MASTER

A blockchain-based supply chain contract
an analysis to the development of a supply chain contract on a blockchain

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A blockchain-based supply chain contract

An analysis to the development of
a supply chain contract on a blockchain

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Abstract

In this master thesis, it is investigated if a blockchain-based supply chain contract is able to coordinate a two-level supply chain with risk-averse members. Although supply chain contracts are widely acknowledged as a useful tool to improve the performance of a supply chain, the contracts are not prevalent in each industry. This thesis investigated two of the underlying reasons. First, the assumption that members are risk-neutral is relaxed by incorporating an adjusted Capital Asset Pricing Model (CAPM) to model risk. This thesis shows that the buyback contract and revenue-sharing contract are able to coordinate a supply chain with risk-averse members. Second, blockchain is investigated as a tool to decrease the administrative costs that are associated with supply chain contracts. The potential value that a blockchain-based system gives to decrease the administration cost is investigated based on a (fictive) use case. According to a numerical example, it is shown that implementing a blockchain-based supply chain contract is able to coordinate a supply chain and improves supply chain performance.
Preface

This report is the result of my master thesis project that has been executed in close collaboration with Atos. Furthermore, this project is the final step in achieving what I have been working for the last five years as a student: A Master of Science in Operations, Management, and Logistics. I would like to take this opportunity to thank the people that supported me during this wonderful and informative time.

First, I want to thank my mentor Boray Huang. About two years ago we had our first meeting when I just started my masters program. Each meeting that followed, you gave me the feedback required to take the next step, even though you had to finish your own research. Without your thoughtful and educational feedback, I could not have done this. Therefore, I would like to thank you Boray. Second, I would like to thank my second supervisor Rob Broekmeulen. Rob, I am grateful that our paths crossed once again during my master thesis project. Based on your supervision during my bachelor project, I knew that your supervision, support, and guidance would positively contribute to my master thesis project. Thank you!

Furthermore, I want to thank Raacha Naoum and Hans Kwaspen for giving me the opportunity to execute my research within Atos. Raacha and Hans, you gave me the opportunity and freedom to design my research project within my interests. During the research, several (practical) struggles had to be overcome. I am grateful that both of you put a lot of effort and time in helping me to overcome these struggles. Furthermore, the meetings we have got were always fun and gave me a positive feeling. In addition, I want to thank my fellow interns at Atos. You created such a great atmosphere that I preferred working on my master thesis at Atos instead of at home or at the university, even during the summer holidays. However, I must apologize to you all for giving you the feeling that you had to be present as much as I did, sorry!

Finally, I would like to thank my friends, my parents, and my girlfriend. You guys are one of the most important people in my life. I would like to thank you all. Not only for the relaxing moments during my master thesis project but for all the wonderful experiences and moments that I experienced with each one of you. Hope that our friendships will last for life. Pap and Mam, you guided and supported me in all choices during my school life. From helping to choose which program to follow, to supporting me to move to Helsinki for a semester. Thank you for all help, support, and love. Last, I want to thank my girlfriend. Romy, thank you for being there at the times I needed you the most. You made it possible for me to keep on going even when things were not going as smoothly as I would like them to be.

Kevin Korsten
Executive summary

The last decade, competition is more focused on the performance of a supply chain versus supply chain based environment than on a company versus company based environment (Şahin & Topal, 2018). A supply chain consists of several parties. In practice there is usually no central authority that makes decisions for the whole supply chain. Instead, each member makes decisions that are aimed at maximizing one’s own profit. However, the decision made by one party influences the outcomes of other supply chain partners as well. This way, the local rational behavior of one firm can be inefficient for the supply chain. This phenomenon of local rational behavior that leads to an inefficient supply chain is called double marginalization (Cachon, 2003). One way to address the problem of double marginalization is to align the objectives of each member with the supply chain’s objectives.

Supply chain contracts are one of the different applications to align the objectives of each member with the supply chain’s objectives. According to Cachon (2003), a contract coordinates the supply chain if the set of supply chain optimal actions is a Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions. Cachon (2003) described several contracts that are able to coordinate the supply chain. In general, each contract introduces a set of transfer payments that can result in supply chain coordination. Although most research showed that implementing a supply chain contract results in a win-win situation for members of the supply chain, these contracts are not prevalent in industry. The literature review prior to this master thesis project identified two issues that at least partly explain why these contracts are not prevalent in industry. First, in practice companies are considering risk when they make decisions. However, literature that incorporates risk considerations in their models is limited. Second, the implementation of a supply chain contract can result in additional administrative costs. These additional costs might exceed the benefits of implementing the contract. As a result, the supply chain contract will not be implemented.

To address the issues described, this master thesis investigated the possibility of coordinating a supply chain with risk-averse members by means of a blockchain-based supply chain contract. Therefore, this master thesis focused on two directions. First, a supply chain model that relaxes the assumption of risk-neutral supply chain members has to be developed. The publication of Cachon (2003) presented a standard regarding the coordination of a two-level newsvendor model with risk-neutral members. Therefore, the models described in Cachon (2003) are used as the starting point. These models are adjusted such that the assumption of risk-neutral supply chain members can be relaxed. Second, in this digitizing world, it is hard to imagine that companies cooperate without any form of a shared platform. As a result, research on new technologies is executed. Currently, a lot of research is done on the possible applications of blockchain technology. In short, blockchain is a technology for securely sharing information with regard to transactions between a network of participants. The value blockchain achieves for contract processes in a supply chain is being investigated. Last, the results of both directions are combined to conclude on the possibility of coordinating a supply chain with risk-averse members by means of a blockchain-based supply chain contract.

The supply chain contract models discussed in Cachon (2003) are operational models and the models consider risk-neutral members. As a result, the financial considerations of the decision-
maker are neglected. However, in reality, decision-makers are considering risk in their decision process. In addition, operational decisions are influencing financial considerations, and vice versa (Birge, 2014). Therefore, the interaction of the operational decisions and financial decisions should be taken into account when relaxing the assumption of risk-neutrality in supply chain contract models. Some papers acknowledged the need for relaxing the assumption of risk-neutral supply chain members (Chiu, Choi & Li, 2011; Gan, Sethi & Yan, 2004; Tsay, 2002). However, to the best of my knowledge, none of the papers incorporated the interaction between operations and finance. As a result, more research to supply chain coordination in a supply chain with risk-averse members is required.

This master thesis used the well-known Capital Asset Pricing Model (CAPM) introduced by Birge (2014) in combination with the results achieved by Anvari (1987). This CAPM only measures systematic risk. Systematic risk is not diversifiable by investors, which makes it the relevant risk for the supply chain contract situation. Birge says that uncertain cash flows should be discounted with the risk-free interest rate \( r_f \) and a risk premium. The risk premium is the product of the covariance between a random future cash flow \( \tilde{f} \) and a market portfolio’s return \( \tilde{r}_m \) and the market risk premium \( \lambda_m \). The market risk premium is determined by \( \lambda_m = \frac{r_m - r_f}{\sigma_m^2} \).

The present value \( s \) of the uncertain cash flow can thus be described as

\[
s = \frac{1}{1 + r_f} (\bar{f} - \lambda_m \text{Cov}(\tilde{f}, \tilde{r}_m))
\]  

(1)

However, the interaction between operations and finance is not considered yet. To incorporate this interaction, the results of Anvari (1987) are used. By assuming that the joint distribution of demand \( D \) and the market return \( r_m \) are jointly normal, Anvari showed that the covariance between an uncertain cash flow and the market return can be determined as follows:

\[
\text{Cov}(\tilde{f}, r_m) = \tilde{m} \text{Cov}(D, r_m) F(q)
\]  

(2)

In which \( \tilde{m} \) is determined by the parameters of the supply chain contract model used, the covariance between demand and market return by \( \text{Cov}(D, r_m) = \rho \sigma_D \sigma_{r_m} \), and \( F(q) \) by the cumulative distribution function given the order quantity. Thus, by incorporating the equation to determine the covariance between the uncertain cash flow and the market return, the interaction between operations and finance is guaranteed. In addition, it is now possible to determine the present value of uncertain (future) cash flows.

The discounting formula presented above is used to relax the assumption of risk-neutral supply chain members. The formula is applied to the models described in Cachon (2003). However, in these models, not all cash flows are uncertain. In addition, some cash flows do not have to be discounted as they do not happen in the future. Therefore, for each cash flow it is individually determined how to discount it. Although Cachon (2003) presented more contracts, this master thesis investigated the possibility of coordination for the wholesale-price contract, the buyback contract, and the revenue-sharing contract only (due to time constraints). The analysis showed the following results:

- The wholesale-price contract is not able to coordinate a supply chain with risk-averse members.
- The buyback contract is able to coordinate a supply chain with risk-averse members.
- The revenue-sharing contract is able to coordinate a supply chain with risk-averse members.
- The optimal order quantity is lower in a risk-averse environment than in a risk-neutral environment.
At this point, it is shown that there are supply chain contracts that can coordinate a supply chain with risk-averse members. However, implementing these contracts often lead to additional administration costs. To address this issue, it is investigated if a blockchain-based system could be used to reduce the administration costs associated with a supply chain contract. To do so, a practical use case is constructed inspired by a real-life practical use case.

A retailer (Company A) is having issues with regard to its contractual processes with its suppliers (Company B). To make sure that products flow from the supplier to the customer, a process needs to be executed (see figure 1 for the steps). Company A states that this process is exposed to several issues. This master thesis investigated two of these issues: (1) the process is manually intensive and (2) price-differences occur. First, the process consists of several steps that require the interaction between Company A and Company B. However, the systems of both companies are not connected to each other. This results in process steps that could be executed automatically but are executed manually. Second, the execution of the contract process for promotional activities is not done well-ordered. As a result, Company A and Company B have different understandings of the agreements that are made. These misunderstandings are called price-differences and result in a dispute when invoices have to be fulfilled.

To solve these issues a solution that makes use of a blockchain-based system is designed, see figure 1. The steps that have to be executed remained the same but several steps (represented in yellow) have to be executed differently by introducing the 'blockchain solution'. First, the ‘blockchain solution’ introduces a tamper-proof shared database on which the contract agreements are only stored when both companies agree on them. In addition, the contract parameters must be stored by means of a standardized format. As a result, part of the causes that result in price-differences are addressed. Thus, fewer price-differences will occur. Second, a blockchain-based smart contract is developed that interacts with the systems of both companies and the shared database. This way, the steps deployment, order execution, sending invoice, and fulfilment can (partly) be executed automatically. As a result, human interaction is decreased for the contract process.

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Figure 1: Blockchain-based contract process

The analysis showed that the implementation of the ‘blockchain solution’ results in several benefits, challenges, and limitations. The benefits can shortly be described by (1) a reduced processing time, (2) a reduced number of price-differences, (3) improved visibility, and (4) providing a secure digital information system. The challenges are (1) scalability and (2) immaturity. Last, the limitations can be described by the (1) development costs and (2) suitability.

At last, this master thesis combined the two directions to answer the main research question: Is it possible to coordinate a supply chain with risk-averse members by means of a blockchain-based supply chain contract? To execute the contract process for supply chain contracts, additional process steps have to be executed. These steps arise with the introduction of additional payments that happen after demand is faced. However, it is shown that all of these steps can be automated by using the blockchain-based system. As a result, the increasing administration cost associated with a supply chain contract can be reduced at the cost of additional development costs. When the additional benefits of coordination exceed the additional development costs and
associated administration costs, it is beneficial to use a supply chain contract instead of a regular contract. However, this is not the only condition that should be met to achieve coordination. For each different supply chain contract multiple conditions should be met. The analysis showed that it is possible to meet the conditions related to each individual contract and related to the blockchain-based system. Thus, this master thesis showed that it is possible to coordinate a supply chain with risk-averse members by means of a blockchain-based supply chain contract.
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Chapter 1

Introduction

The last decade, competition is changing from a company versus company based environment to a supply chain versus a supply chain based environment (Şahin & Topal, 2018). A supply chain consists of several parties (suppliers, manufacturers, retailers, customers, etc.) that are dependent on each other. Units are transformed from raw material to an end-product which is delivered to the customers. This process is executed by the several parties of the supply chain. One party’s decision influences the outcomes of the other supply chain partners as well. Unfortunately, those actions are not always in the best interest of the supply chain. Each member is primarily concerned with their own objectives. Willing to maximize one’s own profit often results in poor performance. This phenomenon is called double marginalization and often leads to a (global) inefficient supply chain (Cachon, 2003). However, as the supply chain is becoming more important, companies acknowledge the need for cooperation. One way to improve the performance of the whole supply chain is to coordinate the actions of each individual company (Arshinder, Kanda & Deshmukh, 2011). Supply chain contracts are one of the different applications of supply chain coordination. The contract introduces a set of transfer payments that should result in each firm’s optimal decision is optimal for the supply chain as well. When the contract results in the alignment of each firm’s optimal decision with the supply chain’s optimal decision, it is called supply chain contract coordination. By achieving supply chain coordination, the problem of double marginalization is addressed.

Although most research shows that implementing a supply chain contract can result in a win-win situation, those contracts are not prevalent in each industry. The literature review previous to this master thesis showed two issues that at least partly explain why these supply chain contracts are not prevalent in each industry. First, in practice companies are considering risk when they make their decisions. However, literature with regard to risk-averse members of a supply chain is limited (Chiu et al., 2011; Tsay, 2002). Most research assumed that members of the supply chain are risk-neutral and maximize their expected profit. Researchers that did acknowledge the need for relaxing this assumption, developed reasonable models and methods. However, these methods could be improved to better represent the situation. Second, the implementation of a supply chain contract can result in additional administrative costs. For example, when a revenue-sharing contract is implemented, the supplier should validate the revenue that has been earned at the retailer. As a result, additional administration costs arise. These additional costs might exceed the benefits of the contract. As a result, companies may prefer a simple contract even if that contract does not optimize the supply chain’s performance (Cachon, 2003; Cachon & Lariviere, 2005).

In this digitizing world, it is hard to imagine that companies cooperate without any form of a shared platform. As a result, researchers and companies are investigating new technologies. Currently, a lot of research is done on the possible applications of blockchain technology. Blockchain is mostly known as the technology behind Bitcoin. In short, blockchain is a technology for securely sharing information with regard to transactions between a network of participants. Although a lot of research says that blockchain is beneficial for a lot of applications, only a num-
ber of applications moved into production (Pradhan, Klappich, Stevens, De Muynck & Johnson, 2018). Due to its main characteristics (distributed database, information immutability, information transparency, and security), it may serve as a tool to implement supply chain contracts. Furthermore, blockchain enables smart contracting (automatically executing contracts). When these contracts are used in practice it has the potential to make processes more effective and efficient (Casado-Vara, Prieto, De la Prieta & Corchado, 2018).

To fill the identified gaps above, this master thesis focused on the application of blockchain for supply chain contract coordination in a risk-averse environment. The focus has been executed in twofold: (1) relaxing the risk-neutral environment results in a better representation of a decision-maker considerations and (2) blockchain is investigated as an application to implement supply chain contracts. First, based on Cachon (2003), Birge (2014), and Anvari (1987) a supply chain model is developed to investigate if coordination is possible in a risk-averse environment. This model aims at improving the risk measurement method by using a different method for measuring risk and by incorporating the interaction between operations and finance. Second, one of the clients of Atos faces issues in their contract process with their suppliers. Based on this practical use-case, a fictive use case is developed in collaboration with employees of Atos. This fictive use case is used to investigate the value of implementing a blockchain-based system for supply chain contract coordination.

The rest of this master thesis is organized as follows. Chapter 2 offers a broad overview of background information related to this project. In chapter 3, the basic models with regard to supply chain contracts are explained in detail. Chapter 4 introduces the supply chain contract models with risk-averse supply chain members. To give practical insight into the differences between the risk-neutral and risk-averse situation, a numerical example is given in chapter 5. In chapter 6, blockchain is explained in more detail to provide readers with a proper understanding of blockchain. The information with regard to blockchain technology is needed for the analysis of the implementation of blockchain for contract processes. Which is discussed in chapter 7. In chapter 8, based on the knowledge gained during the master thesis the value of a blockchain-based supply chain contract is evaluated. In chapter 9, conclusions are drawn and a reflection on the research as a whole is given.
Chapter 2

Research information

This chapter aims at giving background information with regard to this master thesis. First, this master thesis is executed in close collaboration with Atos. Therefore, an introduction to Atos is given. Second, the theoretical background on the problem introduced in the introduction is provided. The theory with regard to supply chain contract coordination and blockchain is given. Third, the literature review prior to this master thesis identified some research gaps. Based on these gaps, the motivation for this research is explained. Fourth, to address the problems described in the introduction, research questions are developed which will be solved in this master thesis. Last, the methods that are used in executing this master thesis are explained.

2.1 Company introduction

This master thesis project is executed in collaboration with Atos, to be more specific, with Atos-BTN (Atos Benelux & the Nordics). Atos is an IT corporation with its headquarters based in Bezons (France), serving customers around the world (73 countries). Atos employs approximately 120,000 employees, which are located all over the world. Atos is established out of a merger between two French IT companies. Throughout time, Atos acquired multiple companies which resulted in the current state of Atos. Atos supports customers in all business sectors with their digital transformation. This is done with a focus on system development and consultancy. The main services of Atos are Big Data & Security, Business & Platform Solution, Digital payments and e-Transactions, Infrastructure & Data Management, and Unified Communication & Collaboration. With this expertise, Atos is able to support their clients to respond to the rapidly changing environment and to create new business opportunities.

Atos is divided into three main divisions: Infrastructure & Data Management, Business & Platform Solutions, and Big Data & Security. Besides, the Transactional services are provided by Worldline, which is a brand within Atos. In addition, there is a collaboration between the multiple divisions in order to deliver end-to-end solutions for their clients, with the Digital Transformation Factory. This Digital Transformation Factory focuses on the different challenges (business efficiency, business models, customer intimacy and trust) clients face in the digitizing environment.¹

Each of the mentioned divisions is subdivided into units. As Atos wanted to gain more knowledge about the application of blockchain in the domain of supply chain, this master thesis is executed in close collaboration with the Blockchain unit. Blockchain is a quite new technology and implementations are limited. Therefore, the Blockchain unit (part of the Business & Platform Solutions division) is trying to gain more knowledge and experience. This is done by doing research on the different applications and by solving practical use cases to gain experience. A client of Atos is facing contractual issues with its suppliers. To solve these issues, they are in collaboration with Atos looking for the possibilities that blockchain can bring for solving the problem.

¹https://atos.net/en/about-us
2.2 Theoretical background

2.2.1 Supply chain coordination with contracts

Literature that deals with supply chain contracts in a two-level risk-neutral environment is rich. Cachon (2003) developed a standard in the field of supply chain coordination. The paper investigated several types of contracts that are able to coordinate the supply chain in the basic situation. The basic situation consists of a two-level supply chain with a risk-neutral supplier and a risk-neutral retailer. In this situation, the retailer faces stochastic demand. Based on the basic contracts, other researchers extended the contracts with practical issues such as price-dependent demand, effort-dependent demand, multiple retailers, multiple suppliers, or a three-level supply chain. However, there is only limited research that investigates the possibility of coordinating a supply chain consisting of risk-averse members by means of a contract. Taking risk into consideration is important, as members considering risk make different behavioral actions (Tsay, 2002). The papers that do investigate supply chain contract coordination with risk-averse members are acceptable but can be improved. Therefore, more research to supply chain contract coordination with risk-averse members is needed. Below a summary of several papers that assume risk-averse members is demonstrated to give some background.

Tsay (2002) studied the two-level supply chain consisting of a supplier and a retailer, in which both parties are risk-averse. He studied different scenarios of relative strategic power and the influence of a return policy on these dynamics. It is assumed that the supplier first announces a return policy, after which the retailer chooses an order quantity without knowing the exact demand. Then, the retailer chooses a retail price after which demand is observed. Within the model, both the retailer and supplier maximize their own expected profit minus the product of a risk-aversion parameter $k$ and mean-standard deviation $StDev$ of the random financial outcome $Z$, thus $(E[Z] - kStDev[Z])$. The paper shows that relaxing the assumption of risk-neutrality lead to different insights. Tsay (2002) showed that the penalty for errors in estimating the sensitivity to risk can be substantial and that relaxing the risk-neutrality assumption can lead to different behaviors than predicted by risk-neutral models.

Gan et al. (2004) developed coordinating contracts for three specific cases: (1) a risk-neutral supplier and a retailer averse to downside risk, (2) the supplier and retailer are both risk-averse and maximize their own mean-variance trade-off, and (3) the supplier and retailer maximize their own expected concave utility. In the first case, the risk-averse retailer maximizes his expected profit under the constraint that the probability of his profit being less than his target profit level $\alpha$ does not exceed a given level $\beta$. In the second case, both members maximize their payoff function which is described as the expected profit according to an action pair $E\Pi(s, \Theta(s))$ minus the product of a risk aversion parameter $\lambda$ and the mean-variance trade-off $V(\Pi(s, \Theta(s)))$. In the third case, both members want to maximize their expected utility function. It is said that Pareto-optimal actions are needed in order to coordinate the supply chain. When risk-neutral members are assumed, it is easy to find these Pareto-optimal actions and to design the coordinating contract. However, it is much harder to design the coordinating contract when risk-averse members are assumed. The paper shows that (for each considered case) it is possible to obtain Pareto-optimal actions with risk-averse agents, but does not conclude if in all cases coordination is possible.

Choi (2008) studied several contracts (wholesale-price, buyback contract, and revenue-sharing contract) in a two-level supply chain with risk-averse members. The model has the following sequence: the manufacturer first defines the wholesale-price and other parameters, depending on the kind of contract. Then the retailer responds by placing an order at the supplier. Assumed is that the manufacturer is always able to meet the retailer’s order size. The return and risk are
characterized by the expected profit and standard deviation of profit, respectively. Within the model, the retailer is maximizing its expected profit such that its standard deviation of the profit $SP_R$ is smaller or equal to a pre-determined risk-aversion threshold level $k_R$. Thus, the retailer’s objective is described as $\max EP_R \text{ s.t. } SP_R \leq k_R$. It is concluded, that coordination is not always achievable in the mean-variance domain. It is an important finding since coordination is always achievable in the risk-neutral environment.

Chiu et al. (2011) investigated the possibility of coordinating supply chains with risk-sensitive agents with a target sales rebate contract. A mean-variance analysis to a supply chain with a risk-neutral supplier and a risk-averse retailer facing uncertain market demand is carried out. In this situation, the retailer sells a newsboy product and wants to minimize its variance level $V_{R,i}$ subject to his expected profit $E_{R,i}$ being above a certain target threshold $\kappa_R$. It results in the following objective $\min V_{R,i}(.) \text{ s.t. } E_{R,i}(.) \geq \kappa_r$. The study found that in order to coordinate the single supplier single retailer supply chain, the supplier requires a two-parameter target sales rebate contract. The two parameters are the target sales level $t$ and the risk-aversion indicator $\phi$. When these parameters are used, it is shown that there exist multiple target sales rebate contracts that are able to coordinate the supply chain with a risk-neutral supplier and a risk-averse retailer.

2.2.2 Blockchain

About a decade ago, Nakamoto et al. (2008) introduced Bitcoin as the first distributed peer-to-peer electronic payment system that can operate without the need for a trusted third party, like a bank. Although Bitcoin is often seen as the innovative technology, Bitcoin is just an application of the so-called blockchain technology. Blockchain is the technology behind Bitcoin and is widely seen as a major technology breakthrough. Currently, the hype might be over, but a lot of research is going on to the opportunities that can be achieved with blockchain technology. At this point, one might have issues understanding what blockchain exactly is, but these issues are addressed in chapter 6. For now, it is sufficient to know that blockchain is a technology for securely sharing information with regard to transactions between a network of participants. First, an introduction to current research to blockchain technology is given. As said, a lot of research is done to potential applications of blockchain technology. Most research focused on financial applications. However, research is done for other directions as well. The summary is not claimed to be exhaustive but will provide an overview of the directions of investigations so far.

Financial applications - The most well-known application of blockchain is, as said before, Bitcoin. However, research to blockchain for other financial applications is done as well. Research is, for example, done to explore the possibilities of using blockchain for financial assets (Fanning & Centers, 2016; Paech, 2017; Peters & Panayi, 2016), research is done to the impact of blockchain on accounting (Yu, Lin & Tang, 2018), on trade clearing systems (Tsai, Deng, Ding & Li, 2018), and on financial auditing (Dai & Vasarhelyi, 2017). However, there are much more directions of research to financial applications (Korsten, 2019).

Integrity applications - Blockchain is able to store information with regard to each step in the process of a supply chain. Transactions and information related to the whole lifecycle of a product or service can be stored in a blockchain integrity application. The field of integrity verification in relation to blockchain technology is emerging. Possible applications in this field are provenance and counterfeit (H. M. Kim & Laskowski, 2018), insurance (Gatteschi, Lambert, Demartini, Pranteda & Santamaria, 2018), and intellectual property management (Josep, El-Fakdi, Torres & Amengual, 2017).

Governance applications - At this moment, official records of enterprises and citizens are
stored and managed by different governments. Blockchain could offer accountability, automation, and safety for the management of these records. As a result, governments could make their services more efficient and eventually could obstruct corruption by implementing blockchains. The application of blockchain for government functions is another research direction. For example, research focused on a decentralized passport service (Sullivan & Burger, 2017), delegated democracy (Swan, 2015), and voting (Moura & Gomes, 2017).

Healthcare management applications - Research is done to improve services and processes within the healthcare industry by introducing blockchain. Most research is focused on the use of blockchain technology to solve problems of scientific credibility of findings. Examples of applications are using blockchain in online patient data sharing (Li et al., 2018), drug counterfeit (Sylim, Liu, Marcelo & Fontelo, 2018; Tseng, Liao, Chong & Liao, 2018), and clinical trials (Maslove, Klein, Brohman & Martin, 2018). Most research is done to Electronic Healthcare Records (EHRs), for EHRs blockchain has some benefits: blockchain distributes its data, all information is shared among each of the actors, and data is always available and updated (Casino, Dasaklis & Patsakis, 2019).

Supply Chain - Due to the fact that blockchain can be used as a platform for multiple parties within a network, it might be beneficial for supply chains. Blockchain enables transparency and accountability in supply chain networks. The potential of using blockchain can be found in three areas of the supply chain: visibility, optimization, and demand (Korsten, 2019). Although research to the implementation of blockchain for supply chain solutions is increasing, only a few examples are given to give an overview of the directions of research. Research is done to origin tracking (Casado-Vara et al., 2018), information security (Tse, Zhang, Yang, Cheng & Mu, 2017), sustainability (Kouhizadeh & Sarkis, 2018), and supply chain finance (Hofmann, Strewe & Bosia, 2017).

Although only five directions for the application of blockchain are explained, research is investigating blockchain for a lot of other applications as well. However, based on Korsten (2019) it is concluded that these are the most important ones. The literature review prior to this master thesis also showed that most of the research is limited to laboratory research or contains hypothetical settings. It is in accordance with (Pradhan et al., 2018), that states that less than 4 percent of the plan of concepts has moved into production. Thus, it can be concluded that research should investigate the value of blockchain by analyzing the implementation of blockchain in practical case studies.

2.3 Research motivation

The motivation of executing this research can be seen in a twofold: (1) the theoretical issue faced by supply chain contract coordination and (2) the practical issue faced by Atos. Both issues are further elaborated below.

First, research to supply chain contracts is mostly limited to assuming risk-neutral supply chains. However, in practice most members of the supply chain are risk-averse. The need to relax the assumption of risk-neutral supply chain members has among other been identified by Tsay (2002), Gan et al. (2004), Choi (2008), and Chiu et al. (2011). The approaches used in these papers are acceptable but could be improved to better represent a decision-maker its considerations. Furthermore, to the best of my knowledge, none of the papers considers the interaction between operations and finance. Operational decisions influence financial considerations, and vice versa (Birge, 2014). As a result, the interaction should be taken into account in supply chain contract models. Thus, the theoretical motivation for this research arose by improving the current ways of measuring risk in supply chain contract models.
Second, Atos is currently investigating the potential value that blockchain has for one of its clients. The client faces issues with their suppliers regarding contractual agreements during promotion weeks. The client approached Atos to develop a blockchain-based system that addresses these issues. It is said, that these issues occur at other clients of Atos as well. In addition, the client describes that their current process contains several non-value adding steps. These steps could be removed by the implementation of blockchain. Therefore, Atos is willing to gain more knowledge with regard to the potential value of blockchain for contractual processes in a supply chain. Thus, the practical motivation for this research arose by the lack of knowledge to the potential value of blockchain for contractual processes.

In summary, this master thesis was motivated by the lack of research to supply chain contract coordination with risk-averse members and the lack of knowledge to the potential value of blockchain for contractual processes in a supply chain.

### 2.4 Research questions and scope

The goal of this master thesis is to investigate the possibility of implementing a blockchain-based supply chain contract that is able to coordinate a supply chain with risk-averse members. This goal can be seen in a twofold: (1) one objective of this master thesis was to investigate the possibility of supply chain contracts to coordinate a risk-averse supply chain, and (2) the second objective aimed at investigating the potential value of blockchain for contracts in a supply chain. To reach this goal, it is needed to answer the main research question:

*Is it possible to coordinate a supply chain with risk-averse members by means of a blockchain-based supply chain contract?*

Answering the main research question has relevance in two aspects. First, it contributes to academic knowledge as it further investigated supply chain contracts in a supply chain with risk-averse members. Second, it contributes to practical knowledge as it investigated the value of blockchain for contracts in a supply chain which is relevant for Atos. In order to answer the main research question, four sub-questions have to be answered:

1. **Which conditions should be met in order to achieve coordination in a supply chain with risk-averse members?**

   First, it is needed to know which conditions should be met before coordination is achieved in a supply chain with risk-averse members. In order to answer this question, the conditions that should be met in a risk-neutral situation are investigated. After which literature is reviewed to determine which adjustments have to be made to achieve coordination in a risk-averse supply chain. Only the basic contracts as they are explained in Cachon (2003) are reviewed, as they received academic attention and support.

2. **Which basic type of supply chain contracts are able to coordinate the supply chain with risk-averse members?**

   In order to answer this research question, a supply chain model is developed. The basic models of Cachon (2003) are used and adjusted with the information gained by answering the first research question. A method for discounting uncertain cash flows is developed based on Birge (2014) and Anvari (1987). This discounting method is used to measure risk. This way, the model represents a supply chain with risk-averse members.

