n	Initial inventory of the product supplier n
W_n^{cap}	Warehouse capacity of the product supplier n
M_n^{cap}	Manufacturing capacity of the product supplier n
D_i	Consumer demand for the e-commerce supply chain for the period i
$Q_i^{\min}$	Minimum order quantity of the supply chain in period i
V_m^{cap}	The maximum carrying capacity of the 3PL operator m
$B_i^{\min}$	The minimum delivery capacity of the supply chain in period i
$VC_{i,j}$	Blockchain implementation and maintenance cost of player j in period i
$TC_{i,j}$	The variable transaction cost of the blockchain of player j in period i
BC_{cap}	The maximum transaction volume of the blockchain
W_j	The weight allocated for player j in the objective function
$OC_{i,n}$	Unit ordering cost of e-tailer paid to the product supplier n in period i
$SC_{i,m}$	Unit service fee paid by the e-tailer to the 3PL operator m in period i
Decision variables	
$q_{i,n}$	Production quantity of the product supplier n in period i
$a_{i,n}$	Delivery quantity of the product supplier n in period i
$s_{i,n}$	Inventory level of the product supplier n in period i
$b_{i,m}$	Number of units carrying by the 3PL operator m in period i

$\pi_{i,j}$	Total operational costs of player j in period i
$X_{i,n}$	Binary variable defining whether the product supplier n deliver products or not
$Y_{i,m}$	Binary variable defining whether the 3PL operator m deliver products or not
V	Overall supply chain cost

Assumptions

The following assumptions were considered when developing the proposed blockchain model:

1. The e-tailer bears the initial investment cost of the blockchain system construction.
2. All players in the supply chain share the operational and maintenance costs of the blockchain system.
3. The e-tailer pays a higher portion of the operational and maintenance costs of the blockchain than is paid by the product supplier or the 3PL operator: $VC_{BC(i,j;j=1,3)} \leq VC_{BC(i,j;j=2)}$
4. The transaction fee paid by the product supplier and the 3PL operator is less than that paid by the e-tailer: $TC_{BC(i,j;j=1,3)} \leq TC_{BC(i,j;j=2)}$
5. The product suppliers will be pre-selected after checking the quality levels in the operational platform. Therefore, cost and quantity levels are considered as the selection criteria through smart contracts.
6. The number of transactions is determined based on the quantities handled by each player in a given operational transaction.
7. The 3PL operator only handles the delivery operation.
8. The supply chain handles a single product.

Objective function

As the primary focus of this model is to analyse the cost-effectiveness of blockchain implementation in a traditional e-tailer lead supply chain, the objective function is taken as the minimising of overall supply chain costs, similar to the functions of the models presented in previous chapters.

$$\text{Minimize} \quad V = \left[W_1 \sum_{\forall_i} \pi_{i,1} + W_2 \sum_{\forall_i} \pi_{i,2} + W_3 \sum_{\forall_i} \pi_{i,3} \right] \quad [6.1]$$

The objective is to minimise the overall supply chain cost (V), using the weighted sum of individual total costs of each supply chain member (Eq. [6.1]).

$$\pi_{i,1} = \sum_{\forall_n} \left[\left\{ (UC_{i,n} \cdot q_{i,n}) + HC_{i,n} \left(\frac{s_{i,n} + s_{i-1,n}}{2} \right) \right\} + VC_{i,n} + TC_{i,1}(a_{i,n}) \right] \quad [6.2]$$

$$\pi_{i,2} = \sum_{\forall_n \forall_m} \left[\left\{ (OC_{i,1} \cdot a_{i,n}) + (SC_{i,3} \cdot b_{i,m}) \right\} + TC_{i,2}(a_{i,n} + b_{i,m}) + VC_{i,2} \right] \quad [6.3]$$

$$\pi_{i,3} = \sum_{\forall_m} \left[\left\{ DC_{i,m} \cdot b_{i,m} \right\} + TC_{i,3}(b_{i,m}) + VC_{i,3} \right] \quad [6.4]$$

The product suppliers' total individual costs are denoted by Eq. [6.2]. This includes the total production, total inventory handling costs, and the blockchain implementation and maintenance costs, with the total transaction fees paid to the blockchain system by the product supplier n in each period i . Eq.[6.3] expresses the total individual cost of the e-tailer in each period i includes the total order costs paid to the product suppliers, the total service costs paid to the 3PL operators, total investment and maintenance costs, and the transaction fees paid to the blockchain. The total individual costs of the 3PL operators are indicated by Eq. [6.4]. This includes the total distribution costs, total investment and maintenance cost of the blockchain and the transaction fees paid to the blockchain system in each period i .

Subject to the constraints:

Inventory constraints

$$s_{i,n} = q_{i,n} - a_{i,n} + s_{i-1,n}; \forall_i \forall_n, i > 1 \quad [6.5]$$

$$s_{1,n} = q_{1,n} - a_{1,n} + II_n; \forall_n, i = 1 \quad [6.6]$$

Capacity constraints

$$s_{i,n} \leq W_n^{cap}; \forall_i \forall_n \quad [6.7]$$

$$q_{i,n} \leq M_n^{cap}; \forall_i \forall_n \quad [6.8]$$

$$X_{i,n} \cdot Q_i^{\min} \leq a_{i,n} \leq X_{i,n} \cdot D_i; \forall_i \forall_n \quad [6.9]$$

$$b_{i,m} \leq V_m^{cap}; \forall_i \forall_m \quad [6.10]$$

$$Y_{i,n} \cdot B_i^{\min} \leq b_{i,m} \leq Y_{i,n} \cdot D_i; \forall_i \forall_m \quad [6.11]$$

Demand constraints

$$\sum_{\forall_n} a_{i,n} \geq D_i \quad [6.12]$$

$$\sum_{\forall_m} b_{i,m} \geq D_i \quad [6.13]$$

Blockchain capacity constraint

$$\sum_{\forall_n} (a_{i,n} + q_{i,n} + s_{i,n}) + \sum_{\forall_m} b_{i,m} \leq BC_{cap} \quad [6.14]$$

Binary variables

$$X_{i,n} \in \{0,1\} \quad \forall_i \in N \quad [6.15]$$

$$Y_{i,m} \in \{0,1\} \quad \forall_i \in N \quad [6.16]$$

Non-negativity constraints

$$q_{i,n} \geq 0; s_{i,n} \geq 0; a_{i,n} \geq 0; b_{i,m} \geq 0; \pi_{i,j} \geq 0 \quad [6.17]$$

Eq. [6.5] and [6.6] indicate the inventory levels to be maintained by the product supplier n in each period i . The inventory level in each period i is determined by the production quantity, order quantity and the inventory level of the previous period. The inventory level of period 1 is determined by the production and order quantity of period 1 and the initial inventory of the product supplier (I_n). The model includes maximum production and warehousing capacity levels for the product supplier, denoted by Eq. [6.7] and [6.8], respectively. Eq. [6.9] denotes the minimum and maximum order quantity levels that need to be fulfilled by the product supplier n . It enables the product supplier n , who can meet the minimum order quantity levels, to be selected to fulfil the order. Eq. [6.10] explains the maximum delivery capacity level of the 3PL operator m , which cannot be exceeded in each period i . Eq. [6.11] denotes the minimum and maximum delivery quantities for the selected 3PL operator m in each period i , which ensures that only the 3PL operator who can meet the capacity requirements will be selected. Eq. [6.12] and [6.13] ensure capacity levels and demand. Therefore, the total order quantity by the player n and total delivery quantity of the player m should be greater than the demand in each period i for the product suppliers and the 3PL operators to satisfy the demand in every period. Eq. [6.14] denotes the total capacity of the blockchain system, which determines the

maximum number of transactions handled by the blockchain. Therefore, the total number of transactions of this e-commerce supply chain cannot exceed the maximum capacity of the blockchain system within the total periods considered.

6.6 Numerical Analysis

6.6.1 Data

Data was gathered from multiple sources relating to actual operational settings to test the model and analyse the blockchain system feasibility within the e-commerce supply chain (see Table 6.5). Initially, the blockchain adopted model was tested and then compared with the traditional e-commerce supply chain model within the same operational framework to evaluate the effectiveness of blockchain adoption. Table 6.5 includes data gathered for both these models.

Table 6.5 Data related to the model analysis

Description of the data	Type of costs	Source
Blockchain system costs	Investment cost, Maintenance cost, Transaction costs	Ernst & Young (2019)
Operational costs of 3PL	Unit distribution costs	United Parcel Service of America (2017)
ERP system costs	License cost, Support and upgrade costs	Oracle Corporation (2019)
	Maintenance costs	MariaDB Corporation (2018)

Blockchain system costs

The blockchain system costs are crucial in this analysis as they determine the feasibility of the system implementation. A report by Ernst & Young (2019) analysed blockchain implementation costs for different blockchain frameworks. The average operational setting of a private blockchain system considered in this report included ten full nodes and 250 end-users and, therefore, this operational setting was considered suitable for a small/medium scale supply chain operation. Furthermore, the authors segregated operational costs according to four major attributes: transaction volume, transaction size, node hosting method, and consensus protocol of the blockchain system. Accordingly, the appropriate costs relevant to the proposed blockchain system are considered in this chapter. The proposed blockchain system in this study adopted a consortium blockchain with PBFT consensus protocol and smart contracts. Therefore, the transaction size should be large. Based on these facts, the following private blockchain data from Ernst & Young (2019) were extracted in deciding the relevant data set to carry out the numerical illustration:

- Daily transaction volume = 1000

- Transaction size = Large (500 Bytes)
- Node hosting method = Cloud-based
- Consensus protocol = PBFT

In this setting, the operational and maintenance costs comprise onboarding, cloud, and the maintenance and monitoring costs of the blockchain system. Data were available for a five-year period. Based on that, the data for $VC_{i,j}$ was determined. As per the model assumptions, the annual operational costs of the blockchain are shared among the total number of players in the supply chain, while the e-tailer pays a higher portion of the overall operational and maintenance costs. The average transaction cost of the consortium blockchain system was calculated in this study by gathering data for $TC_{i,j}$, which consists of the audit costs for transactions, cloud storage costs, and transaction size-related costs as interpreted by Ernst & Young (2019).

ERP system costs

The blockchain system integrates with the existing ERP systems and creates a collaborative platform, absorbing its unique features into the operations. Therefore, it was necessary to identify the ERP system costs that are replaced when the blockchain system is adopted. From ORACLE (2019), the license costs and the support and upgrade system costs were obtained for the “ORACLE E-Business Suite”, which has a user-range of between 25 and 1000. Hence, this was considered suitable for small/medium scale operations. This is an all-inclusive system, comprising functions such as marketing, sales, finance, supply chain management, materials management, manufacturing, customer relationship management and database management. The values of $C_{i,j}^{ERP}$ were determined by amalgamating the license costs, support and upgrade costs and the maintenance costs obtained based on the reports of the MariaDB Corporation (2018) and Oracle Corporation (2019).

Other relevant data for the operational model were extracted from Ragsdale (2017) and through spreadsheet simulation using the normal distribution and uniform distribution. The data used for the analysis are presented in Appendix J.

The model was tested using multiple suppliers and 3PL operators in this operational setting, with a scenario that included three suppliers and two 3PL operators.

6.6.2 Computer Experiments

The model formulated above includes integer values and, therefore, was solved as a Mixed Integer Linear Programming (MILP) model. As explained before, the GUSEK solver can solve large-scale integer programming problems and, therefore, was once again used to solve the models presented in this chapter. When the model is a MILP, the GUSEK solver uses branch and cut algorithms to generate optimal solutions. The AMPL model code of the blockchain adopted model is provided in Appendix C.

6.6.3 Results Analysis

6.6.3.1 Results of Blockchain Adopted Supply Chain Operations

The execution of the model derived an integer optimal solution for the given data set. Initially, the blockchain model was tested by considering the higher operational cost scenario for all players (as asymmetric information exists in the traditional decentralised e-tailer supply chain, two discrete cost values were taken as higher and lower, which was applicable to the comparison analysis presented in this chapter). The optimal solution is presented in Appendix L. Based on the results of the optimal solution, the following findings were generated.

According to the smart contract execution for supplier selection, the supplier who is capable of providing the minimum order quantity with the lowest possible cost is selected (see Figure 6.5). In the initial period, both product supplier 1 and 2 are chosen to fulfil the delivery quantity requirements.

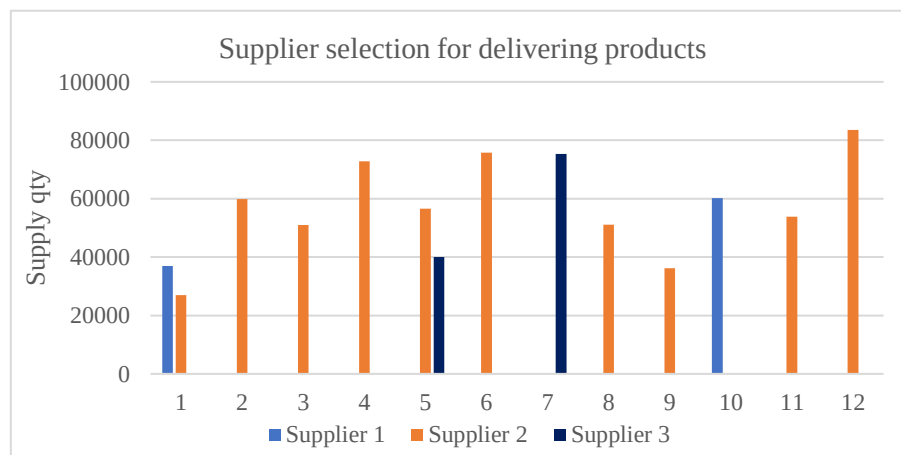


Figure 6.5 Supplier selection based on the minimum quantity criteria

Similarly, the 3PL operator selection is decided based on the capacity to deliver the minimum delivery quantity to the consumer (see Figure 6.6).

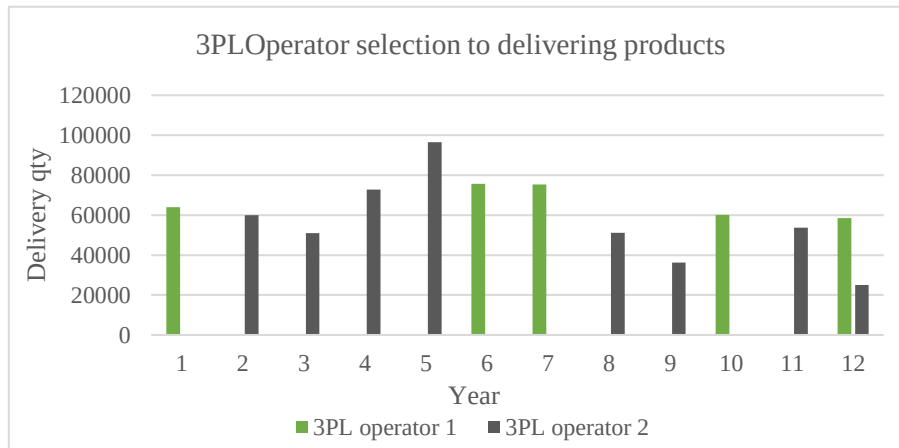


Figure 6.6 3PL operator selection based on the minimum quantity criteria

The results reveal that the model not only evaluates the minimum quantity requirements but also analyses the lower operational costs when selecting the product suppliers and 3PL operators. Therefore, this aligns with the objective of cost minimisation in this operation.

A sensitivity analysis was conducted to analyse the impact of the critical parameters of the numerical analysis on the supply chain costs of the proposed model.

6.6.3.2 Impact of Demand (D_i) on the Blockchain Adopted Supply Chain costs

When there is an increasing demand trend over periods, V increases; it decreases when there is a decreasing demand trend, which is illustrated in Figure 6.7. When the demand has a fluctuating trend, the supply chain costs vary in each period. Therefore, the individual total costs of the suppliers, e-tailer and the 3PL operators have a positive relationship with demand. As manufacturing costs are comparatively high in this numerical illustration, product suppliers have the highest costs in all periods, compared with the e-tailer and 3PL operators.

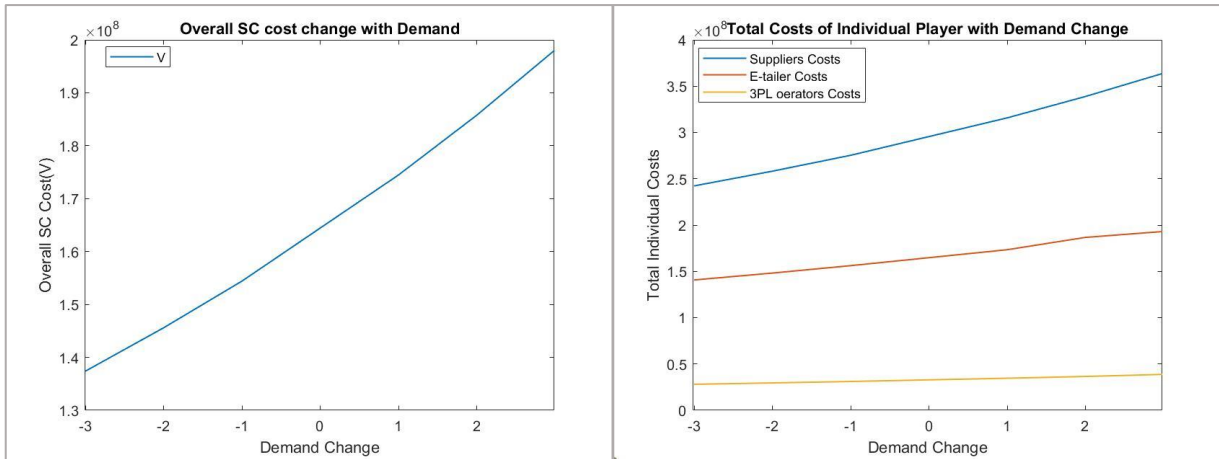


Figure 6.7 Impact of demand on supply chain costs

Therefore, in this analysis, the total costs of the product suppliers have the highest impact on increasing costs compared with the e-tailer and 3PL operators, as manufacturing is the highest cost.

6.6.3.3 Impact of Blockchain Implementation and maintenance cost ($VC_{i,j}$) on the Blockchain Adopted Supply Chain Costs

It is assumed that the e-tailer pays a greater portion of the blockchain implementation and maintenance costs ($VC_{i,j}$), where $VC_{i,2} \geq VC_{i,1}$ and $VC_{i,2} \geq VC_{i,3}$. In the above numerical illustration (see also Appendix J), the portions are considered as $VC_{i,2} = 29\%$, $VC_{i,1} = 14\%$ and $VC_{i,3} = 14\%$, as blockchain implementation and management costs are shared among all members of the supply chain. In this sub-section, the impact of $VC_{i,j}$ on overall supply chain costs and total individual costs is examined (Figure 6.8).

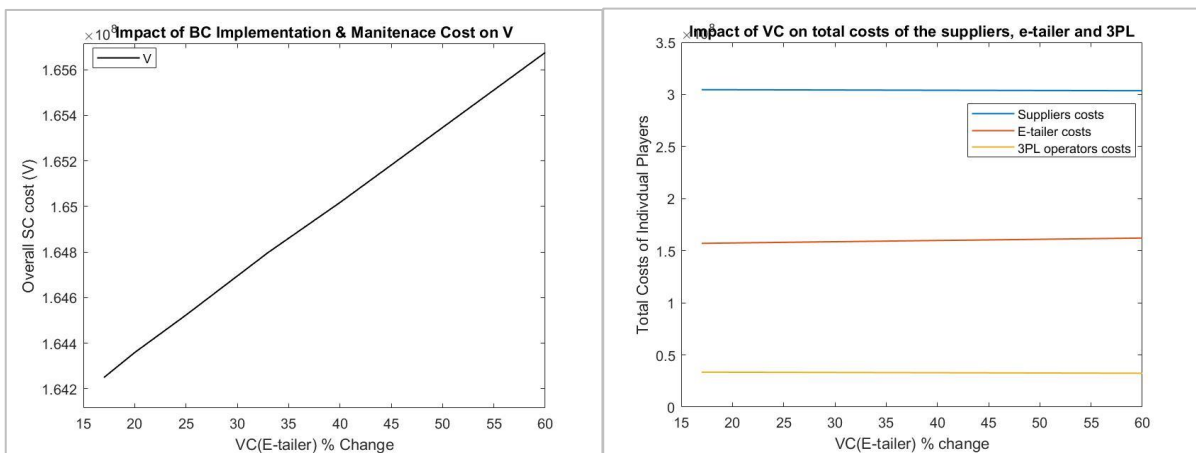


Figure 6.8 Impact of blockchain implementation and maintenance costs on supply chain costs

For the sensitivity analysis, equal costs for the $VC_{i,j}$ were initially considered, with all players bearing 17% of the cost. The percentage share was then increased up to a point, which e-tailer was paying 60% of those costs. Results show that both the overall supply chain costs and the e-tailer's overall costs increased, while the suppliers' and 3PL operators' costs reduced (see Figure 6.8). By sharing this cost among the supply chain members and also paying a higher portion, the e-tailer is able to encourage the participation of product suppliers and 3PL operators in the system, but this increases the overall supply chain costs and the e-tailer's total costs. Hence, a more suitable percentage needed to be determined to create a win-win outcome for all parties.