3. **What value can blockchain achieve for risk-averse members with regard to contract issues?**

   Blockchain has multiple characteristics that can create value in several different ways. However, this research focuses on the value that it can create for contracts in a supply chain. Atos is
currently busy with a pilot that investigates the potential value that blockchain has for contract management issues in the retail industry. Within the pilot, blockchain is used as the ‘single-source of truth’. This research went one step further and investigated the value that blockchain, in general, can have for contract situations in a supply chain.

4. **What value does a blockchain-based supply chain contract achieve?**

It is needed to get insight into the value that a blockchain-based supply chain contract can achieve for the members of a supply chain model. Therefore, in collaboration with a focus group, the situation in which a blockchain-based system is used for supply chain contract processes is designed. As Atos has employees working on different projects, they have a broader knowledge than the individual case only. This way, the situation can be generalized to gain broader insights. Furthermore, the process is analyzed to identify the value that blockchain achieved in this situation.

### 2.5 Research method

This master thesis is conducted by using multiple methods: (1) the problem-solving cycle of van Aken, Berends and van der Bij (2007), (2) the research method of Mitroff, Betz, Pondy and Sagasti (1974), (3) expert interviews, and (4) a case study. These methods set the framework for tackling the objectives of the report. The different aspects and perspectives of these methods were needed to do research with both rigor and relevance.

The **problem-solving cycle** (van Aken et al., 2007) consist of five sequential steps. These stages are fulfilled in order to conduct research in a structured manner. When all stages have been fulfilled, one should start again with a problem definition. This way, continuous improvement can be achieved. The **Problem Definition** phase is considered by conducting the literature review. The **Analysis & Diagnosis** phase is considered in the first research question. The **Solution Design** phase is considered by answering the second and third research question. The **Implementation** phase is considered by answering the fourth research question. Last, the **Evaluation** phase is considered by answering the main research question. After which research directions for further research are given.

![Figure 2.1: The problem-solving cycle of van Aken, Berends and van der Bij (2007)](image)

Besides the problem-solving cycle of van Aken et al. (2007), this study used the research model of Mitroff et al. (1974) to make this research both rigorous and relevant. The **research method** proposed by Mitroff et al. (1974) consists of four main steps. The first step of the research model...
Chapter 2  

A blockchain-based supply chain contract

is Conceptualization and in this master thesis, it is considered by the execution of the literature review. The Modeling step is considered by answering the first and third research questions. The Model Solving step is considered by the answer to the second research question. The fourth and main research question consider the Implementation step. The Feedback and Validation step activities are taken into account by executing the fictive use case analysis within a focus group.

A draft version is developed, which is discussed with the focus group to receive feedback and to validate it with regard to practice. This research model contributed most to the development of the supply chain models. During the development, the research model was used to make sure that the model is of relevance to Atos and for contributing to academic knowledge.

Figure 2.2: The research method of (Mitroff, Betz, Pondy & Sagasti, 1974)

Contributing to the execution of the implementation phase and implementation step, a fictive case study is executed. This fictive case study is inspired by the practical use case of Atos. This practical use case focuses on a client of Atos that has contractual issues with a supplier (these issues arise with more suppliers of the company). Based on the processes that are currently executed, a new situation in which blockchain changes or removes current processes is developed. This new situation is analyzed in order to capture the value of blockchain. The use case is specific to one situation. However, employees of Atos are working for other clients as well. As a result, it is possible to get a more general situation in the fictive use case.

In addition to the above-described methods, a Focus group is developed to gain a deeper understanding of the potential value of blockchain for contract agreements in supply chains. The focus group consisted of four experts with knowledge of the industry field and the field of blockchain. The aim of the focus group is to review and validate the blockchain solution. In addition, the focus group is used to gain a better understanding of the added value of blockchain. Thus, this focus group is needed to gain Feedback on and for being able to Validate the blockchain solution.
Chapter 3

Basic models

In this chapter, the basic supply chain contracts are introduced as a starting point for further investigation. Cachon (2003) provided a standard for two-level supply chain coordination contracts. This standard is used to introduce the several types of contracts that can coordinate the two-level supply chain. He studied the possibility of coordination in a supply chain with one supplier and one retailer. The retailer (or supply chain) faces stochastic demand. Before the selling period starts, the retailer orders inventory from the supplier. The retailer has only one opportunity to order inventory. The order is placed before the start of the selling period. In his paper, Cachon (2003) defined a coordinating contract as "A contract coordinates the supply chain if the set of supply chain optimal actions is a Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions". In the situation that risk-neutral members are assumed, this definition covers the most important aspects of coordination. However, when risk-averse members are assumed, this definition should be changed. In the next chapter, an adjusted definition is introduced but for this chapter, the definition as in (Cachon, 2003) is used. Based on Cachon (2003) the following contracts are discussed below: (1) wholesale-price contract, (2) buyback contract, and (3) revenue-sharing contract. In addition, the discussion of the quantity-flexibility contract, the sales-rebate contract, and the quantity-discount contract can be found in Appendix A. The chapter first explains the used newsvendor model in which no contract is implemented.

3.1 Newsvendor model

The first model that is explained is the two-level newsvendor model. The model consists of a retailer \( r \) and a supplier \( s \) in which the retailer faces stochastic demand \( D > 0 \), with a cumulative distribution function \( F \) and a density function \( f \): \( F \) is differentiable, strictly increasing and \( F(0) = 0 \). In addition, it is said that \( F(x) = 1 - F(x) \) and \( \mu = E[D] \). In the model, the retailer must choose its order quantity before the start of a single selling period. Cachon (2003) made a set of costs that arise in the process. However, in practice, more costs might arise. To produce a unit the supplier faces a unit production cost \( c_s \) and the marginal cost incurred at the retailer is \( c_r \). The produced unit is then sold by the retailer for a price \( p \), which is assumed to be greater than the sum of production costs \( (c_r + c_s < p) \). The retailer must place its order before facing demand, which might result in leftovers or unsatisfied customers. When the retailer is not able to satisfy all demand, the retailer incurs a goodwill penalty cost \( g_r \) and the supplier faces the analogous cost \( g_s \). When the retailer is stuck with unsold units, they can be salvaged for a net salvage value \( v \). It is assumed that the salvage value is smaller than the total production costs, \( (v < c_r + c_s) \). Cachon (2003) assumed that the net salvage value is greater for the retailer than for the supplier. Thus, leftover units are salvaged at the retailer’s place.

In the newsvendor model, the supplier first offers a contract to the retailer. Based on this offer, the retailer decides to either reject or accept the contract. If the contract is accepted, the retailer determines its order quantity \( q \). Then, the supplier produces and delivers the order quantity before the start of the selling period. During the selling period, demand occurs at the retailer. After the period is finished, payments between both firms occur based on the faced de-
mand and agreed contract. Since Cachon (2003) used several different parameters, the following list is developed to serve as a summary:

- $c_r$: Retailer’s marginal cost per unit
- $c_s$: Supplier’s production cost per unit
- $c$: Supply chain’s cost per unit, $c = c_r + c_s$
- $p$: Customer retail price
- $g_r$: Retailer’s goodwill cost per unit
- $g_s$: Supplier’s analogous cost per unit
- $g$: Supply chain’s cost per unit unmet demand, $g = g_r + g_s$
- $v$: Retailer’s salvage value
- $D$: Stochastic customer demand
- $f$: Probability density function of demand
- $F$: Cumulative distribution function of demand
- $\mu$: Mean of the customer demand $D$
- $q$: Retailer’s order quantity

In addition, Cachon (2003) made several assumptions in his model. Although some of them are already explained above, a list of assumption is made below to give a clear overview the assumptions that are made:

- $D > 0$ during the selling period, $F$ is both differentiable and strictly increasing.
- $c > v$, otherwise, the supply chain (retailer) can make a profit out of producing an infinite number of units because the supply chain (retailer) makes a profit out of salvaging a unit.
- $p > c$, otherwise, the supply chain is not able to make a profit at all. Thus, $p > v$ which make sense because it should be more beneficial for the supply chain to sell a unit to its customers than to salvage it.
- The net salvage value of the supplier is less or equal to the net salvage value of the retailer, so all units are salvaged at the retailer’s place. Thus, $v_s \leq v_r$.
- It is assumed that the members of the supply chain are risk-neutral. Thus, each member is maximizing its expected profit.
- Full information is assumed so that both parties know all costs, parameters, and rules.
- It is assumed that the demand is independent of the retail price.
- Forced compliance is assumed, which means that the retailer believes that the supplier never chooses to deliver less than the retailer’s order quantity.
- Last, all costs and prices are greater than or equal to zero, so $c_r \geq 0, c_s \geq 0, g_r \geq 0, g_s \geq 0, v \geq 0$.

To determine the profit of the supply chain and its members, Cachon (2003) introduced the following functions for the expected sales $S(q)$, expected leftover inventory $I(q)$, and expected lost-sales $L(q)$, respectively: $S(q) = q - \int_0^q F(y) \, dy$, $I(q) = q - S(q)$, $L(q) = \mu - S(q)$. Using these functions, it is possible to describe the profit functions. The profit functions for the retailer, supplier, and supply chain are introduced:

$$\pi^r(q) = pS(q) + vI(q) - g_rL(q) - c_rq - T = (p - v + g_r)S(q) - (c_r - v)q - g_r\mu - T \quad (3.1)$$

$$\pi^s(q) = T - g_sL(q) - c_sq = g_sS(q) - c_sq - g_s\mu + T \quad (3.2)$$
\[
\Pi(q) = \pi_r(q) + \pi_s(q) = pS(q) + vI(q) - gL(q) - cq = (p - v + g)S(q) - (c - v)q - g\mu \quad (3.3)
\]

In the profit functions of the retailer and supplier, one can spot the parameter \( T \), which was not yet introduced. \( T \) is the transfer payment that occurs between the retailer and the supplier. \( T \) is dependent on different observations, for example on the order quantity or on the leftover inventory. When supply chain contracts come into play, \( T \) is adjusted to the specific conditions of the agreed contract, which is shown later. In the newsvendor situation, it is not possible to determine the optimal order quantity for the retailer because \( T \) is dependent on the contract. However, in the profit function of the supply chain, the transfer payment is not taken into account. This is the result of the fact that the transfer payment happens internally in the supply chain, between the supplier and retailer. In addition, this leads to the fact that the profit function of the supply chain is not dependent on the agreed contract. Thus, it is possible to determine the optimal order quantity for the supply chain. Cachon (2003) assumed that \( \Pi(q^o) > 0 \). Since \( F \) is strictly increasing, it follows that \( \Pi' = (p - v + g)(1 - F(q)) - (c - v) \) is strictly decreasing and that \( \Pi'' = -(p - v + g)F'(q) \) which is negative for a positive \( q \). Thus, \( \Pi \) is strictly concave. Based on these assumptions he showed that the optimal order quantity is unique and satisfies:

\[
S'(q^o) = F'(q^o) = \frac{c - v}{p - v + g} \quad (3.4)
\]

One condition that should be met to achieve coordination is that the optimal order quantity of the retailer should equal the optimal order quantity for the supply chain. The formula above determines the optimal order quantity of the supply chain, and by using this formula it is possible to determine if a contract is able to align the retailer’s optimal order quantity. A more widely used formula for determining the optimal order quantity can be gathered by rewriting the formula of Cachon (2003):

\[
F(q^o) = 1 - F(q^o) = \frac{p + g - c}{p + g - v} \quad (3.5)
\]

This formula is used to determine if a contract is able to coordinate the supply chain. Below, each of the supply chain contracts introduced by Cachon (2003) are explained in more detail.

### 3.2 Wholesale-price contract

The traditional pricing contract in a supply chain is the wholesale-price contract. In a wholesale-price contract, the supplier produces units at a cost \( c_s \) and sells it for a wholesale price \( w \) to the retailer. The retailer sells these units to the customer at a price \( p \). So, the transfer payment in the wholesale-price contract is \( T(w, q) = wq \). In the wholesale-price contract, three new assumptions are introduced:

- \( w > c_s \), otherwise, the supplier would not be able to make a profit on selling units to the retailer.
- \( w > v \), otherwise, the retailer would be able to make an infinite profit by salvaging an infinite number of ordered units.
- \( w < p - c_r \), otherwise, the retailer would not be able to make a profit.

Using these assumptions and the assumptions introduced in the newsvendor model, it is possible to determine the profit functions of the retailer and supplier:

\[
\pi_r(q, w) = (p - v + g_r)S(q) - (w + c_r - v)q - g_r\mu \quad (3.6)
\]
\[ \pi_s(q, w) = g_s S(q) + (w - c_s)q - g_s \mu \]  

(3.7)

As explained above, the profit function of the supply chain remains the same due to the fact that the transfer payment \( T \) is internal. It is known that the optimal order quantity for the supply chain is not dependent on the contract. As a result, the first condition for coordination can be defined: the optimal order quantity of the retailer \( (q^*) \) should equal the optimal order quantity of the supply chain \( (q^o) \). Thus, the following should hold:

\[ q^* = q^o. \]

Therefore, the optimal order quantity of the retailer has to be found. It is known that \( \pi_r(q, w) \) is strictly concave in \( q \), thus the retailer’s optimal order quantity should satisfy:

\[ F(q^*) = \frac{p + g_r - w - c_r}{p + g_r - v} \]

(3.8)

When the optimal orders should be aligned, it is found that the following should hold:

\[ w = \frac{p + g_r - v}{p + g - v} (c - v) - (c_r - v) \]

(3.9)

This equation shows that coordination is only achieved when \( w \leq c_s \). However, when \( w \leq c_s \) the supplier is not able to make a profit out of selling units to the retailer. Thus, the supplier has an incentive to change its behavior, for example by charging a higher wholesale price. Therefore, it can be concluded that the wholesale-price contract is not able to coordinate the supply chain with risk-neutral members. The second condition for coordination of a supply chain is introduced in this contract: ‘None of the members of the supply chain should have an incentive to deviate its behavior’. Thus, coordination is achieved when the set of individual optimal actions result in a Nash equilibrium, and preferably a unique Nash equilibrium.

Although the wholesale-price contract is not coordinating the supply chain it is interesting in two ways. First, as explained in the introduction supply chain contracts are aimed at addressing the negative outcomes of double marginalization by achieving the supply chain optimum. For the supply chain, it would have been better to set up a wholesale price smaller than \( c_s \). However, due to the individual decision making of companies, this would not be possible. Therefore, it can be said that the double marginalization problem is not solved by implementing a wholesale-price contract. Second, the wholesale-price contract is often observed in practice even though it does not coordinate the supply chain. One reason that it is often used in practice is that it is simple(r) to administer. The order quantity is the only parameter that influences the transfer payment, while in other contract multiple parameters come into play. This results in the fact that the wholesale-price contract is widely studied in literature, see Cachon (2003) for a summary of several studies on the wholesale-price contract in different settings.

### 3.3 Buyback contract

The buyback contract is an adjustment of the wholesale-price contract. When the buyback contract is implemented, the retailer has the opportunity to sell unsold items back to the supplier. Although the supplier is ‘buying back’ the unsold items, it does not have to mean that the items are physically returning to the supplier, it depends on the situation and agreements made between both parties. Next to the agreement that should be made on the wholesale price, the supplier and retailer have to agree on a buyback price \( b \) in this contract as well. Thus, the implementation results in an adjusted transfer payment \( T(q, w, b) = wq - b I(q) = bS(q) + (w - b)q \). Cachon (2003) assumed that the retailer still salvages the leftover inventories. Thus, an extra assumption is made when analyzing the buyback contract:

- \( b + v \leq w \), otherwise, the retailer is able to make a profit by salvaging units. This would result in the retailer ordering an infinite number of units, which could be salvaged for an infinite profit.
Based on the assumptions and information above, it is possible to determine the profit functions of the retailer and supplier:

\[
\pi_r(q, w, b) = (p - v + g_r - b)S(q) - (w - b + c_r - v)q - g_r \mu
\]  
(3.10)

\[
\pi_s(q, w, b) = (g_s + b)S(q) + (w - b - c_s)q - g_s \mu
\]  
(3.11)

In the buyback contract the transfer payment is, again, only internal. Thus, the supply chain’s profit function remains the same. The retailer’s profit function is then used to find the retailer’s optimal order quantity, which is needed to determine if coordination might be possible. \(\pi'_r\) is strictly decreasing and \(\pi''_r < 0\) for a positive \(q\). Thus, \(\pi'_r(q, w, b)\) is strictly concave in \(q\). As a result, the retailer’s order quantity should satisfy:

\[
F(q^*) = \frac{p + g_r - w - c_r}{p + g_r - v - b}
\]  
(3.12)

for being optimal. Thus, the following equation should hold to achieve coordination:

\[
\frac{p + g_r - w - c_r}{p + g_r - v - b} = \frac{p + g - c}{p + g - v}
\]  
(3.13)

Hence, the following relationship between \(b\) and \(w\) must hold in order to achieve coordination:

\[
w = (p + g_r - c_r) - \frac{(p + g_r - v - b)(p + g - c)}{p + g - v}
\]  
(3.14)

Cachon (2003) showed that coordination is possible. However, the optimal solution is no longer a unique Nash equilibrium. There are different combinations of the buyback price and the wholesale price possible. Each of them results in different expected profit allocations. This way, the buyback contract can serve as a risk-sharing mechanism. The adjustment of the wholesale and buyback price results in the possibility of allocating the profit. One remark to the implementation of this buyback contract, the supplier should be able to verify the number of unsold items at a lower cost than the benefits of the contract. Otherwise, it would not be beneficial to implement the contract.

### 3.4 Revenue-sharing contract

The revenue-sharing contract is also an adjusted version of the wholesale-price contract. When a revenue-sharing contract is implemented, the retailer agrees to share a percentage \(\Phi\) of its revenue with the supplier. In return, the supplier offers a lower wholesale price \(w\) to the retailer. Thus, the retailer and supplier have to agree on a combination of a wholesale price and shared percentage that is beneficial for both members. Cachon (2003) defined \(\Phi\) as the percentage of the revenue that is kept by the retailer. So, \((1 - \Phi)\) is the percentage that is shared with the supplier. The retailer gets revenue by either selling units to customers or by salvaging the leftover units. This results in the following transfer payment \(T(q, w, \Phi) = (w + (1 - \Phi)v)q + (1 - \Phi)(p - v)S(q)\). The assumption \(w > c_s\) is ignored in the revenue-sharing contract because the retailer shares a part of its revenue with the supplier. Therefore, new assumptions are introduced:

- \(w + (1 - \Phi)p > c_s\), otherwise, the supplier is not able to make a profit on selling units to the retailer.
- \(w + c_r < \Phi p\), otherwise, the retailer would not be able to make a profit.
- \(w > \Phi v\), otherwise, the retailer would be able to make an infinite profit by salvaging units.
Based on the information with regard to the revenue-sharing contract and the assumptions made it is possible to determine the profit functions:

\[
\pi_r(q, w, \Phi) = (\Phi(p - v) + g_r)S(q) - (w + c_r - \Phi v)q - g_r \mu \tag{3.15}
\]

\[
\pi_s(q, w, \Phi) = (g_s + (1 - \Phi)(p - v))S(q) + (w + (1 - \Phi)v - c_s)q - g_s \mu \tag{3.16}
\]

In the revenue-sharing contract no external transfer payments take place, so the supply chain’s profit function remains the same. The retailer’s profit function is then used to find the retailer’s optimal order quantity, which is needed to determine if coordination might be possible. \(\pi'_r\) is strictly decreasing and \(\pi''_r < 0\) for a positive \(q\). Thus, \(\pi_r(q, w, \Phi)\) is strictly concave in \(q\), the retailer’s order quantity should hold:

\[
F(q^*) = \frac{\Phi p + g_r - w - c_r}{\Phi(p - v) + g_r} \tag{3.17}
\]

for being optimal. Thus, in order to achieve coordination, the following equation should hold:

\[
\frac{\Phi p + g_r - w - c_r}{\Phi(p - v) + g_r} = \frac{p + g - c}{p + g - v} \tag{3.18}
\]

Hence, the following relationship between \(\Phi\) and \(w\) must hold in order to achieve coordination:

\[
w = (\Phi p + g_r - c_r) - \frac{(\Phi(p - v) + g_r)(p + g - c)}{p + g - v} \tag{3.19}
\]

Cachon (2003) showed that coordination is possible by implementing a revenue-sharing contract. In addition, depending on the situation multiple combinations might arise to achieve coordination. The different combinations of the shared percentage and the wholesale price result in different expected profit allocations. Thus, adjusting the wholesale price and shared percentage, such that the equation is satisfied, results in the possibility of allocating profit among the members of the supply chain. A remark should be made, the supplier should be able to verify the revenues gained at the retailer at a lower cost than it benefits from the implementation of the contract. Otherwise, the supplier would make a loss on implementing the contract.
Chapter 4

Risk-averse models

In practical situations, companies are considering risk in their decision-making process. However, in the models described in Cachon (2003) it is assumed that members of the supply chain are risk-neutral. Relaxing this assumption results in a supply chain model that is more representative for practical circumstances. Some papers acknowledged the need for relaxing this assumption. However, the methods used in these models are exposed to some drawbacks. In addition, none of these papers regarded the interaction between operations and finance. Therefore, this master thesis contributes to academic knowledge by developing a method that only measures the relevant systematic risk risk and by including the interaction between operations and finance. To do so, a discounting formula is developed based on Birge (2014) and Anvari (1987). Furthermore, to the best of my knowledge, there is no clear definition for supply chain contract coordination with risk-averse members. Therefore, this master thesis introduces a definition based on the developed discounting formula. The definition and discounting formula are then used to relax the assumption of risk-neutral members in the basic supply chain contract models described in chapter 3.

4.1 Considering risk

The supply chain contract models discussed in Cachon (2003) are operational models and the models consider risk-neutral members. As a result, the financial considerations of the decision-maker are neglected. However, in practice, decision-makers are considering risk in their decision process. In addition, operational decisions are influencing financial considerations, and vice versa (Birge, 2014). For example, in a newsvendor situation when demand is high but the order quantity is low, the financial considerations are different from the situation in which demand is low but the order quantity is high. In the first situation, the cash flow has only little correlation with the market. Therefore, it should be discounted fairly similar to certain cash flows. Whereas in the second situation, the number of sales is much more dependent on the demand. Therefore, the cash flow should be discounted with a large risk adjustment. As a result, the interaction of the operational decisions and financial decisions should be taken into account when relaxing the assumption of risk-neutrality in supply chain contract models.

Previous research to supply chain contract coordination in a risk-averse environment did not consider the interaction between finance and operations. Research did consider the total variability of the resulting benefits (Chiu et al., 2011; Choi, 2008), or considered the linear trade-off between risk and return, and thus an objective function (Tsay, 2002), or maximized the probability of achieving a certain level of profit (Gan et al., 2004) to relax the assumption of risk-neutral members. These ways of measuring risk in supply chain contract models are reasonable. However, when using these methods in a classical newsboy problem, there arise some issues (Anvari, 1987). First, when investors hold diversified portfolios of financial assets, the total variance of the return is not an appropriate measure for the relevant risk of an investment that is done by a value-maximizing firm. In this situation, the proper measure of risk is its systematic risk. Systematic risk is not diversifiable by the investors, which makes it the relevant risk for the supply chain contract situation. Second, the measure of risk aversion in these models represents
the risk-aversion level of the decision-maker. However, this measure might be different when it represents the shareholders. Thus, the model may imply agency problems. Third, when a company maximizes the probability of achieving a certain level of profit, it avoids the definition of risk.

The attempts of relaxing the assumption of risk-neutrality in previous research suffer from several drawbacks. In addition, none of the models incorporate the interaction of finance and operations. Therefore, this master thesis contributes to academic knowledge by measuring the relevant systematic risk only and by including the interaction between operations and finance. To do so, the well-known Capital Asset Pricing Model (CAPM) is used to measure risk (Anvari, 1987; Birge, 2014). However, a market-valuation approach for modeling working-capital decisions of the firm requires special care. Assumptions under which the valuation model is developed should not result in logical inconsistencies. For example, the original CAPM was derived under the assumption of perfect capital markets which shows that a value-maximizing firm should not hold any short-term financial assets, which may limit the usefulness in practice. However, the CAPM does not require the assumptions of perfect commodity markets. Therefore, without resulting in the logical inconsistency described above one can use the CAPM to model inventory decisions (Anvari, 1987). The situation of inventory decisions as described in Anvari (1987) is similar to the situation of an order quantity in a supply chain contract model. Therefore, the model as it is described in Anvari (1987) can be used to describe supply chain contract models as well. This will be further explained in the next section. However, not all cash flows in supply chain contracts are uncertain. As a result, this master thesis combined the method of Anvari (1987) and Birge (2014). As the basic supply chain models only consider a one-period analysis, the simple version of the CAPM can be used. This simple version also considers only one time-period. This one-period analysis can serve as a building block for further research. In the next section, the model that is used in this master thesis is explained in more detail.

4.2 Discounting the uncertain cash flow

In this section, a step-for-step explanation is given to describe the formula that is used for discounting uncertain cash flows. The starting point is the formula described in Birge (2014). It is said that an uncertain cash flow should be discounted with the risk-free interest rate \( r_f \) and a risk premium. The risk-free interest rate is determined by the market. The risk premium is the product of the covariance between a random future cash flow \( \tilde{f} \) and a market portfolio’s return \( \tilde{r}_m \) and the market risk premium \( \lambda_m \). Thus, the risk premium is denoted as \( \lambda_m \text{Cov}(\tilde{f}, \tilde{r}_m) \). The present value \( s \) of an uncertain cash flow \( \tilde{f} \) with mean \( \bar{f} \) and covariance \( \text{Cov}(\tilde{f}, \tilde{r}_m) \) is described as:

\[
s = \frac{1}{1 + r_f} (\bar{f} - \lambda_m \text{Cov}(\tilde{f}, \tilde{r}_m))
\]  

(4.1)

Although this CAPM version is quite useful for general market trends, it can be obstructive when it is used for evaluating operational decisions. As said before, operational decisions affect financial considerations and should be taken into account. In supply chain contract models, the risk premium is dependent on the order quantity. As explained before, the order quantity determines the correlation between the cash flow and the demand. Therefore, the risk premium should be a function of the order quantity. In general, it is not easy to describe the behavior of the covariance as a function of the order quantity. Therefore, this master thesis uses the model of Anvari (1987) to describe \( \text{Cov}(\tilde{f}, \tilde{r}_m) \).

In the model of Anvari (1987), \( V(x) \) denotes the net end of the period cash flow as a function of the order quantity \( x \) and is denoted as \( V(x) = bx + (b - p)Z(x) \). The parameters can be described as follows: the leftover units are represented by \( Z(X) = 0 \) if \( R \geq x \) and \( Z(X) = R - x \).
if \( R < x \), \( b \) is the retail price net of storage charges, \( p \) is the salvage value, \( M \) represents the value of the market portfolio, and \( R \) is the retailer’s demand. First, Anvari (1987) shows that

\[
\text{Cov}(V(x), M) = (b - p)\text{Cov}(Z(x), M)
\]  

(4.2)

However, the behavior of \( \text{Cov}(Z(x), M) \) as a function of the order quantity is difficult to describe. To obtain useful results, Anvari (1987) assumed that the joint distribution of demand \( R \) and the market return \( M \) are jointly normal with the probability density function. It is said that this assumption is consistent with the underlying assumptions of the CAPM. Although the derivation is difficult, the expression for \( \text{Cov}(Z(x), M) \) is simple. Anvari (1987) proofed the following:

\[
\text{Cov}(Z(x), M) = F(x)\text{Cov}(R, M)
\]  

(4.3)

Using the equation for \( \text{Cov}(Z(x), M) \) and \( V(x) = bx + (b - p)Z(x) \) it follows that

\[
\text{Cov}(V(x), M) = (b - p)\text{Cov}(R, M)F(x)
\]  

(4.4)

To see the detailed derivation of this proof, one should look in the appendix of Anvari (1987). At this point it is known how to determine the covariance of the net end of the period cash flow. However, the model used in Anvari (1987) is somewhat different than the model used in Birge (2014). To use the formula described in Birge (2014) the parameters used in Anvari (1987) should be adjusted. Birge denoted the uncertain cash flow as \( \tilde{f} \) and the market return as \( r_m \). Since the cash flow is not specified further, the parameters are interchangeable. It results in the following: \( \text{Cov}(V(x), M) = \text{Cov}(\tilde{f}, r_m) \), which results in

\[
\text{Cov}(\tilde{f}, r_m) = (b - p)\text{Cov}(R, r_m)F(x)
\]  

(4.5)

In view of this equation and equation 4.1,

\[
s = \frac{1}{1 + rf}[(\tilde{f} - \lambda_m((b - p)\text{Cov}(R, r_m)F(x))]
\]  

(4.6)

The expression above determines the present value of an uncertain future cash flow that is denoted by \( V(x) = bx - (b - p)Z(x) \) as a function of the order quantity \( x \). However, the situation described in Anvari (1987) is different than the situation described in chapter 3. Therefore, for each supply chain contract model, the situation is compared to the situation described in Anvari (1987) to proof that his equations can be used. This is done in the supply chain contract related sections. Thus, equation 4.6 is representing the situation as it is in Anvari (1987).

Next, it is needed to know how to determine the covariance between demand and market return and how to determine the market risk premium. In this master thesis, demand is denoted as \( D \). First, it is well known that the covariance itself can be determined by \( \text{Cov}(D, r_m) = \rho \sigma_D \sigma_{r_m} \), where \( \rho \) is the correlation between demand and the market return. Second, the market price of risk can be determined by \( \lambda_m = \frac{\gamma_m - rf}{\sigma_m} \) (Birge, 2014), where \( \sigma_m \) is the standard deviation of the market return and the other parameters are previously introduced. Concluding, all parameters are introduced and it is shown how to determine them. Thus, risk is now being measured by using the simple one-period CAPM model that takes into account the interface between operations and finance.

In the supply chain contract models that are discussed below, not all cash flows are uncertain. As a result, these cash flows are not correlated with the market, which results in a risk premium equal to zero. However, these cash flows may arise in future moments of time. Therefore, they should be discounted with the risk-free rate only (Birge, 2014). In the following sections, for each contract, it is specified how to discount the individual cash flows.
4.3 Supply chain coordination

In the supply chain contract coordination literature, there are several definitions of coordination. However, only a few of these definitions take into account risk considerations but these definitions are limited. To the best of my knowledge, there is no clear definition for supply chain coordination with risk-averse members. Therefore, a new definition for supply chain contract coordination is developed. This definition is based on the definition of Cachon (2003): “A contract coordinates the supply chain if the set of supply chain optimal actions is a Nash equilibrium, i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions.” He introduces two important features of coordination: (1) the actions of the individual players should lead to a supply chain optimum, and (2) the contract should provide partners with an action that results in having no incentive to deviate from this action. Based on these features and taking into account risk considerations of supply chain members, the following definition for a coordinating contract is developed:

A contract coordinates the supply chain if the individual risk-averse members make independent, optimizing, risk considering actions that lead to a maximum supply chain present value of the expected profit, in which no member has an incentive to change its behavior

By denoting that individuals are risk-averse it is meant that they discount uncertain cash flows with the formula presented above. In addition, the two important features are included in the definition as well. Cachon (2003) said coordination is achieved when the expected profit of the supply chain is maximized \( \max_q EP_{SC}(q) \). However, this definition shows that the supply chain present value of the expected profit should be maximized (which satisfies the first condition for coordination). Therefore, this research says coordination is achieved when:

\[
\max_q PV(EP_{SC}(q))
\]  

(4.7)

The present value of the expected profit for the supply chain is determined by taking the sum of the certain cash flows and the discounted uncertain cash flows. As explained, the uncertain cash flows are discounted by \( s = \frac{1}{1+r_f} (\tilde{f} - \lambda_m Cov(\tilde{f}, r_m)) \). By assuming joint normality between sales and demand, it is possible to determine \( Cov(\tilde{f}, r_m) \). To achieve \( \max_q PV(EP_{SC}(q)) \), the optimal order quantity of the retailer should be aligned with the supply chain’s optimal order quantity. Otherwise, the retailer has an incentive to change its behavior. Furthermore, when the retailer’s optimal order quantity is aligned with the supply chain’s, it is needed that the supplier does not have an incentive to change behavior as well. Thus, the contract has to align the retailer’s optimal order quantity with the supply chain’s optimal order quantity subject to the reservation payoff of both the supplier and retailer is met and that no member has the incentive to change its behavior (which satisfies the second condition for coordination). At this point, the necessary information is gained to relax the assumption of risk-neutral members in the supply chain contract models. The next sections apply the discounting formula and the definition for supply chain contract coordination in a risk-averse environment to the basic supply chain contract models to incorporate the risk considerations of supply chain members.

4.4 Newsvendor Situation

Cachon (2003) assumed that the members of the supply chain are risk-neutral. However, as explained before, members of the supply chain do consider risk when making decisions. By incorporating the CAPM to discount uncertain cash flows, this master thesis relaxed the assumption of risk-neutrality. In addition, by using the formula’s described in Anvari (1987) it incorporated the interaction between operations and finance. In this section, the standard newsvendor situation as described in section 3.1 is adjusted such that the risk-neutrality assumption is relaxed.
The new situation is still explained by a two-level newsvendor model consisting of a supplier $s$, retailer $r$, and the supply chain as a whole $SC$. The retailer faces stochastic demand $D > 0$, with a cumulative distribution function $F$ and density function $f$: $F$ is differentiable, strictly increasing and $F(0) = 0$. Furthermore, it is said that $F(x) = 1 - F(x)$ and $\mu = E(D)$. To give an overview of all parameters used in the supply chain contract models the following list is developed:

- $c_r$: Retailer’s marginal cost per unit
- $c_s$: Supplier’s production cost per unit
- $c$: Supply chain’s cost per unit
- $p$: Customer retail price
- $g_r$: Retailer’s goodwill cost per unit
- $g_s$: Supplier’s analogous cost per unit
- $g$: Supply chain’s cost per unit for unmet demand
- $v$: Retailer’s salvage value
- $D$: Stochastic customer demand
- $f$: Probability density function of demand
- $F$: Cumulative distribution function of demand
- $\mu$: Mean of the customer demand $D$
- $q$: Retailer’s order quantity

\[ \tilde{f} \quad \text{The uncertain cash flow} \]
\[ \tilde{m} \quad \text{The multiplier of the uncertain cash flow} \]
\[ r_{ft} \quad \text{Risk-free rate for time period } t, \text{ with } t \in [0, 1, 2] \]
\[ r_m \quad \text{Market return} \]
\[ \lambda_m \quad \text{Market risk premium} \]
\[ X \quad \text{Number of sales} \]
\[ Cov(\tilde{f}, r_m) \quad \text{Covariance between the uncertain cash flow and market return} \]

In the risk-averse environment, (uncertain) future cash flows have to be discounted. Globally speaking, the process can be divided in three main moments ($t \in [0, 1, 2]$): (1) the retailer places an order at the supplier at moment $t = 0$, (2) the order quantity is delivered at the start of the selling period at moment $t = 1$, and (3) demand is satisfied and the selling period ends at moment $t = 2$. At each moment in time, there might be a different risk-free rate and a different market return. Therefore, the time at which a cost or transfer payment occur is important. The occurrence of these moments is visualized in figure 4.1:

![Figure 4.1: Time frame newsvendor situation](image)

In addition, it is assumed that costs and transfer payments only occur at one of these moments. As explained, at each moment one should differently discount the (future) cash flow. This discounting is dependent on two issues: (1) the time of occurrence and (2) the certainty of the
cash flows. First, cash flows that arise in the future are worth less than cash flows happening today. Therefore, cash flows happening in the future should be discounted with the appropriate risk-free rate. The risk-free rate is time-dependent and not fixed (Brealey, Myers & Allen, 2014). Second, the size of a cash flow can be certain or uncertain. In the supply chain contract models, the cash flow is uncertain when it depends on the number of sales and it is assumed to be certain when it is not. As the uncertain cash flows happen in the future (after demand is faced), these are discounted with the discounting formula. The certain cash flows have a correlation with demand equal to zero. As a result, they only have to be discounted with the risk-free rate (if they happen in the future). Concluding, depending on the occurrence in time and the certainty of the cash flow it is determined how to discount a cash flow. For the newsvendor situation, the following steps are executed and the following cash flows occur:

1. Prior to or at moment 0
   • The supplier offers a contract to the retailer, who accepts or rejects the contract.
   • The retailer orders a quantity \( q \in [0, \infty) \) from the supplier.
   • The supplier produces the units at a cost \( c_s \). It is assumed that transportation costs are also included in these costs.

2. At moment 1
   • The retailer receives the order quantity and incurs a marginal cost per unit \( c_r \).
   • Depending on the contract, payments are made between the retailer and the supplier.

3. At moment 2
   • The retailer sold a number of \( \min(q, D) \) to the market at a price \( p \).
   • The selling period ends: goodwill penalties are paid and leftovers are salvaged.
   • Depending on the agreed contract, payments are made between the retailer and the supplier.

Above, one can see the time a cash flow occurred and if a cash flow is dependent on the number of sales. In the newsvendor situation, all costs that occur at moment 0 are only depending on the order quantity. Therefore, they are denoted as certain. As a result, these cash flows do not have to be discounted. The cost that occurs at moment 1 is only dependent on the order quantity. Thus, it is denoted as certain. As a result, it should only be discounted with the risk-free rate for moment 1 \( (r_{f1}) \). Although the transfer payment is depending on the contract, it can not be influenced by the number of sales as it happens before the selling period starts. Therefore, it should only be discounted with the risk-free rate for moment 1 \( (r_{f1}) \). The revenue earned by the retailer and the costs occurring at moment 2 are dependent on the number of sales. As a result, these cash flows should be discounted with the discounting formula presented above. However, the contract determines if the transfer payment is certain or uncertain. Therefore, for the newsvendor situation, the transfer payment is only discounted by the risk-free rate for moment 1. Furthermore, the size of the costs and transfer payments are determined by the order quantity, the number of sales, and the agreed contract. Based on Cachon (2003) the expected sales are denoted as \( S(q) = q - \int_0^q F(y)dy \), the expected leftover inventory as \( I(q) = q - S(q) \), and expected lost sales as \( L(q) = \mu - S(q) \).

To develop the supply chain contract model for risk-averse members, several assumptions are made. To give an overview of the assumptions made in this model, the following list is developed:

- \( D > 0 \) during the selling period, \( F \) is both differentiable and strictly increasing. In addition, the demand and market return are assumed to be jointly normal.
\begin{itemize}
  \item $c > \frac{v}{1 + r_{f_2}}$, otherwise, the supply chain is able to make a profit out of producing an infinite number of units because the supply chain makes a profit out of salvaging a unit.
  \item $\frac{p}{1 + r_{f_2}} > c$, otherwise, the supply chain is not making a profit at all. Thus, $p > v$ which makes sense because it should be more beneficial for the supply chain to sell a product to its customers than it would be to salvage the product.
  \item The net salvage value of the supplier is less or equal to the net salvage value of the retailer, so all products are salvaged at the retailer’s place. Thus, $v_s \leq v_r$.
  \item It is assumed that the members of the supply chain are risk-averse. Thus, each member is maximizing its present value of the expected profit based on the interactions between operations and finance.
  \item It is assumed that the risk-free rate is positively related to time. The larger a period, the larger the risk-free rate. Thus, $r_{f_2} \geq r_{f_1}$.
  \item Costs occur at one of the three moments in time.
  \item Transfer payments occur at one of the three moments in time, which is determined by the agreed contract.
  \item Full information is assumed so that both parties know all costs, parameters, and rules.
  \item It is assumed that the demand is independent of the retail price.
  \item Forced compliance is assumed, which means that the retailer believes that the supplier never chooses to deliver less than the retailer’s order quantity.
  \item All costs and prices are greater than or equal to zero, so $c_r \geq 0$, $c_s \geq 0$, $g_r \geq 0$, $g_s \geq 0$, $v \geq 0$.
  \item Risk variables are greater than or equal to zero, so $\lambda_m \geq 0$, $r_{f_t} \geq 0$, $r_m \geq 0$.
\end{itemize}

Based on the in chapter 3 introduced functions for the expected profit, it has to be proven that the results of Anvari (1987) can be used for determining the covariance of the uncertain cash flows with the market return. First, $V(x)$ consisted of a certain part $bx$ and an uncertain part $(b - p)Z(x)$. In the model of Anvari (1987), $(b - p)$ is the multiplier of the uncertain function. This multiplier is determined by the situation in which the model is used. Anvari (1987) only considered a retail price $p$ and a salvage value $b$. However, the models in this master thesis consider the goodwill cost $g$ as well. As a result, the uncertain cash flows for the retailer, supplier, and supply chain equal 

\begin{align*}
\hat{f}_r &= pS(q) + vI(q) - g_rL(q) = (p - v + g_r)S(q) + vq - g_r\mu, \\
\hat{f}_s &= g_sL(q) = g_s\mu - g_sS(q), \text{ and } \\
\hat{f}_{SC} &= pS(q) + vI(q) - gL(q) = (p - v + g)S(q) + vq - g\mu,
\end{align*}

respectively. Within our supply chain contract models, the uncertain function is described as $S(q)$ and the multipliers are described as $(p - v + g_r)$, $g_s$, and $(p - v + g)$, respectively. Both models have the same structure of a certain part and an uncertain part dependent on sales. As a result, the covariance of an uncertain cash flow with the market return in the supply chain contract model can be determined as it is done in Anvari’s model. Based on the information given above, the following expressions for the newsvendor consider the goodwill cost $g$ as well. As a result, the uncertain cash flows for the retailer, supplier, and supply chain equal 

\begin{align*}
PV_r(EP_r(q)) &= \frac{1}{1 + r_{f_2}}[\hat{f}_r - \lambda_m\text{Cov}(\hat{f}_r, r_m)] - c_rq + T \\
PV_s(EP_s(q)) &= \frac{T}{1 + r_{f_1}} - \frac{1}{1 + r_{f_2}}[\hat{f}_s + \lambda_m\text{Cov}(\hat{f}_s, r_m)] - c_sq \\
PV_{SC}(EP_{SC}(q)) &= \frac{1}{1 + r_{f_2}}[\hat{f}_{SC} - \lambda_m\text{Cov}(\hat{f}_{SC}, r_m)] - cq
\end{align*}

\begin{equation}
(4.8)
\end{equation}

\begin{equation}
(4.9)
\end{equation}

\begin{equation}
(4.10)
\end{equation}

\text{Number of units because the supply chain makes a profit out of salvaging a unit.}

\text{number of units because the supply chain makes a profit out of salvaging a unit.}
In which \( \text{Cov}(\hat{f}_r, r_m) = (p - v + g_r)\text{Cov}(D, r_m)F(q) \), \( \text{Cov}(\hat{f}_s, r_m) = g_s\text{Cov}(D, r_m)F(q) \), and \( \text{Cov}(\hat{f}_{SC}, r_m) = (p - v + g)\text{Cov}(D, r_m)F(q) \) and \( c = c_s + \frac{c_r}{1 + rf_1} \). One can see that the transfer payment \( T \) is not discounted with the discounting formula in these expressions. However, depending on the contract it might be the case that (part of) the transfer payment is executed at moment 3. As a result, (part of) the transfer payment should be discounted with the discounting formula. For example, in the buyback-price contract, the transfer payment is dependent on the amount of leftover inventory. The leftover inventory is dependent on the demand, which is uncertain. In addition, the payment occurs after demand is satisfied (at moment 3). Thus, in case of the buyback-price contract, a part of the transfer payment should be discounted with the discounting formula.

In the next sections, the transfer payments for each specific contract are explained. In addition, for each contract, it is discussed whether or not the contract is able to coordinate the supply chain with risk-averse members. As one can see, the supply chain’s optimal order size is not dependent on the transfer payment \( T \). Thus, the contract agreements do not influence the present value of the expected profit for the supply chain. For most demand situations it is reasonable to assume that \( \text{Cov}(D, r_m) > 0 \) (Y. H. Kim & Chung, 1989), for simplicity this assumption is made as well. Since it is assumed that \( PV_{SC}(EP_{SC}(q)) > 0 \) and since \( F \) is strictly increasing, \( PV_{SC}(EP_{SC}(q))' \) is strictly decreasing and \( PV_{SC}(EP_{SC}(q))'' \) is negative. Thus, it can be concluded that \( PV_{SC}(EP_{SC}(q)) \) is strictly concave. Therefore, the supply chain’s optimal order quantity is unique and should satisfy:

\[
F(q) + \lambda_m f(q)\text{Cov}(D, r_m) = \frac{p + g - c(1 + rf_2)}{p - v + g}
\]

The proof of this equation can be found in Appendix B. The optimal order quantity for the retailer \( q^*_r \) is dependent on the transfer payment, which in return is dependent on the implemented contract. Thus, a number of contract types have been applied to this model to see whether or not a contract is able to coordinate a supply chain with risk-averse members.

### 4.5 Wholesale-price contract

Within the traditional wholesale-price contract the retailer buys units at the supplier for a wholesale price \( w \). The sequence of events in the wholesale-price contract can be described as:

1. Prior to or at moment 0
   - The supplier offers a wholesale price to the retailer, who accepts or rejects it.
   - The retailer orders a quantity \( q \in [0, \infty) \) from the supplier.
   - The supplier produces the units at a cost \( c_s \). It is assumed that transportation costs are also included in these costs.

2. At moment 1
   - The retailer receives the order quantity and incurs a marginal cost per unit \( c_r \).
   - The retailer pays \( wq \) to the supplier.

3. At moment 2
   - The retailer sold a number of \( \min(q, D) \) to the market at a price \( p \).
   - The selling period ends: goodwill penalties are paid and leftovers are salvaged.

With regard to the newsvendor situation, the transfer payment is the only parameter that is changed. In the wholesale-price contract, the transfer payment is executed before the selling
period at moment 1. Therefore, the transfer payment should be discounted with the risk-free rate \( r_{f1} \) only. The transfer payment becomes \( T(w, q) = \frac{wq}{1+r_{f1}} \). The other costs and cash flows remain unchanged. Based on the information it is possible to determine the uncertain cash flows for the retailer and supplier, respectively: \( \tilde{f}_r = (p-v+g_r)S(q) + vq - g_r \mu \) and \( \tilde{f}_s = g_s \mu - g_s S(q) \). Furthermore, it is required to make some additional assumptions with regard to the newsvendor situation:

1. \( \frac{w}{1+r_{f1}} > c_s \), otherwise, the supplier would not be able to make a profit on selling units to the retailer.
2. \( \frac{w}{1+r_{f1}} > \frac{v}{1+r_{f2}} \), otherwise, the retailer would be able to make an infinite profit by salvaging an infinite number of ordered units.
3. \( \frac{w}{1+r_{f1}} < \frac{p}{1+r_{f2}} - \frac{c_v}{1+r_{f1}} \), otherwise, the retailer would not be able to make a profit on selling units.

Using these assumptions, the assumptions introduced in the newsvendor model, and the transfer payment, it is possible to determine the present values of the expected profit of the retailer and supplier:

\[
PV_r(EP_r(q)) = \frac{1}{1+r_{f2}} \left[ \tilde{f}_r - \lambda_m \text{Cov}(\tilde{f}_r, r_m) \right] - \frac{(c_r + w)q}{1+r_{f1}} \tag{4.12}
\]

\[
PV_s(EP_s(q)) = \frac{wq}{1+r_{f1}} - \frac{1}{1+r_{f2}} \left[ \tilde{f}_s + \lambda_m \text{Cov}(\tilde{f}_s, r_m) \right] - c_s q \tag{4.13}
\]

Since no changes are made to the uncertain cash flow, the way of determining the covariance remained the same: \( \text{Cov}(\tilde{f}_r, r_m) = (p-v+g_r)\text{Cov}(D, r_m)F(q) \) and \( \text{Cov}(\tilde{f}_s, r_m) = g_s \text{Cov}(D, r_m)F(q) \). Literature assuming risk-neutral members showed that it is not possible to coordinate a supply chain with a wholesale-price contract. Despite, a lot of researchers did investigate the wholesale-price contract as it is a commonly observed contract in practice. One benefit of the contract is that it is simple to administer. As a result, it might be favorable over other contracts. Therefore, this report also investigated if the wholesale-price contract is able to coordinate the supply chain with risk-averse members. In addition, a numerical example is used to demonstrate the differences between the supply chains with risk-neutral and risk-averse members. This numerical example can be found in chapter 5.

To see if coordination is possible, the optimal order quantity of the retailer is determined. Since it is assumed that \( PV_r(EP_r(q^*)) > 0 \) and that \( F \) is strictly increasing, it is shown that \( PV_r(EP_r(q^*))' \) is strictly decreasing and \( PV_r(EP_r(q^*))'' \) is negative for a positive \( q \). As a result, \( PV_r(EP_r(q^*)) \) is strictly concave in \( q \). Therefore, the retailer’s optimal order quantity should satisfy:

\[
\frac{1}{1+r_{f2}} \left[ ((p-v+g_r)S'(q) + v) - \lambda_m (p-v+g_r)f(q)\text{Cov}(D, r_m) \right] - \frac{w + c_r}{1+r_{f1}} = 0 \tag{4.14}
\]

Since \( S'(q) \) is decreasing, the optimal order quantity of the retailer is only equal to that of the supply chain \( (q^* = q^0) \) if:

\[
\frac{w}{1+r_{f1}} = \frac{p-v+g_r}{p-v+g_r} \left( c - \frac{v}{1+r_{f2}} \right) - \frac{c_r}{1+r_{f1}} - \frac{v}{1+r_{f2}} \tag{4.15}
\]

To align the retailer’s optimal order quantity with the supply chain’s, the equation should be satisfied. However, it is assumed that \( c = c_s + \frac{c_r}{1+r_{f1}} \), \( g = g_s + g_r \) and that \( \frac{p}{1+r_{f2}} > c > \frac{v}{1+r_{f2}} \). These assumptions result in \( 0 \leq \frac{p-v+g_r}{p-v+g_r} \leq 1 \), which in return results in the fact that \( \frac{w}{1+r_{f1}} \leq c_s \).
This results in the fact that the supplier is not able to make a profit by selling units. When the wholesale price would be higher, the retailer’s optimal order quantity would not equal the supply chain’s optimal quantity. In addition, when the order quantities were aligned, the supplier would not make a profit and has an incentive to change its behavior. Thus, the following theorem can be developed:

**Theorem 1** - The wholesale-price contract is not able to coordinate the supply chain with risk-averse members.

The derivations of the equations and the proof of this Theorem can be found in Appendix B. This Theorem is in accordance with literature that investigated risk-neutral supply chains. As in the risk-neutral situation, the wholesale-price contract is not able to coordinate the supply chain. However, since the wholesale-price contract is a widely used contract in practice, in this master thesis it is used as the 'current situation’. The 'current situation’ is used in the numerical example as a starting point. This starting point is needed to determine whether members would have an incentive to change behavior or not.

### 4.6 Buyback contract

As explained in the previous chapter, the buyback contract offers the opportunity to the retailer to sell unsold items back to the supplier for a buyback price \( b \). Although the supplier is 'buying back' the unsold items, it does not have to mean that the items are physically returning to the supplier. Therefore, it is assumed that the retailer salvages the leftover inventory and gets an additional \( b \) from the supplier for each unsold item. Thus, the sequence of events can be described as follows:

1. Prior to or at moment 0
   - The supplier and retailer have to agree on a wholesale price and buyback price.
   - The retailer orders a quantity \( q \in [0, \infty) \) from the supplier.
   - The supplier produces the units at a cost \( c_s \). It is assumed that transportation costs are also included in these costs.

2. At moment 1
   - The retailer receives the order quantity and incurs a marginal cost per unit \( c_r \).
   - The retailer pays \( wq \) to the supplier.

3. At moment 2
   - The retailer sold a number of \( \min(q, D) \) to the market at a price \( p \).
   - The selling period ends: goodwill penalties are paid and leftovers are salvaged.
   - The supplier pays \( b \) per unit to the retailer for remaining items.

Again, the only adjustment with regard to the newsvendor situation is made for the transfer payment. As one can see, the transfer payment consists out of two payments. First, the retailer pays the supplier \( w \) per unit at moment 1. The transfer payment is only dependent on the ordered quantity. As a result, the first part of the transfer payment is described by \( T(q, w, b) = \frac{wq}{1 + r_f} \). Second, the supplier pays the retailer \( b \) per unit of leftovers at moment 2. The number of leftovers is dependent on the number of sales. As a result, the second part is uncertain and should be discounted as \( T(q, w, b) = \frac{1}{1 + r_f} [bI(q) - \lambda_m Cov(bI(q), r_m)] \). Based on the information it is possible to determine the uncertain cash flows for the retailer and supplier, respectively:

\[ \tilde{f}_r = (p - v - b + g_r)S(q) + (b + v)q - g_r \mu \] and

\[ \tilde{f}_s = bq + g_s \mu - (b + g_s)S(q) \]. In comparison to
the previous contracts, the multiplier of the uncertain part has been changed for both uncertain cash flows. However, as one can see, the structure of the uncertain cash flow remained the same: there is an uncertain part dependent on the number of sales and a certain part. As a result, the covariance of the uncertain cash flow with the market return can still be determined as it is done in Anvari’s model. Last, in the buyback contract, an extra assumption in comparison to the wholesale-price contract is needed:

1. \( \frac{b+v}{1+r_{f_2}} \leq \frac{w}{1+r_{f_1}} \), otherwise, the retailer is able to make a profit by salvaging units. This would result in the retailer ordering an infinite number of units, which could be salvaged for an infinite profit.

Based on the information given above, it is possible to determine the present values of the expected profit for the retailer and supplier, respectively:

\[
P_V(r(EP_r(q))) = \frac{1}{1 + r_{f_2}} [\bar{f}_r - \lambda_m \text{Cov}(\bar{f}_r, r_m)] - \frac{(c_r + w)q}{1 + r_{f_1}}
\]

\[
P_V(s(EP_s(q))) = \frac{wq}{1 + r_{f_1}} - \frac{1}{1 + r_{f_2}} [\bar{f}_s + \lambda_m \text{Cov}(\bar{f}_s, r_m)] - c_s q - \frac{1}{1 + r_{f_2}} [(p-v-b+g_r)S'(q) + (b+v)] - \lambda_m (p-v-b+g_r) \text{Cov}(D, r_m) - \frac{w + c_r}{1 + r_{f_1}} = 0
\]

In which \( \text{Cov}(\bar{f}_r, r_m) = (p-v-b+g_r)\text{Cov}(D, r_m)F(q) \) and \( \text{Cov}(\bar{f}_s, r_m) = (b+g_s)\text{Cov}(D, r_m)F(q) \). To achieve coordination, the contract should align the optimal order quantities of the retailer with the supply chain’s. In addition, none of the members should have an incentive to change its behavior. To see if coordination is possible, the optimal order quantity for the retailer is determined. Since it is assumed that \( P_V(r(EP_r(q^*)) > 0 \) and that \( F \) is strictly increasing, it is shown that \( P_V(r(EP_r(q^*)) \) is strictly decreasing and \( P_V(r(EP_r(q)^{*})) \) is negative for a positive \( q \). As a result, \( P_V(r(EP_r(q))) \) is strictly concave in \( q \). Thus, it is known that the retailer’s optimal order quantity should satisfy:

\[
\frac{1}{1 + r_{f_2}} [(p-v-b+g_r)S'(q) + (b+v)] - \lambda_m (p-v-b+g_r) \text{Cov}(D, r_m) - \frac{w + c_r}{1 + r_{f_1}} = 0
\]

Since \( S'(q) \) is decreasing, the optimal order quantity of the retailer is only equal to that of the supply chain when:

\[
\frac{w}{1 + r_{f_1}} = \frac{p-v-b+g_r}{p-v+g} (c_r - \frac{v}{1 + r_{f_2}}) - (\frac{c_r}{1 + r_{f_1}} - \frac{v}{1 + r_{f_2}}) + \frac{b}{1 + r_{f_2}}
\]

The derivation for this wholesale price can be found in Appendix B. When both members agree on a wholesale price and buyback price such that the equation is satisfied, then the retailer’s optimal order quantity equals the supply chain’s optimal order quantity. It is assumed that \( c = c_s + \frac{c_r}{1+r_{f_1}}, g = g_s + g_r, \) that \( \frac{p}{1+r_{f_2}} > c > \frac{v}{1+r_{f_2}} \) and \( \frac{b+v}{1+r_{f_2}} < \frac{w}{1+r_{f_2}} < \frac{p}{1+r_{f_2}} \), which results in \( 0 \leq \frac{p-v-b+g_r}{p-v+g} \leq 1 \). Thus, in order to achieve coordination, the following condition should be satisfied:

\[
\frac{b}{1+r_{f_2}} \geq (1 - \frac{p-v-b+g_r}{p-v+g}) (c_s + \frac{c_r}{1+r_{f_1}} - \frac{v}{1+r_{f_2}}).
\]

Otherwise, the wholesale-price must be smaller than \( c_s \) to satisfy the function of the wholesale-price described above. As a result, the supplier will not be able to make a profit and has an incentive to change its behavior. It seems that (in most situations) multiple combinations are able to satisfy both conditions. The combinations function as a risk-sharing mechanism as they differently allocate the present values of the expected profit. The agreement on the combination of a buyback price and a wholesale price should lead to an allocation that results in both members being better off than in their current situation. Thus, the following theorem can be developed:

**Theorem 2** - The buyback contract is able to coordinate the supply chain with risk-averse members.
The derivations of the equations and the proof of Theorem 2 can be found in Appendix B. The theorem is in accordance with literature that investigated risk-neutral supply chains. The buyback contract is able to coordinate the supply chain with both risk-neutral and risk-averse members. This is the result of the risk-sharing function that occurred by implementing the contract. Changing the pricing policy results in different present values of the expected profits for both the retailer and the manufacturer. In the numerical example, the differences between the risk-neutral and risk-averse situation are numerically demonstrated.

4.7 Revenue-sharing contract

As explained in the previous chapter, in a revenue-sharing contract the retailer agrees to share a percentage $\Phi$ of its revenue with the supplier at the cost of a lower wholesale price $w$. Thus, the retailer and supplier have to agree on a wholesale price and a shared percentage which are able to coordinate the supply chain. $\Phi$ is the percentage of the revenue that is kept by the retailer, and $(1 - \Phi)$ is the percentage of the revenue that is given to the supplier. Thus, the sequence of events can be described as follows:

1. Prior to or at moment 0
   - The supplier and retailer agree on a combination of the wholesale price and shared percentage.
   - The retailer orders a quantity $q \in [0, \infty)$ from the supplier.
   - The supplier produces the units at a cost $c_s$. It is assumed that transportation costs are also included in these costs.

2. At moment 1
   - The retailer receives the order quantity and incurs a marginal cost per unit $c_r$.
   - The retailer pays $wq$ to the supplier.

3. At moment 2
   - The retailer sold a number of $\min(q, D)$ to the market at a price $p$.
   - The selling period ends: goodwill penalties are paid and leftovers are salvaged.
   - The retailer pays $1 - \Phi$ of its revenues to the supplier.

As one can see, the transfer payment consists of two payments that are made. First, the retailer pays the supplier $w$ per unit at moment 1 and is only dependent on the ordered quantity. As a result, the first part of the transfer payment is described by $T(q, w, \Phi) = \frac{wq}{1+f}$. Second, the retailer pays a shared percentage $\Phi$ of its revenues to the supplier at moment 2. The revenues are dependent on the number of sales. As a result, the second part of the transfer payment is described by $T(q, w, \Phi) = \frac{1+r_m}{(1-\Phi)vI(q) + (1-\Phi)pS(q)) - \lambda_m\text{Cov}((1-\Phi)vI(q) + (1-\Phi)pS(q), r_m)}$. Based on the information it is possible to determine the uncertain cash flows for the retailer and supplier, respectively: $\tilde{f}_r = (\Phi p - \Phi v + g_r)S(q) + \Phi wq - g_r \mu$ and $\tilde{f}_s = ((1-\Phi)(p-v) + g_s)S(q) + (1-\Phi)wq - g_s \mu$. As in the buyback contract, the multiplier of the uncertain part has been changed for both uncertain cash flows. Again, the structure of the uncertain cash flow remains the same. As a result, the method of determining the covariance of the uncertain cash flow with the market return can still be done as in Anvari’s model. In addition, several adjustments to the assumptions in the wholesale-price contract are made:

1. The assumption that the wholesale price should be larger than the supplier’s cost per unit is ignored.
2. \( \frac{w}{1+r_{f_1}} + \frac{(1-\Phi)p}{1+r_{f_2}} > c_s \), otherwise, the supplier would not be able to make a profit on selling units to the retailer.