The lowest overall supply chain costs are obtained when all players share an equal percentage of the $VC_{i,j}$, which is 17%. However, as the e-tailer's objective is to encourage the integration of product suppliers and 3PL operators into this blockchain system, the e-tailer must accept a higher percentage of the $VC_{i,j}$ in the initial periods as an additional incentive to these supply chain partners. As the $VC_{i,j}$ has a positive linear relationship with the overall supply chain costs (see Figure 6.8), the e-tailer has to decide the maximum percentage of the blockchain implementation and management costs he is willing to bear. The results of the sensitivity analysis indicate that the most suitable percentages vary between 20% to 40% for the e-tailer. This also gives a fair percentage of costs to the other players, as within this setting, they have more than a 10% allocation of the $VC_{i,j}$.

As blockchain costs are shared among the parties involved (Dib et al. 2018), increasing the number of product suppliers as well as 3PL operators can further reduce the blockchain implementation and maintenance costs within this operation. When the e-tailer bears 20%, 25% or 29% of the $VC_{i,j}$, this allows for more players in the blockchain because the percentages for the other players are 16%, 15% or 14% respectively. However, when the $VC_{i,2}$ increases up to 50%, the other players have a comparatively lower cost percentage (e.g., 10% in this numerical analysis). Therefore, bringing in more players is one strategy to reduce the blockchain management costs. However, the capacity of the blockchain system is a key factor that needs to be considered when adding more supply chain members, as the involvement of more players increases the transaction volume and, accordingly, the system capacity (e.g. cloud storage, system volume) must be increased (Ernst & Young 2019). Therefore, these results

indicate that when the operational network of the supply chain gets bigger, blockchain implementation can bring significant cost reductions to the supply chain.

However, it is necessary to evaluate whether implementing a blockchain system is beneficial in terms of cost optimisation for small/medium scale e-tailer supply chain as discussed in this chapter (with three product suppliers, two 3PL operators and an e-tailer setting).

Hence, the blockchain adopted model is compared with the traditional e-commerce supply chain operation to investigate whether blockchain system implementation can improve traditional e-commerce supply chain costs.

6.6.4 Comparison of the Blockchain Adopted E-commerce Supply Chain Model with the Traditional E-commerce Operation Model

This section examines the traditional e-commerce supply chain operations to compare the cost-effectiveness of the proposed blockchain framework. The same data set is used for the comparison; however, instead of blockchain related costs, several other parameters that are applicable to the traditional e-commerce-based supply chain operation are defined. The following additional parameters are included in the traditional model:

This section examines traditional e-commerce supply chain operations to compare the cost-effectiveness of the proposed blockchain framework. The same data set was used for the comparison; however, instead of blockchain related costs, several other parameters were defined as applicable to traditional e-commerce-based supply chain operations. These additional parameters are discussed below.

6.6.4.1 Traditional E-commerce Supply Chain Model

The following facts are associated with the traditional e-commerce supply chain model:

1. The supply chain members use central databases and ERP systems in their organisations.
2. The e-tailer cannot observe the actual operational costs of the product supplier and the 3PL operator, which creates an asymmetric information scenario.
3. Inventory is held at both the product supplier and the e-tailer.

6.6.4.2 Assumptions of the model

The following assumptions associated with the traditional e-commerce model were also considered:

1. All supply chain members have already implemented ERP systems when the operation commences, and all members are using ORACLE systems in their organisations (ORACLE is ranked the world's number two ERP system (Pang, Markoviski & Micik 2019)).
2. When the blockchain is integrated into the existing ERP systems, financial management and database management costs will be replaced in the traditional supply chain. As all other sub-systems of the ERP system remain in both scenarios, only the financial and database management costs of the ERP system are considered in the traditional operation for comparison.
3. All payments of the supply chain members include the same credit card surcharge rate.
4. ERP license costs are renewed annually (based on ORACLE license definitions and rules).
5. ERP support and upgrade costs are increased every two years by 4% (based on ORACLE license definitions and rules).

Based on the above discussion, the differences between the blockchain adopted supply chain and the traditional supply chain were examined and are summarised in Table 6.6:

Table 6.6 Comparison between the blockchain adopted supply chain model and traditional supply chain model

Description	Blockchain adopted e-commerce supply chain	Traditional e-commerce supply chain
E-tailer's inventory level	No inventory	Positive inventory holding
Financial and database management costs	Blockchain system provides integrated support for financial and database management	ERP system costs of financial and database management
Information asymmetry	No information asymmetry, actual costs are reported	No guarantee of the actual costs of the individual supply chain member
Transaction costs	Transaction fee per each transaction	Bank surcharge fees (e.g. credit cards)

6.6.4.3 Traditional e-Commerce Supply Chain Model Formulation

Additional parameters and variables of the traditional e-commerce system are defined in Table 6.7, with several related to the asymmetric information setting discussed in Chapter 3. Others were defined based on the additional operational costs related to administration and system management.

Table 6.7 Parameters and decision variables of the traditional e-commerce supply chain system

#	Notation	Description
<u>Sets and Indexes</u>		
1	i	Time period (1, 2, 3, ..., t)
2	j	Type of supply chain members (1: Product supplier, 2: E-tailer, 3: 3PL operator)
3	n	Number of product suppliers (1, 2, ..., r)
4	m	Number of 3PL operators (1, 2, ..., z)
<u>Additional parameters</u>		
5	$\overline{UC}_{i,n}$	The higher unit production cost of the product supplier n in period i
6	$\underline{UC}_{i,n}$	The lower unit production cost of the product supplier n in period i
7	$\overline{HC}_{i,n}$	The higher unit cost of storage of the product supplier n in period i
8	$\underline{HC}_{i,n}$	The lower unit cost of storage of the product supplier n in period i
9	$\overline{DC}_{i,m}$	Higher unit distribution cost of the 3PL operator m in period i
10	$\underline{DC}_{i,m}$	Lower unit distribution cost of the 3PL operator m in period i
11	EC_i	Unit inventory handling cost of the e-tailer
12	II^E	Initial inventory of the e-tailer in period i
13	S^{cap}	Warehouse capacity of the e-tailer
14	$C_{i,j}^{ERP}$	ERP system management costs in period i for player j
15	BF_j	Bank surcharge fees player j
16	$\overline{OC}_{i,n}$	Higher unit ordering cost of e-tailer paid to the product supplier n in period i
17	$\underline{OC}_{i,n}$	Lower unit ordering cost of e-tailer paid to the product supplier n in period i
18	$\overline{SC}_{i,m}$	Higher unit service fee paid by the e-tailer to the 3PL operator m in period i
19	$\underline{SC}_{i,m}$	Lower unit service fee paid by the e-tailer to the 3PL operator m in period i
20	θ	The probability that the e-tailer believes the cost of product supplier is at a higher state
21	γ	The probability that the e-tailer believes the cost of the 3PL operator is at a higher state
<u>Decision variables</u>		
22	$q_{i,n}$	Production quantity of the product supplier n in period i
23	$a_{i,n}$	Delivery quantity of the product supplier n in period i
24	$s_{i,n}$	Inventory level of the product supplier n in period i
25	d_i	Order quantity by the e-tailer in period i
26	e_i	Inventory level of the e-tailer in period i
27	$b_{i,m}$	Number of units carrying by the 3PL operator m in period i
28	$c_{i,j}^{tra}$	Total operational costs of player j in period i
27	$X_{i,n}$	Binary variable defining whether the product supplier n deliver products or not
28	$Y_{i,m}$	Binary variable defining whether the 3PL operator m deliver products or not

29	V^{tra}	Overall supply chain cost

Objective function of the traditional e-commerce supply chain

$$\text{Minimize} \quad V^{tra} = W_j \sum_{\forall_i} c_{i,j}^{tra}, \forall_j \quad [6.18]$$

$$c_{i,1}^{tra} = \sum_{\forall_n} \left[\left\{ \left(\theta \cdot \overline{UC_{i,n}} + (1-\theta) \cdot \underline{UC_{i,n}} \right) q_{i,n} + \left(\theta \cdot \overline{HC_{i,n}} + (1-\theta) \cdot \underline{HC_{i,n}} \right) \left(\frac{s_{i,n} + s_{i-1,n}}{2} \right) \right\} + C_{i,1}^{ERP} \right] \quad [6.19]$$

$$c_{i,2}^{tra} = \sum_{\forall_n \forall_m} \left[\left\{ EC_i \left(\frac{e_i + e_{i-1}}{2} \right) \right\} + \left\{ \left(\theta \cdot \overline{OC_{i,1}} + (1-\theta) \cdot \underline{OC_{i,1}} \right) (d_{i,n}) \right\} + \left\{ \left(\gamma \cdot \overline{SC_{i,3}} + (1-\gamma) \cdot \underline{SC_{i,3}} \right) b_{i,m} \right\} + BF_1(d_{i,n}) + BF_2(b_{i,m}) + C_{i,2}^{ERP} \right] \quad [6.20]$$

$$c_{i,3}^{tra} = \sum_{\forall_m} \left[\left\{ \left(\gamma \cdot \overline{DC_{i,m}} + (1-\gamma) \cdot \underline{DC_{i,m}} \right) b_{i,m} \right\} + C_{i,3}^{ERP} \right] \quad [6.21]$$

The objective function is to minimise the total supply chain costs, as denoted in Eq. [6.18]. Here, the weighted sum is considered as the model includes the costs of three different types of players, with the e-tailer operating as the main link of the operation. This is similar to the models presented in Chapters 3 and 4. The individual total costs include the probability of higher and lower costs, as the e-tailer cannot observe actual operational costs. Eq. [6.19] represents the total supply chain costs of the product suppliers, which include the total production costs and total inventory holding costs and the ERP system operational costs. Eq. [6.20] denotes the total costs of the e-tailer, which consist of the inventory holding costs, the payments for the product supplier and the 3PL operator, the total bank surcharge of all payments and the ERP system maintenance costs. The 3PL operator's total costs are denoted by Eq. [6.21], which include the total distribution costs of 3PL operators and the ERP system management costs.

Subject to the constraints:

All constraints from [6.5] to [6.11] apply to the traditional e-commerce model. Additionally, the following inventory and demand constraints were formulated for this model.

Inventory constraints

$$e_1 = D_1 - d_1 + II^E \quad [6.22]$$

$$e_{i+1} = D_i - d_i + e_i \quad ; i < t \quad [6.23]$$

Eq. [6.22] represents the inventory levels of the e-tailer in the first period of the operation, and Eq. [6.23] represents the inventory levels of the e-tailer in all other periods.

Demand constraint

$$\sum_{\forall_n} a_{i,n} \geq d_i \quad [6.24]$$

The delivery quantities of the product supplier n should be equal to or greater than the order quantity in each period i for the product supplier to fulfil the order quantity requirements without any shortages. Eq. [6.13] from the blockchain adopted model is applicable for the 3PL operator.

Capacity constraint

$$e_{i+1} \leq S^{cap} \quad [6.25]$$

The inventory levels at the end of each period cannot exceed the maximum warehouse capacity of the e-tailer.

Binary variables

Eq. [6.15] and Eq. [6.16] are applicable as binary variables in this setting as well.

Non-negativity constraints

$$q_{i,n} \geq 0; s_{i,n} \geq 0; a_{i,n} \geq 0; b_{i,m} \geq 0; e_i \geq 0; d_i \geq 0; \pi_{i,j}^{tra} \geq 0; \quad [6.26]$$

Non-negativity constraints include all the decision variables of the traditional e-commerce supply chain model.

Data used for the traditional e-tailer supply chain operations are included in Appendix K.

6.6.4.4 Results of the Comparison between the Blockchain Adopted Supply Chain and the Traditional Supply Chain

Optimal solution of the traditional e-tailer supply chain operation considered in this section is included in Appendix M. A comparison between the overall supply chain costs of the blockchain adopted model and the traditional model is shown in Figure 6.9.

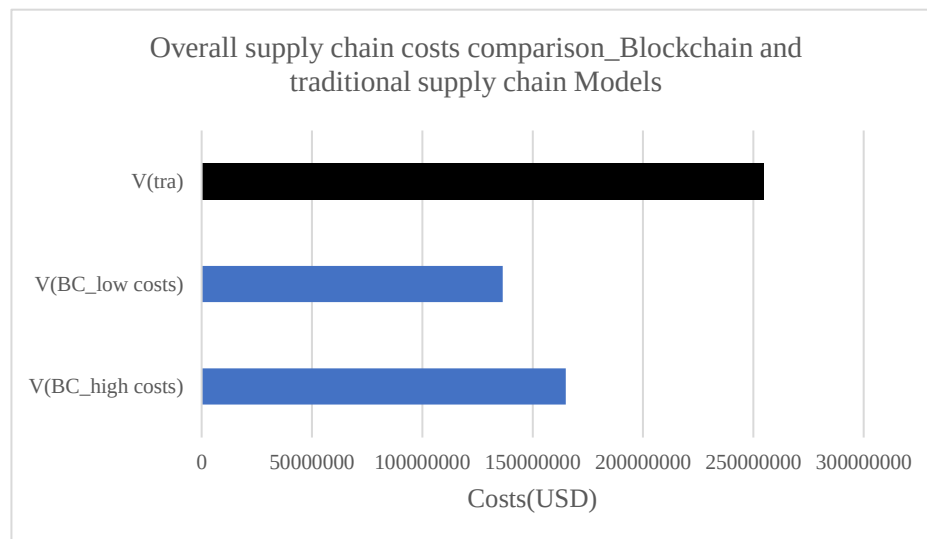


Figure 6.9 Comparison of overall supply chain costs

The comparison illustrates that the blockchain adopted model has lower costs compared to the traditional e-commerce supply chain with similar conditions. The blockchain model with higher operational costs results in a 35% cost reduction, while the blockchain model with lower operational costs indicates a 46% cost reduction compared with the traditional supply chain model. The main reasons for these outcomes are the significant ERP system costs and information asymmetry costs in the traditional e-tailer supply chain. In the above comparison, the probability of having higher operational costs for product suppliers and 3PL operators is considered 0.5. Even with symmetric probabilities, the traditional e-tailer supply chain costs are higher. Therefore, blockchain implementation is substantially beneficial for small/medium scale e-commerce supply chain operations, which are the focus of this study. A sensitivity analysis was conducted to determine the impact of the information asymmetric probabilities on the overall supply chain cost.

A subsequent analysis was conducted to identify the impact of blockchain implementation on the total costs of individual supply chain members. Figures 6.10, 6.11 and 6.12 illustrate the impact of blockchain implementation on the total costs of each type of supply chain member. Significant cost reductions are visible for 3PL operators as well as the e-tailer. Product supplier

costs vary according to production levels, as manufacturing costs are substantially higher in this scenario.

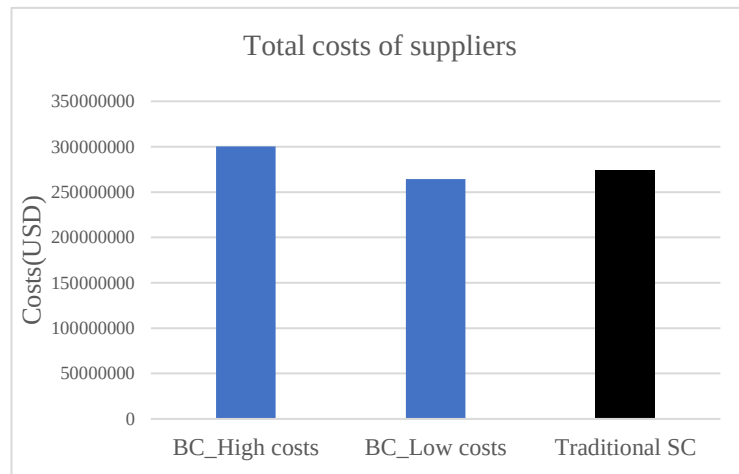


Figure 6.10 Total costs comparison of product suppliers

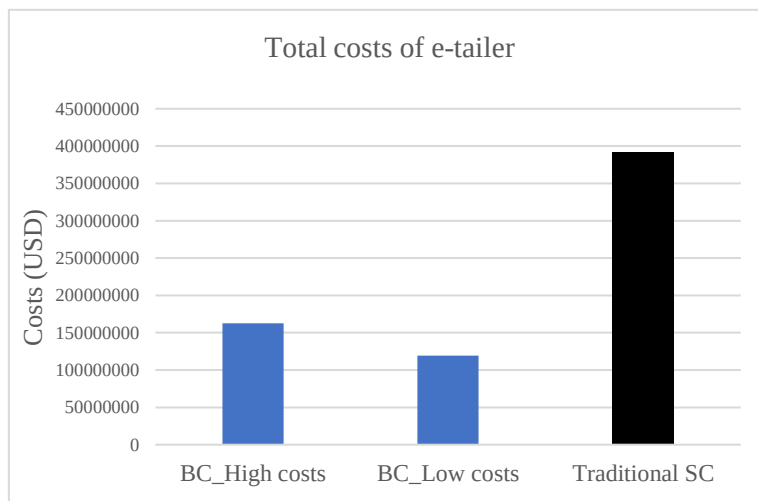


Figure 6.11 Total costs comparison of e-tailer

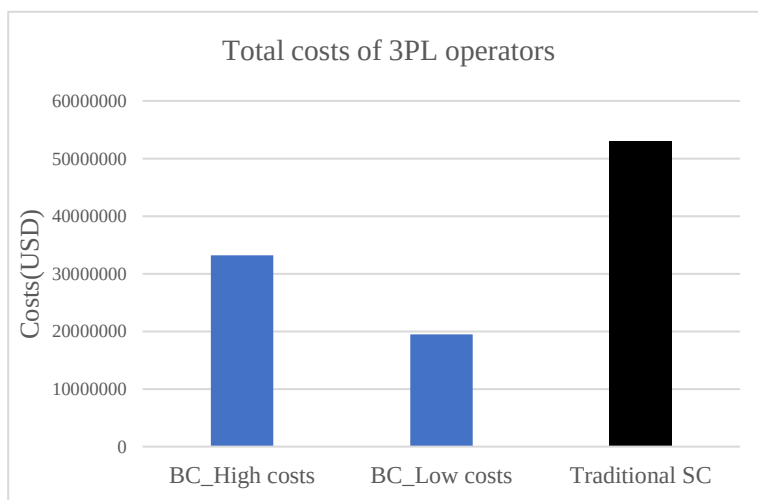


Figure 6.12 Total costs comparison of 3PL operators

As revealed by the analysis, the main cost drivers that affect the traditional supply chain are the asymmetric operational costs of the product suppliers and 3PL operators and the ERP system costs. When the information is shared truthfully among the supply chain members, which occurs through the blockchain implementation, supply chain members are informed about the actual costs, thereby eliminating the impact of information asymmetry. Hence, it is evident that blockchain implementation eliminates the costs associated with asymmetric information and, thereby, improves the transparency and trust within the e-tailer supply chain.

It is essential to identify the impact of ERP system costs on the optimal costs in traditional supply chain operations. As each player has a separate ERP system in their organisation, they must spend on maintenance, licences, support, and upgrade separately. This increases the individual total costs of the suppliers, e-tailer and 3PL operators. In contrast, blockchain system costs are shared among the supply chain members, thereby reducing the marginal operating costs of the members participating in this system. This study has taken ERP costs from ORACLE, which is a high-end ERP system that has shown 4.2% year on year growth (Pang, Markoviski & Micik 2019). However, costs may be lower in other ERP systems, which would then further reduce the operational costs of the traditional supply chain. Nevertheless, license costs are high in an ERP system, which does not include in the blockchain system. Therefore, comparing ERP system costs with blockchain system costs is imperative for e-commerce supply chain organisations to acknowledge the level of cost reduction that can be achieved from blockchain implementation.

Bank surcharge fees, which determine the transaction costs of the traditional e-commerce supply chain, also affect supply chain costs. Blockchain transaction costs in a consortium system are lower, as it depends on the variable costs of the system, which gradually reduce over the years, unlike in a public blockchain system. Therefore, the transaction costs of the blockchain system and the transaction costs of the banks must be compared when implementing a blockchain system.