3. \( \frac{w+c_s}{1+r_{f_1}} < \frac{\Phi p}{1+r_{f_2}} \), otherwise, the retailer would not be able to make a profit on selling units.

4. \( \frac{w}{1+r_{f_1}} > \frac{\Phi v}{1+r_{f_2}} \), otherwise, the retailer would be able to make an infinite profit by salvaging units.

Based on the information above it is possible to develop the functions for the present value of expected profit for both the retailer and supplier, respectively:

\[
P V_{r}(EP_{r}(q)) = \frac{1}{1+r_{f_2}}[\tilde{f}_r - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}} \tag{4.20}
\]

\[
P V_{s}(EP_{s}(q)) = wq + \frac{1}{1+r_{f_2}}[\tilde{f}_s - \lambda_m \text{Cov}(\tilde{f}_s, r_m)] - c_sq \tag{4.21}
\]

In which \( \text{Cov}(\tilde{f}_r, r_m) = (\Phi p - \Phi v + g_r)\text{Cov}(D, r_m)F(q) \) and \( \text{Cov}(\tilde{f}_s, r_m) = ((1-\Phi)(p-v) - s_g)\text{Cov}(D, r_m)F(q) \). To achieve coordination, the contract should align the optimal order quantities. In addition, none of the members should have an incentive to change its behavior. To see if coordination is possible, the optimal order quantity for the retailer is determined. Since it is assumed that \( PV_{r}(EP_{r}(q^*)) > 0 \) and that \( F \) is strictly increasing, it is shown that \( PV_{r}(EP_{r}(q))' \) is strictly decreasing and \( PV_{r}(EP_{r}(q))'' \) is negative for a positive \( q \). As a result, \( PV_{r}(EP_{r}(q)) \) is strictly concave in \( q \). Thus, it is known that the retailer’s optimal order quantity should satisfy:

\[
\frac{1}{1+r_{f_2}}[(\Phi p - \Phi v + g_r)S'(q) + \Phi v - \lambda_m(\Phi p - \Phi v + g_r)f(q)\text{Cov}(D, r_m)] - \frac{w + c_r}{1 + r_{f_1}} = 0 \tag{4.22}
\]

Since \( S'(q) \) is decreasing, the wholesale price should satisfy the following equation in order to achieve coordination:

\[
\frac{w}{1+r_{f_1}} = \frac{\Phi p - \Phi v + g_r}{p-v+g_r}(c - \frac{v}{1+r_{f_2}}) - \frac{c_r}{1+r_{f_1}} - \frac{\Phi v}{1+r_{f_2}} \tag{4.23}
\]

The derivation of the wholesale price can be found in Appendix B. One can see that coordination is only possible when \( w \leq c_s \). Otherwise, the shared percentage does not have a natural interpretation. It is assumed that \( c = c_s + \frac{c_r}{1+r_{f_2}} \), \( g = g_s + g_r \), that \( \frac{p}{1+r_{f_2}} > c > \frac{v}{1+r_{f_2}} \), and that \( 0 \leq \Phi \leq 1 \). So, the function for the wholesale-price in the revenue-sharing contract, is quite the same as in the wholesale-price contract. However, in the revenue-sharing contract it is allowed to have a wholesale-price lower than \( c_s \). In this contract, it is possible to coordinate the supply chain only if both parties do not have an incentive to change their behavior and if the payoff is greater than their reservation payoff. In addition, the combination of a wholesale-price and a shared percentage should also achieve both \( \frac{w}{1+r_{f_1}} + \frac{(1-\Phi)p}{1+r_{f_2}} > c_s \) and \( \frac{w+c_r}{1+r_{f_2}} < \frac{\Phi p}{1+r_{f_2}} \). Thus, as long as the wholesale price equation is reached and both members do not have an incentive to change behavior, the following can be said:

**Theorem 3 -** The revenue-sharing contract is able to coordinate the supply chain with risk-averse members.

The derivations of the equations and the proof of Theorem 3 can be found in Appendix B. The theorem is in accordance with literature that investigated risk-neutral supply chains. By sharing the risk of the uncertain cash flow, it is possible to coordinate the supply chain. In the revenue-sharing contract, this risk is shared by offering a lower wholesale price in return for a
percentage of the revenue gained at the retailer. Changing the pricing policy results in different present values of the expected profits for both the retailer and the manufacturer. In the numerical example, the differences between the risk-neutral and risk-averse situation are numerically demonstrated.
Chapter 5

Numerical example

In the previous chapters, the supply chain models for situations with risk-neutral and risk-averse members are elaborated. Although the models are different, the supply chain models with risk-averse members gave the same conclusions as to the supply chain models with risk-neutral members. However, incorporating risk in the supply chain models lead to different outcomes. For example, the models have different optimal order quantities. To show these differences, a numerical example is used. The example is first applied to contracts in the risk-neutral environment, after which it is applied to the risk-averse environment. For each contract, the coordinating order quantity and corresponding (present value of the) expected profits are given. The newsvendor situation is used to analyze the supply chain’s optima.

The numerical example that is used is shown in table 5.1 below and is inspired by Anvari (1987) and Birge (2014):

Table 5.1: Parameters numerical example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Supplier</th>
<th>Retailer</th>
<th>Supply Chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand distribution</td>
<td>-</td>
<td>$N(10000, 2500)$</td>
<td>$N(10000, 2500)$</td>
</tr>
<tr>
<td>Cost per unit</td>
<td>$c_s = 50$</td>
<td>$c_r = 20$</td>
<td>$c = 70$</td>
</tr>
<tr>
<td>Goodwill cost per unit</td>
<td>$g_s = 5$</td>
<td>$g_r = 20$</td>
<td>$g = 25$</td>
</tr>
<tr>
<td>Salvage value per unit</td>
<td>$v_s = 0$</td>
<td>$v_r = 30$</td>
<td>$v = 30$</td>
</tr>
<tr>
<td>Retail price per unit</td>
<td>-</td>
<td>$p = 200$</td>
<td>$p = 200$</td>
</tr>
<tr>
<td>Risk-free rate per year $r_f$</td>
<td>$r_f = 0.06$</td>
<td>$r_f = 0.06$</td>
<td>$r_f = 0.06$</td>
</tr>
<tr>
<td>Market risk premium $\lambda_M$</td>
<td>$\lambda_M$</td>
<td>$\lambda_M$</td>
<td>$\lambda_M$</td>
</tr>
<tr>
<td>Correlation coefficient $\rho_{D,M}$</td>
<td>$\rho_{D,M}$</td>
<td>$\rho_{D,M}$</td>
<td>$\rho_{D,M}$</td>
</tr>
<tr>
<td>Market deviation $\sigma_m$</td>
<td>$\sigma_m$</td>
<td>$\sigma_m$</td>
<td>$\sigma_m$</td>
</tr>
</tbody>
</table>

With regard to the risk-free rate, an additional assumption is made. It is assumed that the risk-free rate is 6% per year and is fixed over time. In addition, the time between moment 0 and 1 is assumed to be three months, and the time between 1 and 2 is assumed to be six months. Therefore, the risk-free rate used at moment 1 equals $r_{f_1} = (1 + r_f)^{0.25} - 1$ and at moment 2 $r_{f_2} = (1 + r_f)^{0.75} - 1$.

5.1 Risk-neutral environment

Newsvendor situation

To achieve coordination, the optimal order quantity of the retailer should be aligned with the optimal order quantity for the supply chain. As explained in section 3.1, the optimal order quantity for the supply chain can be found by using the following formula:

$$F(g^*) = \frac{p + g - c}{p + g - v} = \frac{200 + 25 - 70}{200 + 25 - 30} = 0.7949$$
The relative high fraction shows that the cost of lost sales are higher than the costs of inventory. Taking the demand distribution into account ($D = \mathbb{N}(10000, 2500)$), it is found that the optimal order quantity for the supply chain in the risk-neutral environment is $q^* = 12,059$. Thus, to coordinate the supply chain the retailer’s optimal order quantity $q^*$ should equal 12,059 as well. Using an order quantity of 12,059, the supply chain faces an expected profit equal to $EP_{SC} = 1,161,441$.

Wholesale-price contract

The coordinating order quantity and the profit functions in the wholesale-price contract are known: $EP_r(q) = (p-v+g_r)vS(q) - (w+c_s-v)q - g_r\mu$ and $EP_s(q) = g_sS(q) + (w-c_s)q - g_s\mu$. This information is needed to determine whether the contract is able to coordinate the supply chain. Although it is known that the wholesale-price contract is not able to coordinate the supply chain, it is analyzed for two reasons. First, it is analyzed to show the quantitative differences between the implementation of the wholesale-price contract in the risk-neutral environment and the risk-averse environment. Second, it is analyzed to be used as a starting point. The wholesale-price contract is often used in practice. Therefore, this master thesis used the contract as the ‘current situation’. Using the Matlab script in Appendix C it was possible to analyze the contract. To satisfy the assumptions, the wholesale price is analyzed in the range of $c_s + 1 < w < p - 1$, with an increasing step of 1. For further notice, it is assumed that both members have to face a positive expected profit. Otherwise, no units will be delivered or ordered. The analysis results in Table 5.2.

Table 5.2: Numerical example risk-neutral wholesale-price contract

<table>
<thead>
<tr>
<th>Optimal strategy</th>
<th>$w$</th>
<th>$q$</th>
<th>$EP_r(q)$</th>
<th>$EP_s(q)$</th>
<th>$EP_{SC}(q)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>for the retailer</td>
<td>51</td>
<td>11,966</td>
<td>1,150,918</td>
<td>10,428</td>
<td>1,161,345</td>
</tr>
<tr>
<td>for the supplier</td>
<td>168</td>
<td>7,599</td>
<td>521</td>
<td>883,548</td>
<td>884,068</td>
</tr>
</tbody>
</table>

Table 5.2 shows that it is best for the retailer to have the lowest possible wholesale price. It makes sense because with a lower wholesale price the retailer’s margin is higher. However, it does not result in an optimal order quantity for the retailer that equals the supply chain’s. In addition, table 5.2 shows that for the supplier, it is more beneficial to have a high wholesale price. It also makes sense because a higher wholesale price results in a higher margin for the supplier. However, this higher wholesale price leads to an inefficient supply chain. The expected profit for the whole supply chain is much lower than in the coordinating situation. To create a starting point it is assumed that none of the members has a monopoly position and the wholesale price is the mean of both optima $w = 110$. Using a wholesale price of $w = 110$ results in $q^* = 9,835$ and the following expected profits:

$EP_r(q) = 510,918 \quad EP_s(q) = 584,688 \quad EP_{SC}(q) = 1,095,606$

Buyback contract

In this subsection the implementation of the buyback contract in the risk-neutral environment is discussed. The profit functions for the retailer and supplier are known: $EP_r(q) = (p-v+g_r-b)vS(q) - (w+b+c_r-v)q - g_r\mu$, and $EP_s(q) = (g_s+b)S(q) + (w-b-c_s)q - g_s\mu$. These profit functions are then used in the Matlab script to analyse the buyback contract (see Appendix C). The script is used to determine which combination(s) of the wholesale price and buyback price are able to coordinate the supply chain. The analysis uses a range of the buyback price between 1 and 200, this wide range is used to make sure that each allowed combination is investigated. Furthermore, to achieve coordination the following equations have to be satisfied:

$w = (p + g_r - c_r) - \frac{(p+g_r-v-b)(p+g-c)}{p+g-v}$, $b \leq w$, $EP_r(q) \geq 510,918$, and $EP_r(q) \geq 584,688$.

The Matlab script shows that there exist several combinations that achieve coordination. Some of these combinations are shown in Table 5.3.
Table 5.3: Numerical example risk-neutral buyback contract

<table>
<thead>
<tr>
<th>( w )</th>
<th>( b )</th>
<th>( q )</th>
<th>( EP_r(q) )</th>
<th>( EP_s(q) )</th>
<th>( EP_{SC}(q) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>114.95</td>
<td>83</td>
<td>12,059</td>
<td>574,483</td>
<td>586,958</td>
<td>1,161,441</td>
</tr>
<tr>
<td>115.74</td>
<td>84</td>
<td>12,059</td>
<td>567,244</td>
<td>594,196</td>
<td>1,161,441</td>
</tr>
<tr>
<td>120.51</td>
<td>90</td>
<td>12,059</td>
<td>523,816</td>
<td>637,624</td>
<td>1,161,441</td>
</tr>
<tr>
<td>121.31</td>
<td>91</td>
<td>12,059</td>
<td>516,578</td>
<td>644,863</td>
<td>1,161,441</td>
</tr>
</tbody>
</table>

Table 5.3 shows that coordination can be achieved with multiple combinations of a buyback price and a wholesale price. In this numerical example, it is possible to coordinate the supply chain with a buyback price in the range of \( 83 \leq b \leq 91 \) in combination with a wholesale price that is determined by \( w = (p + g_r - c_r) - \frac{\Phi (p + g_r - c_r)(x - b)}{p + g_r - v - c_r} \). As explained before, the used policy determines the allocation for the (increased) expected profits. For example, the combination of \( b = 83 \) and \( w = 114.95 \) increases the retailer’s expected profit with 63,565 and the supplier’s expected profit with 2,270, while the combination of \( b = 91 \) and \( w = 121.31 \) increases the retailer’s expected profit with 5,660 and the supplier’s expected profit with 60,175. In this numerical example, the implementation of the buyback contract could increase the total the supply chain’s expected profit with 65,835, when no extra costs arise. However, as said before the implementation of supply chain contracts most likely involve extra cost, e.g. the cost of administrating the units that have to be bought back.

**Revenue-sharing contract**

In this subsection the revenue-sharing contract in the risk-neutral environment is discussed. The profit functions for the retailer and supplier are known: \( EP_r(q) = (\Phi(p - v) + g_r)S(q) - (w + c_r - \Phi v)q - g_r \mu \) and \( EP_s(q) = (g_s + (1 - \Phi)(p - v))S(q) + (w + (1 - \Phi)v - c_s)q - g_s \mu \). These profit functions are then used in the Matlab script to analyse the revenue-sharing contract (see Appendix C). The script is used to determine the combinations of a shared percentage \( \Phi \) and wholesale price. In the revenue-sharing contract the assumption that \( w > c_s \) is relaxed which makes it possible to use a range of \( 0 \leq \Phi \leq 1 \) for the shared percentage. Within the range an increasing step of 1% is used. To achieve coordination the following equations should be satisfied: \( w = (\Phi p + g_r - c_r) - \frac{\Phi (p + g_r - c_r)(\Phi p + g_r - c_r)}{p + g_r - v}, w + (1 - \Phi)p > c_r, w + c_r < \Phi p, \) and \( w > \Phi v \). In addition, no member should have an incentive to deviate its behavior. It results in the following equations that should be satisfied \( EP_r(q) \geq 510,918, \) and \( EP_r(q) \geq 584,688. \) This results in five combinations, which can be found in table 5.4.

Table 5.4: Numerical example risk-neutral revenue-sharing contract

<table>
<thead>
<tr>
<th>( w )</th>
<th>( \Phi )</th>
<th>( q )</th>
<th>( EP_r(q) )</th>
<th>( EP_s(q) )</th>
<th>( EP_{SC}(q) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.59</td>
<td>0.47</td>
<td>12,059</td>
<td>523,092</td>
<td>638,349</td>
<td>1,161,441</td>
</tr>
<tr>
<td>15.24</td>
<td>0.48</td>
<td>12,059</td>
<td>535,397</td>
<td>626,044</td>
<td>1,161,441</td>
</tr>
<tr>
<td>15.89</td>
<td>0.49</td>
<td>12,059</td>
<td>547,702</td>
<td>613,739</td>
<td>1,161,441</td>
</tr>
<tr>
<td>16.54</td>
<td>0.50</td>
<td>12,059</td>
<td>560,007</td>
<td>601,434</td>
<td>1,161,441</td>
</tr>
<tr>
<td>17.19</td>
<td>0.51</td>
<td>12,059</td>
<td>572,311</td>
<td>589,129</td>
<td>1,161,441</td>
</tr>
</tbody>
</table>

Table 5.4 shows that coordination can be achieved with five different combinations of a shared percentage and wholesale price. In this numerical example, it is possible to coordinate the supply chain with a shared percentage in the range of \( 0.47 \leq \Phi \leq 0.51 \) in combination with a wholesale price that is determined by \( w = (\Phi p + g_r - c_r) - \frac{\Phi (p + g_r - c_r)(\Phi p + g_r - c_r)}{p + g_r - v} \). This model first chooses a shared percentage and based on the shared percentage the wholesale price is determined. As long as the equations for \( w \) and \( \Phi \) are satisfied, it could be analysed the other way around as well. The allocation of the (increased) expected profits is determined by the
contract policy that is used. For example, the combination of $\Phi = 0.47$ and $w = 14.59$ increases the retailer’s expected profit with 12,174 and the supplier’s expected profit with 53,661, while the combination of $\Phi = 0.51$ and $w = 17.19$ increases the retailer’s expected profit with 61,393 and the supplier’s expected profit with 4441. In this numerical example, the implementation of the revenue-sharing contract could increase the total supply chain’s expected profit with 65,835, when no extra costs arise. However, as said before the implementation of supply chain contracts most likely involve extra cost, e.g. the cost of fairly and properly administrating the revenues.

5.2 Risk-averse environment

Newsvendor situation

To achieve coordination, the optimal order quantity of the retailer should be aligned with the optimal order quantity for the supply chain. As explained in section 4.4, the optimal order quantity for the supply chain can be found by using the following equation:

$$F(q^o) + \lambda_m f(q^o) \text{Cov}(D, r_m) = \frac{p + g - c(1 + r_{f_2})}{p - v + g}$$

In the risk-neutral environment, it was easier to determine $q$. However, for the risk-averse environment, a Matlab script is used (see Appendix C). This Matlab script is able to determine the order quantity such that the equation is satisfied. Taking the parameters of the numerical example into account, it is found that $q^o = 7,964$. Thus, the contracts should be able to make the optimal order quantity for the retailer $q^* = q^o = 7,964$. Ordering the optimum, the supply chain faces a present value of the expected profit equal to $PV_{SC}(EP_{SC}(7,964)) = 672,253$.

Wholesale-price contract

The coordinating order quantity is found and the profit functions in the risk-averse environment are known: $PV_r(EP_r(q)) = \frac{1}{1+r_{f_2}}[(pS(q) + vI(q) - g_rL(q)) - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_v)q}{1+r_{f_1}}$ and $PV_s(EP_s(q)) = \frac{wq}{1+r_{f_1}} - \frac{1}{1+r_{f_2}}(g_sL(q) + \lambda_m \text{Cov}(\tilde{f}_s, r_m)) - c_sq$, respectively. In the previous chapter it is shown that the wholesale-price contract is not able to coordinate the supply chain with risk-averse members. However, as wholesale-price contracts are often used in practice, it is assumed as a starting point. The wholesale-price contract is reviewed by means of the Matlab script (see Appendix C) to determine the current position. To satisfy the assumptions, the wholesale price is analysed in the range of $c_s + 1 \leq w \leq \frac{p}{1+r_{f_2}} - \frac{c_l}{1+r_{f_1}}$ with an increasing step of 1. In addition, it is assumed that when either one of the members faces a negative present value of the expected profit, there will no units be delivered or ordered. This results in table 5.5.

<table>
<thead>
<tr>
<th>Optimal strategy</th>
<th>$w$</th>
<th>$q$</th>
<th>$PV(EP_r(q))$</th>
<th>$PV(EP_s(q))$</th>
<th>$PV(EP_{SC}(q))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>for the retailer</td>
<td>53</td>
<td>7,904</td>
<td>670,681</td>
<td>1,471</td>
<td>672,152</td>
</tr>
<tr>
<td>for the supplier</td>
<td>151</td>
<td>5,741</td>
<td>1,592</td>
<td>545,714</td>
<td>547,305</td>
</tr>
</tbody>
</table>

As in the risk-neutral environment, it is optimal for the retailer to have the lowest wholesale price and for the supplier to have a much higher wholesale price. With a low wholesale price the retailer has a large margin, with a high wholesale price the supplier has a large margin. As done in the risk-neutral environment, a starting point is determined. Again it is assumed that none of the members has a monopoly position and the wholesale price is determined by the mean of both optima. When it is assumed that in the starting position the wholesale price is $w = 102$, the order quantity is $q = 6,975$ and is used to determine the starting points:

$$PV(EP_r(q)) = 310,919 \quad PV(EP_s(q)) = 334,557 \quad PV(EP_{SC}(q)) = 645,476$$
Buyback contract

In this subsection the buyback contract in the risk-averse environment is discussed. The profit function for the retailer and supplier are known: $PV_r(EP_r(q)) = \frac{1}{1+r_{f_2}} ((pS(q) + (v + b)I(q) - g_rL(q)) - \lambda_mCov(\tilde{f}_r, r_m)) - \frac{(w + c_r)q}{1+r_{f_1}}$ and $PV_s(EP_s(q)) = \frac{wq}{1+r_{f_1}} - \frac{1}{1+r_{f_2}} ((bI(q) + g_sL(q)) + \lambda_mCov(\tilde{f}_s, r_m)) - c_s q$. These profit functions are then used in the Matlab script to analyse the buyback contract with risk-averse members (see Appendix C). The script is used to determine the combination(s) of wholesale price and buyback price that coordinate the supply chain. The buyback price is analysed in the range of 1 and 200 with an increasing step of 1. This range is used to make sure that possible combinations are investigated. To achieve coordination, the following equations have to be satisfied: $rac{w}{1+r_{f_1}} = \frac{w-v-b+g_r(c-v)}{p-v+g} - (\frac{c_r}{1+r_{f_2}} - \frac{v}{1+r_{f_2}}) + \frac{b}{1+r_{f_2}}$, $\frac{b}{1+r_{f_2}} \leq \frac{w}{1+r_{f_1}}$, $PV(EP_r(q)) \geq 310,919$, and $PV(EP_s(q)) \geq 334,557$. This results in six combinations, which can be found in table 5.6.

<table>
<thead>
<tr>
<th>$w$</th>
<th>$b$</th>
<th>$q$</th>
<th>$PV(EP_r(q))$</th>
<th>$PV(EP_s(q))$</th>
<th>$PV(EP_{SC}(q))$</th>
</tr>
</thead>
<tbody>
<tr>
<td>108.03</td>
<td>77</td>
<td>7,964</td>
<td>336,791</td>
<td>335,462</td>
<td>672,253</td>
</tr>
<tr>
<td>108.79</td>
<td>78</td>
<td>7,964</td>
<td>332,117</td>
<td>340,137</td>
<td>672,253</td>
</tr>
<tr>
<td>109.55</td>
<td>79</td>
<td>7,964</td>
<td>327,442</td>
<td>344,811</td>
<td>672,253</td>
</tr>
<tr>
<td>110.31</td>
<td>80</td>
<td>7,964</td>
<td>322,767</td>
<td>349,486</td>
<td>672,253</td>
</tr>
<tr>
<td>111.06</td>
<td>81</td>
<td>7,964</td>
<td>318,092</td>
<td>354,161</td>
<td>672,253</td>
</tr>
<tr>
<td>111.82</td>
<td>82</td>
<td>7,964</td>
<td>313,418</td>
<td>358,835</td>
<td>672,253</td>
</tr>
</tbody>
</table>

In accordance with the Theorem, table 5.6 shows that coordination can be achieved in the risk-averse environment. The table shows that there are six different policies for the buyback contract to coordinate the supply chain. In this numerical example, it is possible to coordinate the supply chain with a buyback price in the range of 77 ≤ $b$ ≤ 82 in combination with a wholesale price that is determined by $\frac{w}{1+r_{f_1}} = \frac{w-v-b+g_r(c-v)}{p-v+g} - (\frac{c_r}{1+r_{f_2}} - \frac{v}{1+r_{f_2}}) + \frac{b}{1+r_{f_2}}$. Within the table one can see that the combination of a wholesale price and a buyback price determines the allocation of the benefits of the contract. Since coordination can be achieved, the implementation of the buyback contract increases the present value of the supply chain’s expected profit with 26,777. So, the extra present value of the implementation costs of the contract should be smaller than 26,777 in order for the contract to be beneficial.

Revenue-sharing contract

In this subsection the revenue-sharing contract in the risk-averse environment is discussed. The implementation of the revenue-sharing contract results in the following functions for the present value of the expected profit of the retailer and supplier, respectively: $PV_r(EP_r(q)) = \frac{1}{1+r_{f_2}} [(\Phi p S(q) + \Phi v I(q) - g_r L(q)) - \lambda_m Cov(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1+r_{f_1}}$ and $PV_s(EP_s(q)) = \frac{wq}{1+r_{f_1}} - \frac{1}{1+r_{f_2}} [(1 - \Phi) p S(q) + (1 - \Phi) v I(q) - g_s L(q)) - \lambda_m Cov(\tilde{f}_s, r_m)] - c_s q$. The revenue-sharing contract is analysed by means of the Matlab script in Appendix C. The Matlab script is used to determine the combination(s) of a shared percentage and wholesale price that are able to coordinate the supply chain. The shared percentage is analysed in the range of 0 ≤ $\Phi$ ≤ 1, with increasing steps of 1%. To achieve coordination, the following equations have to be satisfied: $\frac{w}{1+r_{f_1}} = \frac{\Phi p - \Phi v + \Phi g_r (c - \frac{v}{1+r_{f_2}} - \frac{\Phi v}{1+r_{f_2}})}{p-v+g} - (\frac{c_r}{1+r_{f_2}} - \frac{\Phi v}{1+r_{f_2}})$, $\frac{w}{1+r_{f_1}} + (1-\Phi)q > \frac{w+c_r}{1+r_{f_1}}$, $\frac{w}{1+r_{f_2}} < \frac{\Phi p}{1+r_{f_2}}$, $\frac{w}{1+r_{f_2}} > \frac{\Phi v}{1+r_{f_2}}$. In addition, no member should have the incentive to change its behavior. Thus, the following equations should be satisfied as well: $PV(EP_r(q)) \geq 310,919$, and $PV(EP_s(q)) \geq 334,557$. This results in four combinations, which can be found in table 5.7.
Table 5.7: Numerical example risk-averse revenue-sharing contract

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>PV($E_P(v)$)</th>
<th>PV($E_P(w)$)</th>
<th>PV($E_P_{SC}(q)$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.27</td>
<td>0.52</td>
<td>7,964</td>
<td>315,288</td>
<td>356,965</td>
<td>672,253</td>
</tr>
<tr>
<td>18.93</td>
<td>0.53</td>
<td>7,964</td>
<td>323,235</td>
<td>349,019</td>
<td>672,253</td>
</tr>
<tr>
<td>19.58</td>
<td>0.54</td>
<td>7,964</td>
<td>331,182</td>
<td>341,072</td>
<td>672,253</td>
</tr>
</tbody>
</table>

Table 5.7 shows that coordination can be achieved in a risk-averse environment by using one of the three different policies for the revenue-sharing contract. In this numerical example, it is possible to coordinate the supply chain with a shared percentage in the range of $0.52 \leq \Phi \leq 0.53$ in combination with a wholesale price determined by $\frac{w}{1+r_f} = \frac{\Phi p - \Phi v + v}{p - v + g} \left( c - \frac{v}{1+r_f} \right) - \frac{\phi_v}{1+r_f^2}$. The shared percentage determines the allocation of the benefits of the contract. Again, since coordination can be achieved, the implementation of the revenue-sharing contract increases the present value of the supply chain’s expected profit with 26,777.

5.3 Differences

The numerical example is used to demonstrate differences between the risk-neutral environment and risk-averse environment. The numerical example showed some quantitative differences between both environments:

1. The supply chain model with risk-neutral members is maximizing the member’s expected profit, while the supply chain models with risk-averse members are maximizing the member’s present value of the expected profit. As a result, it is not interesting to compare these values. However, it is interesting to compare the improvements by implementing a supply chain contract that coordinates the supply chain. In the risk-neutral environment, coordinating the supply chain improves the expected profit with $1.161441 - 1.095606 \times 100\% = 6.01\%$. In the risk-averse environment, coordinating the supply chain improves the present value of the expected profit with $\frac{672,253 - 645,476}{645,476} \times 100\% = 4.15\%$. The smaller increase is the result of the fact that the improvement is also discounted.

2. A second quantitative difference can be found in the optimal order quantity. The optimal order quantity in the risk-neutral environment is 12,059 and in the risk-averse environment 7,964. Thus, relaxing the assumption of risk-neutral members of a supply chain results in a decrease of the optimal order quantity. Two reasons are underlying this result. First, the order quantity is positively related to the risk premium that is subtracted from the expected profit. Having a larger order quantity results in a higher risk premium, which in turn decreases the present value of the expected profit (at a certain point). Second, the critical fractile is slightly lower as a result of the introduced risk-free rate. When all other parameters remain the same, the risk-free rate decreases the numerator, while the denominator remains the same. As one can see, the higher the risk-free rate the lower the critical fractile will be. A lower critical fractile results in a lower optimal order quantity. Third, in the risk-neutral environment we got $F(q^o) = \text{critical fractile}$, while in the risk-averse environment we got $F(q^o) + \lambda_m f(q^o) \text{Cov}(D, r_m) = \text{critical fractile}$. Thus, in order to get the same critical fractile, a lower order quantity is needed because of the added value of $\lambda_m f(q^o) \text{Cov}(D, r_m)$. These are results of relaxing the assumption that members of a supply chain are risk-neutral.

3. Table 5.7 shows the combinations of a buyback price and wholesale-price that results in supply chain coordination. The figure shows two differences. First, in this numerical example, the risk-neutral environment has a larger set of supply chain coordination combinations than the risk-averse environment. It is the result of the smaller increase that is achieved in the risk-averse environment. Due to the smaller increase, it is harder to
allocate profit such that the reservation payoffs are reached. Second, the combinations in the risk-averse environment are lower than the combinations in the risk-neutral environment. It can be seen as a compromise for both members: A lower wholesale price is beneficial for the retailer as it increases its margin, while a lower buyback price is beneficial for the supplier as it decreases its costs. It seems that this reduce is needed to achieve coordination.

Figure 5.1: Coordination combinations for a buyback contract

4. Figure 5.2 shows the combinations of a shared percentage and a wholesale-price that result in supply chain coordination. The figure shows two differences. First, in this numerical example, the risk-neutral environment has again a larger set of supply chain coordination combinations than the risk-averse environment. It is the result of the smaller increase that is achieved in the risk-averse environment. Due to the smaller increase, it is harder to allocate profit such that the reservation payoffs are at least reached. Second, the combinations in the risk-averse environment are higher than the combinations in the risk-neutral environment. Again, it can be seen as a compromise for both members: A higher wholesale price is beneficial for the supplier as it increases its margin, while a higher shared percentage is beneficial for the retailer as it increases its kept revenue. It seems that this compromise is needed to achieve coordination.

Figure 5.2: Coordination combinations for a revenue-sharing contract
5.4 Stability of coordination

The numerical example used in this master thesis showed that coordination can be achieved both with the buyback contract as with the revenue-sharing contract. In addition, both contracts have multiple combinations of parameters that result in coordination. To achieve these results, the numerical example assumed that parameters are fixed and known. However, in practice parameters can change over time or may not be known exactly. As a result, the numerical example showed that coordination is possible for one unique situation. However, the unique situation is not representing the situation for each supply chain. Therefore, from a practical point of view, it is interesting to see if coordination is achievable when parameters are changed.

To give more insight, one of the parameters is analysed in more detail. In a supply chain, costs arise to produce units. These costs arise at or in between of the different members of the supply chain. However, it is hard to exactly determine these costs (Pettersson & Segerstedt, 2013). It becomes even harder if these costs have to be determined or estimated prior to the moment that they occur. As a result, the cost per unit is exposed to uncertainty. Therefore, it is interesting to see the relationship between the supplier (or retailer) its cost per unit on the combinations that result in supply chain coordination. In addition, it is interesting to see if there arise differences between the risk-neutral and risk-averse environment. To get insight in this relationship and in the differences, a Matlab script (see Appendix C) that determines the possible combination parameters for different supplier cost per units is used. Within the Matlab script all other parameters remain the same. Thus, the total supply chain cost per unit remains the same ($c = 70$) as well. The changed costs per unit result in different optimal decisions. Figures 5.3 and 5.4 show the combinations of a wholesale-price and buyback price that result in coordination of the supply chain for a changing supplier cost per unit.

![Figure 5.3: Risk-neutral environment](image)
![Figure 5.4: Risk-averse environment](image)

Both figures show a field of combinations between a buyback price and a wholesale-price that are able to coordinate a supply chain with risk-neutral and a supply chain with risk-averse members, respectively, given a supplier’s cost per unit. The figures show similarities and differences between the risk-neutral environment and the risk-averse environment, which are discussed below.

First, the figures show that in both environments the supplier should pay the largest part of the supply chain costs per unit. In this numerical example, it is required that the supplier pays at least 49 and 47 of the supply chain cost per unit in the risk-neutral and risk-averse environment, respectively. If the retailer has to pay more than $21(= 70 - 49)$ or $23(= 70 - 47)$ the costs of overage are too high. As a result, it is not possible to have a combination of a wholesale-price
and a buyback price that satisfies the constraint that both members have to gain at least their reservation payoff. Second, both figures show that from a certain point (49 or 47) having a lower supplier cost per unit result in the most possible combinations for achieving coordination. Increasing the cost per unit for the supplier is negatively related to the number of possible combinations. Third, even though the numbers are different both figures show boundaries for the same reasons. The combination of a buyback price and a wholesale-price determines the allocation of risk and of profit. Outside of the colored box, either one of the members is allocated to much risk. As a result, coordination is not possible.

In accordance to the previous section, the risk-neutral environment contains a larger set of possible coordination combinations than the risk-averse environment. It is the result of the smaller increase that is achieved in the risk-averse environment. Due to the smaller increase, it is harder to allocate profit such that the reservation payoffs are reached. In addition, increasing the cost per unit of the supplier has a smaller influence on the number of possible combination in the risk-neutral situation than in the risk-averse situation. Last, in the risk-neutral environment the combination of a buyback price and a wholesale-price is higher than in the risk-averse environment.

Figures 5.5 and 5.6 show the combinations of a wholesale-price and a shared percentage that result in coordination of the supply chain for a changing supplier cost per unit.

Both figures show a field of combinations between a shared percentage and a wholesale-price that are able to coordinate a supply chain with risk-neutral and a supply chain with risk-averse members, respectively, given a supplier’s cost per unit. The figures show similarities and differences, which are discussed below.

First, the figures (again) show that the supplier should pay the largest part of the supply chain cost per unit. It is even that the minimums are equal for the revenue-sharing contract and the buyback contract in both environments. It can be explained by the fact that both contracts are allocating the risk between both members. If the costs at the retailer are too high, too much risk should be allocated to the supplier, who in return will not agree on that. As a result, coordination can not be achieved. Second, both figures show a positive relationship between the shared percentage and the wholesale-price. A higher wholesale-price is beneficial for the supplier but it harms the retailer. To compensate the retailer, a higher shared percentage is required to achieve coordination. But this compensation is higher in the risk-averse environment. This can be seen by the steeper slope in the figure demonstrating the risk-averse environment. Third, both figures
shows that having a higher cost per unit for the supplier, results in a higher wholesale-price, which in return has to be compensated with a higher shared percentage. The higher wholesale-price is required, otherwise, the supplier will not be able to make a profit. Last, as for the buyback contract and in accordance with the previous section, the set of possible combinations is larger in the risk-neutral environment than in the risk-averse environment.
Chapter 6

Blockchain technology

It is hard to imagine that, in this digitizing world, companies would cooperate with each other without any form of a shared platform. That is one of the reasons that companies are interested in innovative information technologies. These technologies can be used to improve both the retailer and supplier as well as the supply chain’s performance. At the moment, a lot of companies are investigating the possibilities of blockchain as a platform to cooperate on. However, there are several misunderstandings on what blockchain is and is not. Therefore, this master thesis provides background information, to make sure that the basic understanding of blockchain is known. This basic information is given by (1) a clear definition, (2) an explanation of the main characteristics, (3) an explanation of the transaction process, (4) an explanation of the different types, and (5) an explanation of the main challenges and limitations.

6.1 Definition of blockchain

Blockchain is a distributed ledger that is shared among all participating parties. The ledger keeps track of all transactions or digital events that have been executed among the participating members. All these transactions are verified by a consensus mechanism before they are added to the blockchain. There are different types of consensus mechanisms (see Appendix D), it is agreed upon during the development of the blockchain. Once a new block is added to the chain, it is not possible to alter or erase the block from the chain. Therefore, the blockchain contains a chronological record of each verified transaction that is ever made (Crosby, Pattanayak, Verma, Kalyanaraman et al., 2016). Below, an example of a blockchain is given.

![Figure 6.1: Example of a blockchain](image)

Information about a transaction is stored in a so-called ‘block’. Each time new data is available and stored in a block, this block is added to the end of the ‘chain’. The first block of the blockchain is called the genesis block. Furthermore, next to transaction information, the blocks contain a ‘cryptographic hash’ of the previous block, information of the number of transactions, and a ‘nonce’. A cryptographic hash is a unique string of bits of a fixed size. This string can be obtained by applying a mathematical algorithm to data of arbitrary size. A nonce is a unique identifier for each block that is used for verifying the hash (Franco, 2014).
6.2 Main characteristics of blockchain

This subsection gives a technical description of the main characteristics of blockchain, based on Korsten (2019) and Rudolphi (2018). The main characteristics discussed are (1) distributed database, (2) information immutability, (3) information transparency, and (4) security.

Distributed database - One of the most important characteristics of blockchain is that it is distributed among all participants of the network rather than being decentralized or centralized. The difference is shown in figure 6.2. In a blockchain, all information is shared among the participants of the network. It means that no central database is involved, but each participant has the same copy of the information. As a result, blockchain eliminates the need for a trusted third party and the possibility that a single party governs the system. Therefore, the strength of a distributed ledger is that it gives the opportunity to do business without having to authenticate the other party. In addition, it eliminates the risk of a single point of failure as each party has an updated version of the information.

![Figure 6.2: Schematic overview distributed, centralized, and decentralized nodes (Kuijpers, 2018)](image)

Information immutability - All participants have a copy of the entire chain stored on their database. If someone wants to change or modify information, one needs to change the information of all participants. To do so, a consensus mechanism is used that allows or denies someone to change information (add a new block). There are different rules and methods for this verification step which can be used. Using verification for new and changed information results in a history of transactions that is reliable and unaltered. As a result, participants in the blockchain are able to trust the information on the blockchain.

Information transparency - A third important characteristic of blockchain is the transparency of the information. The blockchain is a database of records that consists of all the transactions that have been executed and shared among the participants within the network. Since each participant has a copy of the ledger, each participant is able to see the complete history of transactions. As the blockchain is immutable, each participant can trust the information on the blockchain. As a result, participants have the possibility to check and trace information on the blockchain.

Security - The blockchain provides security in multiple ways. First, a blockchain is distributed among all participants of the network. Thus, the information is stored at multiple locations. When a failure to one of the locations happens, the other locations still have the most recent copy of the ledger. So, blockchain eliminates the possibility of a single point of failure. Second, blockchain uses asymmetric cryptography for digital signatures and encryption of data, through the use of private and public key pairs. A public key is used to create a public shareable address for the user and a private key is used to sign the public key and to create a digital signature that is unique. Third, blockchain uses hash pointers to connect blocks into a chain. Next to the information, each block contains a hash pointer that shows where the value of the previous
block is. In addition, the blocks contain a digest value that verifies that the information is not changed. As a result, the blockchain is a secure solution for transactions.

6.3 The transaction process

When a participant of the network wants to add new information into the blockchain, a transaction process has to be executed. This transaction process is explained by Froystad and Holm (2016). The process can be described in five phases and a visual representation is given in figure 6.3:

1. **Transaction definition** - A sender wants to send a transaction to the network. The transaction is generated and sent to the peer-to-peer network. These transactions always include the receivers public address, the information of the transaction, and a cryptographic digital signature that authenticate the sender and the transaction.

2. **Transaction authentication** - When the network receives the transaction, the transaction must be authenticated. The validity of the transaction is authenticated by the nodes by decrypting the digital signature. After the transaction is being concluded valid, the transaction waits in a pool of pending transactions until the block is created.

3. **Block creation** - Then one of the network participants creates a block that consists of the pending transactions, which is the most updated version of the ledger. At a specific time interval, the participant will update the block into the network for validation.

4. **Block validation** - During the creation of a blockchain network, the participants agree on a consensus mechanism that determines which blocks are validated by the network and which are not. There are different consensus mechanisms. However, all mechanisms ensure the validity of the process, making it nearly impossible to make fraudulent transactions.

5. **Block chaining** - As soon as all transactions in the block are validated, the block is added to the chain through hash functions. These functions make sure that the block cannot be altered as soon as it is connected to the chain. Directly after the block is added to the chain, the most recent version of the ledger is updated on each node.

![Figure 6.3: Visualisation of a blockchain transaction (Froystad & Holm, 2016)](image_url)
6.4 Different types of blockchain

Multiple types of blockchain exist, these are different based on their structure. To distinguish the different types of blockchains, a distinction is made between an open and a closed blockchain. An open blockchain is, as the word implies, open to anyone and any node in the network is able to read transactions. Within a closed blockchain, participants have to be granted with access before one is able to read, execute, or validate transactions. Thus, not everyone is able and allowed to be a member of the network. In addition, a further distinction is made between permissionless and permissioned blockchains. Within a permissionless blockchain, all members of the blockchain have the possibility to read, write, and validate transactions. For permission blockchains, members are individually given the possibility for writing and validating transactions. During the development of a blockchain, it is chosen which participants are granted with what possibilities. An overview of the four main types of blockchains distinguished by their openness and permission model is given in figure 6.4:

<table>
<thead>
<tr>
<th></th>
<th>Read</th>
<th>Write</th>
<th>Commit</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Open to anyone</td>
<td>Anyone</td>
<td>Anyone*</td>
<td>Bitcoin, Ethereum</td>
</tr>
<tr>
<td>Public permissionless</td>
<td>Open to anyone</td>
<td>Authorised participants</td>
<td>All or subset of authorised participants</td>
<td>Sovrin</td>
</tr>
<tr>
<td>Consortium</td>
<td>Restricted to an authorised set of participants</td>
<td>Authorised participants</td>
<td>All or subset of authorised participants</td>
<td>Multiple banks operating a shared ledger</td>
</tr>
<tr>
<td>Private permissioned (‘enterprise’)</td>
<td>Fully private or restricted to a limited set of authorised nodes</td>
<td>Network operator only</td>
<td>Network operator only</td>
<td>Internal bank ledger shared between parent company and subsidiaries</td>
</tr>
</tbody>
</table>

Figure 6.4: Overview of the main types of blockchain (Hileman & Rauchs, 2017)

6.5 Smart contracts

As explained before, blockchain is a platform that can be used for different applications. In summary, using blockchain eliminates the need for a central authority by providing a distributed, transparent, immutable, and secure ledger. One next step of blockchain is to use it for the automatic execution of more complex agreements. That is where so-called smart contracts come into play. According to Clack, Bakshi and Braine (2016), a smart contract is ‘an automatable and enforceable agreement. Automatable by computer, although some parts may require human input and control. Enforceable either by legal enforcement of rights and obligations or via tamper-proof execution of computer code’. Clack et al. (2016) described a smart contract as automatable instead of automated because human input and control may be required in practice. However, most of the agreement should be capable of being automatically executed. Otherwise, the program will not be smart. The automation of (part of) the smart contract is provided by computer code. The computer code is a translation of the contractual agreements into ‘If-Then’ states. For example, if the retailer receives goods, then the payment system is triggered to pay the supplier. As blockchain provides a distributed, immutable, transparent, and secure ledger developing a smart contract on blockchain technology, results in a tamper-proof and immutable
and transparent history of transactions. Simply said, it means that no participant of the network is able to adjust the contract agreements without the consent of other participants.

6.6 Challenges and issues

As with all new emerging technologies, issues and challenges arise for blockchain. However, for this thesis, it is sufficient to focus on the important ones. The following challenges and issues are found during the literature review prior to this master thesis.

1. **Suitability** - In almost all sectors, companies are excited about blockchain technology and some think it adds value to each project. However, a lot of companies do not understand the fundamental ideas behind blockchain. In a lot of cases, blockchain will not add any value. For example, when only one participant makes use of it. In this situation, blockchain will not add value because the main characteristics are not exploited. One does not have to trust others, there is no distributed network, and there is less need for transparency. On the other hand, when a transaction should be executed between distrusting partners blockchain could be suitable. Therefore, one should examine if the technology is suitable for the specific project before implementing a blockchain-based solution (Casino et al., 2019).

2. **Latency and scalability** - Blockchain architectures face serious latency issues. To explain this problem, the example of Bitcoin is used. Approximately it takes 10 minutes to execute a Bitcoin block transaction along with the security checks that are done. In comparison, credit card processing networks are able to handle thousands of transactions each second. In small networks, these issues are less of a problem. However, when networks scale over time it results in serious latency problems (Casino et al., 2019).

3. **Adoption and interoperability** - Looking at the developed blockchain-based applications, one can see a wide diversity of implementations and features. It implies that there are interoperability issues, which are difficult. These issues hinder the standardization of blockchain. As businesses, companies, governments and other potential users of blockchain are already working towards the digitization and automation of their supply chain processes, a blockchain solution should be able to inter-operate with these processes. Otherwise, no party will adopt blockchain. The difficulty increases with the number of participants in the network. Participants in the supply chain may use different kinds of systems in order to regulate their supply chain processes. Therefore, blockchain should enable interoperability with the systems of the participants. Otherwise, the benefit of using blockchain will decrease or will not exist (Casino et al., 2019). As a result, people do not want to implement it.

Next to the discussed challenges above, there are some (less important) other issues and challenges with regard to blockchain. These issues and challenges are considered less important because it is thought that they are, for example, easier to solve, related to a lot of other technologies, or should not have to be a problem at all. Some papers write about the following issues: privacy leakage, human error, waste of resources, transaction cost, and public perception. For an explanation with regard to these issues, one should look at Meva (2018).
Chapter 7

Blockchain study

A client of Atos (Company A) is having issues with regard to their contractual processes with their suppliers (Company B). Company A is a retailer that purchases products from its suppliers. Afterward, these products are sold to customers in the market. To make sure that products flow from the supplier to the customer, a process is executed. In this master thesis, the process steps considered are negotiation, deployment, order placement, order execution, sending invoices, fulfillment, and payment processing. When promotions are considered, the process is executed differently. Although the process steps remain the same, the execution of the process steps is adjusted. The process steps and the differences are explained in more detail in the next section. However, Company A states that both ‘type’ of process faces issues. This master thesis investigates two of these issues: (1) the process is manually intensive and (2) price-differences occur.

First, the process is manually intensive. The process consists of 7 steps and an additional step when issues need to be solved. Several steps require the interaction between Company A and Company B. However, the systems of both companies are not connected to each other. As a result, human intervention is required to connect both companies. This results in the fact that most of the process steps are executed manually, while automation may be possible as well.

Second, during promotions there arise price-differences. Promotional activities are executed on top of regular activities. To introduce a promotion, Company A and Company B have to make temporarily agreements. These agreements are made during the negotiation step. In the regular process, the negotiation step is executed face-to-face. However, during promotions, the execution is done by means of a phone call or e-mail. Executing the step this way is not well-ordered. As a result, the companies have a different understanding of the agreements that are made. These different understandings are called ‘price-differences’ and result in a dispute when invoices have to be fulfilled. Over 2018 Company A encountered 165,000 price-differences, which demonstrates the size of the problem.

To solve these issues, Atos is approached to develop a blockchain-based system. In first instance, the system will serve as the ‘single-source of truth’. This way, the second issue is (partly) addressed because the companies have to document their agreements on the blockchain. As a result, both companies have the same version of the agreements. The invoice is constructed based on this version, which results in fewer disputes. This problem could be addressed with other solutions as well. However, the blockchain-based system will serve as the foundation for further improvements. Implementing the system will give rise to the possibility of automating (parts of) the process. However, Atos did not investigate these possibilities yet. Therefore, this master thesis investigated how blockchain could be used to address the problems and the value that it generates. In the next section, each process step that is executed in the traditional situation is described in more detail. Based on this traditional situation, a solution that makes use of a blockchain-based system is designed. This solution is explained in section 7.2. Then, the solution is analyzed and compared to the traditional situation in section 7.3. In this section,
rough estimates are made to quantify the benefits, challenges, and limitations. Last, a numerical example is developed based on (rough) estimates\(^1\) in section 7.4

### 7.1 The traditional situation

The issues are faced and the processes are executed by an external company (Company A). However, Atos serves other companies that are similar to Company A as well. Therefore, the process is described to represent a more general situation instead of only representing the process as it is executed by Company A. To develop the general process, information with regard to contract processes is gained. A semi-structured interview (see Appendix E) is held to get a practical overview of the process. In addition, literature (Kuijpers, 2018; Salle, 2002) and white papers (Guyonnet & Mohammed, 2016; IBM Cognitive Process Transformation, 2017) are analyzed. The combination of the practical use case, the semi-structured interview, and investigated literature and white papers resulted in the following process:

![Figure 7.1: Traditional contract process](image)

The figure shows the steps that are executed during the contract process in a supply chain. In the supply chain, a retailer (Company A) has the desire to order a number of units from the supplier (Company B). As one can see, the process consists of seven steps with an additional step that is executed when issues arise in the fulfillment step. The process steps are similar for regular products and promotional products. However, the way of execution may be different. The differences are explained as well. Furthermore, it is assumed that the supplier and the retailer have had contact before the process starts and will have contact after the process is finished. These steps are considered out of scope, as they are less relevant for the practical use case. The steps shown in the figure are explained in more detail below.

#### 1. Negotiation

Both companies are involved in the negotiation step. Company A has the desire to order an x number of units from Company B. The first step in the process is to negotiate and agree on the contract that will be used for the rest of the process. During the negotiations, the parties have to discuss on different values, for example, the price per unit, delivery time, and order quantity. Usually, the kind of agreements are similar for each type of product, only their values will differ. During the negotiations, Company A is represented by a Category Manager and Company B is represented by a Client Manager. The Category Manager is responsible for a specific group of products (dairy, meat, cleaning supplies, etc.) and each retailer is being served by one Client Manager. The negotiations happen manually and managers often prefer to have the negotiations face-to-face, as it may contribute to a better relationship.

When promotional agreements are made, two differences occur with regard to the regular way of negotiation. First, during the regular process companies agree on the same set of agreements, i.e. a standardized format. However, during promotions companies negotiate on different kinds of contracts, for example, one plus one for free or an X\% discount on each unit. During these negotiations, no standardized format is used for the contract. Second, negotiations are done by a phone call or by e-mail conversations. Neither do they use a shared document nor do they

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\(^1\) All estimates in this chapter are discussed with a (senior) employee of Atos
sign a contract. As a result, misunderstandings arise about the agreements that are made. As a result, price-differences occur.

2. **Deployment**

Both companies are involved in the deployment step. If the Category Manager and Client Manager agree on a contract, the contract information is loaded into their systems. The loading of the contract into the system is executed manually by the managers themselves.

When promotional agreements are made, no differences occur with regard to the regular way of deployment.

3. **Order placement**

Only Company A is involved in the order placement step. The Category Manager is responsible for the placement of the order. The system provides the Category Manager with information, for example, amount of sales, forecasts, and constraints, that is needed to make a considered decision. When the Category Manager determined the order quantity, he has to manually load the order into Company A’s system. Nowadays, these systems are able to automatically place the order at Company B.

When promotional agreements are made, no differences occur with regard to the regular way of order placement.

4. **Order execution**

Only Company B is involved in the order execution step. An Operations Manager of Company B gets information about the order(s) out of their system. This information is translated into actions that result in the delivery of the order quantity to Company A. Depending on the supplier, the transportation of the units is executed either by the supplier themselves, by a logistics provider or by multiple logistics providers. Within the practical use case, the time of arrival is logged by Company A as a result of contractual agreements. The arrival time is one of the parameters that determine the price that should be paid.

When promotional agreements are made, no differences occur with regard to the regular way of order execution.

5. **Sending invoice**

Only Company B is involved in the sending invoice step. A Financial Manager of Company B receives the order and translates it into valuable information for making an invoice. Depending on the maturity level of the supplier’s systems, this information is either automatically translated into an invoice or a back-office employee translates the information into an invoice manually. Furthermore, based on the process the invoice is either sent physically (with the transport of the units) or digitally (after the units have arrived). When the invoice is physically sent, it may be exchanged between multiple parties that provide transportation.

When promotional agreements are made, no differences occur with regard to the regular way of sending an invoice.

6. **Fulfilment**

Only Company A is involved in the fulfilment step. When the invoice is sent physically together with the units, a logistics operator loads the invoice into the system after checking the units manually. When the invoice is sent digitally, a back-office employee loads the invoice into the
system manually. After the invoice is loaded into the system, it depends on the maturity level of the supplier’s systems whether the invoice can be checked automatically or not. Nowadays, a lot of companies have systems that are able to check the correctness of invoices automatically. However, in the practical use case (back office) employees have to manually check the correctness of an invoice.

When promotional agreements are made, one difference occurs compared to the regular way of fulfillment. In the regular process, it depends on the maturity of the system whether an invoice is checked automatically or not. In the process during promotions, the invoices are always checked manually.

Solving issues

Both companies are involved in the solving issues step. This step only takes place when the fulfillment step shows differences between the invoice and contract agreements. When it does happen, the Category Manager of Company A investigates the cause of the difference. For example, a mistake is made during the deployment of the contract into the system or it might be that price-differences occurred during the negotiations. Depending on the cause that is found, the Category Manager decides which actions should be followed to solve these issues. The Category Manager gets into contact with the Client Manager to discuss and solve the issue. When the issue is solved, a new invoice is developed that will be fulfilled by Company A.

When promotional agreements are made, no differences occur with regard to the regular way of solving issues. However, when issues arise in the process during promotions it is more difficult to solve the issue. It is caused by the fact that no (standardized) documentation of the negotiations is available.

7. Payment processing

Only Company A is involved in the payment processing step. After the invoice is checked and concluded being correct, the payment system of Company A is automatically triggered to pay the invoice to Company B. Nowadays, it is common that no human interaction is needed to pay the invoice. The financial system will automatically pay Company B when both companies agree on the invoice.

When promotional agreements are made, no differences occur with regard to the regular way of payment processing.

7.2 The solution using blockchain technology

In the previous section, one can see the contract process as it currently is executed. To solve the issues that Company A faces in the process, a solution that makes use of blockchain technology is designed. Company A has two reasons for willing to use blockchain. First, blockchain can provide a tamper-proof shared database between Company A and its supplier(s). It should result in a decrease of price-differences with the suppliers. Second, blockchain can provide the security and trust required to automatically execute (part of) the contract process. It should result in a decrease in the time spent on the process by employees. From now on, the solution is called 'blockchain solution’. Within this solution a system that makes use of blockchain technology is used, which is called a 'blockchain-based system’. To make sure that the design is relevant for practice, a focus group is developed (see Appendix E). The aim of the focus group is to gain feedback on and to validate the process of the blockchain solution. During the focus group, a draft version and a set of questions are presented to the members of the group. The members of the focus group gave feedback to the draft version and validated if the process is realistic. Based on the feedback, adjustments to the design are made which resulted in a design that is relevant to practical situations. Finally, the design resulted in the process as it is described below.
Figure 7.2: Blockchain-based contract process

Figure 7.2 shows the blockchain solution for the contract process. As one can see, the steps remain the same as in traditional situations. However, colors are added to the process steps that are influenced by the implementation of the blockchain solution. The yellow-colored steps imply that the implementation of the blockchain solution influences the process step. When the block does not contain color, it means that the implementation of the blockchain solution does not influence the process step. Each step is described in more detail below.

1. Negotiation

Implementing the blockchain solution influences the regular negotiation step. The blockchain-based system is developed such that both companies can easily interact with the system. When Company A has the desire to order an x number of units from Company B a standardized template is uploaded to the blockchain to start the negotiations. The Category Manager and Client Manager can either meet face-to-face to negotiate on the contract or they can negotiate digitally. When meeting each other face-to-face, the managers fill in the digital contract together after they agree on it. Then, both managers have to digitally sign the contract with their private keys. When negotiating digitally, a contract offer is sent to the blockchain-based system and the other party gets a message. Then, the manager decides if he accepts or rejects the offer. If he rejects the offer, he can change the parameters and send the new offer back to the blockchain-based system. The blockchain explicitly shows which parameters are changed. Both members can send new offers to the blockchain-based system until both members accept the contract. Then, they have to digitally sign the contract with their private keys.

Implementing the blockchain solution influences the promotional negotiation step in two ways. First, the blockchain-based system replaces phone calls and e-mail conversations as a mean for negotiation. Thus, the managers send offers to each other through the blockchain-based system. As it is done in the regular process. Second, the blockchain-based system requires a standardized format to negotiate on. Thus, for each type of promotion a standardized format is developed. When either one of the companies wants to introduce a promotion, one of the standardized formats is uploaded to the blockchain and negotiations can start.

2. Deployment

Implementing the blockchain solution influences both deployment processes. When the negotiating step is fulfilled and both managers agreed on the contract, they have to digitally sign the contract with their private key. The blockchain-based system is able to automatically load the contract into the respective system(s). This way, the manager does not have to load the contract manually into the systems.

3. Order placement

Implementing the blockchain solution does not influence both types of order placement processes. Based on the information that is gained out of the internal systems, the Category Manager determines the order quantity that can be ordered from Company B. If the Category Manager determined the order quantity, it is loaded into their system. This system is already able to place the order at Company B automatically. Thus, the blockchain-based system does not have
to be involved. However, the blockchain-based system should be able to retrieve information with regard to the order quantity.

4. Order execution

Implementing the blockchain solution influences both order execution processes. When the order quantity arrived at Company A, the arrival time is directly logged into the system. One representative of Company A and one representative of Company B have to digitally sign the arrival time directly. As a result, the arrival time is two-sided logged on the blockchain. The rest of the process remains the same. The Operations Manager of Company B extracts information from the system. He translates this information into actions that result in the delivery of the order quantity to Company A. Depending on the supplier, the transportation of the units is executed either by the supplier themselves, by a logistics provider or by multiple logistics providers.

5. Sending invoice

Implementing the blockchain solution influences both sending invoice processes. However, the impact is dependent on the maturity of Company B’s system. Logging the arrival time into the blockchain triggers the system to create an invoice. The blockchain contains the agreed contract and the arrival time, and it is able to extract the order quantity out of the internal system(s). Based on this information, the blockchain-based system is able to construct an invoice automatically. However, some companies have a system that is already able to automatically construct the invoice. Then, the blockchain-based system will only provide input to their system for constructing an invoice. When the invoice is constructed, the blockchain-based system is able to automatically send the invoice to Company A. Although digitally sending the invoice is already possible, for suppliers with low mature systems it is a beneficial characteristic (Christidis & Devetsikiotis, 2016).

6. Fulfilment

Implementing the blockchain solution influences both fulfillment processes. As the invoice is constructed based on the information of the contract in the blockchain, the invoice will match the contract agreements as they are in the blockchain. However, there might be disputes related to other factors. For example, the quality of the delivered goods is not appropriate. If disputes arise, the managers have to get into contact with each other and manually solve the dispute. When no disputes arise, both members have to digitally sign the invoice. When the invoice is digitally signed, the blockchain-based system triggers the system that is able to fulfill the invoice.

Solving issues

Implementing the blockchain solution influences the solving issues processes. However, it should result in the fact that this process is not executed frequently. As both companies have the same copy of the contract and can check the contract before signing, no differences should occur. However, when issues or disputes related to the contractual parameters occur, the blockchain-based system is checked. The system provides a full history of transactions, which results in a clear overview of made arrangements.

7. Payment processing

Implementing the blockchain solution has no influence on the payment processing processes. Nowadays, most systems are able to automatically trigger the financial system to pay the invoice when the invoice is checked to be correct. Using a blockchain-based system will take over this function from already existing functions. However, it does not change anything in the process.
7.3 Traditional situation versus blockchain solution

The previous sections explained how process steps are executed in the traditional situation and how they are supposed to be executed when the blockchain solution is implemented. The blockchain solution reduces the need for human intervention and automated several processes. In addition, it is designed such that price-differences should occur less often. However, the implementation of the blockchain solution faces some challenges and limitations as well. Therefore, this section provides a qualitative analysis of the implementation of the blockchain solution. The analysis is based on the focus group, literature, and own-thinking. In addition, data generated through the practical use case and estimates are used to quantify the data and to give numerical insight. First, the benefits of implementing the blockchain solution in comparison to the traditional process are analyzed. Second, the challenges that the implementation of the blockchain solution faces are discussed. Third, the limitations that may result in the fact that the solution will not be implemented are discussed.