6.6.4.5 Impact of Information Asymmetry on the Supply Chain Costs

The sensitivity of the probability included in the asymmetric costs of the product suppliers and 3PL operators was analysed in a similar manner to the analysis discussed in Chapters 3 and 4. In the initial analysis, equal probabilities were allocated for both the product suppliers and the 3PL operators (See Appendix K).

The traditional supply chain costs are lowest when the higher cost probabilities are lowest for both the product suppliers and the 3PL operators (see Figure 6.13), which is when $\theta = 0.1$ and $\gamma = 0.1$. Furthermore, all individual total costs of the supply chain members are at the lowest when $\theta = 0.1$ and $\gamma = 0.1$, consistent with the results presented in both Chapters 3 and 4. The results of the sensitivity analysis are elaborated in Appendix N.

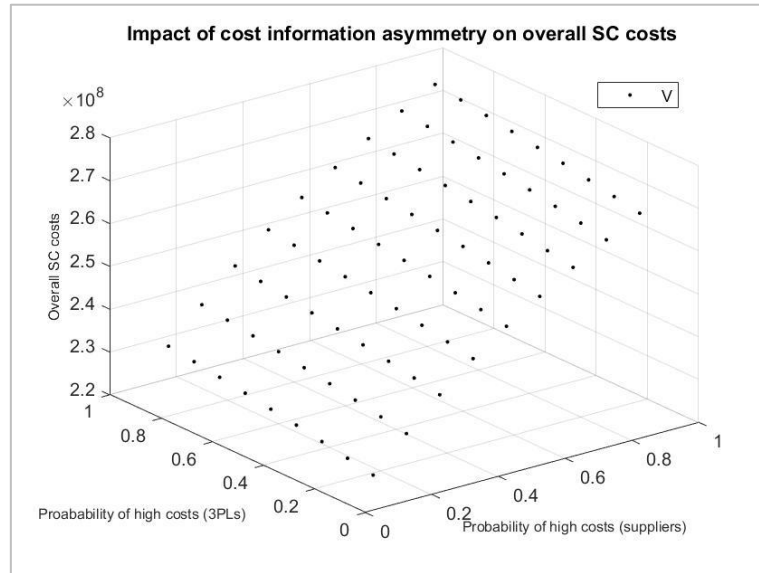


Figure 6.13 Impact of cost information asymmetry (based on probabilities) on overall supply chain costs

These results indicate that both product suppliers and 3PL operators have the lowest operational costs in the traditional supply chain operation, which was compared with the blockchain system with lower operational costs. Accordingly, the blockchain system costs are 76% lower than the traditional supply chain costs with the lowest operational costs. Furthermore, it was proven that when there is no cost information asymmetry, supply chain operational costs are reliable and accurate, which generates accurate outcomes in blockchain-based operations.

6.6.5 Comparison of Public and Consortium Blockchain Implementation

Up to this point, this chapter has discussed the analysis of blockchain implementation in a consortium blockchain system. However, as discussed in the literature and evidence presented by practical examples, public blockchains are also used in supply chain organisations. Therefore, in this section, blockchain costs for public and consortium blockchain systems are compared, using the optimisation model presented in Section 6.5 to identify which blockchain system is more effective for the operational setting considered in this study and to further verify on the suitability the proposed blockchain system in this chapter. The main differences in this

analysis are based on the blockchain costs, as transaction costs, investment costs, and system maintenance costs are differentiated according to the type of blockchain.

It was assumed that the public blockchain platform was based on Ethereum, which is the most famous public blockchain system presently being used in the industry (Zheng et al. 2020). The transaction fees in the public blockchain system is a crucial factor. In the Ethereum blockchain operations, the transaction fee is determined based on gas price and the amount of gas spent on transactions. In this model, financial payments are only considered as transactions, which require a comparatively lower gas amount for processing (Rimba et al. 2018). The data related to public blockchain investment and maintenance were also obtained from Ernst & Young (2019), while the transaction costs were taken from the Ether Gas Station (<https://ethgasstation.info/>), which includes the Ether gas prices of the Ethereum blockchain. Longo et al. (2019) also referred to the Ether Gas Station to determine the transaction costs of their public blockchain system. The additional data related to the public blockchain system is included in Appendix O.

6.6.5.1 Comparison Analysis Between Public and Consortium Blockchain Systems Adopted Supply Chains

Based on the optimal solutions generated for the consortium and public blockchain models, the results indicate that the $V(Public) > V(Consortium)$. However, no significant difference between $V(Public)$ and $V(Consortium)$ could be obtained in this numerical illustration based on the 12 years of data. The reasons for these results needed to be explored further (see Figure 6.14). The results suggest that the overall costs of the public blockchain supply chain are 2% higher than the consortium blockchain supply chain. One of the main reasons for this is that the public blockchain investment costs are lower in Ethereum (as it is an open-source operational platform) than in the consortium blockchain, which is developed especially for the requirements of the supply chain. However, transaction fees are comparatively high in the Ethereum platform (an average of four times higher than the transaction fees of consortium blockchains in the numerical illustration), as the prices depend on the gas price in the current Ethereum market. Gas and ether prices frequently change according to market demand, which has a significant impact on the outcomes generated in this analysis.

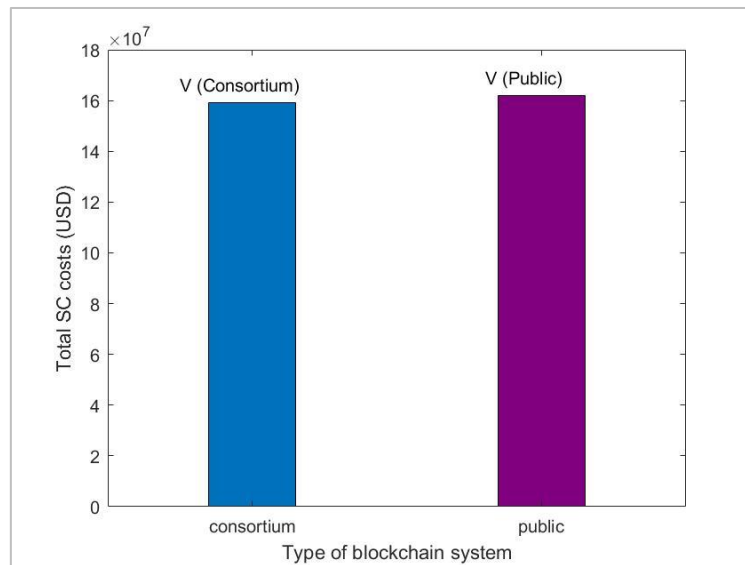


Figure 6.14 Total supply chain costs comparison between public and consortium blockchain systems

The individual players' total costs were analysed further (see Figure 6.15), with the results revealing that the highest impact was on the blockchain costs of 3PL operators (a 14% increase in the public blockchain compared with the consortium blockchain). Costs increased by only 1% for the suppliers and 2% for the e-tailer in the public blockchain. As the operational costs of the 3PL operators are low compared with those of the suppliers in the numerical data used for this study, the impact of blockchain system costs is greater for the total costs of 3PL operators. Therefore, when the supply chain members have lower operational costs, transaction fees and blockchain system management costs have a more substantial influence on total supply chain cost.

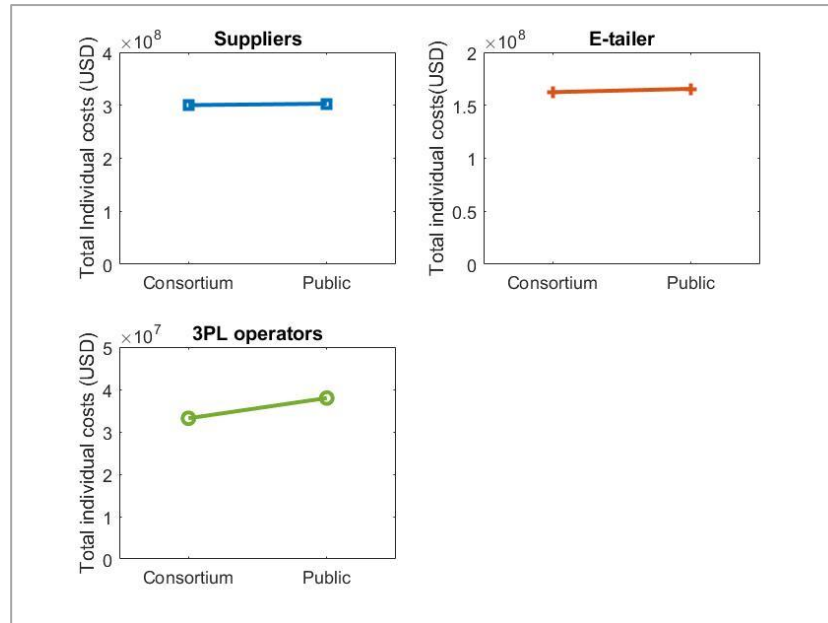


Figure 6.15 Comparison of total individual costs of suppliers, the e-tailer and 3PL operators

6.6.5.2 Impact of Transaction Costs on Overall Supply Chain Costs

Next, a sensitivity analysis was carried out to explore the impact of transaction fees on the supply chain costs of the Ethereum blockchain system. As gas prices of the market determine transaction fees, it is imperative to identify the impact of transaction fees on the total supply chain costs.

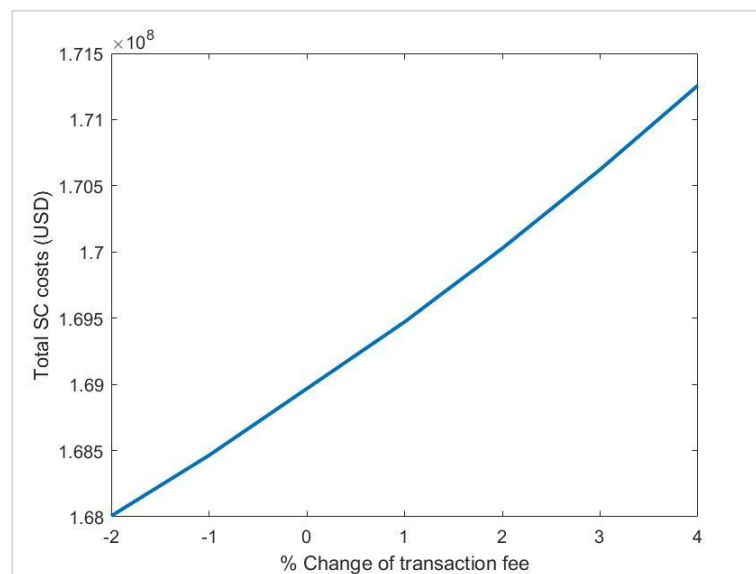


Figure 6.16 Impact of the transaction fee of public blockchains on the total costs of the e-tailer supply chain

The transaction fee has a direct relationship with the total supply chain costs (see Figure 6.16). Supply chain costs increase in public blockchains if gas prices increase over time. In contrast, the transaction fee is reduced over time in consortium blockchain systems, as it depends on the

internal variable costs of the system. Therefore, in the long run, public blockchain adoption is more costly for e-tailer supply chains than consortium blockchain operations. Therefore, for a long-term supply chain operation considered in this study, public blockchain implementation will be costly.

6.7 Discussion of Key Findings

The implications of these results are discussed in this section based on the sub-questions identified earlier in this chapter.

1. How does the implementation of a blockchain system reduce information asymmetry issues and improve the transparency of the e-commerce supply chain?

This chapter has discussed the operational setting of the blockchain system and how information is integrated into that system (see Figure 6.2). In the traditional e-tailer supply chain, information sharing is limited to two supply chain members at a given time, whereas blockchain enables information access to all members (see Figure 6.3). The operational framework based on a consortium blockchain creates an environment that enables the actual costs of supply chain members to be revealed. This improves transparency within the system. Therefore, the operational nature of the blockchain eliminates information asymmetry among supply chain members. The comparison analysis between the blockchain adopted and traditional e-commerce supply chains also reveals that having asymmetric information increases the overall supply chain costs, which is not applicable to the blockchain system. This makes the blockchain system extremely beneficial for long-term operations as it increases trust and improves integration.

2. What type of blockchain framework should be adopted by the e-commerce supply chain organisations?

Through the literature analysis, the operational requirements of different blockchain systems and their adoption within various operational settings were identified. As e-commerce supply chains rely on information, it is necessary to maintain the confidentiality of the data shared within the blockchain. As this study focuses on small/medium scale e-commerce supply chain operations, having a consortium blockchain system is appropriate for all supply chain members, since it ensures the confidentiality of the information as the information is shared only among the participants of the blockchain (see Figure 6.4). Furthermore, the comparison between public and consortium blockchain systems highlights that managing a public blockchain is more costly in the long-term operations.

3. How can blockchain implementation improve e-commerce supply chain operations in terms of cost minimisation?

This chapter formulated an optimisation model based on cost minimisation to assess blockchain implementation along with the operational costs of e-commerce supply chains to identify any significant benefits. The comparison of blockchain adopted supply chain costs with traditional e-commerce supply chain costs indicates that the former generates substantial cost reductions for the overall supply chain within multi-period operations. The sensitivity analysis based on blockchain implementation and maintenance costs indicated that bearing a higher portion of those costs by the e-tailer encourages the participation of other supply chain members in the system. Nevertheless, the e-tailer must determine the appropriate cost percentage that will enable win-win outcomes for all parties. As found in this study, having more supply chain members reduces the blockchain costs, which verifies the findings of Dib et al. (2018). It further reduces the blockchain maintenance costs over the years. However, system capacity and storage costs are the main determinants of the system, allowing the e-tailer to decide on how many members can be accommodated in the proposed blockchain system. Moreover, the results suggest the blockchain system is suited for small/medium scale supply chain that is more established with a supply chain network in upstream and downstream as presented in the numerical illustration of this study.

The comparison between blockchain adopted and traditional e-tailer supply chains reveals that the ERP system costs, and information asymmetry are two main drivers affecting increases in the traditional supply chain costs. ERP system costs contribute to increasing asymmetric information since each supply chain member owns an individual centralised system with their own database management. The results emphasise that it hinders the information sharing, which is analysed based on probabilities associated with the operational costs. The results highlight that even when the probabilities are lowest, blockchain adopted supply chain acquire lower operational costs than the traditional e-commerce supply chain. Therefore, the research findings create new knowledge relating to blockchain implementation in supply chain operations and provide significant managerial insights for e-commerce supply chain organisations. This will help supply chain members make careful and effective decisions before implementing blockchain systems in their supply chains.

6.8 Conclusion

Blockchain implementation is becoming more common due to its unique benefits, including efficiency improvements, and the capacity to eliminate issues pertaining to information sharing, transparency, traceability and trust in supply chain operations. However, research is still emerging in relation to blockchain implementation within e-commerce supply chain operations. There is no study on how blockchain costs affect supply chain costs when shifting from a traditional online setting, which includes information asymmetry and transparency issues among supply chain members. This chapter has focused on addressing these issues to determine whether blockchain implementation can generate significant operational improvements for supply chain members. The findings provide important practical insights for e-commerce supply chain organisations, helping them to determine the benefits they can obtain through blockchain implementation and the important cost drivers that affect supply chain operational outcomes.

This chapter has presented a blockchain framework that can be implemented to fulfil the requirements of the supply chain. Based on the integration of information, how information asymmetry can be eliminated through blockchain implementation was also discussed. Next, an optimisation model, including the blockchain system and operational costs, was formulated. The model results underline that the blockchain adopted supply chain optimises supply chain costs. The comparison between the blockchain adopted model and traditional e-commerce operations highlights that blockchain implementation substantially reduces overall supply chain costs by 46% (in the high operational cost scenario) and 35% (in the lower operational cost scenario). Through sensitivity analysis, the blockchain implementation and maintenance costs were identified as the key cost drivers in blockchain adopted supply chains. This requires cautious management to obtain win-win supply chain benefits.

Moreover, the comparison between public and consortium blockchain systems highlights that the public blockchain adopted supply chain costs are higher than those of the consortium adopted blockchain system, but with no significant difference. The main reasons for this outcome relate to transaction fees and investment costs, as transaction fees are higher while investment costs are lower in the public blockchain system than the consortium blockchain. However, the transaction fee of a public blockchain like Ethereum has a positive relationship with total supply chain costs as it depends on fluctuating gas prices. Therefore, the transaction

fee is a significant cost determinant, which differentiates the outcomes of public and consortium blockchain adoption.

This chapter has provided the final analysis of the modelling work based on the research objectives defined in Chapter 1. All research objectives have been discussed, tested and analysed in detail throughout this thesis, and significant findings have been presented. In the next chapter, the summary and conclusions of the thesis are discussed, along with the limitations of the study and suggestions for future research directions.

CHAPTER 7 : SUMMARY, LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

7.1 Summary and Conclusions

Across the world, supply chains are moving gradually towards virtual operations, with online retailing now one of the fastest growing business areas. The present pandemic has further elevated the need for online channels, even for basic grocery shopping. These trends, supported by the growing use of technological advancements, are expected to continue in the future. Therefore, it is necessary to explore innovative and effective strategies to derive optimal e-commerce supply chain performances.

However, strategic decision-making relies on the ability to address a range of operational issues in these supply chains, including ineffective coordination, information sharing issues, ineffective integration and sub-optimal costs. These issues need to be eliminated to improve performance. Therefore, this study has sought to address these strategic issues in e-commerce supply chains. Although supply chain coordination and optimal supply chain strategies have been studied extensively, less focus has been given to deriving strategies for small/medium scale e-tailer supply chains. Hence, this research has focused on designing optimal strategies for an e-commerce supply chain operation within a small/medium scale e-tailer setting. The intent of these strategies is to eliminate the issues noted above and generate effective supply chain tactics to enable long-term survival and successful performance in the highly competitive online retailing market.

First, an extensive literature review was conducted on e-commerce supply chain operations to identify the type of e-commerce issues, models, and methods analysed by previous researchers. The analysis revealed that game theory models have been utilised widely in addressing strategic issues and deriving optimal strategies. Furthermore, incentive contracts have been designed to eliminate conflicting operations and offer win-win solutions, based on the game theory modelling concepts. According to further analysis, multi-stage, multi-player models have been explored to a lesser extent when contract models are formulated. In addition, little attention has been given to designing sharing contracts when asymmetric information exists, which is crucial in e-commerce supply chains. The literature review further disclosed that, generally, the inclusion of operational constraints has been overlooked in the contract models, despite the fact that supply chain operations are always subject to operational limitations. The focus on using

multi-period contracts to achieve long-term integration has also been given little attention. Furthermore, the use of disruptive technologies to improve supply chain performance needed to be explored in greater depth, as very limited research is presently available. Therefore, this study aimed to address these limitations in the supply chain literature by designing optimal strategies to improve e-commerce supply chain operations.

This study has used an optimisation modelling approach in designing models to develop optimal strategies. These were solved as MOO models using LP, NLP and MILP methods according to the model requirements. An optimisation solver tool, GUSEK, was used to program and solve the models. In the LP and MILP scenarios, the GUSEK solver obtained optimal solutions using simplex and branch and cut algorithms, respectively. In the NLP scenarios, the model was solved using the BARON solver, and computer experiments were conducted in the NEOS server to obtain global optimal solutions.

First, a cost-sharing contract was designed, based on the screening contract approach and revelation principle, to address the issues of asymmetric information and conflicts of interest that hinder effective supply chain coordination. The proposed cost-sharing model was designed for an operational context of a three-stage, three-player e-tailer operation, with a product supplier, e-tailer and 3PL operator. While online retailing has several operational structures, this study considered a pure e-tailer setting as the most appropriate operational structure for small/medium scale or start-up e-tailer supply chains. The model was designed based on cooperative game concepts as this supply chain aimed to achieve a common objective to optimise the overall costs of the supply chain. The model included both contract related constraints and operational constraints, unlike the previous cost-sharing contract models. The proposed model was validated using numerical analysis, based on hypothetical data, followed by a sensitivity analysis. The model results revealed that the proposed cost-sharing contract significantly reduces the overall supply chain costs, and the menu of contract eliminates asymmetric information and motivates supply chain members to minimise their internal operational costs. The model solution produced the optimal cost-sharing levels that can coordinate the supply chain in all periods, which has not been found in former studies.