7.3.1 Benefits

**Reduced processing time** - The implementation of the blockchain solution changes several process steps. The traditional situation contains multiple steps that are manually intensive. In the blockchain solution, the steps that can be automated are automatically executed by the blockchain-based system. In addition, the blockchain solution is designed such that process steps are either being automated or being easier to execute. As a result, the processing time will decrease or fewer mistakes are made. In the previous chapter, it is said that blockchain faces latency issues. The latency issues are about the time required to execute a transaction process digitally. However, this latency issue is not relevant to this blockchain solution for two reasons. First, the latency issue arises due to a large number of participants. However, in this situation the number of participants is limited. Second, no employees are required during the execution of a transaction process by the blockchain-based system. As a result, employees do not lose time when the system is executing a transaction. Below, the estimates for the processing times of the blockchain solution and the traditional process are compared.

- **Negotiation** - During the negotiation step, the Category Manager and Client Manager decide on the contract parameters. For regular contracts, both situations require human intervention as managers are doing the negotiations. Usually, managers prefer to meet each other face-to-face. Instead of filling and signing a contract on paper, the managers have to fill in and sign the contract digitally. The time needed for signing a paper-based contract and for signing a digital contract is assumed to be equal. As a result, both processing times are estimated to take 60 minutes.

  For promotional contracts, managers are traditionally negotiating by e-mail or by phone. During these phone calls, the managers have to discuss which type of promotion will be introduced and on the contract parameters of the promotion. By implementing the blockchain solution, it is required that one of the managers uploads the standardized document representing the specific type of promotion. Then both members can send each other new offers until both members agree on the contract. It is assumed that talking by phone is quicker than uploading documents. However, the phone conversation is not standardized but the documents that are uploaded to the blockchain are standardized. As a result, the processing times are estimated to be equal and takes 20 minutes.

- **Deployment** - Implementing the blockchain solution eliminates the need for manually deploying the contract into the system. After the managers digitally sign the contract, the blockchain-based system automatically deploys the contract into the right systems of Company A and Company B. As a result, the need for human intervention is eliminated. This elimination occurs both in the regular process and in the promotional process. The time
for deploying the contract into the proper system is estimated to be 0.5 minutes. Both companies have to execute this process step. As a result, the processing time is decreased by 1 minute because no human intervention is needed.

- **Order execution** - Implementing the blockchain solution requires (representatives of) both companies to digitally sign the arrival time directly if units arrived. Thus, both representatives have to fulfill an additional task. They have to come together at the moment of arrival and sign the arrival time at the same moment. The task can be fulfilled by means of an application that can be installed on a phone or it can be done on a computer located nearby. As a result, the processing time is expected to increase with 1.5 minutes only.

- **Sending invoice** - Implementing the blockchain solution decreases the processing time of the sending invoice step. However, the reduction depends on the maturity of the systems currently used. When the supplier has high mature systems, the decrease is small. This decrease is generated by automatically triggering each process when certain conditions are met. Current systems can automatically construct and send invoices, but these processes have to be started manually. As a result, the processing time is decreased a little. However, when the supplier has low mature systems, the decrease is significant. Blockchain will automatically construct and send invoices when units arrived at the retailer. The time required for triggering the payment system is estimated to be 1 minute and the time required for constructing an invoice is estimated at 2 minutes. As a result, the processing time is decreased a little. However, when the supplier has low mature systems, the decrease is significant. Blockchain will automatically construct and send invoices when units arrived at the retailer. The time required for triggering the payment system is estimated to be 1 minute and 3 minutes for situations with high mature systems and low mature systems, respectively.

- **Fulfilment** - Implementing the blockchain solution decreases the processing time by automatically checking the invoice. Information stored on the blockchain is used to construct the invoice. As a result, the invoice matches the agreed contract. However, there might be disputes related to other factors. The blockchain-based system does not have an impact on these issues. When the invoice is digitally signed, the blockchain system automatically triggers the payment system. The time for checking the invoice and triggering the payment system is estimated to be 1 minute. As a result, the processing time is decreased by 1 minute.

- **Solving issues** - Implementing the blockchain solution decreases the processing time by making it easier to find the cause of a price-difference. In the traditional situation, the Category Manager had to make phone calls and check e-mails to find out what caused the price-difference. Now, the full history of the negotiations is visible on the blockchain, which results in the fact that it is easier to see what causes the price-difference. The time required for solving issues is estimated to be 2 minutes and 1 minutes for the traditional situation and blockchain solution, respectively. As a result, the processing time is decreased by 1 minute.

Above, only the processes that are influenced by the blockchain solution are described. It is said that all other processing times are not affected by the blockchain solution. It is estimated that the implementation of the blockchain solution decreases the total processing time with $2 \times 0.5 - 1.5 + 1 + 1 = 1.5$ minutes for companies with high mature systems and $2 \times 0.5 - 1.5 + 3 + 1 = 3.5$ minutes for companies with low mature systems. In addition, the time required for solving issues is reduced with 1 minute. However, this process step is not executed for all contract processes. The total time that is saved by the implementation of the blockchain solution is dependent on the size of the number of contract processes being executed. In the retail industry, companies have to execute this process often. Thus, the impact of a decrease in minutes can be significant in total. To give more insight a numerical example is executed in section 7.4.
Reduced price-differences - Next to the number of time inefficient steps, having price-differences is the second problem faced by Company A. It is hard to determine the exact value that blockchain has for addressing this problem because companies have a different size of price-differences. Therefore, the practical use case is used to provide insights. Over 2018 Company A encountered 165,000 price-differences with more than 1,600 different suppliers. Every time a price-difference occurs it needs to be investigated. As a result, 85 hours a week are spent on solving price-differences. Company A uses the policy that price-differences should be solved within three weeks. Otherwise, the invoice from the supplier is seen as truth. However, due to the magnitude, not all price-differences are acted upon (within three weeks). As a result, 12% of the price-difference results in automatic approval of the invoice. Within these automatic approvals, there may be payments that are higher than supposed to be. Therefore, it is assumed that not acting on a price-difference is costly. Thus, price-differences result in costs in two ways: (1) it takes time to solve the price-differences and (2) not all price-differences are acted upon. Implementing the blockchain solution reduces these costs in three ways.

1. Implementing the blockchain solution reduces the processing time for solving issues (price-differences) with 1 minute. In the traditional situation, 85 hours per week are spent on addressing 165,000 * (1 - 0.12) = 145,200 price-differences. As a result, the average time spent on a price-difference is \( \frac{85 \times 52 \times 60}{145,200} = 1.83 \) minutes per price-difference. Thus, for Company A the processing time for solving issues in the blockchain solution is estimated to be 0.83 minutes. If the number of price-differences that are addressed would remain the same, the implementation of blockchain reduces the processing time with 145,200 minutes in total. This results in \( \frac{145,200 \times 0.83}{52 \times 60} = 38.5 \) hours a week. Thus, the weekly time spent on price-differences decreases with 75 – 38.5 = 36.5 hours a week.

2. Implementing the blockchain solution reduces the number of price-differences. Within the practical use case, price-differences occur as a result of (1) human errors made in writing the contract, (2) disagreements on the arrival time, (3) having misunderstandings about the contract parameters, and (4) loading different versions of the contract into the system. Implementing the blockchain solution eliminates three of these causes. First, representatives of both companies have to sign the arrival time, which eliminates disagreement on the arrival time. Second, a standardized format is used for each type of promotional contract. This format has to make sure that is clear on which agreements the companies agreed on. As a result, both companies have the same understanding of the contract parameters. Third, the blockchain-based system automatically deploys the agreed contract into the specific systems only when both companies signed the contract digitally. Thus, no different versions are loaded to their individual systems. Assume that each of the four causes contributes to 25% of the total price-differences. As a result, the number of price-differences is reduced with 75% which equals a reduction of 165,000 * 0.75 = 123,750 price-differences.

3. The time needed for solving price-differences is reduced and the number of price-differences is reduced. As a result, Company A will be able to act on each price-difference. As assumed, it is beneficial to address price-differences. As a result, 19,800 additional price-differences can be addressed. Because price-differences that are not acted upon result in costs, additional savings are gained by solving all price-differences.

In the traditional situation, 85 hours a week are spent on solving 145,200 price-differences. When the blockchain solution is implemented there only occur 41,250 price-differences and \( \frac{41,250 \times 0.83}{52 \times 60} = 11 \) hours a week are spent on solving the price-differences. Concluding, the costs associated with price-differences is decreased when the blockchain solution is implemented.

Improved visibility - The blockchain solution improves visibility in two ways. First, blockchain technology is a ledger and keeps track of the full history of transactions. Therefore, both
companies can see the full history of negotiations and the full history of contract processes executed. Second, the blockchain solution requires a standardized format to negotiate on. This format gives a clear overview of which contract parameters to negotiate on. Every time a new offer is proposed, the blockchain-based system highlights the changed parameters. As a result, the visibility of the contract process is improved.

**Provides a secure digital information system** - The blockchain solution provides a secure digital information system that communicates between both companies. The security is provided in three ways. First, using a blockchain-based system provides each company with the same copy of the ledger stored at its own location. It eliminates the possibility of a single point of failure. Second, the blockchain solution uses asymmetric cryptography for digital signatures and encryption of data. This way, companies are ensured that the sender or receiver is the one they expected to be. Third, the information that is stored on the blockchain is immutable. In order to change a transaction, all blocks in the blockchain have to be changed as a result of the changed hash value. These aspects result in a secure digital information system.

### 7.3.2 Challenges

**Scalability** - This issue is explained by means of the practical example. The implementation of the blockchain solution can reduce the processing time by 1 or 3 minutes. Executing this process only once a year results in a decrease of 1.5 or 3.5 minutes per year, which is negligible. However, executing this process one million times a year results in a significant decrease. Furthermore, Company A encountered 165,000 price-differences over 2018. However, these price-differences occurred with over 1,600 different suppliers. Concluding, to have a significant impact, the blockchain solution should be implemented with multiple suppliers. As a result, three challenges arise:

1. The suppliers should be willing to cooperate on implementing the blockchain solution. For suppliers, the system is only communicating with one of its customers (Company A) as it is developed by Company A. As a result, the reduced processing time and reduced number of price-differences are not significant for suppliers that only sell a few products to Company A. Therefore, Company A should create a situation in which it is beneficial for suppliers to connect to the system. The more suppliers required to make the impact significant, the harder the challenge of getting all suppliers willing to cooperate.

2. The blockchain solution automatically transfers information from the blockchain-based system to the system of the participants and vice versa. As a result, the blockchain-based system should be interoperable with the systems of all these participants. Each participating company may have a different kind of system, which results in the challenge of interoperability. The larger the number of participants, the bigger the challenge. Furthermore, a supplier may not want other suppliers to have insight in the transactions that he made with Company A. As a result, one should either design the blockchain-based system such that information can be isolated or build a blockchain-based system for each supplier.

3. At Company A and at each participating supplier, the blockchain solution should be implemented. From which follows, that current systems have to be adjusted, employees have to learn how to work with the blockchain-based system, employees have to learn how to execute the changed processes, and employees have to be trained to be capable of adjusting the blockchain-based system. These implementation challenges will be faced at each participating supplier.

**Immaturity** - Blockchain is a rapidly developing technology, a lot of researchers and companies are investigating and experimenting with the possibilities of blockchain (Casino et al., 2019). As a result, new opportunities present themselves rapidly. However, it is not possible to predict
Chapter 7 A blockchain-based supply chain contract

the impact of these opportunities on a developed solution. Therefore, it is important to take into account that new opportunities might arise. Thus, one should make the solution flexible. Although it is difficult to do so, this should result in the possibility of changing and adjusting the solution when new opportunities arise.

7.3.3 Limitations

Development costs - To implement the blockchain solution a blockchain-based system should be developed. Most companies do not have the knowledge required for the development of a blockchain-based system. As a result, a third party (like Atos) should be approached to develop the system. Probably, each third party will address the development differently. Therefore, the practical use case is used as an example to demonstrate how costs arise.

In the practical use case, the blockchain-based system is first implemented in the process of Company A and only one supplier. This situation is used as a starting point on which other suppliers will be added later on. A meeting with both companies and the third party is organized to clearly map the process flow, to identify bottlenecks, and to identify system requirements. The companies have to be present at the same time to avoid misunderstandings. Based on the information gained, a pilot version is developed that will be used for a short period of time (several months). During the pilot, the companies have the possibility to give feedback. This way, the system can be adjusted to the needs of the companies. Based on the feedback a final version is developed that can be implemented for the contract process between Company A and a supplier. The time required to bring the system into practice is roughly estimated to be 650 hours. 90 hours for setting up, preparing, executing, and reviewing the meeting (10 hours for each company, each company is represented by 3 employees). 240 hours for developing the pilot version (2 employees working 3 full weeks). 160 hours to develop the final version (2 employees working 2 full weeks). 80 hours to get the final version into practice and to train people.

From the moment that the blockchain-based system is in process, more suppliers can be added to the system. To add a new supplier, the same process has to be executed because each supplier can have a (slightly) different system and a (slightly) different process flow. However, the total time required is decreased because the blockchain-based system is already developed and only has to be adjusted to the specific needs of the new supplier. The time required to add a new supplier to the system is roughly estimated to be 300 hours. 40 hours for setting up, preparing, executing, and reviewing the meeting (10 hours for each company, each company is represented by 2 employees). 80 hours for developing the pilot (2 employees working 1 full week). 30 hours to introduce the pilot version. 20 hours to gather and process feedback on the pilot version. 80 hours to develop the final version (2 employees working 1 full week). 50 hours to get the final version into practice and to train people. When more suppliers will be connected to the system, the time required to implement the blockchain solution is estimated to be 250 hours.

Suitability - In almost all sectors companies are excited about blockchain technology. However, blockchain does not add value in all of these applications. Critical thinking should decide whether blockchain will have value for the application or not. The contract process as described in section 7.1 consists of multiple participants that do not fully trust each other. In addition, companies want to have a shared system to communicate with each other. Thus, blockchain might be a suitable solution for the process. However, one should critically determine the savings that are achieved and the costs that will arise, when implementing a blockchain-based system as the solution. Furthermore, there are other technologies that do not contain all of the characteristics that blockchain does but might worth considering. Not all characteristics of blockchain
might be needed. Therefore, one should determine which characteristics must be included and which characteristics will be a side benefit. As other technologies might be less costly to implement, one should determine at which costs the side benefits of blockchain come. Last, designing the process differently may solve the problems as well at a much lower cost. For example, always using a standardized format during the negotiations may result in fewer price-differences during promotions. Participants of the network will have a better understanding of which contract parameters to negotiate. As a result, the problem of having different understandings about the agreed contract is reduced to a minimum.

7.4 Numerical example

To determine if the blockchain-based contract process is beneficial, it is needed to quantify the benefits, challenges, and limitations. However, as no practical data is available, a numerical example is used. The numerical example is based on (rough) estimates. As a result, it cannot be concluded if the blockchain solution is always beneficial/worthless. However, the numerical example gives practical insight into the blockchain solution. Therefore, the numerical example contributes to the qualitative analysis. The following situation is used to quantitatively analyze the benefits, challenges, and limitations of the blockchain solution.

- Company A has more than 1,600 suppliers. Each supplier delivers a number of products to Company A, who sells these products to the customers. The companies execute the contract process (see section 7.1) to make sure products flow from the supplier to the retailer.

- Over 2018 Company A encountered 165,000 price-differences. The 100 largest suppliers accounted for 25,000 price-differences. These suppliers execute the contract process 300 times a year for regular products (150 different products, two times a year) and 400 times a year for promotional products (100 different products, four times a year). It is assumed that these numbers are stable for the coming years.

- 12% of the price-differences are not acted upon. If Company A does not act on a price-difference, it costs them on average €250. In situations of price-differences, it is assumed that in most cases the received invoice exceeds the expected invoice. Company A orders large order quantities during promotions. For example, Company A order 2,500 products during promotions and receives an invoice with a price that is €0.10 higher than agreed. Not solving the issue, would result in a cost of €250.

- Internal employees (at Company A and suppliers) cost €40 per hour. External employees cost €100 per hour.

- The implementation of the blockchain solution decreases the processing time for contract processes with 1.5 minutes and for solving issues with 1 minute because participating companies are assumed to have high mature systems.

- The implementation of the blockchain solution reduces the number of price-differences with 75%.

- The implementation of the blockchain solution results in a development time of 650 hours for the first supplier, 300 hours for the second supplier, and 250 hours for additional suppliers. Around 75% of this time is spent by the external company.

The implementation of the blockchain solution for the largest 100 suppliers results in the benefits, challenges, and limitations discussed below.
7.4.1 Benefits

The benefits of implementing the blockchain solution are reduced processing time, a reduced number of price-differences, improved visibility, and a secure digital information system. However, it is assumed that the benefits of improved visibility and the security of the information system do not directly result in savings or additional gained money. These benefits contribute indirectly to savings related to the reduced processing time and reduced number of price-differences. Therefore, only the benefits of the reduced processing time and reduced number of price-differences are discussed.

The implementation of the blockchain solution with the 100 largest suppliers results in a decrease of 25,000 * 0.75 = 18,750 price-differences. In addition, it reduces the processing time for solving issues with 1 minute for each price-difference. As a result, Company A is able to act upon each price-difference. In the traditional situation, 12% of the price-differences are not acted upon. Thus, the savings equal 0.12 * 165,000 * €250 = €4,950,000 a year. Furthermore, the processing time required to solve the price-differences caused by this group of suppliers is reduced with 1 minutes. However, there are 0.12 * 165,000 – 18,750 = 1,050 more price-differences being solved. As a result, the total processing time for solving issues is decreased with 6,250 * 1 – 1050 * 1.83 = 4,329 minutes = 72 hours. Thus, the additional savings equal 72 * €40 = €2,886 a year.

The implementation of the blockchain solution with the 100 largest suppliers results in a decrease of 1.5 minutes for each contract process executed by these suppliers. In total, the largest 100 suppliers execute the contract process with Company A 100 * 300 + 100 * 400 = 70,000 times a year. As a result, the total processing time for contract process is reduced with 70,000 * 1.5 = 105,000 minutes = 1,750 hours. Which equals a saving of 1,750 * €40 = €70,000.

7.4.2 Challenges

The challenges of implementing the blockchain solution are scalability and immaturity. These challenges are not quantifiable because they do not directly result in costs. However, these challenges are indirectly included in the benefits and limitations. For example, the fact that only 100 suppliers are co-operating in the process is the result of the challenge scalability. A beneficial situation can be created for large suppliers because they contribute to a significant number of price-differences. It is (probably) not beneficial to implement the blockchain solution with a supplier with only 1 price-difference a year. Therefore, a beneficial situation can not be guaranteed for small suppliers. Furthermore, immaturity is indirectly taken into account in the development cost by additional time required for developing the blockchain-based system.

7.4.3 Limitations

The limitations of implementing the blockchain solution are the development costs and suitability. This research did not investigate other options for solving the issues faced by Company A. Regarding the benefits, one can see that the savings due to a reduced number of price-differences are much larger than the savings due to the processing time. Therefore, if Company A investigates into other solutions for solving the price-differences it may limit the implementation of the blockchain solution.

The implementation of the blockchain solution with the 100 largest suppliers results in 650 + 300 + 250 * 98 = 25,450 hours required for the development and implementation. It is estimated that 75% of these hours are executed by a third party. As a result, the costs associated to the development are equal to 25,450 * 0.75 * €75 + 25,450 * 0.25 * €40 = €1,686,063.
7.4.4 Insights

The aim of executing the numerical example was to get more quantitative insights into the benefits, challenges, and limitations. Although the numerical example is based on rough estimates, three interesting insights are generated.

- The benefit of reducing the number of price-differences is much higher than the benefit of reducing the processing time. The reduced number of price-differences results in a saving of €4,950,000, while the reduced processing time results in a saving of €72,886. Thus, in this situation, it is more important for Company A to reduce the (i.e., to act on all) number of price differences than to reduce the processing time. To the best of my knowledge, blockchain is not the only way for doing it.

- The implementation of the blockchain solution results in benefits, challenges, and limitations that cannot be quantified. However, these could have an additional value or can do additional harm to the implementation. One should take these into account when investigating the possibility of implementing the blockchain solution.

- In this situation, the implementation of the blockchain solution results in savings equal to €4,950,000 + €2,886 + 70,000 − €1,686,063 = €3,336,803. However, one should take into account that the implementation of the blockchain solution at 100 suppliers is a large project. There are 25,450 hours required but companies have to come together to execute some part of the project. As a result, scheduling issues may arise as well. In addition, it is an expected profit. As a result, the decision-maker should use a cost of capital to discount the value generated by the project. It is assumed that Company A uses a cost of capital of 11%, that the benefits are generated in two years from now, and that the costs are incurred in one year from now. As a result, the present value of the expected profit equals $5,022,886 \cdot \frac{1}{(1+0.11)^2} - \frac{1,686,063}{(1+0.11)} = €2,557,711.$
Chapter 8

Evaluation

In previous chapters, supply chain contract models with risk-averse members (chapter 4) and the potential value of blockchain for contract processes (chapter 7) are discussed. However, the aim of this master thesis is to investigate the possibility of implementing a blockchain-based supply chain contract to coordinate a supply chain with risk-averse members. As explained before, although coordination results in higher present values of expected profits, a general contract might be favorable over supply chain contracts because they are simpler to administer. Implementing a blockchain-based system could reduce these administration costs. Therefore, this chapter aims at combining the previously gained information to get insight into the value of blockchain for supply chain contracts. Supply chain contracts require several adjustments in comparison to the regular contract processes. First, the blockchain-based supply chain contract process is analyzed to clarify the adjustments required in section 8.1. Second, the additional benefits, challenges, and limitations are discussed in section 8.2. Last, the different contracts discussed in this master thesis are compared to each other in section 8.3.

8.1 Blockchain-based supply chain contract process

The blockchain solution for contract processes is based on the contract used by Company A: a wholesale-price contract. As a result, the process for a blockchain-based wholesale-price contract is similar to the blockchain solution described in section 7.2. Furthermore, the benefits, challenges, and limitations are similar as well.

To implement a buyback contract additional steps have to be executed in the process. By means of a buyback contract, supply chain coordination can be achieved. It often happens that multiple combinations are possible to achieve coordination. Thus, during the negotiation step companies have to determine the possible combinations between a buyback price and wholesale-price to achieve coordination. As the different combinations result in different allocations of the profit, the supplier and retailer have to negotiate on which contract they agree. The steps that follow do not change by the implementation of the buyback contract. However, after the last step (payment processing), additional steps have to be executed due to an additional payment between the supplier and retailer, based on the number of leftover units. Figure 8.1 shows the adjusted contract process.
Figure 8.1: Blockchain-based buyback contract process

To implement a revenue-sharing contract additional steps have to be executed in the process. Like the buyback contract, the revenue-sharing contract is able to coordinate the supply chain. Thus, the revenue-sharing contract also requires that companies investigate which combinations between a shared percentage and wholesale-price result in coordination. Then, the companies determine which combination is used in the contract. The process steps after the members agreed on a contract are not changed by the implementation of the revenue-sharing contract. However, after the last step (payment processing), additional steps have to be executed due to an additional payment between the supplier and retailer. This payment is based on the revenue that is gained by the retailer. Figure 8.2 shows the adjusted contract process.

Figure 8.2: Blockchain-based revenue-sharing contract process

To implement the buyback contract or revenue-sharing contract additional process steps are required. These additional steps are represented by yellow-colored boxes. These process steps have to be executed as a result of (1) the possibility of coordination and (2) an additional payment after demand is faced. The only difference between the blockchain-based buyback contract process and blockchain-based revenue-sharing contract process is the company that executed a process step. Therefore, the process of these contracts is called the blockchain-based supply chain contract process. The additional steps for the blockchain-based supply chain contract are explained in more detail below.

8. Demand is faced\(^1\) - The assumption is made that the supply chain model is a newsvendor situation. Therefore, demand occurs during a selling period. Based on its order quantity, the retailer will either have leftover units or faces lost sales. At the end of the selling period, the system of the retailer automatically sends the right information to the blockchain. This information is dependent on the contract used. For example, when a buyback contract is considered the system sends the number of leftover inventories to the blockchain.

\(^1\)In the regular process demand is also faced. However, it was not regarded because no further actions had to be made between the members of the supply chain.
9. **Sending invoice** - The blockchain contains information with regard to the agreed contract and to contract specific information. Based on this information, the blockchain automatically constructs a second invoice at the end of the selling period. This invoice is directly sent to the concerned party. In addition, the systems of both parties are updated with the required information.

10. **Fulfilment** - After the demand is faced and the invoice is sent, both parties have to sign the invoice. An extra check can be executed before digitally signing the invoice. After both companies signed the invoice, the blockchain system automatically triggers the payment system of the concerned member.

**Solving issues** - When issues arise, the blockchain can easily be used to investigate the cause of the issue. The process of solving issues remains the same as in the regular process.

11. **Payment processing** - When the payment system is triggered, it will automatically pay the invoice.

### 8.2 Benefits, challenges, and limitations

In the previous chapter, the benefits, challenges, and limitations of the blockchain-based solution are discussed. However, it is shown that the blockchain-based supply chain contract is slightly different. As a result, the benefits, challenges, and limitations are slightly different as well. Therefore, the benefits, challenges, and limitations for blockchain-based supply chain contracts are discussed below.

**Benefits** - The implementation of a blockchain-based supply chain contract has the benefits of the individual implementation of (1) a blockchain-based system for contract processes and (2) a supply chain contract. On top of that, the blockchain-based system could be designed such that the additional steps associated with a supply chain contract are partly automated. These additional steps should be developed in the system by the third party. Additional code has to be programmed into the blockchain-based system that is able to execute the additional process steps. The time required is estimated to be 20 hours (one employee working 0.5 weeks). As a result, the administration costs associated with a supply chain contract are reduced at the price of higher development costs. Thus, implementing a blockchain-based supply chain contract has the benefit of reduced processing time, reduced cost associated with price-differences, improved visibility, providing a secure digital information system, (relatively) low administration cost, and a coordinating supply chain.

**Challenges** - The implementation of a blockchain-based supply chain contract has the challenges of the individual implementations. The supply chain contract models in this master thesis assumed forced compliance. It means that the supplier always delivers the order quantity that is ordered by the retailer. However, due to practical issues, it might be more beneficial for the supplier to deliver less or more products. Cachon (2003) showed that the buyback contract and revenue-sharing contract still coordinate the supply chain even if full compliance is not assumed. Therefore, it is seen as a challenge instead of a limitation. Thus, implementing a blockchain-based supply chain contract has the challenges of full compliance, scalability, and immaturity.

**Limitations** - The implementation of a blockchain-based supply chain contract results in the same limitations as the individual implementations. As explained above, the process requires the blockchain-based system to execute additional steps. Therefore, an additional limitation arises called profitability. Implementing the supply chain contract instead of a general contract results in additional benefits due to coordination. However, it also results in additional costs.
due to the additional development costs and process steps that have to be executed. Thus, the additional benefits associated with coordination should exceed the additional costs. This is seen as a limitation because Cachon (2003) says the benefit of coordination might be small in a lot of situations. Furthermore, the supply chain contract models in this master thesis assumed full information. It means that the supplier and retailer have full information about each other’s cost and revenue parameters. However, in practice companies often lack full information. In that case, coordinating the supply chain requires more than just coordinating individual actions. It requires the sharing of information. However, in some situations, companies are not willing to share information with each other or it costs money to share this information. Therefore, the need for sharing information in a supply chain contract is seen as a limitation. Thus, implementing a blockchain-based supply chain contract faces the limitations of profitability, full information, development costs, and suitability.

8.3 Comparison on the different contracts

The information that is gained during the execution of this master thesis, is used to compare the different contracts. Within this master thesis, there are, roughly said, four types of contracts discussed: (1) a regular contract (wholesale-price contract), (2) a supply chain contract, (3) a blockchain-based regular contract, and (4) a blockchain-based supply chain contract. These contracts are compared on the discussed benefits (table 8.1), challenges (table 8.2), and limitations (table 8.3). Promotional contracts are not considered individually. However, they are taking into account by comparing the contracts on their impact on price-differences. If a value (benefit, challenge, or limitations) positively applies to a contract it is demonstrated with +, if a value negatively applies to a contract it is demonstrated with −, and if a value does not apply to a contract it is demonstrated with +/- . Below, each aspect is discussed by means of a table.

<table>
<thead>
<tr>
<th></th>
<th>Regular contract</th>
<th>Supply chain contract</th>
<th>Blockchain-based regular contract</th>
<th>Blockchain-based supply chain contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing time</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Price-differences</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Visibility</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Secure information system</td>
<td>+/-</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Simple to administer</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+/-</td>
</tr>
<tr>
<td>Coordination</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

In table 8.1, the contracts are compared on the discussed benefits. It is explained that executing a contract by means of the blockchain solution results in a lower processing time and a lower number of price-differences. In addition, visibility and a secure information system are provided by the implementation on a blockchain. However, these values are not negatively applying to the regular contract and supply chain contract. Furthermore, the regular contract and blockchain-based regular contract are simple to administer. This is a negative character of the supply chain contract and does not apply to the blockchain-based supply chain contract as automation is partly provided. However, the supply chain contract and blockchain-based supply chain contract have the additional benefit of coordination. Concluding, the blockchain-based regular contract and the blockchain-based supply chain contract score best on the discussed benefits. The numerical example in chapter 5 showed that a supply chain contract results in additional gains of 26,777, which is assumed to be in €.
In table 8.2, the contracts are compared on the discussed challenges. Full compliance may be negatively for these contracts if delivering the order quantity is not optimal for the supplier. Furthermore, the challenges with regard to scalability and immaturity negatively apply to the blockchain-based regular contract and the blockchain-based supply chain contract. It is the result of using blockchain technology to execute part of the contract process. Concluding, the regular contract scores best on the discussed challenges.

In table 8.3, the contracts are compared on the discussed limitations. Profitability regards the benefits of coordination with the additional costs associated with supply chain contracts. If the benefits of coordination exceed (are less than) the additional costs, the value applies positively (negatively) to the supply chain contract and blockchain-based supply chain contract. The additional cost of developing a supply chain contract on blockchain, results in 20 additional hours spent by the third party. As a result, the additional costs are 20 \times 75 = 1,500. In addition, it is estimated that the processing time increased with 1 minute. The latter is negligible because coordination results in an additional gain of 26,777 each time it is executed. Thus, in the numerical example, it is profitable to introduce the coordination contract. However, full information is required to achieve coordination. As full information is rare in practice, it negatively applies to these contracts. In addition, the development costs apply negatively to the blockchain-based regular contract and blockchain-based supply chain contract because it is required to develop a costly blockchain-based system. Furthermore, suitability is positively applying to the regular contract because it is a widely used contract in practice and to the supply chain contract because it is a suitable way of coordinating the supply chain. Because no investigation is done to solutions using other technologies for automating and solving price-differences, it is said that it is not applying to the blockchain-based regular contract and not applying to the blockchain-based supply chain contract.

During this master thesis, two numerical examples are executed. One numerical example is executed to get more insight in the value of a supply chain contract for risk-averse members (see chapter 5), the other numerical example is executed to get more insight on the value of the blockchain-based solution (see section 7.4). This chapter combined both implementations in a blockchain-based supply chain contract. In addition, a comparison of the different contracts is executed. Table 8.4 shows the quantitative savings or additional gains achieved by the implementation of a contract, based on the numerical examples executed in this master thesis.
(the values are in €). The regular contract is used as a starting point and expected profits are discounted with a cost of capital of 11%.

Table 8.4: Quantitative comparison

<table>
<thead>
<tr>
<th></th>
<th>Regular contract</th>
<th>Supply chain contract</th>
<th>Blockchain-based regular contract</th>
<th>Blockchain-based supply chain contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduced processing time</td>
<td>0</td>
<td>0</td>
<td>59,155</td>
<td>59,155</td>
</tr>
<tr>
<td>Reduced number of price differences</td>
<td>0</td>
<td>0</td>
<td>4,017,531</td>
<td>4,017,531</td>
</tr>
<tr>
<td>Development cost</td>
<td>0</td>
<td>0</td>
<td>-1,518,975</td>
<td>-1,520,327</td>
</tr>
<tr>
<td>Coordination</td>
<td>0</td>
<td>26,777</td>
<td>0</td>
<td>26,777</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>26,777</td>
<td>2,557,711</td>
<td>2,583,136</td>
</tr>
</tbody>
</table>

The numerical analysis shows that a blockchain-based supply chain contract is most beneficial. However, full information and full compliance are required to gain the additional benefits of coordination. As said before, full information is rare in practice. Thus, it is recommended to implement the blockchain-based supply chain contract if full information is not available or possible at a low cost.

The numerical examples are not representing the real use case that Atos is setting up with Company A. However, they give quantitative insight into the benefits, challenges, and limitations of the blockchain solution for contract processes. The main benefit is achieved by reducing the number of unaddressed price-differences. However, not all of the main characteristics of blockchain technology did contribute to addressing the number of price-differences. To reduce the number of price-differences, it is not required to have a history of transactions. Although it is a beneficial characteristic for solving issues, it does not reduce the number of price-differences. As a result, other solutions might be available to solve the issue of price-differences as well. The costs that are associated with the implementation of a blockchain-based system are large and the added benefit that is achieved by the reduced processing time is small. As a result, it is recommended for Atos to investigate other solutions for addressing the number of price-differences. If no solutions if found to be as beneficial as implementing the blockchain solution, then continue working on developing the blockchain solution.
Chapter 9

Discussion

In this chapter, conclusions are drawn on the main results achieved by this master thesis. Furthermore, this chapter discusses the relevance of this master thesis and gives a reflection on it. Last, directions for future research are suggested.

9.1 Main conclusions

The goal of this master thesis was to investigate the possibility of implementing a blockchain-based supply chain contract that is able to coordinate a supply chain with risk-averse members. Therefore, a supply chain contract model with risk-averse members is created. In addition, a study on the potential value of blockchain for contract processes is executed. The combination of these studies is used to answer the main research question:

Is it possible to coordinate a supply chain with risk-averse members by means of a blockchain-based supply chain contract?

The question can be seen in a twofold: (1) supply chain contract coordination with risk-averse members and (2) the added value of blockchain. Therefore, it was not possible to answer the question at once. As a result, four sub-questions have been developed that result in the capability of answering the main research questions. Although the sub-questions have been answered throughout the report, they are answered in a structured way below. Starting with the first sub-question.

1. Which conditions should be met in order to achieve coordination in a supply chain with risk-averse members?

Cachon (2003) showed the conditions that should be met to achieve coordination in a supply chain with risk-neutral members. These conditions are (among others) based on the definition that is provided for supply chain contract coordination. Investigating literature that measures risk, resulted in the possibility of re-defining this definition such that it is applicable for the risk-averse supply chain: A contract coordinates the supply chain if the individual risk-averse members make independent, optimizing, risk considering actions that lead to a maximum supply chain present value of the expected profit, in which no member has an incentive to change its behavior. Based on this new definition, it was possible to construct the conditions required for achieving coordination in a supply chain with risk-averse members. First, coordination is only achieved when the maximum supply chain its present value of the expected profits is reached. Second, to achieve coordination, no member of the supply chain should have an incentive to change its behavior. With regard to supply chain contracts, it means that the supply chain contract should align the retailer its optimal order quantity with the supply chain its optimal order quantity subject to the supplier being able to achieve its reservation payoff. These conditions are more detailed explained for each individual contract in chapter 4. Having the first sub-question being answered, this master thesis moved on to answering the second sub-question:

2. Which basic type of supply chain contracts are able to coordinate the supply chain with risk-averse members?
Cachon (2003) constructed the basic models of supply chain contract coordination with risk-neutral members. To relax the assumption of risk-neutral members, a literature review is done to investigate how to measure risk in supply chain contract models. As a result, the models described in Anvari (1987) and Birge (2014) are combined such that systematic risk is measured only and that the interaction between finance and operations is incorporated. Combining this information with the basic supply chain contract models, resulting in a supply chain contract models with risk-averse members. This model is applied to the wholesale-price contract, buyback contract, and revenue-sharing contract. The analysis showed that the wholesale-price contract is not able to coordinate a supply chain with risk-averse members. However, the buyback contract and revenue-sharing contract are able to coordinate a supply chain with risk-averse members. These results are in agreement with the conclusions drawn in the risk-neutral environment. Having the first part of the goal investigated, it was possible to go further with the third research question:

3. **What value can blockchain achieve for risk-averse members with regard to contract issues?**

To identify the value of blockchain for supply chain contracts, this master thesis first identified the value of blockchain for contract issues. Atos is approached for a pilot to investigate the value that a blockchain-based system may have for the contract processes of Company A. Within the pilot, the blockchain-based system serves as a ‘single-source of truth’ to reduce the number of price-differences that are faced at Company A. However, blockchain is chosen as it can be used for further improvements as well. As a result, this master thesis investigated the value that blockchain can achieve for contract processes executed between a retailer and its supplier(s). To identify this value, a solution for the issues of Company A is designed in collaboration with employees of Atos. Based on this design, a qualitative analysis is executed to identify the benefits, challenges, and limitations. A summary of the results is given. The identified benefits are (1) reduced processing time for contract processes, (2) a reduced number of price-differences, (3) improved visibility in the process, and (4) a secure information sharing system. The challenges identified are (1) scalability and (2) immaturity. Last, the limitations of implementing the blockchain solution are (1) the development costs and (2) the suitability of the blockchain-based system. By having identified the benefits, challenges, and limitations for regular contracts, this thesis continued with the fourth sub-question:

4. **What value does a blockchain-based supply chain contract achieve?**

Supply chain contracts and regular contract are slightly different. Within a supply chain contract, an additional payment and process steps have to be executed after demand is faced. Therefore, the blockchain-based system should be designed differently. As a result, additional benefits, challenges, and limitations arose. These are shortly summarized. In comparison to a regular contract, a blockchain-based supply chain contract has the benefits of (1) a reduced processing time, (2) a reduced number of price-differences, (3) improved visibility in the process, (4) a secure information system, (5) it achieves coordination at a small cost of additional development costs for the blockchain. Furthermore, the challenges identified are (1) full compliance, (2) scalability, and (3) immaturity. Last, the limitations identified are (1) profitability depending on the achieved benefit of coordination, (2) full information, (3) development cost, and (4) suitability.

Based on the information gained by answering the sub-questions, it is possible to answer the main research question. A blockchain-based supply chain contract is able to coordinate a supply chain with risk-averse members. However, not in each situation, it is possible to achieve coordination. The identified conditions should be met, the implementation of blockchain should be beneficial, and the assumptions made in the models should apply for the practical situation.
9.2 Relevance

First, this master thesis contributed to the literature by providing a supply chain contract model with risk-averse members. The literature review showed models that relaxed the assumption of risk-neutral members as well. However, the model provided in this master thesis is qualitatively different. For investors, systematic risk is the only relevant risk in supply chain contracts. However, current research considered risk-averse members by measuring all types of risk (variance) or by not measuring risk at all. In addition, the operational decision influences the financial decision, and vice versa. However, none of the models for supply chain contracts with risk-averse members did incorporate this interaction. Therefore, the model provided uses an adjusted version of the CAPM to measure the systematic risk only and to incorporate the interaction between finance and operations.

Second, this master thesis analyzed the possibility of coordinating a supply chain with risk-averse members by means of a wholesale-price contract, buyback contract, and revenue-sharing contract. Other researchers did investigate the possibility of coordination in a risk-averse environment. However, these researchers based their conclusions on models that suffered from some drawbacks. Therefore, a new analysis is done based on the model provided in this master thesis. The analysis shows that it can be concluded that the buyback contract and revenue-sharing contract are able to coordinate a supply chain with risk-averse members.

Last, no research did investigate the value that blockchain technology has for supply chain contracts. Therefore, this master thesis has practical relevance by analyzing the value of blockchain for supply chain contracts. Among others, a practical use case at Atos is used to design the general process of contract execution of a retailer with its suppliers. Based on this current situation, the processes in which blockchain is applied to the traditional process is designed. This process was then analyzed to identify the benefits, challenges, and limitations of the blockchain solution for contract processes. The information gained about supply chain contracts is then used to analyze the value that blockchain may have for supply chain contracts. To provide insights for readers, a numerical example is developed and executed in this master thesis.

9.3 Reflection

First, one of the reasons to relax the assumption of risk-neutral supply chain members is to make the supply chain model increasingly relevant for practice. To do so, the basic models of Cachon (2003) are used as a starting point. Based on these models, the assumption of risk-neutral supply chain members is relaxed. However, the model contains other assumptions that are not representing practical characteristics. One of the assumptions is that demand is not dependent on the retail price. However, the retail price is one of the most used parameters to influence demand (Cachon, 2003). Although these assumptions should be relaxed to make the supply chain model more relevant for practical situations, this master thesis took an important step in making supply chain models more relevant for practice.

Second, Atos was approached by Company A to develop a blockchain-based system for a pilot that was supposed to be used in practice. This way, it should have been possible to design the contract process based on a real-life situation. However, due to issues at Company A, this collaboration did not take place (yet). This led to the decision of developing a fictive use case, inspired by the use case of Company A. Based on this fictive use case, the process in which a blockchain-based system is used for contract process is designed in collaboration with a focus group. Unfortunately, the members of the focus group did not have senior experience in the retail industry. Therefore, it was not possible to have a detailed analysis of the contract process for retailers. This led to the decision of using literature, white-papers, and a semi-structured
interview to construct a general contract process between a retailer and its supplier. However, the members did have senior experience in blockchain technology. As a result, it was beneficial for identifying the (qualitative) benefits, challenges, and limitations.

Last, it was supposed to do a quantitative analysis based on the real-life use case. However, as Company A did not collaborate with Atos yet, no data is available. That led to the decision of constructing a numerical example. This example is based on rough estimates that are verified with a senior employee of Atos. However, having a quantitative analysis based on a numerical example instead of on a real-life situation is seen as a limitation of this master thesis. In addition, it would have been much more interesting for Atos if the analysis could have been based on the real-life situation with Company A.

9.4 Future research

First, within this master thesis three of the supply chain contracts described in Cachon (2003) are discussed. However, Cachon (2003) described more contracts: a quantity-flexibility contract, a sales-rebate contract, or a quantity-discount contract. Therefore, if one wants to see if coordination in a supply chain with risk-averse members is achievable by means of these contracts, one could use this master thesis for their research (chapter 4 and Appendix A).

Second, as said in the previous section, this master thesis used the basic models described in Cachon (2003). Further research should relax some of the assumptions made in this master thesis, to take a step further in making supply chain contracts more relevant for practice. In addition, this master thesis used a newsvendor period consisting of one selling period. However, risk plays an important role in future payments. Therefore, it would be interesting to see the impact on multiple selling periods.

Last, the analysis of the value that blockchain achieves for (supply chain) contract processes is mostly qualitative. Additionally, a numerical example is used to give quantitative insights. However, a numerical example is not as reliable as a practical data. Therefore, if the practical use case with Company A takes place, one could use this master thesis in combination with the data gathered during the real-life use case.

Carrying out these directions for improvement on top of this master thesis would make the resulting paper be a more practical representation.
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Appendix A

Additional supply chain contracts

Cachon (2003) discussed several contracts. However, only two of these contracts are used and build upon in this master thesis. The explanation of the other contracts can be found in this Appendix.

Quantity-flexibility contract

The quantity-flexibility contract is another supply chain contract that is based on the wholesale-price contract. Although it is at a high level similar to the buyback contract, there is a major difference. The buyback contract provides the retailer with partial protection on the retailer’s order, whereas the quantity-flexibility contract gives full protection on a part of the retailer’s order. To be more specific, within the quantity-flexibility contract the supplier pays a credit to the retailer at the end of the selling period equal to

\[
(w + c_r - v) * \min(max(0, I(q)), \delta q),
\]

where \(\delta \in [0, 1]\) is the agreed percentage. So, the cost at the retailer is fully refunded to a maximum of an agreed percentage of the order quantity. Using the quantity-flexibility contract the following transfer payment take place:

\[
T(q, w, \delta) = wq - (w + c_r - v) \int_{(1-\delta)q}^{q} F(y)dy.
\]

The assumptions that have to be made when reviewing the quantity-flexibility contract are the same as described in the wholesale price, no extra or changed assumptions have to be made. With the transfer payment known, it is possible to determine the profit functions of the retailer and supplier:

\[
\pi_r(q, w, \delta) = (p - v + g_r)(1 - F(q^o)) - (w + c_r - v)(1 - F(q^o) + (1 - \delta)F((1 - \delta)q)) = 0
\] (A.3)

Since the retailer’s optimal order quantity should equal the supply chain’s optimal order quantity \(q^o_{qf}\) is replaced by \(q^o\).

\[
w = \frac{(p - v + g_r)(1 - F(q^o))}{1 - F(q^o) + (1 - \delta)F((1 - \delta)q)} - c_r + v
\] (A.4)

Cachon (2003) showed that \(w\) is indeed coordinating when the retailer’s profit function is concave:

\[
\frac{\delta^2 \pi_r(q, w, \delta)}{\delta q^2} \leq 0.
\]

It holds when \(v - c_r \leq w \leq p + g_r - c_r\), which can be satisfied. Though one remark should be made, since it is assumed the supplier has forced compliance coordination is possible because the supplier’s action is not relevant. However, when voluntary compliance is assumed coordination is not assured as a result of the second-order condition being ambiguous at \(q^o\). Assuming coordination is possible, it follows that all allocations of the profit are possible (Cachon, 2003).
Sales-rebate contract

The fifth contract that is discussed in Cachon (2003) is the sales-rebate contract. Within a sales-rebate contract, the supplier charges the retailer a wholesale price \( w \) for each unit ordered but gives back a rebate \( r \) (discount) on every unit that is sold above an agreed threshold \( t \). Thus, the retailer gets a discount on each unit sold above the threshold, and not on the units ordered. Implementing a sales-rebate contract can result in two different transfer payments. It is possible that the retailer does not order above the threshold unit, then the transfer payment equals the wholesale-price contract, thus \( T(q, w) = wq \). When the retailer’s order quantity is above the threshold level the transfer payment is \( T(q, w, r, t) = (w - r)q + r(t + \int_t^q F(y)dy) \). In addition to the wholesale-price contract, an extra assumption has to be made:

1. \( t < q^o \), otherwise, the contract equals the wholesale-price contract, which we know is not able to coordinate the supply chain.

When taking into account the assumption above, it is possible to determine the profit functions for the retailer and supplier:

\[
\begin{align*}
\pi_r(q, w, r, t) &= (p - v + g_r)S(q) - (w + c_r - v - r)q - g_r \mu - r(t + \int_t^q F(y)dy) \\
\pi_s(q, w, r, t) &= g_sS(q) + (w - r - c_s)q + r(t + \int_t^q F(y)dy) - g_s \mu
\end{align*}
\]

In order to coordinate the supply chain, the retailer’s profit function should, among others, be at a (local) maximum. The wholesale price that satisfies the first-order condition is given by:

\[
w = (p - v + g_r + r)\bar{F}(q^o) - c_r + v
\]

The second-order condition confirms that \( q^o \) is a local maximum because the profit function for the retailer is strictly concave in \( q > t \). However, there is a ‘kink’ at \( t = q \). This ‘kink’ is the result of the discount that the retailer gains on the units sold above the agreed threshold level. Thus, when assuming that \( \bar{q} = \text{argmax}_{q \leq t} \pi_r \) it is needed to show that \( q^o \) is the maximum order quantity instead of \( \bar{q} \). Cachon (2003) showed that there is a set of combinations possible that show that \( q^o \) is the optimal order quantity, and, thus, the contract is able to coordinate the supply chain. Furthermore, Cachon (2003) showed that the different combinations of a wholesale price, threshold level, and rebate are able to allocate the profit between the retailer and supplier. However, when the assumption of forced compliance is relaxed and the supplier is able to deviate from the order quantity, it is not possible to coordinate the supply chain with a sales-rebate contract. The first-order of the supplier’s profit function is only positive if \( r < g_s \), but the supplier is not making a positive profit when \( r < g_s \). However, when \( r > g_s \) the supplier loses money on the items sold above the threshold level which is not preferred by the supplier.

Quantity-discount contract

The last contract that is discussed in the quantity-discount contract. As the name suggests a discount is given on an increasing order quantity. When a quantity-discount contract is implemented, the retailer faces a wholesale price that is dependent on the size of its order quantity. Assuming that this discount is given on each unit ordered, the transfer payment becomes \( T(q, w) = w(q)q \), where \( w(q) \) is the function for the wholesale price which is dependent on the order quantity. Within the quantity-discount contract, the wholesale price is decreasing in \( q \). Minor adjustments are made to the assumptions of the wholesale-price contract:

1. \( w(q) > c_s \), otherwise, the supplier would not be able to make a profit on selling units to the retailer.
2. \( w(q) > v \), otherwise, the retailer would be able to make an infinite profit by salvaging an infinite amount of ordered units.

3. \( w(q) < p - c_r \), otherwise, the retailer would not be able to make a profit.

The assumptions are changed such that the function of the wholesale price is incorporated. Based on the information given, it is possible to make the profit functions of the retailer and supplier:

\[
\pi_r(q, w(q)) = (p - v + g_r)S(q) - (w(q) + c_r - v)q - g_r \mu
\]  
(A.8)

\[
\pi_s(q, w(q)) = g_s S(q) + (w(q) - c_s)q - g_s \mu
\]  
(A.9)

Cachon (2003) showed that coordination is possible by using the quantity discount contract. He provided a technique that divides the profit among the retailer and supplier, such that coordination is possible. This technique says to choose the payment schedule such that the retailer’s profit equals a constant fraction of the total profit. Thus, the following equation should hold for the wholesale-price contract function:

\[
w(q) = ((1 - \lambda)(p - v + g) - g_s \frac{S(q)}{q}) + \lambda(c - v) - c_r + v
\]  
(A.10)

When \( \lambda \leq \bar{\lambda} = \frac{p - v + g_s}{p - v + g} \), the wholesale price is decreasing in \( q \). The retailer’s profit is now optimal at \( q^* \). In addition, this order quantity is also the optimal order quantity for the supplier. So, by implementing the quantity-discount contract it is possible to coordinate the supply chain.
Appendix B

Derivations of risk-averse supply chain contract models

Derivation of supply chain’s optimal order quantity

The optimal order quantity is found by deriving the profit function of the supply chain. In addition, the equality $S'(q) = F(q) = 1 - F(q)$ is used to find the optimal order quantity $q^*$ (Cachon, 2003). Furthermore, it is known that $c = c_s + \frac{c_r}{1 + r_f}$. The profit function of the supply chain is independent of the transfer payment and is:

$$PV_{SC}(EP_{SC}(q)) = \frac{1}{1 + r_f}[\hat{f}_{SC} - \lambda_m \text{Cov} (\hat{f}_{SC}, r_m)] - cq$$

Since $\hat{f}_{SC} = pS(q) + vI(q) - gL(q)$, we got the following expression

$$PV_{SC}(EP_{SC}(q)) = \frac{1}{1 + r_f}[(pS(q) + vI(q) - gL(q)) - \lambda_m \text{Cov} (\hat{f}_{SC}, r_m)] - cq$$

Because $I(q) = q - S(q)$ and $L(q) = \mu - S(q)$, we can redefine the profit function of the supply chain such that we are only left with $S(q)$:

$$PV_{SC}(EP_{SC}(q)) = \frac{1}{1 + r_f}[(pS(q) + vI(q) - gL(q)) - \lambda_m \text{Cov} (\hat{f}_{SC}, r_m)] - cq$$

When we rewrite the covariance and denote $\bar{m} = p - v + g$ we get the following:

$$PV_{SC}(EP_{SC}(q)) = \frac{1}{1 + r_f}[(\bar{m}S(q) + v\mu) - \lambda_m \text{Cov} (\hat{f}_{SC}, r_m)] - cq$$

Thus, by deriving the profit function of the expected profit for the supply chain we get:

$$\frac{dPV_{SC}(EP_{SC}(q))}{dq} = \frac{1}{1 + r_f}[(\bar{m}S'(q) + v) - \lambda_m \bar{m} f(q) \text{Cov}(D, r_m)] - c$$

The first order derivative consists out of three parts. For the derivation the assumptions of the supply chain model are taken into account. The first part is $\frac{1}{1 + r_f} (\bar{m}S'(q) + v)$, which is strictly decreasing in $q$. The second part is $\frac{1}{1 + r_f} (\lambda_m \bar{m} f(q) \text{Cov}(D, r_m))$, which is increasing because it is assumed that $D > 0$ and $F$ is strictly increasing in $q$. The third part is $c$, which remains equal in $q$. As a result, the first order derivative of the present value of the expected profit for the supply chain is strictly decreasing in $q$. In addition, the second order derivative equals

$$\frac{d^2PV_{SC}(EP_{SC}(q))}{dq^2} = \frac{1}{1 + r_f}[(\bar{m}S''(q)) - \lambda_m \bar{m} f'(q) \text{Cov}(D, r_m)]$$

The second order derivative consists out of two parts. The first part is $\frac{1}{1 + r_f} (\bar{m}S''(q))$, which result in a negative value for a positive $q$. The second part is $\frac{1}{1 + r_f} (\lambda_m \bar{m} f'(q) \text{Cov}(D, r_m))$,
which is positive because $D > 0$ and $F$ is strictly increasing in $q$. As a result, the second order derivative of the present value of the expected profit for the supply chain is negative. Thus, $PV_{SC}(EP_{SC}(q))$ is strictly concave.

To find the optimum of the profit function, the first order derivative should equal 0. Thus we get:

$$
\frac{1}{1 + r_{f_2}}[(\tilde{m}S'(q) + v) - \lambda_m\tilde{m}f(q)\text{Cov}(D, r_m)] - c = 0
$$

$$
\tilde{m}S'(q) - \lambda_m\tilde{m}f(q)\text{Cov}(D, r_m) = c(1 + r_{f_2}) - v
$$

$$
S'(q) - \lambda_mf(q)\text{Cov}(D, r_m) = \frac{c(1 + r_{f_2}) - v}{\tilde{m}}
$$

Since $\tilde{m} = p - v + g$, we get the following equation:

$$
S'(q) - \lambda_mf(q)\text{Cov}(D, r_m) = \frac{c(1 + r_{f_2}) - v}{p - v + g}
$$

Thus, we found $S'(q) = \frac{c(1 + r_{f_2}) - v}{p - v + g} + \lambda_mf(q)\text{Cov}(D, r_m)$, which is the supply chain’s $S'(q)$. Since, $S'(q) = F(q) = 1 - F(q)$, we get the following equation:

$$
F(q) + \lambda_mf(q)\text{Cov}(D, r_m) = 1 - \frac{c(1 + r_{f_2}) - v}{p - v + g}
$$

The following equation should be satisfied to find $q^*$

$$
F(q^*) + \lambda_mf(q^*)\text{Cov}(D, r_m) = \frac{p + g - c(1 + r_{f_2})}{p - v + g}
$$

**Derivation of section 4.5**

In order to conclude if the wholesale-price contract is able to coordinate a supply chain with risk-aware members, we have to see if the contract is able to align the retailer’s optimal order quantity with the supply chain’s optimal order quantity. Therefore, the first order of the retailer’s profit function has to be found. We start with the profit function of the retailer:

$$
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[\tilde{f}_r - \lambda_m\text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
$$

Since, we found that $\tilde{f}_r = pS(q) + vI(q) - g_rL(q)$ we get

$$
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[(pS(q) + vI(q) - g_rL(q)) - \lambda_m\text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
$$

Again, we can rewrite this profit function to a function that only incorporates $S(q)$:

$$
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[\{p - v + g_r\}S(q) + vq - g_r\mu - \lambda_m\text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
$$

When we rewrite the covariance and denote $\tilde{m} = p - v + g_r$ we get the following:

$$
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[(\tilde{m}S(q) + vq - g_r\mu) - \lambda_m\tilde{m}F(q)\text{Cov}(D, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
$$

Thus, by differentiating the profit function of the expected profit for the retailer we get:

$$
\frac{dPV_r(EP_r(q))}{dq} = \frac{1}{1 + r_{f_2}}[(\tilde{m}S'(q) + v) - \lambda_m\tilde{m}f(q)\text{Cov}(D, r_m)] - \frac{w + c_r}{1 + r_{f_1}}
$$
Thus, following equation has to be satisfied to find $q^*$. Since \( D > 0 \) and \( F \) is strictly increasing in \( q \). The first part is \( \frac{1}{1+r_f_2}[(\tilde{m}S'(q)+v)] \), which is strictly decreasing in \( q \). The second part is \( \frac{1}{1+r_f_1} [\lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] \), which is increasing because it is assumed that \( D > 0 \) and \( F \) is strictly increasing in \( q \). The third part is \( \frac{w+c_r}{1+r_f_1} \), which remains equal in \( q \). As a result, the first order derivative of the present value of the expected profit for the supply chain is strictly decreasing in \( q \). In addition, the second order derivative equals

\[
\frac{d^2 PV_r(EP_r(q))}{dq^2} = \frac{1}{1+r_f_2}[(\tilde{m}S''(q)) - \lambda_m \tilde{m} f'(q) \text{Cov}(D,r_m)]
\]

The second order derivative consists out of two parts. The first part is \( \frac{1}{1+r_f_2}[(\tilde{m}S''(q))] \), which result in a negative value for a positive \( q \). The second part is \( \frac{1}{1+r_f_1} [\lambda_m \tilde{m} f'(q) \text{Cov}(D,r_m)] \), which is positive because \( D > 0 \) and \( F \) is strictly increasing in \( q \). As a result, the second order derivative of the present value of the expected profit for the supply chain is negative. Thus, \( PV_r(EP_r(q)) \) is strictly concave.

To find the optimum of the profit function, the first order derivative should equal 0. Thus, we get:

\[
\frac{1}{1+r_f_2}[(\tilde{m}S'(q)+v) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] - \frac{w+c_r}{1+r_f_1} = 0
\]

\[
\frac{1}{1+r_f_2}[(\tilde{m}S'(q)+v) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] = \frac{(w+c_r)}{1+r_f_1}
\]

\[
S'(q) - \lambda_m f(q) \text{Cov}(D,r_m) = \frac{\frac{w+c_r}{1+r_f_1} (1+r_f_2) - v}{\tilde{m}}
\]

Since \( \tilde{m} = p - v + g_r \), we get the following equation:

\[
S'(q) - \lambda_m f(q) \text{Cov}(D,r_m) = \frac{\frac{w+c_r}{1+r_f_1} (1+r_f_2) - v}{p - v + g_r}
\]

Since \( S'(q) = F(q) = 1 - F(q) \), we get the following equation:

\[
F(q) + \lambda_m f(q) \text{Cov}(D,r_m) = 1 - \frac{\frac{w+c_r}{1+r_f_1} (1+r_f_2) - v}{p - v + g_r}
\]

Thus, following equation has to be satisfied to find \( q^* \):

\[
F(q^*) + \lambda_m f(q^*) \text{Cov}(D,r_m) = \frac{p + g_r - \frac{w+c_r}{1+r_f_1} (1+r_f_2)}{p - v + g_r}
\]

To see if coordination is possible, we investigated what wholesale-price should be used in order to get \( q^* = q^* \). Since \( S'(q) \) is decreasing, we only get \( q^* = q^* \) when \( S'(q) \) equals the \( S'(q) \) of the whole supply chain, which we found in the newsvendor situation. Thus, when we go further on \( \frac{1}{1+r_f_2}[(\tilde{m}S'(q)+v) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] - \frac{w+c_r}{1+r_f_1} = 0 \), we get

\[
\frac{w}{1+r_f_2} = \frac{1}{1+r_f_2}[(\tilde{m}S'(q)+v) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] - \frac{c_r}{1+r_f_1}
\]

\[
\frac{w}{1+r_f_1} = \frac{1}{1+r_f_1}[(\tilde{m}S'(q) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m))] - (\frac{c_r}{1+r_f_1} - \frac{v}{1+r_f_2})
\]

\[
\frac{w}{1+r_f_1} = \frac{1}{1+r_f_2}[(\tilde{m} \frac{c(1+r_f_2) - v}{p - v + g} + \lambda_m f(q) \text{Cov}(D,r_m)) - \lambda_m \tilde{m} f(q) \text{Cov}(D,r_m)] - (\frac{c_r}{1+r_f_1} - \frac{v}{1+r_f_2})
\]
We can rewrite the expression so that we are only left with supply chain model are taken into account. The first part is
\[\frac{w}{1 + r_{f_1}} = \frac{1}{1 + r_{f_2}} (\tilde{m} \frac{c(1 + r_{f_2}) - v}{p - v + g}) - \left( \frac{c_r}{1 + r_{f_1}} - \frac{v}{1 + r_{f_2}} \right)\]

Since, we denoted \(\tilde{m} = p - v + g\), we get the following formula for the wholesale-price \(w\):
\[\frac{w}{1 + r_{f_1}} = \frac{p - v + g}{p - v + g} (\frac{c - v}{1 + r_{f_2}}) - \left( \frac{c_r}{1 + r_{f_1}} - \frac{v}{1 + r_{f_2}} \right)\]

To align the retailer’s optimal order quantity with the supply chain’s, the equation should be satisfied. However, it is assumed that \(c = c_r + \frac{c_r}{1 + r_{f_1}}\), \(g = g_s + g_r\) and that \(p > c > v\). These assumptions result in \(0 \leq \frac{p - v + g}{p - v + g} \leq 1\), which in return result in the fact that \(\frac{w}{1 + r_{f_1}} \leq c_s\). This result in the fact that the supplier is not able to make a profit by selling units. When the wholesale-price would be higher, the retailer’s optimal order quantity would not equal the supply chain’s optimal quantity. In addition, when the order quantities are aligned, the supplier would not make a profit and has an incentive to change its behavior.