In Chapter 4, this study analysed how to achieve long-term integration for the e-tailer supply chain through the proposed cost-sharing contract. In that setting, dynamic contract aspects were explored, as contemporary literature did not provide clear evidence of how dynamic consistency and re-negotiation can be used to achieve long-term integration in a supply chain

setting. Therefore, the proposed base contract model was extended by introducing consistency constraints. Some propositions were also derived for the dynamic contract model based on KKT optimality conditions. The propositions identified that the cost-sharing percentage is the key determinant of the contract. The numerical analysis determined the optimal cost-sharing percentages for each period of the contract, which had not been analysed in the previously designed dynamic contracts with asymmetric information and consistency constraints. The consistency constraints resulted in improved incentive levels in each contract period, thereby guaranteeing that players have sufficient incentives to remain in the contract for the long-term. Therefore, the dynamic contract eliminates the opportunity for re-negotiation and enables long-term integration. This would be extremely beneficial for small/medium scale operators, ensuring a stable operational network. As the e-tailer supply chain focused on a common objective, cost minimisation, ultimately, the benefit of reduced costs can be transferred to the consumer through low-priced products. This will help expand the customer base and market share in the long-term.

Given that cost concepts are a central focus of this study, after designing effective cost-sharing contracts that can optimise supply chain costs, it was necessary to explore further how these organisations derive cost information. Previous studies highlight that the cost measurement techniques used by different organisations have a direct impact on supply chain costs and contracts. Based on that verification, a theoretical framework was designed, as presented in Chapter 5, which clearly illustrates how different accounting methods impact supply chain contracts. To prove the validity of the theoretical framework, three propositions were developed to measure the impact of HCA, FVA and creative accounting on supply chain contracts and cost optimisation. The dynamic contract model was incorporated into the testing of the propositions based on numerical illustrations. The results disclosed that both HCA and FVA affect the supply chain outcomes and, when asymmetric information exists, HCA is the better accounting method to be employed by supply chain members. FVA is more suited to cost minimisation, as it uses current information conforming with market conditions. Crucial theoretical knowledge was generated through the analysis of proposition 3 in Chapter 5, as designing incentive compatibility constraints in contracts ensures that supply chain organisations have no opportunity to use creative accounting practices to alter their cost information.

Finally, this research has analysed the growing trend of adopting disruptive technologies in optimising e-commerce supply chain operations. Blockchain is an advanced technology that

can fundamentally eliminate the issues of asymmetric information due to its operational context of decentralisation and data immutability. Hence, blockchain implementation can derive significant benefits to e-tailer supply chains as it enables effective information sharing. In Chapter 6, the characteristics and features of blockchain technology were analysed extensively and, accordingly, a suitable blockchain framework for e-tailer operations was designed. A consortium blockchain system was identified as an appropriate framework due to such operational features as the authority, privacy, resources and the level of information sharing. An optimisation model was then developed to test the feasibility of implementing blockchain technology in small/medium scale e-tailer operations. The model was tested using both hypothetical and industrial data gathered from secondary sources. Blockchain implementation costs were included in the model, and it was extended for multi-player operations to derive more practical results. The blockchain adopted model was compared with the traditional e-tailer operation, with ERP system costs and third-party bank charges additionally included in the model.

The results indicated that blockchain implementation eliminates asymmetric information and reduces supply chain costs more effectively than tradition e-tailer operations. However, there were several limitations in the results, as the industrial data gathered for ERP system costs are comparatively high, which can be an obstacle for a small/medium scale operation. The main reasons for cost minimisation in the blockchain implementation were identified as the sharing of blockchain system management costs among the supply chain partners, which does not occur in traditional supply chain operations. Public and consortium blockchain operations were compared to identify which blockchain framework generates the most cost-effective long-term operational outcomes. The results indicated that the public blockchain system is costly in long-term operations, while consortium blockchains are expensive in the initial operations. Therefore, these results from this analysis offer important insights, both to theoretical knowledge and practitioners in e-commerce supply chain organisations.

Overall, this study has designed optimal strategies to improve the effectiveness of e-commerce supply chain operations while resolving issues related to effective strategic decision-making. Through each chapter, this study has addressed different but interconnecting issues from which small/medium scale e-tailer supply chains can benefit. The focus of this thesis has been on improving supply chain performance by minimising overall supply chain costs, eliminating asymmetric information, enabling successful integration with contracts, as well as determining the feasibility of future investments in advanced technology implementation such as

blockchain. The overall study offers significant theoretical and practical contributions, as described clearly throughout the thesis. On a practical level, the findings could be used to increase market share, deliver competitive pricing strategies to attract more customers, and ensure long-term survival within a highly competitive market and successful adaptation to progressive technologies emerging across the world.

7.2 Limitations of the Research

As with any other research, this study has its limitations, particularly as it does not cover all aspects of optimal e-commerce operational outcomes. However, these limitations do not undermine the validity of the research findings but provide opportunities to suggest important future research directions.

As mentioned previously in this study, there is an extensive amount of literature on game theory and contract modelling. Even though many of these studies are relevant to this topic, and many have been reviewed in this thesis, some may have been missing from the analysis.

It is often difficult to get real data from companies, as they are reluctant to share such data due to confidentiality issues. This study required data such as operational costs, pricing values, inventory holding costs and distribution costs, which are confidential and difficult to obtain with such clarity. Therefore, this study adopted a simulation-based data analysis by creating a case scenario for a hypothetical operation as required for the proposed models.

Furthermore, the operational models were developed considering a single supplier, single e-tailer and single 3PL operator in this study, which is hard to find in actual operations as supply chains often rely on multiple suppliers and 3PL operators. Since this research focused on start-up and small-scale online retailers, the assumption of single-player in each level is taken into consideration. It can be extended in a future study.

Even though this study focused on creating optimal strategies for e-commerce supply chain operations, not every operational aspect was incorporated into the contract model. For example, distribution operations have many internal factors such as fixed costs, variable costs, distance, and scheduling, which were not considered in detail but rather taken as a total inclusive value in designing the distribution operation of the model. However, this can be considered, and the model could be expanded in the future.

In contract model formulations, demand uncertainties have been incorporated in numerous studies. However, demand values were considered to be known parameters in this study as the literature provides examples where demand is taken as a linear or a deterministic value. When demand or supply uncertainties are included in model formulation, it is computationally challenging to obtain global optimal solutions using classic optimisation techniques used in this study such as NLP and MILP programming techniques (Yoshida et al. 2020). However, including demand and supply uncertainties should be considered in future studies.

Finally, the proposed contract mechanism is only tested based on a hypothetical operational setting. Even though the findings of this study showcase important practical implications, no real-life business was used to test these contract models and the operational mechanism of this study. Therefore, it is crucial to consider how these contract models can be actually implemented in a real-life online retailer business.

7.3 Future Research Directions

As previously mentioned, the limitations of this study can be seen as opportunities for extending this research in the future. In addition, several other vital areas based on extant studies could be considered in determining future research directions from this study.

First, this study can be empirically tested using actual e-tailer supply chain data to derive organisation specific or supply chain specific findings, as these e-tailer supply chains may have numerous levels of operational constraints and additional cost parameters. Therefore, a small/medium scale online retailer sample could be considered in testing the model validity and robustness using real business operations. This would add to both the theoretical and practical contributions. Secondly, it is crucial to break down the operational aspects of each supply chain level, as the models in this study only focused on the collective cost of the main operations: inventory management, production and distribution.

In actual operations, the uncertainties of demand and supply can inhibit the effectiveness of supply chain operations and generate diverse outcomes. Previous studies that have included demand uncertainties are based primarily on analytical solution outcomes, where only contract constraints or non-constrained optimal solutions are derived. When the operational constraints are included within the contract setting, the models are difficult to solve using the classical optimisation techniques as adopted in this study. However, there is a growing trend in using modern optimisation techniques that combine heuristics and modern algorithms in developing

larger mathematical models incorporating game theory concepts (Halat & Hafezalkotob 2019; Pakseresht et al. 2020; Parsaeifar et al. 2019). Hence, this study can be extended by incorporating demand and supply uncertainties into the operational setting and further improving the model implications through modern optimisation techniques and algorithm development.

One of the motivations for this research was to enhance the vertical integration of e-tailer supply chain members. This creates a pure cooperative strategy within the supply chain to derive optimal supply chain outcomes. In online retailing, it is not only vertical integration but also horizontal integration that helps generate cooperation among competitive partners. For example, Tmall and Sunning.com, two prominent online retailers in China, have entered into a partnership to enable horizontal cooperation (Fan, Yin & Liu 2020). The supply chain literature provides some evidence of studies in which horizontal cooperation is considered in e-commerce supply chains and traditional offline supply chains. Therefore, it is important to extend the contract models derived in this study to analyse horizontal cooperation among manufacturers, 3PL operators, and other e-tailers to eliminate the adverse impact of competition.

As a growing stream of literature is emerging related to dual-channel, omni-channel and multi-channel retailing (Modak & Kelle 2019), interesting findings could be generated by extending this study to these operational settings. Since this study has analysed small/medium scale pure e-tailer operations, which is the most cost-effective strategy in the initial phases of operations, the next step could be to consider introducing an offline channel to the operations. With that consideration, several operational structures could be explored, focusing on pricing strategies, different channel integration strategies, and operational optimisation strategies, which will contribute to both the literature and to practice.

The importance of sustainability and the circular economy are another two areas that have gained wider attention in contemporary literature. Online supply chains have considered these sustainability aspects through sustainable sourcing, green distribution strategies with less carbon emissions, and green production and warehouse management strategies. These aspects are critical to making sustainable and effective decisions in e-tailer supply chains. Therefore, the optimisation models in this study could be extended to consider recycling strategies and green practices and their impact on overall supply chain improvements.

The dynamic contract model designed in this study could also be extended to consider several other aspects. The evolving nature of information asymmetry could be considered in the model, as it can change long-term contractual outcomes. Previous studies have argued that in a dynamic contract, the agents may have private information that might change or be revealed over time, thus affecting the operational aspects of the contract (Deb & Said 2015; Rasmusen 2007). If the contract discloses hidden information over time, having a multi-period contract is beneficial as the repetition of the contract reduces the information disadvantage (Macho-Stadler & Pérez-Castrillo 2001). This could be tested in future. Another area for consideration is the extension of the proposed dynamic contract model to analyse how contract terms can be maintained within an infinite period. This study only focused on a finite multi-period operational setting.

Blockchain models in supply chain operations generally incorporate smart contracts. While smart contracts have been discussed in the blockchain adopted model, smart contract conditions were not developed in this study. Therefore, it is necessary to consider smart contract related transactions, which require high energy and resources in terms of smart contract designs (Rimba et al. 2018). Furthermore, the models could be extended to incorporate the smart contract related technical aspects to determine how these affect contractual agreements in supply chain operations.

In terms of cost measurement techniques, hypothetical cost scenarios were taken into consideration in the numerical illustrations presented in Chapter 5. To further enhance the robustness and validity of results, the operational costs could be derived using different financial accounting methods and real-world data. As a result, the findings of this study could be further validated, and practitioners could draw important managerial insights into their decision-making related to contractual agreements with their partners.

In summary, this research provides several interesting future research directions that correspond to the current interests of the research community, providing opportunities for other academics and students.

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APPENDICES

Appendix A – AMPL Code for the Base Cost-sharing Contract

Model Code

#Base-cost Sharing Model Code

```
param n;

set I := 1 .. n; #periods of time
set J := 1 .. 3; #player

# Parameters
param UCH{i in I}; #high production cost per unit of supplier
param UCL{i in I}; #low production cost per unit of supplier
param a{i in I}; # Percentage of production cost that will define the inventory holding cost of
supplier
param HC{i in I}; #inventory holding unit cost of e-tailer
param II{j in J}; #player's initial inventory
param MCAP{i in I}; #player's production capacity
param WCAP{j in J}; #player's warehouse capacity
param DCH{i in I}; # High Unit Distribution Cost
param DCL {i in I}; # Low unit distribution cost
param D{i in I}; #customer demand for each period of time
param W{j in J}; #weight for the objective function of player j
param O; #Probability that the e-tailer believes the cost of supplier is at higher state
param Y; #Probability that the e-tailer believes that the cost of 3PL operator is at higher state
param PH {i in I, j in J}; #higher Price paid by player j to other players in period i
param PL {i in I, j in J}; # lower price paid by player j to the other players in period i

# Decision Variables
var q{i in I} >= 0; #production level of player j during period i
var d{i in I} >= 0; # Units demanded by e-tailer from the product supplier in period i
var s{i in I, j in J} >= 0; #inventory of player j at the end of period i
var sch{i in I, j in J} >= 0; #higher cost that player j will share from the other player in period
i
var scl{i in I, j in J} >= 0; # lower cost that player j will share from the other players in period
i
var c{j in J} >= 0; #costs for player j
var P{i in I, j in J} >= 0, <= 1; # Percentage of cost sharing capacity of player j

#Constraints
subject to inventory_supplier{i in I, j in J : j=1}: s[i,j] = q[i] - d[i] + (if i
= 1 then II[j] else s[i-1,j]);
subject to inventory_e_tailer {i in I, j in J: j=2}: s[i,j] = d[i] - D[i] +(if i =
1 then II[j] else s[i-1,j]);
subject to warehouse{i in I, j in J}: s[i,j] <= WCAP[j];
subject to production{i in I, j in J: j = 1}: q[i] <= MCAP[j];

subject to incentive_compatibility_supplier_1 {i in I, j in J: j = 1}: UCH[i] * q[i
] + a[i] * UCH[i] * (s[i,j]+(if i>1 then s[i-1,j] else II[j])/2) - scl[i,j]-
PH[i,j]* d[i] >= UCL[i] * q[i] + a[i] * UCL[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2) - sch[i,j] - PL[i,j]*d[i];
```

```

subject to incentive_compatibility_supplier_2 {i in I, j in J: j=1}: UCL[i] * (q[i]
+ a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) - scl[i,j] - PL[i,j] * d[i] >= UCH[i] * q[i] + a[i] * UCH[i] *
(s[i,j]+(if i>1 then s[i-1,j] else II[j])/2) - sch[i,j] - PH[i,j]* d[i];
subject to cost_sharing_high_IR_supplier { i in I, j in J: j =1}: sch[i,j] <= P[i,j]
] * ((O * UCH[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2))) + ((1 - O) * UCL[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2))));

subject to cost_sharing_high_IR_3Pl{ i in I, j in J: j=3}: sch[i,j] <= P[i,j] * ((Y
* DCH[i] * D[i]) + (1 -Y) * (DCL[i] * D[i]));
subject to cost_sharing_IR_compatibility{i in I, j in J:j <> 2}:scl[i,j] <= sch[i,j]
];
subject to cost_sharing_IR_Lower_bound {i in I, j in J:j<>2}: scl[i,j] >= 0;

subject to incentive_compatibility_3PL_operator_1 {i in I, j in J: j=3}: DCH[i] * D
[i] - scl[i,j] - PH[i,j] * D[i] >= DCL[i] * D[i] - sch[i,j] - PL[i,j] * D[i];
subject to incentive_compatibility_3PL_operator_2 {i in I, j in J: j=3}: DCL[i] * D
[i] - scl[i,j] - PL[i,j]* D[i] >= DCH[i] * D[i] - sch[i,j]- PH[i,j] * D[i];

subject to total_costs{j in J}: c[j] = sum {i in I}(if j = 1 then (((O * (UCH[i] *
(q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) - (scl[i,j] + PH[i,j]*d[i]))) + (1-
O) * ((UCL[i] * (q[i] + a[i]* (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) - (sch[i,j] + PL[i,j]*d[i])))) else if j = 2 then ((HC[i] * (
s[i,j]+(if i>1 then s[i-1,j] else II[j])/2)) + O * (scl[i,1] + PH[i,1]*d[i]) + (1-
O)* (sch[i,1] + PL[i,1]*d[i]) + Y * (scl[i,3] + PH[i,3]*D[i])+ (1-
Y) * (sch[i,3] + PL[i,3]*D[i])) else ((Y * (DCH[i] * D[i] - (scl[i,j] + PH[i,j]*D[i]
])) + (1-Y) * (DCL[i] * D[i] - (sch[i,j] + PL[i,j]*D[i]))));

```

#Objective Function

```

minimize z: sum{j in J} W[j] * c[j];

```

Data File

```

data;

```

```

param n := 12;

```

```

param W := 1 0.3 2 0.4 3 0.3;

```

```

param UCH := 1 240 2 250 3 260 4 280 5 280 6 260 7 260 8 280 9 250 10 240 11 280 12
260;

```

```

param UCL := 1 200 2 190 3 200 4 190 5 200 6 200 7 200 8 180 9 190 10 200 11 190 12
190;

```

```

param a := 1 0.015 2 0.015 3 0.015 4 0.015 5 0.015 6 0.015 7 0.015 8 0.015 9 0.015
10 0.015 11 0.015 12 0.015;

```

```

param HC := 1 5.98 2 5.87 3 6.04 4 5.58 5 2.92 6 4.37 7 4.68 8 4.52 9 5.46 10 5.91
11 5.91 12 4.82;

```

```

param II := 1 2750 2 2500 3 0;

```

```

param MCAP :=

```

```

1 10000
2 10000
3 10000
4 10000
5 10000
6 10000
7 10000

```

```

8 10000
9 10000
10 10000
11 10000
12 10000;

param WCAP := 1 6000 2 6000 3 0;

param DCH := 1 19.65 2 20.22 3 18.90 4 19.85 5 19.59 6 20.65 7 19.56 8 18.94 9 21.4
5 10 20.07 11 19.26 12 18.99;

param DCL := 1 11.21 2 14.16 3 12.49 4 11.34 5 13.15 6 11.97 7 13.08 8 12.75 9 12.2
1 10 12.39 11 11.47 12 12.07;

param D := 1 1000 2 4500 3 6000 4 5500 5 3500 6 4000 7 4500 8 5500 9 6000 10 4500 1
1 4500 12 5500;

param O := 0.5;

param Y := 0.5;

param PH: 1 2 3 :=
1 85 0 10
2 100 0 9
3 105 0 10
4 110 0 10
5 110 0 10
6 95 0 10
7 95 0 10
8 110 0 8
9 90 0 9
10 85 0 10
11 110 0 9
12 95 0 9;

param PL: 1 2 3 :=
1 60 0 5
2 55 0 7
3 60 0 6
4 55 0 5
5 60 0 6
6 60 0 5
7 60 0 6
8 50 0 6
9 55 0 6
10 60 0 6
11 55 0 5
12 55 0 5;

```

Command File for Solver BARON in NEOS

```

option baron_options 'epsa=1e-2 maxtime=7400 ';
solve;
display q, d, s, sch, scl, c, z, P;

```

Appendix B - AMPL Code for the Dynamic Cost-sharing Contract

Model Code

#Dynamic Cost-Sharing Contract Model Code

param n;

set I := 1 .. n; #periods of time

set J := 1 .. 3; #player

#Parameters

param UCH{i in I}; #high production cost per unit of supplier

param UCL{i in I}; #low production cost per unit of supplier

param a{i in I}; # Percentage of production cost that will define the inventory holding cost of supplier

param HC{i in I}; #inventory holding unit cost of e-tailer

param II{j in J}; #player's initial inventory

param MCAP{i in I}; #player's production capacity

param WCAP{j in J}; #player's warehouse capacity

param DCH{i in I}; # High Unit Distribution Cost

param DCL {i in I}; # Low unit distribution cost

param D{i in I}; #customer demand for each period of time

param W{j in J}; #weight for the objective function of player j

param O; #Probability that the e-tailer believes the cost of supplier is at higher state

param Y; #Probability that the e-tailer believes that the cost of 3PL operator is at higher state

param PH {i in I, j in J}; #higher Price paid by player j to other players in period i

param PL {i in I, j in J}; # lower price paid by player j to the other players in period i

param K {j in J}; # Discount rate of each player

#Decision Variables

var q{i in I} >= 0; #production level of player j during period i

var d{i in I} >= 0; # Units demanded by e-tailer from the product supplier in period i

var s{i in I, j in J} >= 0; #inventory of player j at the end of period i

var sch{i in I, j in J} >= 0; #higher cost that player j will share from the other player in period i

var scl{i in I, j in J} >= 0; # lower cost that player j will share from the other players in period i

var c{j in J} >= 0; #costs for player j

var P{i in I, j in J} >= 0, <= 1; # Percentage of cost sharing capacity of player j

#Constraints

subject to inventory_supplier{i in I, j in J : j=1}: s[i,j] = q[i] - d[i] + (if i = 1 then II[j] else s[i-1,j]);

subject to inventory_e_tailer {i in I, j in J: j=2}: s[i,j] = d[i] - D[i] +(if i = 1 then II[j] else s[i-1,j]);

subject to warehouse{i in I, j in J}: s[i,j] <= WCAP[j];

subject to production{i in I, j in J: j = 1}: q[i] <= MCAP[j];

subject to incentive_compatibility_supplier_1 {i in I, j in J: j = 1}: UCH[i] * q[i] + a[i] * UCH[i] * (s[i,j]+(if i>1 then s[i-1,j] else II[j])/2) - scl[i,j]- PH[i,j]* d[i] >= UCL[i] * q[i] + a[i] * UCL[i] * (s[i,j]+(if i>1 then s[i-1,j] else II[j])/2) - sch[i,j] - PL[i,j]*d[i];

subject to incentive_compatibility_supplier_2 {i in I, j in J: j=1}: UCL[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-

```

1,j] else II[j])/2)) - scl[i,j] - PL[i,j] * d[i] >= UCH[i] * q[i] + a[i] * UCH[i] *
(s[i,j]+(if i>1 then s[i-1,j] else II[j])/2) - sch[i,j] - PH[i,j]* d[i];
subject to cost_sharing_high_IR_supplier { i in I, j in J: j =1}: sch[i,j] <= P[i,j]
] * ((O * UCH[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2))) + ((1 - O) * UCL[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2))));

subject to time_consistency_supplier_high {i in I, j in J: i < n and j=1}: sch[i,j]
/ UCL[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) <= sch[i+1,j]/UCL[i+1] * (q[i+1] + a[i+1] * (s[i+1,j]+s[i,j]/2
));
subject to time_consistency_3pl_high {i in I, j in J: i < n and j=3}: sch[i,j]/DCL[
i] * D[i] <= sch[i+1,j]/DCL[i+1] * D[i+1];
subject to time_consistency_supplier_low { i in I, j in J: i > 1 and i < n and j=1}
: scl[i,j]/(UCH[i] * q[i] + a[i] * UCH[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) <= scl[i+1,j]/(UCH[i+1] * q[i+1] + a[i+1] * UCH[i+1] * (s[i+1,
j]+s[i,j]/2));
subject to time_consistency_3pl_low { i in I, j in J: i < n and j=3}: scl[i,j]/DCL[
i] * D[i] <= scl[i+1,j]/DCL[i+1] * D[i+1];

subject to cost_sharing_high_IR_3Pl{ i in I, j in J: j=3}: sch[i,j] <= P[i,j] * ((Y
* DCH[i] * D[i]) + (1 -Y) * (DCL[i] * D[i]));
subject to cost_sharing_IR_compatibility{i in I, j in J:j <> 2}:scl[i,j] <= sch[i,j
];
subject to cost_sharing_IR_Lower_bound {i in I, j in J:j<>2}: scl[i,j] >= 0;

subject to incentive_compatibility_3PL_operator_1 {i in I, j in J: j=3}: DCH[i] * D
[i] - scl[i,j] - PH[i,j] * D[i] >= DCL[i] * D[i] - sch[i,j] - PL[i,j] * D[i];
subject to incentive_compatibility_3PL_operator_2 {i in I, j in J: j=3}: DCL[i] * D
[i] - scl[i,j] - PL[i,j]* D[i] >= DCH[i] * D[i] - sch[i,j]- PH[i,j] * D[i];

subject to total_costs{j in J}: c[j] = sum {i in I}(if j = 1 then (1/(1+K[j])^ i) *
(((O * (UCH[i] * (q[i] + a[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) - (scl[i,j] + PH[i,j]*d[i]))) + (1-
O) * ((UCL[i] * (q[i] + a[i]* (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) - (sch[i,j] + PL[i,j]*d[i])))) else if j = 2 then ((1/(1+K[j]
)^ i) * ((HC[i] * (s[i,j]+(if i>1 then s[i-
1,j] else II[j])/2)) + O * (scl[i,1] + PH[i,1]*d[i]) + (1-
O)* (sch[i,1] + PL[i,1]*d[i]) + Y * (scl[i,3] + PH[i,3]*D[i])+ (1-
Y) * (sch[i,3] + PL[i,3]*D[i])) else ((1/(1+K[j])^ i) * (Y * (DCH[i] * D[i] - (scl
[i,j] + PH[i,j]*D[i])) + (1-Y) * (DCL[i] * D[i] - (sch[i,j] + PL[i,j]*D[i]))));

#Objective Function
minimize z: sum{j in J} W[j] * c[j];

```

Data File

data;

param n := 12;

param W := 1 0.3 2 0.4 3 0.3;

param UCH := 1 240 2 250 3 260 4 280 5 280 6 260 7 260 8 280 9 250 10 240 11 280 12
260;

param UCL := 1 200 2 190 3 200 4 190 5 200 6 200 7 200 8 180 9 190 10 200 11 190 12
190;

param a := 1 0.005 2 0.015 3 0.005 4 0.01 5 0.015 6 0.02 7 0.05 8 0.01 9 0.015 10 0
.005 11 0.01 12 0.015;

param HC := 1 5.98 2 5.87 3 6.04 4 5.58 5 2.92 6 4.37 7 4.68 8 4.52 9 5.46 10 5.91

```

11 5.91 12 4.82;

param II := 1 2750 2 2500 3 0;

param MCAP :=
1 10000
2 10000
3 10000
4 10000
5 10000
6 10000
7 10000
8 10000
9 10000
10 10000
11 10000
12 10000;

param WCAP := 1 6000 2 6000 3 0;

param DCH := 1 19.65 2 20.22 3 18.90 4 19.85 5 19.59 6 20.65 7 19.56 8 18.94 9 21.4
5 10 20.07 11 19.26 12 18.99;

param DCL := 1 11.21 2 14.16 3 12.49 4 11.34 5 13.15 6 11.97 7 13.08 8 12.75 9 12.2
1 10 12.39 11 11.47 12 12.07;

param D := 1 5329.22 2 4991.50 3 4251.12 4 6070.43 5 8044.44 6 6310.14 7 6274.70 8
4257.28 9 3017.59 10 5016.46 11 4482.02 12 6960.01;

param O := 0.5;

param Y := 0.5;

param PH: 1 2 3 :=
1 85 0 10
2 100 0 9
3 105 0 10
4 110 0 10
5 110 0 10
6 95 0 10
7 95 0 10
8 110 0 8
9 90 0 9
10 85 0 10
11 110 0 9
12 95 0 9;

param PL: 1 2 3 :=
1 60 0 5
2 55 0 7
3 60 0 6
4 55 0 5
5 60 0 6
6 60 0 5
7 60 0 6
8 50 0 6
9 55 0 6
10 60 0 6
11 55 0 5
12 55 0 5;

param K := 1 0.1 2 0.1 3 0.1;

```

Command File for Solver BARON in NEOS

```
option baron_options 'epsa=1e-2 maxtime=14400 ';  
solve;  
display q, d, s, sch, scl, c, z, P;
```


Appendix C – AMPL Code for Blockchain Adopted Model

```
param t;
param r;
param z;

set I := 1 .. t; #periods of time
set J := 1 .. 3; #player
set N := 1 .. r; # no of suppliers
set M := 1 .. z; # no of 3PL operators

#Parameters
param UC{i in I, n in N}; #unit production cost of supplier n in period i
param HC{i in I, n in N}; #inventory holding unit cost of the product supplier n in period i
param II{n in N}; #product supplier's initial inventory
param Qmin{i in I} >= 0; # minimum order quantity of the supply chain system
param MCAP{i in I, n in N}; # maximum production capacity for supplier n
param WCAP{i in I, n in N}; #maximum warehouse capacity for supplier n
param VCAP{i in I, m in M}; #maximum carrying capacity for 3PL operator m
param DC{i in I, m in M}; # Unit Distribution Cost of the 3PL operator m in period i
param Bmin{i in I}; # Minimum delivery capacity of the 3PL operator m in period i
param D{i in I}; #customer demand for each period of time
param W{j in J}; #weight for the objective function of player j
param P1{i in I, n in N}; #Unit ordering cost of the e-tailer in period i for supplier n
param P3{i in I, m in M}; # Unit service cost paid by the e-tailer for the 3pl operator m in period i
param IC;
param FCE{i in I}; #Variable costs of BC of E-tailer
param FCS{i in I}; # Variable costs of BC of Supplier n
param FCD{i in I}; # Variable costs of BC of 3PL operator m
param TC{i in I, j in J}; #Transaction fee paid by player j in period i
param TVMAX{i in I}; # Volume of the blockchain based on no. of transactions for all periods

#Decision-variables
var q{i in I, n in N} >= 0; #production quantity of the product supplier n during period i
var a{i in I, n in N} >= 0; # Delivered quantity by the product supplier
var s{i in I, n in N} >= 0; #inventory of the product supplier n at the of period i
var b{i in I, m in M} >= 0; # No. of units carrying by the 3PL operator m in period i
var c{i in I, j in J} >= 0; #costs for player j

#Fixed Variables
var Z{i in I, n in N} binary; # Binary variable defining whether the supplier will deliver the order
quantity or not
var Y{i in I, m in M} binary; # Binary variable defining whether the 3PL operator can deliver the
goods or not

#Inventory Constraints
subject to inventory_supplier_period1{i in I, n in N: i =1}: s[i,n] = q[i,n] - a[i,
n] + II[n];
subject to inventory_supplier_periods{i in I, n in N: i > 1}: s[i,n] = q[i,n] - a[i
,n] + s[i-1,n];
```

#Capacity Constraints (Supplier)

```
subject to order_quantity_constraint_min {i in I, n in N}: Z[i,n] * Qmin[i] <= a[i,n];
subject to order_quantity_constraint_max {i in I, n in N}: a[i,n] <= Z[i,n] * D[i];
subject to warehouse_capacity{i in I, n in N: i < t}: s[i+1,n] <= WCAP[i,n];
subject to production_capacity{i in I, n in N: n <= r}: q[i,n] <= MCP[i,n];

subject to demand_supplier {i in I}: sum {n in N} a[i,n] >= D[i];
```

#Capacity Constraints (3PL Operator)

```
subject to carrying_capacity_3PL{i in I, m in M}: b[i,m] <= VCAP[i,m];
subject to capacity_constraint_3PL_min{i in I, m in M}: Y[i,m] * Bmin[i] <= b[i,m];
subject to capacity_constraint_supplier_max{i in I, m in M}: b[i,m] <= Y[i,m] * D[i];
subject to demand_3PL {i in I}: sum {m in M} b[i,m] >= D[i];
```

#Blockchain Constraints

```
subject to blockchain_volume_of_transactions{i in I}: sum{n in N} (q[i,n] + s[i,n] + a[i,n]) + sum{m in M} b[i,m] + D[i] <= TVMAX[i];
```

#Objective function

```
subject to total_costs_no_binary{i in I, j in J}: c[i,j] = sum {n in N, m in M} (if
j = 1 then ( if i > 1 then ((UC[i,n] * q[i,n]) + (HC[i,n] * (s[i,n]+s[i-1,n]/2)) + ((FCS[i] + (TC[i,j] * (a[i,n]))))) else (UC[i,n] * q[i,n]) + (HC[i,n] * (s[i,n]+II[n]/2)) + ((FCS[i] + (TC[i,j] * (a[i,n]))))) else if j = 2 then ((P1[i,n] * a[i,n] + P3[i,m] * b[i,m]) + ((IC + FCE[i] + TC[i,j] * (a[i,n] + b[i,m])))) else ((DC[i,m] * b[i,m]) + ((FCD[i] + (TC[i,j] * b[i,m])))));
```

```
minimize v: sum{i in I, j in J} W[j] * c[i,j];
```

```
data;
```

```
param t := 12;
```

```
param r := 3;
```

```
param z := 2;
```

```
param W := 1 0.3 2 0.4 3 0.3;
```

```
param UC : 1 2 3:=
```

```
1 240 301 317
2 250 208 263
3 260 170 283
4 280 246 272
5 280 215 236
6 260 197 279
7 260 236 252
8 280 268 300
9 250 209 324
10 240 341 277
11 280 308 259
12 260 181 250;
```

```
param HC : 1 2 3:=
```

```
1 5.98 4.50 1.82
```

```

2 5.87 5.99 3.27
3 6.04 4.98 3.45
4 5.58 5.22 1.70
5 2.92 3.58 4.03
6 4.37 6.54 2.15
7 4.68 8.67 5.01
8 4.52 7.56 3.14
9 5.46 4.33 4.03
10 5.91 4.33 5.60
11 5.91 6.00 3.45
12 4.82 2.55 3.72;

```

```

param II := 1 25000 2 27000 3 22500;

```

```

param MCAP: 1 2 3:=
1 100000 150000 135000
2 100000 150000 135000
3 100000 150000 135000
4 100000 150000 135000
5 100000 150000 135000
6 100000 150000 135000
7 100000 150000 135000
8 100000 150000 135000
9 100000 150000 135000
10 100000 150000 135000
11 100000 150000 135000
12 100000 150000 135000;

```

```

param WCAP: 1 2 3:=
1 60000 90000 85000
2 60000 90000 85000
3 60000 90000 85000
4 60000 90000 85000
5 60000 90000 85000
6 60000 90000 85000
7 60000 90000 85000
8 60000 90000 85000
9 60000 90000 85000
10 60000 90000 85000
11 60000 90000 85000
12 60000 90000 85000;

```

```

param Qmin := 1 20000 2 20000 3 25000 4 30000 5 40000 6 25000 7 35000 8 25000 9 300
00 10 20000 11 25000 12 20000;

```

```

param DC: 1 2 :=
1 14.40 16.65
2 13.62 13.42
3 14.13 12.79
4 13.91 9.79
5 15.52 12.01
6 12.52 16.01
7 12.95 15.23
8 13.49 11.16
9 15.02 13.36
10 13.56 16.15
11 14.42 14.27
12 14.16 14.75;

```

```
param Bmin := 1 25000 2 25000 3 25000 4 35000 5 40000 6 35000 7 35000 8 30000 9 35000 10 25000 11 30000 12 25000;
```

```
param VCAP : 1 2 :=  
1 80000 120000  
2 80000 120000  
3 80000 120000  
4 80000 120000  
5 80000 120000  
6 80000 120000  
7 80000 120000  
8 80000 120000  
9 80000 120000  
10 80000 120000  
11 80000 120000  
12 80000 120000;
```

```
param D := 1 63950.64 2 59898 3 51013.44 4 72845.16 5 96533.28 6 75721.68 7 75296.4  
8 51087.36 9 36211.08 10 60197.52 11 53784.24 12 83520.12;
```

```
param P1: 1 2 3 :=  
1 85 100 110  
2 100 75 90  
3 105 80 80  
4 110 55 75  
5 110 60 50  
6 95 60 80  
7 95 85 70  
8 110 100 115  
9 90 90 125  
10 85 110 70  
11 110 80 70  
12 95 90 60;
```

```
param P3: 1 2 :=  
1 17 18  
2 15 16  
3 15 14  
4 16 11  
5 18 14  
6 14 18  
7 14 16  
8 15 16  
9 18 14  
10 15 14  
11 17 18  
12 17 15;
```

```
param TC : 1 2 3 :=  
1 0.600 0.858 0.600  
2 0.594 0.848 0.594  
3 0.588 0.840 0.588  
4 0.582 0.832 0.582  
5 0.576 0.823 0.576  
6 0.570 0.815 0.570  
7 0.565 0.807 0.565  
8 0.559 0.799 0.559  
9 0.553 0.791 0.553  
10 0.548 0.783 0.548
```

```
11 0.542 0.775 0.542
12 0.537 0.767 0.537;
```

```
param IC := 660000;
```

```
param FCE := 1 43787.67 2 27473.50 3 26956.33 4 26507.67 5 26117.50 6 25856.33 7 25
597.76 8 25341.78 9 25088.37 10 24837.48 11 24589.11 12 24343.22;
```

```
param FCS := 1 43787.67 2 27473.5 3 26956.33 4 26507.67 5 26117.5 6 25856.33 7 2559
7.76 8 25341.78 9 25088.367 10 24837.48 11 24589.11 12 24343.22;
```

```
param FCD := 1 43787.67 2 27473.5 3 26956.33 4 26507.67 5 26117.5 6 25856.33 7 2559
7.76 8 25341.78 9 25088.367 10 24837.48 11 24589.11 12 24343.22;
```

```
param TVMAX := 1 365000 2 365000 3 365000 4 365000 5 365000 6 365000 7 365000 8 365
000 9 365000 10 365000 11 365000 12 365000;
```

```
end;
```

Appendix D-AMPL Code for the Traditional E-commerce Model in Blockchain Chapter

```

param t;
param r;
param z;

set I := 1 .. t; #periods of time
set J := 1 .. 3; #player
set N := 1 .. r; # no of suppliers
set M := 1 .. z; # no of 3PL operators

#Parameters
param UCH{i in I, n in N}; #unit production cost of supplier n in period i
param UCL{i in I, n in N}; # Low unit cost
param HCH{i in I, n in N}; #inventory holding unit cost of the product supplier n in period i
param HCL{i in I, n in N};
param SE{i in I}; # Unit Inventory level of the e-tailer
param II{n in N}; #product supplier's initial inventory
param IIE; # initial inventory of the e-tailer
param Qmin{i in I} >= 0; # minimum order quantity of the supply chain system
param MCAP{i in I, n in N}; # maximum production capacity for supplier n
param WCAP{i in I, n in N}; #maximum warehouse capacity for supplier n
param VCAP{i in I, m in M}; #maximum carrying capacity for 3PL operator m
param ECAP{i in I}; # Maximum warehouse capacity of the e-tailer
param DCH{i in I, m in M}; # Unit Distribution Cost of the 3PL operator m in period i
param DCL{i in I, m in M};
param Bmin{i in I}; # Minimum delivery capacity of the 3PL operator m in period i
param D{i in I}; #customer demand for each period of time
param W{j in J}; #weight for the objective function of player j
param PlH{i in I, n in N}; #Unit ordering cost of the e-tailer in period i for supplier n
param PlL{i in I, n in N};
param P3H{i in I, m in M}; # Unit service cost paid by the e-tailer for the 3pl operator m in period i
param P3L{i in I, m in M};
param FCE{i in I}; #Variable costs of BC of E-tailer
param FCS{i in I}; # Variable costs of BC of Supplier n
param FCD{i in I}; # Variable costs of BC of 3PL operator m
param O; #Probability that the e-tailer believes the cost of supplier is at higher state
param X; #Probability that the e-tailer believes that the cost of 3PL operator is at higher state

#Decison-variables
var q{i in I, n in N} >= 0; #production quantity of the product supplier n during period i
var a{i in I, n in N} >= 0; # Delivered quantity by the product supplier
var s{i in I, n in N} >= 0; #inventory of the product supplier n at the of period i
var e{i in I} >= 0; # inventory level of the e-tailer
var d{i in I} >= 0; #order qty of the e-tailer
var b{i in I, m in M} >= 0; # No. of units carrying by the 3PL operator m in period i
var c{i in I, j in J} >= 0; #costs for player j

#Fixed Variables
#var k{j in J} >= 0, <= 1; # Percentage of cost sharing by the e-tailer (J<>2)
var Z{i in I, n in N} binary; # Binary variable defining whether the supplier will deliver the order

```

quantity or not

```
var Y{i in I, m in M} binary; # Binary variable defining whether the 3PL operator can deliver the goods or not
```

#Inventory Constraints

```
subject to inventory_supplier_period1{i in I, n in N: i =1}: s[i,n] = q[i,n] - a[i,n] + II[n];
subject to inventory_supplier_periods{i in I, n in N: i > 1}: s[i,n] = q[i,n] - a[i,n] + s[i-1,n];
subject to inventory_etailer_1{i in I:i=1}: e[i] = D[i] - d[i] + IIE;
subject to inventory_etailer{i in I: i >1}: e[i] = D[i] - d[i] + e[i-1];
```

#Capacity Constraints (Supplier)

```
subject to order_quantity_constraint_min {i in I, n in N}: Z[i,n] * Qmin[i] <= a[i,n];
subject to order_quantity_constraint_max {i in I, n in N}: a[i,n] <= Z[i,n]* D[i];
subject to warehouse_capacity{i in I, n in N: i < t}: s[i+1,n] <= WCAP[i,n];
subject to production_capacity{i in I,n in N: n <= r}: q[i,n] <= MCAP[i,n];
subject to warehouse_capactiy_etailer{i in I}: e[i] <= ECAP[i];

subject to demand_supplier {i in I}: sum {n in N} a[i,n] >= d[i];
```

#Capacity Constraints (3PL Operator)

```
subject to capacity_constraint_3PL_min{i in I,m in M}: Y[i,m] * Bmin[i] <= b[i,m];
subject to capacity_constraint_supplier_max{i in I, m in M}: b[i,m] <= Y[i,m] * D[i];
```

```
#subject to third_party_Operator_selection_constraint{i in I, m in M: i<=t and m <= z}: D[i]-b[i,m-1] = b[i,m] <= b[i,m-1] else D[i] else D[i] = b[i,m];
```

```
subject to demand_3PL {i in I}: sum {m in M} b[i,m] >= D[i];
```

#Objective function

```
subject to total_costs_no_binary{i in I, j in J}: c[i,j] = sum {n in N, m in M}(if j = 1 then(if i > 1 then O * ((UCH[i,n] * q[i,n]) + (HCH[i,n] * (s[i,n]+s[i-1,n]/2))) + (1-O) * ((UCL[i,n] * q[i,n]) + (HCL[i,n] * (s[i,n]+s[i-1,n]/2))) + ((FCS[i])) else O * ((UCH[i,n] * q[i,n]) + (HCH[i,n] * (s[i,n]+ II[n]/2))) + (1-O) * ((UCL[i,n] * q[i,n]) + (HCL[i,n] * (s[i,n]+ II[n]/2))) + ((FCS[i])) else if j = 2 then (SE[i] * e[i] + ((O * P1H[i,n]+ (1-O) * P1L[i,n])* d[i] * (1 + 0.025)) + ((X * P3H[i,m] + (1-X) * P3L[i,m]) * b[i,m] * (1 + 0.025)) + FCE[i]) else ((X * DCH[i,m] + (1-X) * DCL[i,m]) * b[i,m] + ((FCD[i]))));
```

```
minimize v: sum{i in I, j in J} W[j] * c[i,j];
```

```
data;
```

```
param t := 12;
```

```
param r := 3;
```

```
param z := 2;
```

```
param W := 1 0.3 2 0.4 3 0.3;
```

```
param UCH : 1 2 3 :=
```

```
1 240 301 317
```

```
2 250 208 263
```

```
3 260 170 283
```

```
4 280 246 272
```

```

5 280 215 236
6 260 197 279
7 260 236 252
8 280 268 300
9 250 209 324
10 240 341 277
11 280 308 259
12 260 181 250;

```

```

param UCL : 1 2 3 :=
1 200 189 180
2 190 229 165
3 200 159 147
4 190 195 145
5 200 194 189
6 200 190 183
7 200 202 186
8 180 209 181
9 190 186 158
10 200 186 158
11 190 152 170
12 190 179 178;

```

```

param HCH: 1 2 3 :=
1 5.98 4.50 1.82
2 5.87 5.99 3.27
3 6.04 4.98 3.45
4 5.58 5.22 1.70
5 2.92 3.58 4.03
6 4.37 6.54 2.15
7 4.68 8.67 5.01
8 4.52 7.56 3.14
9 5.46 4.33 4.03
10 5.91 4.33 5.60
11 5.91 6.00 3.45
12 4.82 2.55 3.72;

```

```

param HCL: 1 2 3 :=
1 3.63 3.27 0.23
2 3.14 4.34 0.24
3 3.86 3.71 0.40
4 3.92 4.54 0.75
5 3.84 3.48 1.23
6 4.11 4.31 0.64
7 3.61 3.85 1.07
8 4.04 2.99 0.62
9 4.10 3.59 2.49
10 3.99 4.07 1.56
11 3.52 3.74 0.96
12 3.65 3.93 0.49;

```

```

param SE := 1 5.80 2 5.15 3 5.03 4 11.09 5 7.29 6 8.96 7 7.42 8 8.42 9 8.63 10 8.13
11 8.03 12 9.23;

```

```

param II := 1 25000 2 27000 3 22500;

```

```

param IIE := 30000;

```

```

param MCAP: 1 2 3 :=
1 100000 150000 135000
2 100000 150000 135000
3 100000 150000 135000
4 100000 150000 135000

```



```

5 100000 150000 135000
6 100000 150000 135000
7 100000 150000 135000
8 100000 150000 135000
9 100000 150000 135000
10 100000 150000 135000
11 100000 150000 135000
12 100000 150000 135000;

```

```

param WCAP: 1 2 3 :=
1 60000 90000 85000
2 60000 90000 85000
3 60000 90000 85000
4 60000 90000 85000
5 60000 90000 85000
6 60000 90000 85000
7 60000 90000 85000
8 60000 90000 85000
9 60000 90000 85000
10 60000 90000 85000
11 60000 90000 85000
12 60000 90000 85000;

```

```

param VCAP: 1 2 :=
1 80000 120000
2 80000 120000
3 80000 120000
4 80000 120000
5 80000 120000
6 80000 120000
7 80000 120000
8 80000 120000
9 80000 120000
10 80000 120000
11 80000 120000
12 80000 120000;

```

```

param ECAP := 1 100000 2 100000 3 100000 4 100000 5 100000 6 100000 7 100000 8 1000
00 9 100000 10 100000 11 100000 12 100000;

```

```

param Qmin := 1 20000 2 20000 3 25000 4 30000 5 40000 6 25000 7 35000 8 25000 9 300
00 10 20000 11 25000 12 20000;

```

```

param DCH: 1 2 :=
1 14.40 16.65
2 13.62 13.42
3 14.13 12.79
4 13.91 13.79
5 15.52 12.01
6 12.52 16.01
7 12.95 15.23
8 13.49 11.16
9 15.02 13.36
10 13.56 16.15
11 14.42 14.27
12 14.16 14.75;

```

```

param DCL: 1 2 :=
1 10.82 10.76
2 11.54 11.86
3 11.47 10.11
4 11.08 11.77
5 11.05 11.91

```

```

6 12.01 10.94
7 11.92 13.41
8 9.61 7.78
9 9.58 8.07
10 10.09 9.09
11 12.03 12.14
12 11.44 12.84;

```

```

param Bmin := 1 25000 2 25000 3 25000 4 35000 5 40000 6 35000 7 35000 8 30000 9 350
00 10 25000 11 30000 12 25000;

```

```

param D := 1 63950.64 2 59898 3 51013.44 4 72845.16 5 96533.28 6 75721.68 7 75296.4
8 51087.36 9 36211.08 10 60197.52 11 53784.24 12 83520.12;

```

```

param P1H: 1 2 3 :=
1 85 100 110
2 100 75 90
3 105 80 80
4 110 55 75
5 110 60 50
6 95 60 80
7 95 85 70
8 110 100 115
9 90 90 125
10 85 110 70
11 110 80 70
12 95 90 60;

```

```

param P1L: 1 2 3 :=
1 62 64 60
2 68 63 55
3 61 63 50
4 60 70 50
5 63 66 60
6 73 71 60
7 64 72 61
8 62 65 61
9 63 69 59
10 73 70 59
11 73 67 55
12 69 72 55;

```

```

param P3H: 1 2 :=
1 17 18
2 15 16
3 15 14
4 16 11
5 18 14
6 14 18
7 14 16
8 15 16
9 18 14
10 15 14
11 17 18
12 17 15;

```

```

param P3L: 1 2 :=
1 10 5
2 9 7
3 10 6
4 10 5
5 10 6
6 8 5

```

```
7 9 6
8 7 6
9 10 6
10 10 7
11 10 5
12 5 5;
```

```
param FCE := 1 383080.96 2 383080.96 3 395754.86 4 395754.86 5 408935.72 6 408935.7
2 7 422643.81 8 422643.81 9 436900.22 10 436900.22 11 451726.89 12 451726.89;
```

```
param FCS := 1 302280 2 302280 3 314371.2 4 314371.2 5 326946.05 6 326946.05 7 3400
23.89 8 340023.89 9 353624.85 10 353624.85 11 367769.84 12 367769.84;
```

```
param FCD := 1 302280 2 302280 3 314371.2 4 314371.2 5 326946.05 6 326946.05 7 3400
23.89 8 340023.89 9 353624.85 10 353624.85 11 367769.84 12 367769.84;
```

```
param O := 0.9;
```

```
param X := 0.3;
```

```
end;
```

Appendix E – Proof of Propositions of the Dynamic Cost-sharing Contract

The model designed in this study is a non-linear programming problem. Therefore, the Karush Kuhn-Tucker (KKT) first order necessary conditions are used to derive the optimal conditions for the decision variables of the model. The Lagrangian function of the model is defined from Eq. (1) to (21). Accordingly, KKT conditions are derived as follows;

$$\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5, \lambda_6, \lambda_7, \lambda_8, \lambda_9, \lambda_{10}, \lambda_{11}, \lambda_{12}, \lambda_{13}, \lambda_{14}, \mu_1, \mu_2, \mu_3, \mu_4 \geq 0 \quad (1)$$

The First order derivatives are taken on behalf of the decision variables are represented by Eq. (2) to Eq. (9);

$$W_1 \left(\frac{1}{1+\delta_1} \right)^i \{ \theta \cdot (\overline{UC_i}) + (1-\theta) \cdot (\underline{UC_i}) \} + \lambda_1 (\underline{UC_i} - \overline{UC_i}) + \lambda_2 (\overline{UC_i} - \underline{UC_i}) - \lambda_5 K_{\%_1} \{ \theta \cdot (\overline{UC_i}) + (1-\theta) \cdot (\underline{UC_i}) \} \\ + \lambda_8 (\overline{sc_{i,1}} \cdot \underline{UC_{i+1}} - \overline{sc_{i-1,1}} \cdot \underline{UC_i}) - \lambda_9 (\underline{sc_{i,1}} \cdot \overline{UC_{i+1}} - \underline{sc_{i-1,1}} \cdot \overline{UC_i}) - \mu_1 - \mu_3 + \lambda_{14} = 0 \quad (2)$$

$$-W_1 \left(\frac{1}{1+\delta_1} \right)^i \left[\theta \cdot (\overline{P_{i,1}}) + (1-\theta) \cdot (\underline{P_{i,1}}) \right] + W_2 \left(\frac{1}{1+\delta_2} \right)^i \left[\theta \cdot (\overline{P_{i,1}}) + (1-\theta) \cdot (\underline{P_{i,1}}) \right] \\ + \lambda_1 (\underline{P_{i,1}} - \overline{P_{i,1}}) + \lambda_2 (\overline{P_{i,1}} - \underline{P_{i,1}}) + \mu_1 + \mu_3 + \mu_4 = 0 \quad (3)$$

$$W_1 \left(\frac{1}{1+\delta_1} \right)^i \alpha_i \{ \theta \cdot (\overline{UC_i}) + (1-\theta) \cdot (\underline{UC_i}) \} + W_2 \left(\frac{1}{1+\delta_2} \right)^i \cdot (HC_i) + \lambda_1 \{ \alpha_i (\underline{UC_i} - \overline{UC_i}) \} \\ + \lambda_2 \{ \alpha_i (\overline{UC_i} - \underline{UC_i}) \} - \lambda_5 \{ K_{\%_1} \alpha_i \{ \theta \cdot \overline{UC_i} - (1-\theta) \underline{UC_i} \} \} + \lambda_8 \{ \overline{sc_{i,1}} \cdot \underline{UC_{i+1}} \cdot \alpha_{i+1} \cdot (s_{i-1,1}) - \overline{sc_{i+1,1}} \cdot \underline{UC_i} \cdot \alpha_i \cdot (s_{i,1}) \} \\ + \lambda_9 \{ \underline{sc_{i,1}} \cdot (\overline{UC_{i+1}}) \cdot \alpha_{i+1} \cdot (s_{i-1,1}) - (\underline{sc_{i-1,1}}) (\overline{UC_i})_i \cdot (s_{i,1}) \} + \mu_1 + \mu_2 - \lambda_{12} + \lambda_{13} = 0 \quad (4)$$

$$W_2 \left(\frac{1}{1+\delta_2} \right)^i (\theta + \gamma) - W_1 \left(\frac{1}{1+\delta_1} \right)^i (\theta) - W_3 \left(\frac{1}{1+\delta_3} \right)^i (\gamma) - \lambda_1 - \lambda_2 + \lambda_3 + \lambda_4 - \lambda_7 \\ + \lambda_9 \{ (\overline{UC_{i+1}} (q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2) - (\overline{UC_i} (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \} \\ + \lambda_{11} \{ (\overline{DC_{i+1}} \cdot D_{i+1}) - (\overline{DC_i} \cdot D_{i+1}) \} = 0 \quad (5)$$

$$W_2 \left(\frac{1}{1+\delta_2} \right)^i (2 - \theta - \gamma) - W_1 \left(\frac{1}{1+\delta_1} \right)^i (1 - \theta) - W_3 \left(\frac{1}{1+\delta_3} \right)^i (1 - \gamma) - \lambda_1 - \lambda_2 - \lambda_3 - \lambda_4 - \lambda_7 \\ + \lambda_8 \{ (\underline{UC_{i+1}} (q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2) - (\underline{UC_i} (q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \} \\ + \lambda_{10} \{ (\underline{DC_{i+1}} \cdot D_{i+1}) - (\underline{DC_i} \cdot D_{i+1}) \} = 0 \quad (6)$$

$$\lambda_9 \left\{ \overline{UC_i} \left(q_i + \frac{\alpha_i}{2} (s_i + s_{i-1}) \right) \right\} + \lambda_{11} \{ \overline{DC_i} \cdot D_i \} = 0 \quad (7)$$

$$\lambda_8 \left\{ \underline{UC_i} \left(q_i + \frac{\alpha_i}{2} (s_i + s_{i-1}) \right) \right\} + \lambda_{10} \{ \underline{DC_i} \cdot D_i \} = 0 \quad (8)$$

$$\begin{aligned} & -\lambda_5 \left\{ (\theta \cdot (\overline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2)) + (1 - \theta) \cdot (\underline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2))) \right\} \\ & -\lambda_6 \left\{ \cdot (\gamma \cdot (\overline{DC_i} \cdot D_i) + (1 - \gamma)(\underline{DC_i} \cdot D_i)) \right\} = 0 \end{aligned} \quad (9)$$

$$\lambda_1 \left[\left\{ \underline{UC_i} \cdot q_i + \alpha_i \cdot \underline{UC_i}(s_{i,1} + s_{i-1,1}) / 2 - \overline{sc_{1,i}} - \underline{P_{1,1}} \cdot d_i \right\} - \left\{ \overline{UC_i} \cdot q_i + \alpha_i \cdot \overline{UC_i}(s_{i,1} + s_{i-1,1}) / 2 - \underline{sc_{1,i}} - \overline{P_{1,1}} \cdot d_i \right\} \right] = 0 \quad (10)$$

$$\lambda_2 \left[\left\{ \overline{UC_i} \cdot q_i + \alpha_i \cdot \overline{UC_i}(s_{i,1} + s_{i-1,1}) / 2 - \overline{sc_{1,i}} - \overline{P_{1,1}} \cdot d_i \right\} - \left\{ \underline{UC_i} \cdot q_i + \alpha_i \cdot \underline{UC_i}(s_{i,1} + s_{i-1,1}) / 2 - \underline{sc_{1,i}} - \underline{P_{1,1}} \cdot d_i \right\} \right] = 0 \quad (11)$$

$$\lambda_3 \left[\left\{ \underline{DC_i} \cdot D_i - \overline{sc_{i,3}} - \underline{P_{i,3}} \cdot D_i \right\} - \left\{ \overline{DC_i} \cdot D_i - \underline{sc_{i,3}} - \overline{P_{i,3}} \cdot D_i \right\} \right] = 0 \quad (12)$$

$$\lambda_4 \left[\left\{ \overline{DC_i} \cdot D_i - \overline{sc_{i,3}} - \overline{P_{i,3}} \cdot D_i \right\} - \left\{ \underline{DC_i} \cdot D_i - \underline{sc_{i,3}} - \underline{P_{i,3}} \cdot D_i \right\} \right] = 0 \quad (13)$$

$$\lambda_5 \left[\overline{sc_{i,1}} - k_{i,1}^{\%} \left\{ (\theta \cdot (\overline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2)) + (1 - \theta) \cdot (\underline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2))) \right\} \right] = 0 \quad (14)$$

$$\lambda_6 \left[\overline{sc_{i,3}} - \left\{ k_{i,3}^{\%} \left(\gamma \cdot (\overline{DC_i} \cdot D_i) + (1 - \gamma)(\underline{DC_i} \cdot D_i) \right) \right\} \right] = 0 \quad (15)$$

$$\lambda_7 \left[\overline{sc_{i,j}} - \overline{sc_{i,j}} \right] = 0 \quad (16)$$

$$\lambda_8 \left[\overline{sc_{i,1}} \left((\underline{UC_{i+1}}(q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2)) \right) - \overline{sc_{i+1,1}} \left(\overline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \right) \right] = 0 \quad (17)$$

$$\lambda_9 \left[\underline{sc_{i,1}} \left(\overline{UC_{i+1}}(q_{i+1} + \alpha_{i+1} \cdot (s_{i,1} + s_{i+1,1}) / 2) \right) - (\underline{sc_{i+1,1}}) \left(\overline{UC_i}(q_i + \alpha_i \cdot (s_{i,1} + s_{i-1,1}) / 2) \right) \right] = 0 \quad (18)$$

$$\lambda_{10} \left[(\overline{sc_{i,3}})(\underline{DC_{i+1}} \cdot D_{i+1}) - (\overline{sc_{i+1,3}})(\underline{DC_i} \cdot D_i) \right] = 0 \quad (19)$$

$$\lambda_{11} \left[(\underline{sc_{i,3}})(\overline{DC_{i+1}} \cdot D_{i+1}) - (\underline{sc_{i+1,3}})(\overline{DC_i} \cdot D_i) \right] = 0 \quad (20)$$

$$\mu_1 \left[s_{1,1} - q_1 + d_1 - II_1 \right] = 0 \quad (21)$$

$$\mu_2 \left[s_{1,2} - d_1 + D_i - II_2 \right] = 0 \quad (22)$$

$$\mu_3 \left[s_{i,1} - q_i + d_i - s_{i-1,1} \right] = 0 \quad (23)$$

$$\mu_4 \left[s_{i,2} - d_i + D_i - s_{i-1,2} \right] = 0 \quad (24)$$

$$\lambda_{13} \left[s_{i,j} - W_{capj} \right] = 0 \quad (25)$$

$$\lambda_{14} [q_i - M_{cap}] = 0 \quad (26)$$

$$\left[\overline{UC} \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \underline{P}_{1,1} \cdot d_i \right] - \left[\overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \underline{P}_{1,1} \cdot d_i \right] \leq 0 \quad (27)$$

$$\left[\overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \underline{P}_{1,1} \cdot d_i \right] - \left[\overline{UC}_i \cdot q_i + \alpha_i \cdot \overline{UC}_i (s_{i,1} + s_{i-1,1}) / 2 - \overline{sc}_{1,i} - \underline{P}_{1,1} \cdot d_i \right] \leq 0 \quad (28)$$

$$\left[\overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \right] - \left[\overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \right] \leq 0 \quad (29)$$

$$\left[\overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \right] - \left[\overline{DC}_i \cdot D_i - \overline{sc}_{i,3} - \underline{P}_{i,3} \cdot D_i \right] \leq 0 \quad (30)$$

$$\left[\overline{sc}_{i,1} - k_{i,1}^{\%} \left\{ (\theta \cdot (\overline{UC}_i (q_i + \alpha_i (s_{i,1} + s_{i-1,1}) / 2)) + (1 - \theta) \cdot (\overline{UC}_i (q_i + \alpha_i (s_{i,1} + s_{i-1,1}) / 2)) \right\} \right] \leq 0 \quad (31)$$

$$\left[\overline{sc}_{i,3} - \left\{ k_{i,3}^{\%} \left(\gamma \cdot (\overline{DC}_i \cdot D_i) + (1 - \gamma) \cdot (\overline{DC}_i \cdot D_i) \right) \right\} \right] \leq 0 \quad (32)$$

$$\left[\overline{sc}_{i,j} - \overline{sc}_{i,j} \right] \leq 0 \quad (33)$$

$$\left[\overline{sc}_{i,1} \left(\overline{UC}_{i+1} (q_{i+1} + \alpha_{i+1} (s_{i,1} + s_{i+1,1}) / 2) \right) - \overline{sc}_{i+1,1} \left(\overline{UC}_i (q_i + \alpha_i (s_{i,1} + s_{i-1,1}) / 2) \right) \right] \leq 0 \quad (34)$$

$$\left[\overline{sc}_{i,1} \left(\overline{UC}_{i+1} (q_{i+1} + \alpha_{i+1} (s_{i,1} + s_{i+1,1}) / 2) \right) - (\overline{sc}_{i+1,1}) \left(\overline{UC}_i (q_i + \alpha_i (s_{i,1} + s_{i-1,1}) / 2) \right) \right] \leq 0 \quad (35)$$

$$\left[(\overline{sc}_{i,3}) (\overline{DC}_{i+1} \cdot D_{i+1}) - (\overline{sc}_{i+1,3}) (\overline{DC}_i \cdot D_i) \right] \leq 0 \quad (36)$$

$$\left[(\overline{sc}_{i,3}) (\overline{DC}_{i+1} \cdot D_{i+1}) - (\overline{sc}_{i+1,3}) (\overline{DC}_i \cdot D_i) \right] \leq 0 \quad (37)$$

$$\left[s_{i+1,j} - W_{cap,j} \right] \leq 0 \quad (38)$$

$$\left[q_i - M_{cap} \right] \leq 0 \quad (39)$$

Proof of Proposition 1

Based on the derived conditions for the optimization model, the following values have been derived for the decision variables.

Assuming Eq. (38) and (39) are binding;

$$q_i = M_{cap} \quad (40)$$

$$s_{i+1,j} = W_{cap,j} \quad (41)$$

From the equality constraints Eq. (18) and (19) of the model (See page 14),

$$d_i = W_{cap,2} - s_{i,2} + D_i \quad (42)$$

$$d_i = M_{cap} + s_{i,1} - W_{cap,1} \quad (43)$$

Eq.(27) – Eq.(28) $\Rightarrow$

$$s_{i,1} = \frac{(\underline{UC}_i - \overline{UC}_i) \{2M_{cap} + W_{cap}\} + 2(\overline{P}_i - \underline{P}_i) \{M_{cap} + W_{cap}\}}{(\underline{UC}_i - \overline{UC}_i) + 2(\overline{P}_i - \underline{P}_i)} \quad (44)$$

Eq.(43) and (44) $\Rightarrow$

$$d_i = \frac{M_{cap} \{3(\underline{UC}_i - \overline{UC}_i) + 4(\overline{P}_{i,1} - \underline{P}_{i,1})\}}{(\underline{UC}_i - \overline{UC}_i) + 2(\overline{P}_{i,1} - \underline{P}_{i,1})} \quad (45)$$

From Eq. (42);

$$s_{i,2} = D_i + W_{cap,2} - \frac{M_{cap} \{3(\underline{UC}_i - \overline{UC}_i) + 4(\overline{P}_{i,1} - \underline{P}_{i,1})\}}{(\underline{UC}_i - \overline{UC}_i) + 2(\overline{P}_{i,1} - \underline{P}_{i,1})} \quad (46)$$

Proof of Proposition 2

Assuming Eq. (31) and (32) are binding;

$$\underline{sc}_{i,1} = \frac{k_{i,1}^{\%} \left\{ (1 + \alpha_i) (\underline{UC}_i - \overline{UC}_i) (W_{cap} + 2M_{cap}) + (4 + \alpha_i) (\overline{P}_{i,1} - \underline{P}_{i,1}) \right\} (\theta \cdot \overline{UC}_i + (1 - \theta) \underline{UC}_i)}{2(\underline{UC}_i - \overline{UC}_i) + 4(\overline{P}_{i,1} - \underline{P}_{i,1})} \quad (47)$$

$$\overline{sc}_{i,3} = k_{i,3}^{\%} \left\{ \gamma \cdot \overline{DC}_i + (1 - \gamma) \underline{DC}_i \right\} D_i \quad (48)$$

From Eq. (29);

$$\underline{sc}_{i,3} = D_i \left\{ (\overline{DC}_i - \underline{DC}_i) - (\overline{P}_{i,3} - \underline{P}_{i,3}) + k_{i,3}^{\%} \left\{ \gamma \cdot \overline{DC}_i + (1 - \gamma) \underline{DC}_i \right\} \right\} \quad (49)$$

From Eq. (27);

$$\underline{SC}_{i,1} = \frac{\left(\underline{UC}_i - \overline{UC}_i\right)\left\{2M_{cap}\left(4 + \alpha_i\right) + W_{cap,1}\left(2 + \alpha_i\right)\right\} + 4\left(\overline{P}_{i,1} - \underline{P}_{i,1}\right)\left(3M_{cap} + W_{cap,1}\right) + k_{i,1}^{\%}\left(\theta \cdot \overline{UC}_i + (1 - \theta)\underline{UC}_i\right)\left\{\left(\underline{UC}_i - \overline{UC}_i\right)\left(1 + \alpha_i\right)\left(W_{cap,1} + 2M_{cap}\right) + \left(\overline{P}_{i,1} - \underline{P}_{i,1}\right)\left(4 + \alpha_i\right)\right\}}{2\left(\underline{UC}_i - \overline{UC}_i\right) + 4\left(\overline{P}_{i,1} - \underline{P}_{i,1}\right)} \quad (50)$$

Appendix F – Results of the Sensitivity Analysis Between Cost-Sharing Percentages ($k_1^%$ & $k_3^%$) and Supply Chain Costs of the Base Cost-Sharing Contract

$k_1^%$	$k_3^%$	c_1	c_2	c_3	z
0.9	0.3	475811	189704	59302.9	236415.9
0.9	0.4	475811	189704	59302.9	236415.9
0.9	0.5	475811	189704	59302.9	236415.9
0.9	0.6	475811	189704	59302.9	236415.9
0.9	0.7	475811	189704	59302.9	236415.9
0.9	0.8	475811	189704	59302.9	236415.9
0.9	0.9	475811	189704	59302.9	236415.9
0.8	0.3	475487	190073	59302.9	236466.0
0.8	0.4	475487	190073	59302.9	236466.0
0.8	0.5	475487	190073	59302.9	236466.0
0.8	0.6	475487	190073	59302.9	236466.0
0.8	0.7	475487	190073	59302.9	236466.0
0.8	0.8	475487	190073	59302.9	236466.0
0.8	0.9	475487	190073	59302.9	236466.0
0.7	0.3	475096	190516	59302.9	236526.2
0.7	0.4	475096	190516	59302.9	236526.2
0.7	0.5	475096	190516	59302.9	236526.2
0.7	0.6	475096	190516	59302.9	236526.2
0.7	0.7	475096	190516	59302.9	236526.2
0.7	0.8	475096	190516	59302.9	236526.2
0.7	0.9	475096	190516	59302.9	236526.2
0.6	0.3	475407	190534	59302.9	236626.3
0.6	0.4	475407	190534	59302.9	236626.3
0.6	0.5	475407	190534	59302.9	236626.3
0.6	0.6	475407	190534	59302.9	236626.3
0.6	0.7	475407	190534	59302.9	236626.3
0.6	0.8	475407	190534	59302.9	236626.3
0.6	0.9	475407	190534	59302.9	236626.3
0.5	0.3	474582	191543	59302.9	236782.5
0.5	0.4	474582	191543	59302.9	236782.5
0.5	0.5	474582	191543	59302.9	236782.5
0.5	0.6	474582	191543	59302.9	236782.5
0.5	0.7	474582	191543	59302.9	236782.5
0.5	0.8	474582	191543	59302.9	236782.5
0.5	0.9	474582	191543	59302.9	236782.5
0.4	0.3	472596	193559	59302.9	236993.2
0.4	0.4	472596	193559	59302.9	236993.2
0.4	0.5	472596	193559	59302.9	236993.2
0.4	0.6	472596	193559	59302.9	236993.2
0.4	0.7	472596	193559	59302.9	236993.2
0.4	0.8	472596	193559	59302.9	236993.2
0.4	0.9	472596	193559	59302.9	236993.2
0.3	0.3	470208	196072	59302.9	237282.0
0.3	0.4	470208	196072	59302.9	237282.0
0.3	0.5	470208	196072	59302.9	237282.0
0.3	0.6	470208	196072	59302.9	237282.0
0.3	0.7	470208	196072	59302.9	237282.0
0.3	0.8	470208	196072	59302.9	237282.0
0.3	0.9	470208	196072	59302.9	237282.0
0.2	0.3	575663	180846	59302.9	262828.1

0.2	0.4	575663	180846	59302.9	262828.1
0.2	0.5	575663	180846	59302.9	262828.1
0.2	0.6	575663	180846	59302.9	262828.1
0.2	0.7	575663	180846	59302.9	262828.1
0.2	0.8	575663	180846	59302.9	262828.1
0.2	0.9	575663	180846	59302.9	262828.1
0.1	0.3	734465	158126	59302.9	301380.8
0.1	0.4	734465	158126	59302.9	301380.8
0.1	0.5	734465	158126	59302.9	301380.8
0.1	0.6	734465	158126	59302.9	301380.8
0.1	0.7	734465	158126	59302.9	301380.8
0.1	0.8	734465	158126	59302.9	301380.8
0.1	0.9	734465	158126	59302.9	301380.8

Appendix G – Results of the Sensitivity Analysis Between Asymmetric Cost Probabilities (θ & γ) and Supply Chain Costs of the Base Cost-Sharing Contract (Extended) Model

θ	γ	c_1	c_2	c_3	z
0.1	0.1	4,958,000	4,368,000	273,100	3,317,000
0.1	0.2	4,958,000	4,381,000	296,900	3,329,000
0.1	0.3	4,958,000	4,394,000	320,700	3,341,000
0.1	0.4	4,958,000	4,407,000	344,500	3,354,000
0.1	0.5	4,958,000	4,420,000	368,300	3,366,000
0.1	0.6	4,958,000	4,433,000	392,100	3,378,000
0.1	0.7	4,958,000	4,446,000	415,900	3,390,000
0.1	0.8	4,958,000	4,458,000	439,700	3,403,000
0.1	0.9	4,958,000	4,471,000	463,500	3,415,000
0.2	0.1	5,173,000	4,449,000	273,100	3,413,000
0.2	0.2	5,173,000	4,462,000	296,900	3,426,000
0.2	0.3	5,173,000	4,475,000	320,700	3,438,000
0.2	0.4	5,173,000	4,487,000	344,500	3,450,000
0.2	0.5	5,173,000	4,500,000	368,300	3,463,000
0.2	0.6	5,173,000	4,513,000	392,100	3,475,000
0.2	0.7	5,173,000	4,526,000	415,900	3,487,000
0.2	0.8	5,173,000	4,539,000	439,700	3,499,000
0.2	0.9	5,173,000	4,552,000	463,500	3,512,000
0.3	0.1	5,399,000	4,521,000	273,100	3,510,000
0.3	0.2	5,399,000	4,534,000	296,900	3,522,000
0.3	0.3	5,399,000	4,547,000	320,700	3,534,000
0.3	0.4	5,399,000	4,559,000	344,500	3,547,000
0.3	0.5	5,399,000	4,572,000	368,300	3,559,000
0.3	0.6	5,399,000	4,585,000	392,100	3,571,000
0.3	0.7	5,399,000	4,598,000	415,900	3,584,000
0.3	0.8	5,399,000	4,611,000	439,700	3,596,000
0.3	0.9	5,399,000	4,624,000	463,500	3,608,000
0.4	0.1	5,624,000	4,592,000	273,100	3,606,000
0.4	0.2	5,624,000	4,605,000	296,900	3,618,000
0.4	0.3	5,624,000	4,618,000	320,700	3,631,000
0.4	0.4	5,624,000	4,631,000	344,500	3,643,000
0.4	0.5	5,624,000	4,644,000	368,300	3,655,000
0.4	0.6	5,624,000	4,657,000	392,100	3,667,000
0.4	0.7	5,624,000	4,669,000	415,900	3,680,000
0.4	0.8	5,624,000	4,682,000	439,700	3,692,000
0.4	0.9	5,624,000	4,695,000	463,500	3,704,000
0.5	0.1	5,923,000	4,601,000	273,100	3,699,000
0.5	0.2	5,923,000	4,614,000	296,900	3,711,000
0.5	0.3	5,923,000	4,626,000	320,700	3,724,000
0.5	0.4	5,923,000	4,639,000	344,500	3,736,000
0.5	0.5	5,923,000	4,652,000	368,300	3,748,000

0.5	0.6	5,923,000	4,665,000	392,100	3,760,000
0.5	0.7	5,923,000	4,678,000	415,900	3,773,000
0.5	0.8	5,923,000	4,691,000	439,700	3,785,000
0.5	0.9	5,923,000	4,703,000	463,500	3,797,000
0.6	0.1	6,086,000	4,707,000	273,100	3,791,000
0.6	0.2	6,086,000	4,720,000	296,900	3,803,000
0.6	0.3	6,086,000	4,733,000	320,700	3,815,000
0.6	0.4	6,086,000	4,746,000	344,500	3,827,000
0.6	0.5	6,086,000	4,758,000	368,300	3,840,000
0.6	0.6	6,086,000	4,771,000	392,100	3,852,000
0.6	0.7	6,086,000	4,784,000	415,900	3,864,000
0.6	0.8	6,086,000	4,797,000	439,700	3,877,000
0.6	0.9	6,086,000	4,810,000	463,500	3,889,000
0.7	0.1	6,271,000	4,795,000	273,100	3,881,000
0.7	0.2	6,271,000	4,808,000	296,900	3,894,000
0.7	0.3	6,271,000	4,821,000	320,700	3,996,000
0.7	0.4	6,271,000	4,834,000	344,500	3,918,000
0.7	0.5	6,271,000	4,846,000	368,300	3,931,000
0.7	0.6	6,271,000	4,859,000	392,100	3,943,000
0.7	0.7	6,271,000	4,872,000	415,900	3,955,000
0.7	0.8	6,271,000	4,885,000	439,700	3,967,000
0.7	0.9	6,271,000	4,898,000	463,500	3,980,000
0.8	0.1	6,396,000	4,927,000	273,100	3,971,000
0.8	0.2	6,396,000	4,940,000	296,900	3,984,000
0.8	0.3	6,396,000	4,952,000	320,700	3,996,000
0.8	0.4	6,396,000	4,965,000	344,500	4,008,000
0.8	0.5	6,396,000	4,978,000	368,300	4,021,000
0.8	0.6	6,396,000	4,991,000	392,100	4,033,000
0.8	0.7	6,396,000	5,003,900	415,900	4,045,098
0.8	0.8	6,396,000	5,017,000	439,700	4,057,000
0.8	0.9	6,396,000	5,030,000	463,500	4,070,000
0.9	0.1	6,489,000	5,072,000	273,100	4,057,000
0.9	0.2	6,489,000	5,085,000	296,900	4,070,000
0.9	0.3	6,489,000	5,098,000	320,700	4,082,000
0.9	0.4	6,489,000	5,111,000	344,500	4,094,000
0.9	0.5	6,489,000	5,124,000	368,300	4,107,000
0.9	0.6	6,489,000	5,137,000	392,100	4,119,000
0.9	0.7	6,489,000	5,149,000	415,900	4,131,000
0.9	0.8	6,489,000	5,162,000	439,700	4,143,000
0.9	0.9	6,489,000	5,175,000	463,500	4,156,000

Appendix H – Data Used for the Numerical Analysis of Chapter 5 (Testing Propositions)

Parameter	No. of Periods											
	1	2	3	4	5	6	7	8	9	10	11	12
D_i	6038	7018	9242	9035	7077	6464	6362	6032	8103	9572	7159	5931
D_i _30%	6038	7018	5545	5421	4246	3879	3818	3619	4862	5743	4296	3559
Operational Unit Cost Change with Re-valuation												
$\overline{UC_i}$	240	250	260	280	280	260	260	280	250	240	280	260
$\underline{UC_i}$	200	190	200	190	200	200	200	180	190	200	190	190
$\overline{UC_i}$ _5%	228	237.5	247	266	266	247	247	266	237.5	228	266	247
$\underline{UC_i}$ _5%	190	180.5	190	180.5	190	190	190	171	180.5	190	180.5	180.5
$\overline{UC_i}$ _10%	216	225	234	252	252	234	234	252	225	216	252	234
$\underline{UC_i}$ _10%	180	171	180	171	180	180	180	162	171	180	171	171
$\overline{UC_i}$ _15%	204	212.5	221	238	238	221	221	238	212.5	204	238	221
$\underline{UC_i}$ _15%	170	161.5	170	161.5	170	170	170	153	161.5	170	161.5	161.5
$\overline{UC_i}$ _20%	192	200	208	224	224	208	208	224	200	192	224	208
$\underline{UC_i}$ _20%	160	152	160	152	160	160	160	144	152	160	152	152
$\overline{DC_i}$	19.65	20.22	18.9	19.85	19.59	20.65	19.56	18.94	21.45	20.07	19.26	18.99
$\underline{DC_i}$	11.21	14.16	12.49	11.34	13.15	11.97	13.08	12.75	12.21	12.39	11.47	12.07
$\overline{DC_i}$ _5%	18.66	19.20	17.95	18.85	18.61	19.61	18.58	17.99	20.37	19.06	18.29	18.04
$\underline{DC_i}$ _5%	10.64	13.45	11.86	10.77	12.49	11.37	12.42	12.11	11.59	11.77	10.89	11.46
$\overline{DC_i}$ _10%	17.68	18.19	17.01	17.86	17.63	18.58	17.60	17.04	19.30	18.06	17.33	17.09
$\underline{DC_i}$ _10%	10.08	12.74	11.24	10.20	11.83	10.77	11.77	11.47	10.98	11.15	10.32	10.86
$\overline{DC_i}$ _15%	16.70	17.18	16.06	16.87	16.65	17.55	16.62	16.09	18.23	17.05	16.37	16.14
$\underline{DC_i}$ _15%	9.52	12.03	10.61	9.63	11.17	10.17	11.11	10.83	10.37	10.53	9.74	10.25
$\overline{DC_i}$ _20%	15.72	16.17	15.12	15.88	15.67	16.52	15.64	15.15	17.16	16.05	15.40	15.19
$\underline{DC_i}$ _20%	8.96	11.32	9.99	9.07	10.52	9.57	10.46	10.2	9.76	9.91	9.17	9.65
HC_i	5.98	5.87	6.04	5.58	2.92	4.37	4.68	4.52	5.46	5.91	5.91	4.82
HC_i _5%	5.68	5.576	5.73	5.30	2.77	4.15	4.44	4.29	5.18	5.61	5.61	4.57
HC_i _10%	5.38	5.28	5.43	5.02	2.62	3.93	4.21	4.06	4.91	5.31	5.31	4.33
HC_i _15%	5.08	4.98	5.13	4.74	2.48	3.71	3.97	3.84	4.64	5.02	5.02	4.09
HC_i _20%	4.78	4.69	4.83	4.46	2.33	3.49	3.74	3.61	4.36	4.72	4.72	3.85

Appendix I – Sensitivity Analysis of Operational Scenario 3 of Chapter 5

Variables	No. of Periods											
	1	2	3	4	5	6	7	8	9	10	11	12
C1_10%	233500	801776	712231	492945	497248	454712	514623	382886	537290	723699	465889	398306
C2	316994	645184	527556	533182	447908	387866	378688	366796	438787	502004	438364	352837
C3_15%	40153	48850	35848	23981	16312	14151	15032	19431	25242	28632	20278	16535
Z(S10%, D15%)	4090330											
C1_5%	436206	787389	703744	486864	488711	504217	533154	431778	583904	785296	502786	428468
C2	337413	642795	526556	531849	446501	383361	381901	380854	446471	508437	447436	363144
C3_10%	40153	48850	39913	27943	19395	16923	17713	21851	29015	33019	23240	18868
Z(S5%, D10%)	4261510											
C1_5%	436206	787389	703744	486864	488711	504217	533154	431778	583904	785296	502786	428468
C2	337413	642795	526270	531584	446108	382970	381466	380407	446153	508163	447097	362714
C3_15%	40153	48850	35848	23981	16312	14151	15032	19431	25242	28632	20278	16535
Z(S5%,D15%)	4250340											
C1_5%	436206	787389	703744	486864	488711	504217	533154	431778	583904	785296	502786	428468
C2	337413	642795	525985	531318	445715	382578	381032	379960	445834	508841	447936	363780
C3_20%	40153	48850	31781.9	20019.2	13229.5	11379.3	12351.4	17010.8	21469.5	23293.6	16138.8	12705.6
Z(S5%, D20%)	4239540											
C1_10%	233500	801776	712231	492945	497248	454712	514623	382886	537290	723699	465889	398306
C2	316994	645184	528493	534321	449595	389547	380555	368715	440155	503179	439819	354685
C3_5%	40152.7	48850.1	43614.2	31295.4	21575.7	18796.9	19397.1	23246.2	32057.1	36777.4	25424.3	20214.2
Z(S10%, D5%)	4113450											
C1_10%	233500	801776	712231	492945	497248	454712	514623	382886	537290	723699	465889	398306
C2	316994	645184	527271	532916	447515	387475	378254	366349	438468	502681	439203	353902
C3_20%	40152.7	48850.1	31781.9	20019.2	13229.5	11379.3	12351.4	17010.8	21469.5	23293.6	16138.8	12705.6
Z(S10%, D20%)	4079530											
C1_15%	234085	732952	681014	469268	467060	415892	464046	359535	490563	661969	429117	368144
C2	316994	634265	523816	528772	443580	383758	375483	362244	432770	497006	431116	344808
C3_5%	40152.7	48850.1	43614.2	31295.4	21575.7	18796.9	19397.1	23246.2	32057.1	36777.4	25424.3	20214.2
Z(S15%, D5%)	3950360											
C1_20%	234508	683197	644104	441341	423099	378937	422360	331321	443687	600064	392508	337981
C2	316994	626379	518284	522192	436589	376106	368280	354413	425362	490815	422451	334932
C3_5%	40152.7	48850.1	43614.2	31295.4	21575.7	18796.9	19397.1	23246.2	32057.1	36777.4	25424.3	20214.2
Z(20%, D5%)	3785470											

C1_20%	234508	683197	644104	441341	423099	378937	422360	331321	443687	600064	392508	337981
C2	316994	626379	517633	521318	435294	374816	366848	352941	424313	489914	421335	333515
C3_10%	40152.7	48850.1	39913.3	27943	19395	16923	17713	21851	29015	33019	23240	18868
Z(20%, D10%)	3773520											
C1_20%	234508	683197	644104	441341	423099	378937	422360	331321	443687	600064	392508	337981
C2	316994	626379	517347	521053	434902	374425	366414	352494	423994	489640	420997	333085
C3_15%	40152.7	48850	35848	23981	16312	14151	15032	19431	25242	28632	20278	16535
Z(S20%, D15%)	3762350											
C1_15%	234508	732952	681014	469268	467060	415892	464046	359535	490563	661969	429117	368144
C2	316994	634265	523165	527898	442286	415892	374052	360772	431721	496104	430000	343391
C3_10%	40152.7	48850.1	39913.3	27943	19395	16923	17713	21851	29015	33019	23240	18868
Z(S15%, D10%)	3938400											
C1_15%	234508	732952	681014	469268	467060	415892	464046	359535	490563	661969	429117	368144
C2	316994	634265	522594	527367	441500	381686	373183	359878	431084	496508	430500	344026
C3_20%	40152.7	48850	31781.9	20019.2	13229.5	11379.3	12351.4	17010.8	21469.5	23293.6	16138.8	12705.6
Z(S15%, D20%)	3916440											
C1_5%	436206	787389	703744	486864	488711	504217	533154	431778	583904	785296	502786	428468
C2	337413	642795	527207	532723	447795	384650	383332	382326	447521	509339	448552	364562
C3_5%	40152.7	48850.1	43614.2	31295.4	21575.7	18796.9	19397.1	23246.2	32057.1	36777.4	25424.3	20214.2
Z(S5%, D5%)	4273460											
C1_10%	233500	801776	712231	492945	497248	454712	514623	382886	537290	723699	465889	398306
C2	316994	645184	527842	533447	448301	388258	379123	367242	439105	502277	438703	353267
C3_10%	40152.7	39913.3	27943	19395	16923	17713	21851	29015	33019	23240	18868	
Z(S10%, D10%)	4101490											
C1_15%	234508	732952	681014	469268	467060	415892	464046	359535	490563	661969	429117	368144
C2	316994	634265	522879	527632	441893	382077	373617	360325	431402	495831	429661	342961
C3_15%	40152.7	48850	35848	23981	16312	14151	15032	19431	25242	28632	20278	16535
Z(S15%, D15%)	3927240											
C1_20%	234508	683197	644104	441341	423099	378937	422360	331321	443687	600064	392508	337981
C2	316994	626379	517062	520787	434509	374033	365979	352047	423676	490318	421835	334150
C3_20%	40152.7	48850	31781.9	20019.2	13229.5	11379.3	12351.4	17010.8	21469.5	23293.6	16138.8	12705.6
Z(S20%, D20%)	3751550											

Appendix J - Data of the Blockchain Adopted E-commerce Supply Chain Model

Parameter	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
$UC_{i,1}$	240	250	260	280	280	260	260	280	250	240	280	260
$UC_{i,2}$	301	208	170	246	215	197	236	268	209	341	308	181
$UC_{i,3}$	317	263	283	272	236	279	252	300	324	277	259	250
$HC_{i,1}$	5.98	5.87	6.04	5.58	2.92	4.37	4.68	4.52	5.46	5.91	5.91	4.82
$HC_{i,2}$	4.50	5.99	4.98	5.22	3.58	6.54	8.67	7.56	4.33	4.33	6.00	2.55
$HC_{i,3}$	1.82	3.27	3.45	1.70	4.03	2.15	5.01	3.14	4.03	5.60	3.45	3.72
$DC_{i,1}$	14.40	13.62	14.13	13.91	15.52	12.52	12.95	13.49	15.02	13.56	14.42	14.16
$DC_{i,2}$	16.65	13.42	12.79	9.79	12.01	16.01	15.23	11.16	13.36	16.15	14.27	14.75
D_i	63951	59898	51013	72845	96533	75721	75296	51087	36211	60197	53784	83520
$Q_i^{\min}$	20000	20000	25000	30000	40000	25000	35000	25000	30000	20000	25000	20000
$B_i^{\min}$	25000	25000	25000	35000	40000	35000	35000	30000	35000	25000	30000	25000
$VC_{i,1}$	747575	54947	53913	53015	52235	51713	51195	50683	50176	49674	49178	48686
$VC_{i,2}$	43788	27474	26956	26508	26118	25856	25598	25342	25088	24837	24589	24343
$VC_{i,3}$	43788	27474	26956	26508	26118	25856	25598	25342	25088	24837	24589	24343
$TC_{i,1}$	0.600	0.594	0.588	0.582	0.576	0.570	0.565	0.559	0.553	0.548	0.542	0.537
$TC_{i,2}$	0.858	0.848	0.840	0.832	0.823	0.815	0.807	0.799	0.791	0.783	0.775	0.767
$TC_{i,3}$	0.600	0.594	0.588	0.582	0.576	0.570	0.565	0.559	0.553	0.548	0.542	0.537
$OC_{i,1}$	85	100	105	110	110	95	95	110	90	85	110	95
$OC_{i,2}$	100	75	80	55	60	60	85	100	90	110	80	90
$OC_{i,3}$	110	90	80	75	50	80	70	115	125	70	70	60
$SC_{i,1}$	17	15	15	16	18	14	14	15	18	15	17	17
$SC_{i,m}$	18	16	14	11	14	18	16	16	14	14	18	15
Other Parameters												
II_n	1	25000			2	27000			3	22500		
W_n^{cap}	1	60000			2	90000			3	85000		
M_n^{cap}	1	100000			2	150000			3	135000		
V_m^{cap}	1	80000					2	120000				
W_j	1	0.3		2	0.4			3	0.3			
BC_{cap}	365000											

Appendix K - Data of the Traditional E-commerce Supply Chain Model

Parameter	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
$\overline{UC_{i,1}}$	240	250	260	280	280	260	260	280	250	240	280	260
$\overline{UC_{i,2}}$	301	208	170	246	215	197	236	268	209	341	308	181
$\overline{UC_{i,3}}$	317	263	283	272	236	279	252	300	324	277	259	250
$\underline{UC_{i,1}}$	200	190	200	190	200	200	200	180	190	200	190	190
$\underline{UC_{i,2}}$	189	229	159	195	194	190	202	209	186	186	152	179
$\underline{UC_{i,3}}$	180	165	147	145	189	183	186	181	158	158	170	178
$\overline{HC_{i,1}}$	5.98	5.87	6.04	5.58	2.92	4.37	4.68	4.52	5.46	5.91	5.91	4.82
$\overline{HC_{i,2}}$	4.50	5.99	4.98	5.22	3.58	6.54	8.67	7.56	4.33	4.33	6.00	2.55
$\overline{HC_{i,3}}$	1.82	3.27	3.45	1.70	4.03	2.15	5.01	3.14	4.03	5.60	3.45	3.72
$\underline{HC_{i,1}}$	3.63	3.14	3.86	3.92	3.84	4.11	3.61	4.04	4.10	3.99	3.52	3.65
$\underline{HC_{i,2}}$	3.27	4.34	3.71	4.54	3.48	4.31	3.85	2.99	3.59	4.07	3.74	3.93
$\underline{HC_{i,3}}$	0.23	0.24	0.40	0.75	1.23	0.64	1.07	0.62	2.49	1.56	0.96	0.49
$\overline{DC_{i,1}}$	14.40	13.62	14.13	13.91	15.52	12.52	12.95	13.49	15.02	13.56	14.42	14.16
$\overline{DC_{i,2}}$	16.65	13.42	12.79	9.79	12.01	16.01	15.23	11.16	13.36	16.15	14.27	14.75
$\underline{DC_{i,1}}$	10.82	11.54	11.47	11.08	11.05	12.01	11.92	9.61	9.58	10.09	12.03	11.44
$\underline{DC_{i,2}}$	10.76	11.86	10.11	11.77	11.91	10.94	13.41	7.78	8.07	9.09	12.14	12.84
EC_i	5.80	5.15	5.03	11.09	7.29	8.96	7.42	8.42	8.63	8.13	8.03	9.23
$C_{i,1}^{ERP}$	383080	383080	395754	395754	408935	408935	422643	422643	436900	436900	451726	451726
$C_{i,2}^{ERP}$	302280	302280	314371	314371	326946	326946	340023	340023	353624	353624	367769	367769
$C_{i,3}^{ERP}$	302280	302280	314371	314371	326946	326946	340023	340023	353624	353624	367769	367769
$\overline{OC_{i,1}}$	85	100	105	110	110	95	95	110	90	85	110	95
$\overline{OC_{i,2}}$	100	75	80	55	60	60	85	100	90	110	80	90
$\overline{OC_{i,3}}$	110	90	80	75	50	80	70	115	125	70	70	60
$\underline{OC_{i,1}}$	62	68	61	60	63	73	64	62	63	73	73	69
$\underline{OC_{i,2}}$	64	63	63	70	66	71	72	65	69	70	67	72
$\underline{OC_{i,3}}$	60	55	50	50	60	60	61	61	59	59	55	55
$\overline{SC_{i,1}}$	17	15	15	16	18	14	14	15	18	15	17	17
$\overline{SC_{i,2}}$	18	16	14	11	14	18	16	16	14	14	18	15
$\underline{SC_{i,1}}$	10	9	10	10	10	8	9	7	10	10	10	5
$\underline{SC_{i,2}}$	5	7	6	5	6	5	6	6	6	7	5	5

Other Additional Parameters	
II^E	30000
BF_j	2.5%
S^{cap}	100000
α	0.5
β	0.5

Appendix L - Optimal Solution of the Blockchain Adopted Model

Variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
$q_{i,1}$	11951	0	0	0	0	0	0	0	0	60198	0	0
$q_{i,2}$	13701	59898	120237	3622	56533	106778	16379	3652	89995	0	0	83250
$q_{i,3}$	0	0	0	0	17500	0	75296	0	0	0	0	0
$X_{i,1}$	1	0	0	0	0	0	0	0	0	1	0	0
$a_{i,1}$	36951	0	0	0	0	0	0	0	0	60198	0	0
$X_{i,2}$	1	1	1	1	1	1	0	1	1	0	1	1
$a_{i,2}$	27000	59898	51013	72845	56533	75722	0	51087	36211	0	53784	83250
$X_{i,3}$	0	0	0	0	1	0	1	0	0	0	0	0
$a_{i,3}$	0	0	0	0	40000	0	75296	0	0	0	0	0
$s_{i,1}$	0	0	0	0	0	0	0	0	0	0	0	0
$s_{i,2}$	0	0	69223	0	0	31057	47436	0	53784	53784	0	0
$s_{i,3}$	22500	0	22500	22500	0	0	0	0	0	0	0	0
$Y_{i,1}$	1	0	0	0	0	1	1	0	0	1	0	1
$b_{i,1}$	63951	0	0	0	0	75722	75296	0	0	60198	0	58250
$Y_{i,2}$	0	1	1	1	1	0	0	1	1	0	1	1
$b_{i,2}$	0	58898	51013	72845	96533	0	0	51087	36211	0	53784	25000
$\pi_{i,1}$	6,432,090	25,350,700	42,001,400	2,479,260	32,905,500	42,696,200	46,988,700	2,503,440	38,252,900	29,787,200	507,466	30,449,200
$\pi_{i,2}$	19,627,800	12,216,700	10,796,200	10,992,500	15,504,300	12,841,400	14,271,100	13,134,400	8,440,130	13,433,600	11,809,800	19,362,700
$\pi_{i,3}$	3,102,970	2,695,460	2,186,010	2,402,980	3,779,220	3,106,570	3,184,540	1,926,410	1,640,440	2,675,540	2,540,620	3,955,510

Appendix M – Optimal Solution of the Traditional E-commerce Model in Chapter 6

Variable	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
$q_{i,1}$	19451	0	0	0	0	0	0	0	0	0	0	0
$q_{i,2}$	0	0	141013	0	79378	150000	1018	0	96409	0	0	37304
$q_{i,3}$	0	59898	0	51807	0	0	0	0	0	0	0	0
$X_{i,1}$	1	0	0	0	0	0	0	0	0	0	0	0
$a_{i,1}$	44451	0	0	0	0	0	0	0	0	0	0	0
$X_{i,2}$	1	0	1	1	1	1	1	0	1	1	0	1
$a_{i,2}$	27000	0	51013	72845	96533	75722	75296	0	36211	60198	0	37304
$X_{i,3}$	1	0	0	0	0	0	0	1	0	0	0	0
$a_{i,3}$	22500	59898	0	0	0	0	0	51087	0	0	0	0
$s_{i,1}$	0	0	0	0	0	0	0	0	0	0	0	0
$s_{i,2}$	0	0	90000	17155	0	74278	0	0	60198	0	0	0
$s_{i,3}$	0	0	51087	51087	51087	51087	0	0	0	0	0	0
$Y_{i,1}$	0	0	0	0	0	1	1	1	0	0	0	0
$b_{i,1}$	0	0	0	0	0	75722	75296	51087	0	0	0	0
$Y_{i,2}$	1	1	1	1	1	0	0	0	1	1	1	1
$b_{i,2}$	63951	59898	51013	72845	96533	0	0	0	36211	60198	53784	83520
$\pi_{i,1}$	10,620,000	27,450,000	49,061,700	23,921,500	34,891,100	61,031,400	3,416,960	2,136,190	40,679,900	2,374,580	2,206,620	15,636,200
$\pi_{i,2}$	50,880,000	32,106,000	26,898,000	35,526,400	45,891,200	39,087,800	39,697,500	31,126,900	22,144,600	33,380,100	7,203,630	27,679,100
$\pi_{i,3}$	4,443,010	4,085,010	3,638,540	4,679,110	5,425,290	4,747,860	4,849,080	3,491,540	3,285,750	4,400,830	4,337,280	5,663,100

Appendix N – Results of the Sensitivity Analysis between Asymmetric Information Probabilities and Overall Supply Chain Cost in Traditional E-commerce Supply Chain

θ	γ	$\pi_{i,1}$	$\pi_{i,2}$	$\pi_{i,3}$	V^{tra}
0.1	0.1	241830000	340432000	50599100	223901633
0.1	0.2	241830000	342784000	51323800	225059811
0.1	0.3	241830000	345136000	52048400	226217988
0.1	0.4	241830000	347561000	52463500	227312334
0.1	0.5	241830000	349583000	53046400	228295943
0.1	0.6	241830000	351605000	53629300	229279553
0.1	0.7	241830000	353765000	53921500	230231480
0.1	0.8	241830000	355614000	54469400	231135300
0.2	0.1	252893000	351063000	50599100	231472745
0.1	0.9	241830000	357618000	54634500	231986641
0.2	0.2	252893000	353414000	51323800	232630922
0.2	0.3	252893000	355766000	52048400	233789100
0.2	0.4	252893000	358191000	52463500	234883445
0.2	0.5	252893000	360213000	53046400	235867055
0.2	0.6	252893000	362235000	53629300	236850665
0.2	0.7	252893000	364395000	53921500	237802592
0.3	0.1	262705000	361098000	50599100	238430466
0.2	0.8	252893000	366244000	54469400	238706412
0.2	0.9	252893000	368249000	54634500	239557753
0.3	0.2	262705000	363450000	51323800	239588644
0.3	0.3	262705000	365802000	52048400	240746821
0.3	0.4	262705000	368226000	52463500	241841167
0.3	0.5	262705000	370248000	53046400	242824776
0.3	0.6	262705000	372270000	53629300	243808386
0.4	0.1	268968000	372208000	50599100	244753239
0.3	0.7	262705000	374431000	53921500	244760314
0.3	0.8	262705000	376279000	54469400	245664133
0.4	0.2	268968000	374560000	51323800	245911416
0.3	0.9	262705000	378284000	54634500	246515474
0.4	0.3	268968000	376912000	52048400	247069593
0.4	0.4	268968000	379336000	52463500	248163939
0.4	0.5	268968000	381358000	53046400	249147549
0.4	0.6	268968000	383380000	53629300	250131158
0.5	0.1	273426000	382471000	50599100	250195862
0.4	0.7	268968000	385541000	53921500	251083086
0.5	0.2	273426000	384823000	51323800	251354040
0.4	0.8	268968000	387389000	54469400	251986905
0.5	0.3	273426000	387175000	52048400	252512217
0.4	0.9	268968000	389394000	54634500	252838247
0.5	0.4	273426000	389599000	52463500	253606563

0.5	0.5	273426000	391621000	53046400	254590172
0.6	0.1	276060000	392692000	50599100	255074448
0.5	0.6	273426000	393643000	53629300	255573782
0.6	0.2	276060000	395044000	51323800	256232626
0.5	0.7	273426000	395804000	53921500	256525709
0.6	0.3	276060000	397396000	52048400	257390803
0.5	0.8	273426000	397652000	54469400	257429529
0.5	0.9	273426000	399657000	54634500	258280870
0.6	0.4	276060000	399820000	52463500	258485148
0.6	0.5	276060000	401842000	53046400	259468758
0.7	0.1	278294000	402646000	50599100	259726254
0.6	0.6	276060000	403864000	53629300	260452368
0.7	0.2	278294000	404998000	51323800	260884432
0.6	0.7	276060000	406025000	53921500	261404295
0.7	0.3	278294000	407350000	52048400	262042609
0.6	0.8	276060000	407873000	54469400	262308115
0.7	0.4	278294000	409775000	52463500	263136955
0.6	0.9	276060000	409878000	54634500	263159456
0.8	0.1	276672000	414706000	50599100	264063905
0.7	0.5	278294000	411796000	53046400	264120564
0.7	0.6	278294000	413818000	53629300	265104174
0.8	0.2	276672000	417058000	51323800	265222083
0.7	0.7	278294000	415979000	53921500	266056102
0.8	0.3	276672000	419410000	52048400	266380261
0.7	0.8	278294000	417828000	54469400	266959921
0.8	0.4	276672000	421835000	52463500	267474606
0.7	0.9	278294000	419832000	54634500	267811262
0.9	0.1	278300000	423693000	50599100	268147118
0.8	0.5	276672000	423857000	53046400	268458215
0.9	0.2	278300000	426045000	51323800	269305296
0.8	0.6	276672000	425878000	53629300	269441825
0.8	0.7	276672000	428039000	53921500	270393753
0.9	0.3	278300000	428397000	52048400	270463473
0.8	0.8	276672000	429888000	54469400	271297572
0.9	0.4	278300000	430822000	52463500	271557818
0.8	0.9	276672000	431892000	54634500	272148913
0.9	0.5	278300000	432844000	53046400	272541428
0.9	0.6	278300000	434865000	53629300	273525038
0.9	0.7	278300000	437026000	53921500	274476965
0.9	0.8	278300000	438875000	54469400	275380785
0.9	0.9	278300000	440879000	54634500	276232126

Appendix O – Additional Data for Public Blockchain Analysis

Parameter	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
$VC_{i,2}$	54505	3453	3311	3194	3083	3052	3022	2992	2962	2932	2903	2874
$VC_{i,1}$	2252	1726	1655	1597	1541	1526	1511	1496	1481	1466	1451	1437
$VC_{i,3}$	2252	1726	1655	1597	1541	1526	1511	1496	1481	1466	1451	1437
Ether price	3.394	1.701	4.129	4.697	1.773	3.523	4.843	2.620	0.968	3.480	4.664	2.638
$TC_{i,2}$	3.455	1.761	4.189	4.757	1.831	3.581	4.900	2.677	1.024	3.536	4.719	2.692
$TC_{i,1}$	3.436	1.743	4.171	4.739	1.814	3.564	4.883	2.660	1.007	3.519	4.703	2.676
$TC_{i,3}$	3.436	1.743	4.171	4.739	1.814	3.564	4.883	2.660	1.007	3.519	4.703	2.676
BC_{cap}	365000											