**Derivation of section 4.6**

In order to conclude whether the buyback contract is able to coordinate the supply chain or not, we have to see if the contract is able to align the retailer’s optimal order quantity with the supply chain’s optimal order quantity. Therefore, the expression for the present value is derived first. After which the first order of the retailer’s profit function is found to see if the retailer’s order quantity can be aligned with the supply chain’s optimal quantity.

\[PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}} [\tilde{f}_r - \lambda_m Cov(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}\]

As explained, the uncertain cash flow in the buyback contract is \(\tilde{f}_r = pS(q) + (v + b)I(q) - g_rL(q)\). Thus, we get

\[PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}} [(pS(q) + (v + b)I(q) - g_rL(q)) - \lambda_m Cov(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}\]

We can rewrite the expression so that we are only left with \(S(q)\):

\[PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}} [(p - v - b + g_r)S(q) + (b + v)q - g_r\mu] - \lambda_m Cov(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}\]

When we rewrite the covariance and denote \(\tilde{m} = p - v + g\) we get the following:

\[PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}} [(\tilde{m}S(q) + (b + v)q - g_r\mu] - \lambda_m \tilde{m}F(q)Cov(D, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}\]

Thus, by differentiating the profit function of the expected profit for the retailer, we get the following expression:

\[\frac{dPV_r(EP_r(q))}{dq} = \frac{1}{1 + r_{f_2}} [(\tilde{m}S'(q) + (b + v)] - \lambda_m \tilde{m}f(q)Cov(D, r_m)] - \frac{w + c_r}{1 + r_{f_1}}\]

The first order derivative consists out of three parts. For the derivation the assumptions of the supply chain model are taken into account. The first part is \(\frac{1}{1 + r_{f_2}} [(\tilde{m}S'(q) + (b + v)]\), which is strictly decreasing in \(q\). The second part is \(\frac{1}{1 + r_{f_2}} [\lambda_m \tilde{m}f(q)Cov(D, r_m)]\), which is increasing because it is assumed that \(D > 0\) and \(F\) is strictly increasing in \(q\). The third part is \(\frac{w + c_r}{1 + r_{f_1}}\), which remains equal in \(q\). As a result, the first order derivative of the present value of the expected profit for the supply chain is strictly decreasing in \(q\). In addition, the second order derivative equals

\[\frac{d^2PV_r(EP_r(q))}{dq^2} = \frac{1}{1 + r_{f_2}} [\lambda_m \tilde{m}f'(q)Cov(D, r_m)]\]
The second order derivative consists of two parts. The first part is \( \frac{1}{1+r_{D,\hat{f}2}}(\tilde{m}S''(q)) \), which result in a negative value for a positive \( q \). The second part is \( \frac{1}{1+r_{D,\hat{f}2}}(\lambda_m\tilde{m}f'(q)\text{Cov}(D,r_m)) \), which is positive because \( D > 0 \) and \( F \) is strictly increasing in \( q \). As a result, the second order derivative of the present value of the expected profit for the supply chain is negative. Thus, \( PV_r(EP_r(q)) \) is strictly concave.

To find the optimum of the profit function, the first order derivative should equal 0. Thus, we get:

\[
\frac{1}{1+r_{D,\hat{f}2}}[(\tilde{m}S'(q) + (b + v)) - \lambda_m\tilde{m}f(q)\text{Cov}(D,r_m)] - \frac{w + c_r}{1+r_{D,\hat{f}1}} = 0
\]

\[
\frac{1}{1+r_{D,\hat{f}2}}[(\tilde{m}S'(q) + (b + v)) - \lambda_m\tilde{m}f(q)\text{Cov}(D,r_m)] = \frac{w + c_r}{1+r_{D,\hat{f}1}}
\]

\[
S'(q) - \lambda_mf(q)\text{Cov}(D,r_m) = \frac{w + c_r}{1+r_{D,\hat{f}1}}(1 + r_{D,\hat{f}2}) - b - v \]

Since \( \tilde{m} = p - v - b + g_r \), we get the following equation:

\[
S'(q) - \lambda_mf(q)\text{Cov}(D,r_m) = \frac{w + c_r}{1+r_{D,\hat{f}1}}(1 + r_{D,\hat{f}2}) - b - v \]

Since \( S'(q) = \tilde{F}(q) = 1 - F(q) \), we get the following equation:

\[
F(q) + \lambda_mf(q)\text{Cov}(D,r_m) = 1 - \frac{w + c_r}{1+r_{D,\hat{f}1}}(1 + r_{D,\hat{f}2}) - b - v \]

Thus, following equation has to be satisfied to find \( q^* \):

\[
F(q^*) + \lambda_mf(q^*)\text{Cov}(D,r_m) = \frac{p + g_r - \frac{w + c_r}{1+r_{D,\hat{f}1}}(1 + r_{D,\hat{f}2})}{p - v - b + g_r}
\]

To see if coordination is possible, we investigated what combination of wholesale-price and buyback price is needed to get \( q^* = q^0 \). Since \( S'(q) \) is decreasing, we only get \( q^* = q^0 \) when \( S'(q) \) equals the \( S'(q) \) of the whole supply chain, which we found in the newsvendor situation. Thus, when we go further on \( \frac{1}{1+r_{D,\hat{f}2}}[(\tilde{m}S'(q) + (b + v)) - \lambda_m\tilde{m}f(q)\text{Cov}(D,r_m)] - \frac{w + c_r}{1+r_{D,\hat{f}1}} = 0 \) we get

\[
\frac{w}{1+r_{D,\hat{f}1}} = \frac{1}{1+r_{D,\hat{f}2}}[(\tilde{m}S'(q) + (b + v)) - \lambda_m\tilde{m}f(q)\text{Cov}(D,r_m)] - \frac{c_r}{1+r_{D,\hat{f}1}}
\]

\[
\frac{w}{1+r_{D,\hat{f}1}} = \frac{1}{1+r_{D,\hat{f}2}}[\tilde{m}(\frac{c(1+r_{D,\hat{f}2}) - v}{p - v + g} + \lambda_mf(q)\text{Cov}(D,r_m)) - \lambda_m\tilde{m}f(q)\text{Cov}(D,r_m)] - \frac{c_r}{1+r_{D,\hat{f}1}} - \frac{b + v}{1+r_{D,\hat{f}2}}
\]

\[
\frac{w}{1+r_{D,\hat{f}1}} = \frac{1}{1+r_{D,\hat{f}2}}(\tilde{m}c(1+r_{D,\hat{f}2}) - v) - \frac{c_r}{1+r_{D,\hat{f}1}} - \frac{b + v}{1+r_{D,\hat{f}2}}
\]

Since we denoted \( \tilde{m} = p - v - b + g_r \), we get the following formula for the wholesale-price \( w \):

\[
\frac{w}{1+r_{D,\hat{f}1}} = \frac{1}{1+r_{D,\hat{f}2}}((p - v - b + g_r)\frac{c(1+r_{D,\hat{f}2}) - v}{p - v + g}) - \frac{c_r}{1+r_{D,\hat{f}1}} - \frac{b + v}{1+r_{D,\hat{f}2}}
\]

\[
\frac{w}{1+r_{D,\hat{f}1}} = \frac{p - v - b + g_r - \frac{c(1+r_{D,\hat{f}2}) - v}{p - v + g}}{1+r_{D,\hat{f}2}} - \frac{c_r}{1+r_{D,\hat{f}1}} - \frac{b + v}{1+r_{D,\hat{f}2}}
\]
\[
\frac{w}{1 + r_{f_1}} = \frac{p - v - b + g_r}{p - v + g} \left( c - \frac{v}{1 + r_{f_2}} \right) - \left( \frac{c_r}{1 + r_{f_1}} - \frac{v}{1 + r_{f_2}} \right) + \frac{b}{1 + r_{f_2}}
\]

It is assumed that \( c = c_s + \frac{c_r}{1 + r_{f_1}}, g = g_s + g_r \) and that \( \frac{p}{1 + r_{f_2}} > c > \frac{v}{1 + r_{f_2}} \) and \( \frac{b + v}{1 + r_{f_1}} < \frac{w}{1 + r_{f_2}} < \frac{p}{1 + r_{f_2}} \), which results in \( 0 \leq \frac{p - v - b + g_r}{p - v + g} \leq 1 \). Thus, in order to achieve coordination the following condition should be satisfied: \( \frac{b}{1 + r_{f_1}} \geq (1 - \frac{p - v - b + g_r}{p - v + g})(c_s + \frac{c_r}{1 + r_{f_1}} - \frac{v}{1 + r_{f_2}}) \). Otherwise, the wholesale-price must be smaller than \( c_s \) to satisfy the function of the wholesale-price described above. As a result, the supplier will not be able to make a profit and has an incentive to change its behavior. It seems that (in most situations) multiple combinations are able to satisfy both conditions. The combinations function as a risk-sharing mechanism as they differently allocate the present values of the expected profit. The agreement on the combination of buyback price and wholesale price should lead to an allocation that results in both members being better off than in their current situation.

**Derivation of section 4.7**

In order to conclude whether the revenue-sharing contract is able to coordinate the supply chain or not, we have to see if the contract is able to align the retailer’s optimal order quantity with the supply chain’s optimal order quantity. Therefore, the expression for the present value is derived first. After which the first order of the retailer’s profit function is found to see if and how the retailer’s order quantity can be aligned with the supply chain’s optimal order quantity.

\[
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[(\Phi p S(q) + \Phi v I(q) - g_r L(q)) - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
\]

As explained, the uncertain cash flow in the revenue-sharing contract is \( \tilde{f}_r = \Phi p S(q) + \Phi v I(q) - g_r L(q) \). Thus, we get

\[
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[\Phi p S(q) + \Phi v I(q) - g_r L(q)] - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
\]

We can rewrite this expression so that we are only left with \( S(q) \):

\[
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[\Phi p S(q) + \Phi v I(q) - g_r L(q)] - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
\]

When we rewrite the covariance and denote \( \tilde{m} = \Phi p - \Phi v + g_r \) we get the following expression:

\[
PV_r(EP_r(q)) = \frac{1}{1 + r_{f_2}}[\tilde{m} S(q) + \Phi v q - g_r \mu] - \lambda_m \text{Cov}(\tilde{f}_r, r_m)] - \frac{(w + c_r)q}{1 + r_{f_1}}
\]

Thus, by differentiating the profit function of the expected profit for the retailer, we get the following expression:

\[
\frac{dPV_r(EP_r(q))}{dq} = \frac{1}{1 + r_{f_2}}[(\tilde{m} S'(q) + \Phi v) - \lambda_m \tilde{m} f(x) \text{Cov}(D, r_m)] - \frac{w + c_r}{1 + r_{f_1}}
\]

The first order derivative consists out of three parts. For the derivation the assumptions of the supply chain model are taken into account. The first part is \( \frac{1}{1 + r_{f_2}}(\tilde{m} S'(q) + \Phi v) \), which is strictly decreasing in \( q \). The second part is \( \frac{1}{1 + r_{f_2}}[\lambda_m \tilde{m} f(q) \text{Cov}(D, r_m)] \), which is increasing because it is assumed that \( D > 0 \) and \( F \) is strictly increasing in \( q \). The third part is \( \frac{w + c_r}{1 + r_{f_1}} \), which remains equal in \( q \). As a result, the first order derivative of the present value of the expected profit for the supply chain is strictly decreasing in \( q \). In addition, the second order derivative equals

\[
\frac{d^2PV_r(EP_r(q))}{dq^2} = \frac{1}{1 + r_{f_2}}[(\tilde{m} S''(q)) - \lambda_m \tilde{m} f'(q) \text{Cov}(D, r_m)]
\]

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The second order derivative consists of two parts. The first part is \( \frac{1}{1+r_f} (\tilde{m} S''(q)) \), which result in a negative value for a positive \( q \). The second part is \( \frac{1}{1+r_f} (\lambda_m \tilde{m} f'(q)) \), which is positive because \( D > 0 \) and \( F \) is strictly increasing in \( q \). As a result, the second order derivative of the present value of the expected profit for the supply chain is negative. Thus, \( PV_r(E \Pi_r(q)) \) is strictly concave.

To find the optimum of the profit function, the first order derivative should equal 0. Thus, we get:

\[
\frac{1}{1+r_f} [\tilde{m} S'(q) + \Phi v - \lambda_m \tilde{m} f(x) Cov(D, r_m)] - \frac{w + c_r}{1+r_f} = 0
\]

\[
\frac{1}{1+r_f} [(\tilde{m} S'(q) + \Phi v) - \lambda_m \tilde{m} f(x) Cov(D, r_m)] = \frac{w + c_r}{1+r_f}
\]

\[
S'(q) - \lambda_m Cov(D, r_m) = \frac{w + c_r}{1+r_f} (1+r_f) - \Phi v
\]

Since \( \tilde{m} = \Phi p - \Phi v + g_r \), we get the following equation:

\[
S'(q) - \lambda_m Cov(D, r_m) = \frac{w + c_r}{1+r_f} (1+r_f) - \Phi v
\]

Since \( S'(q) = \mathcal{F}(q) = 1 - F(q) \), we get the following equation:

\[
F(q) + \lambda_m f(q) Cov(D, r_m) = 1 - \frac{\frac{w + c_r}{1+r_f} (1+r_f) - \Phi v}{\Phi p - \Phi v + g_r}
\]

Thus, following equation has to be satisfied to find \( q^* \):

\[
F(q^*) + \lambda_m f(q^*) Cov(D, r_m) = \frac{\Phi p + g_r - \frac{w + c_r}{1+r_f} (1+r_f)}{\Phi p - \Phi v + g_r}
\]

To see if coordination is possible, we investigated what combination of wholesale-price and shared percentage is needed to get \( q^* = q^o \). Since \( S'(q) \) is decreasing, we only get \( q^* = q^o \) when \( S'(q) \) equals the \( S'(q) \) of the whole supply chain, which we found in the newsvendor situation. Thus, when we go further on \( \frac{1}{1+r_f} [\tilde{m} S'(q) + \Phi v - \lambda_m \tilde{m} f(x) Cov(D, r_m)] = \frac{w + c_r}{1+r_f} = 0 \) we get

\[
\frac{w}{1+r_f} = \frac{1}{1+r_f} [\tilde{m} S'(q) + \Phi v - \lambda_m \tilde{m} f(x) Cov(D, r_m)] - \frac{c_r}{1+r_f}
\]

\[
\frac{w}{1+r_f} = \frac{1}{1+r_f} [\tilde{m} S'(q) + \Phi v - \lambda_m \tilde{m} f(x) Cov(D, r_m)] - \left( \frac{c_r}{1+r_f} - \frac{\Phi v}{1+r_f} \right)
\]

\[
\frac{w}{1+r_f} = \frac{1}{1+r_f} \left[ \tilde{m} (\frac{c (1+r_f) - v}{p-v+g} + \lambda_m f(x) Cov(D, r_m)) - \lambda_m \tilde{m} f(x) Cov(D, r_m) \right] - \left( \frac{c_r}{1+r_f} - \frac{\Phi v}{1+r_f} \right)
\]

\[
\frac{w}{1+r_f} = \frac{1}{1+r_f} \left[ \tilde{m} (\frac{c (1+r_f) - v}{p-v+g}) - \left( \frac{c_r}{1+r_f} - \frac{\Phi v}{1+r_f} \right) \right]
\]

Since we denoted \( \tilde{m} = \Phi p - \Phi v + g_r \), we get the following formula for the wholesale-price:

\[
\frac{w}{1+r_f} = \frac{1}{1+r_f} \left( \Phi p - \Phi v + g_r \right) \left( \frac{c (1+r_f) - v}{p-v+g} \right) - \left( \frac{c_r}{1+r_f} - \frac{\Phi v}{1+r_f} \right)
\]

\[
\frac{w}{1+r_f} = \frac{\Phi p - \Phi v + g_r}{p-v+g} \left( \frac{c - v}{1+r_f} \right) - \left( \frac{c_r}{1+r_f} - \frac{\Phi v}{1+r_f} \right)
\]
One can see that coordination is only possible when \( w \leq c_s \). Otherwise, the shared percentage does not have a natural interpretation. It is assumed that \( c = c_s + \frac{c_r}{1+r_1} \), \( g = g_s + g_r \) and that \( \frac{p}{1+r_2} > c > \frac{v}{1+r_2} \) and that \( 0 \leq \Phi \leq 1 \). So, the function for the wholesale-price in the revenue-sharing contract, is quite the same as in the wholesale-price contract. However, in the revenue-sharing contract it is allowed to have a wholesale-price lower than \( c_s \). In this contract it is possible to coordinate the supply chain only if both parties do not have an incentive to change their behavior and if the payoff is greater than their reservation payoff. In addition, the combination of a wholesale-price and a shared percentage should also achieve both \( \frac{w + c}{1+r_1} + \frac{(1-\Phi)p}{1+r_2} > c_s \) and \( \frac{w + c}{1+r_1} < \frac{\Phi p}{1+r_2} \).
Appendix C

Matlab script for numerical example

Numerical example risk-neutral newsvendor situation

The Matlab script that is used to analyze the decisions that the supply chain in a risk-neutral environment would make when working as a centralized company.

```
clear all
mu = 10000; %Mean demand
sigma = 2500; %Standard deviation demand
pd = makedist('Normal',mu,sigma); %Demand distribution
cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution

v = 30; %Salvage value
c_s = 50; %Cost supplier
c_r = 20; %Cost retailer
c = c_s+c_r; %Cost Supply chain
g_s = 5; %Goodwill penalty supplier
g_r = 20; %Goodwill penalty retailer
g = g_s + g_r; %Goodwill penalty Supply Chain
p = 200; %Retail price

critical_fractile = (p+g−c)/(p+g−v); %Critical fractile
q = icdf('Normal',critical_fractile,mu,sigma); %Optimal order quantity
S_Q = q - integral(cdf_demand,0,q); %Amount of expected sales

EP_SC = (p−v+g)*S_Q - (c−v)*q − g*mu; %EP Supply Chain
```

Numerical example risk-neutral wholesale-price contract

The Matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-neutral wholesale-price contract.

```
clear all
mu = 10000; %Mean demand
sigma = 2500; %Standard deviation demand
pd = makedist('Normal',mu,sigma); %Demand distribution
cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution

v = 30; %Salvage value
c_s = 50; %Cost supplier
c_r = 20; %Cost retailer
c = c_s+c_r; %Cost Supply chain
g_s = 5; %Goodwill penalty supplier
g_r = 20; %Goodwill penalty retailer
g = g_s + g_r; %Goodwill penalty Supply Chain
p = 200; %Retail price

max_R = 0;
max_S = 0;
```
Numerical example risk-neutral buyback contract

The Matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-neutral buyback contract.

```matlab
mu = 10000; %Mean demand
sigma = 2500; %Standard deviation demand
pd = makedist('Normal',mu,sigma); %Demand distribution
cdf_demand = @(x) normcdf(x, mu, sigma); %Cumulative demand distribution

v = 30; %Salvage value
c_s = 50; %Cost supplier
c_r = 20; %Cost retailer
c = c_s + c_r; %Cost Supply chain
g_s = 5; %Goodwill penalty supplier
g_r = 20; %Goodwill penalty retailer
g = g_s + g_r; %Goodwill penalty Supply Chain
p = 200; %Retail price
i = 0;
max_R = 0;
max_S = 0;
result = ones(1,6); %Is used to get all data in one table

for b=1:1:p-1 %b is the buyback price
    w = (p+g_r-c_r)-((p+g_r-v-b)*(p+g-c))/(p+g-v); %Wholesale price
    if b+v<=w && w > c_s %Satisfying constraints
        critical_fractile = (p+g_r-w-c_r)/(p+g_r-v); %Critical fractile
        q = icdf('Normal', critical_fractile, mu, sigma); %Optimal order quantity
        S_Q = q - integral(cdf_demand,0,q); %Expected sales
        EP_R = (p-v+g_r)*S_Q - (w+c_r-v)*q - g_r*mu; %EP retailer
        EP_S = g_s*S_Q + (w-c_s)*q - g_s*mu; %EP supplier
        EP_SC = (p-v+g)*S_Q - (c-v)*q - g*mu; %EP Supply Chain
        if EP_R > 0 && EP_S > 0 %Induction to find optimal wholesale price
            if EP_R > max_R
                max_R = EP_R;
                results(1,1) = w;
                results(1,2) = q;
                results(1,3) = max_R;
                results(1,4) = EP_S;
                results(1,5) = EP_SC;
            end
            if EP_S > max_S
                max_S = EP_S;
                results(2,1) = w;
                results(2,2) = q;
                results(2,3) = EP_R;
                results(2,4) = max_S;
                results(2,5) = EP_SC;
            end
        end
    end
end
```

```matlab
Chapter C
```
numerical example risk-neutral revenue-sharing contract

the matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-neutral revenue-sharing contract.

```matlab
clear all
mu = 10000; % Mean demand
sigma = 2500; % Standard deviation demand
pd = makedist('Normal',mu,sigma); % Demand distribution
cdf_demand = @(x) normcdf(x,mu,sigma); % Cumulative demand distribution
v = 30; % Salvage value
c_s = 50; % Cost supplier
c_r = 20; % Cost retailer
c = c_s+c_r; % Cost Supply chain
g_s = 5; % Goodwill penalty supplier
g_r = 20; % Goodwill penalty retailer
g = g_s+g_r; % Goodwill penalty Supply Chain
p = 200; % Retail price
i = 0;
result = ones(1,6); % Is used to get all data in one table
for perc = 0:0.01:1 % Shared percentage
    w = (perc*p+g_r-c_r-c)*S_Q/(perc*p+g_r)/S_Q; % Wholesale price
    if (w+(1-perc)*p+c_s) & (w+c_r<perc*p) & (w>perc*v) % Satisfying assumptions
        critical_fraactile = (perc*p+g_r-c_r-c)/S_Q/(perc*p+g_r)/S_Q; % Critical fractile
        q = icdf('Normal',critical_fraactile,mu,sigma); % Optimal order quantity
        S_Q = q - integral(cdf_demand,0,q); % Expected Sales
        EP_R = (perc*(p-v)+g_r)*S_Q - (w+c_r-perc*v)*q - g_r*mu; % EP Retailer
        EP_S = (g_s+b)*S_Q + (w-b-c_s)*q - g_s*mu; % EP Supplier
        EP_SC = (p-v)*g*r - (c-v)*q - g*mu; % EP Supply Chain
        if (EP_R >= 510918) && (EP_S >= 584688) % Members should have no incentive to deviate
            i = i + 1;
            result(i,1) = w;
            result(i,2) = perc;
            result(i,3) = q;
            result(i,4) = EP_R;
            result(i,5) = EP_S;
            result(i,6) = EP_SC;
        end
    end
end
```
Numerical example risk-averse newsvendor situation

The Matlab script that is used to analyze the decisions that the supply chain in a risk-averse environment would make when working as a centralized company.

```matlab
clear all
mu = 10000; %Mean demand
sigma = 2500; %Standard deviation demand
pd = makedist('Normal',mu,sigma); %Demand distribution
cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution

r_f = 0.06; %Risk-free rate per year
r_f_1 = (1+r_f)^0.25-1; %Risk-free rate for moment 1
r_f_2 = (1+r_f)^0.75-1; %Risk-free rate for moment 2

v = 30; %Salvage value
c_s = 50; %Cost supplier
c_r = 20; %Cost retailer
g_s = 5; %Goodwill penalty supplier
g_r = 20; %Goodwill penalty retailer
g = g_s + g_r; %Goodwill penalty Supply Chain
p = 200; %Retail price

lambda_m = 0.40; %Market risk premium
rho_dm = 0.05; %Correlation coefficient Demand and Market
sigma_m = 100; %Market deviation
cov_dm = rho_dm * sigma_m * sigma; %Covariance demand and market

critical_fractile = (p+g-c*(1+r_f_2))/(p-v+g); %Critical fractile for Supply Chain
equation = cdf(pd,x) + lambda_m*cov_dm*pdf(pd,x) == critical_fractile; %Equality that should be satisfied for finding optimal q
z = vpasolve(equation,x,[0,20000]); %Find value of x
q = double(z); %Get a ’double’ value for q
S_Q = q - integral(cdf_demand,0,q); %Amount of expected sales
m = p-v+g; %Multiplier of covariance

PV_EP_SC = (1/(1+r_f_2)) * ((m*S_Q+v+g+mu) - lambda_m*m*cdf(pd,q)*cov_dm - c*q);
```

Numerical example risk-averse wholesale-price contract

The Matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-averse wholesale-price contract.

```matlab
clear all
mu = 10000; %Mean demand
sigma = 2500; %Standard deviation demand
pd = makedist('Normal',mu,sigma); %Demand distribution
cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution

r_f = 0.06; %Risk-free rate per year
r_f_1 = (1+r_f)^0.25-1; %Risk-free rate for moment 1
r_f_2 = (1+r_f)^0.75-1; %Risk-free rate for moment 2

v = 30; %Salvage value
```
\[c_s = 50; \quad \% \text{Cost supplier}\]
\[c_r = 20; \quad \% \text{Cost retailer}\]
\[c = c_s + c_r/(1+r_f_1); \quad \% \text{Cost Supply chain}\]
\[g_s = 5; \quad \% \text{Goodwill penalty supplier}\]
\[g_r = 20; \quad \% \text{Goodwill penalty retailer}\]
\[g = g_s + g_r; \quad \% \text{Goodwill penalty Supply Chain}\]
\[p = 200; \quad \% \text{Retail price}\]
\[\lambda_m = 0.40; \quad \% \text{Market risk premium}\]
\[\rho_{dm} = 0.05; \quad \% \text{Correlation coefficient Demand and Market}\]
\[\sigma_m = 100; \quad \% \text{Market deviation}\]
\[\text{cov}_{dm} = \rho_{dm} \times \sigma_m; \quad \% \text{Covariance demand and market}\]
\[\text{max}_w = (p)/(1+r_f_2) - (c_r)/(1+r_f_1); \quad \% \text{Satisfying assumptions}\]
\[\text{results} = \text{ones}(2,5); \quad \% \text{Get all results in one table}\]
\[\text{max}_R = 0;\]
\[\text{max}_S = 0;\]
\[\text{for } w = c_s + 1:1:\text{max}_w\]
\[\text{critical}_\text{fractile} = (p+g_r-(w+c_r)/(1+r_f_1))*(1+r_f_2)/(p-v+g_r); \quad \% \text{Critical fractile}\]
\[\text{syms } x; \quad \% \text{Introducing variable } x\]
\[\text{equation} = \text{cdf}(pd,x) + \lambda_m \times \text{cov}_{dm} \times \text{pdf}(pd,x) = \text{critical}_\text{fractile};\]
\[\text{z} = \text{vpasolve}(\text{equation},x,[0,20000]); \quad \% \text{Find value of } x\]
\[\text{q} = \text{double}(z); \quad \% \text{Get a 'double' value for } q\]
\[\text{S}_Q = q - \text{integral}(\text{cdf}_\text{demand},0,q); \quad \% \text{Amount of expected sales}\]
\[m = p-v+g; \quad \% \text{Multiplier of covariance for supply chain}\]
\[m_r = p-v+g_r; \quad \% \text{Multiplier of covariance for retailer}\]
\[m_s = g_s; \quad \% \text{Multiplier of covariance for supplier}\]
\[\text{PV}_\text{EP}_\text{R} = (1/(1+r_f_2)) * ((m_r*\text{S}_Q + v*q - g_r*\mu) - \lambda_m \times m_r \times \text{cdf}(pd,q) * \text{cov}_{dm}) - ((w+c_r)*q)/(1+r_f_1);\]
\[\text{PV}_\text{EP}_\text{S} = (w*\text{q})/(1+r_f_1) - (1/(1+r_f_2)) * ((m_s*\mu - m_s*\text{S}_Q) + \lambda_m \times m_s \times \text{cdf}(pd,q) * \text{cov}_{dm}) - c*\text{q};\]
\[\text{if } (\text{PV}_\text{EP}_\text{R} > 0) \& \& (\text{PV}_\text{EP}_\text{S} > 0) \quad \% \text{Induction to find optimal wholesale-pricing}\]
\[\text{if } \text{PV}_\text{EP}_\text{R} \text{ > max}_R\]
\[\text{max}_R = \text{PV}_\text{EP}_\text{R};\]
\[\text{results}(1,1) = w;\]
\[\text{results}(1,2) = q;\]
\[\text{results}(1,3) = \text{max}_R;\]
\[\text{results}(1,4) = \text{PV}_\text{EP}_\text{S};\]
\[\text{results}(1,5) = \text{PV}_\text{EP}_\text{SC};\]
\[\text{end}\]
\[\text{if } \text{PV}_\text{EP}_\text{S} \text{ > max}_S\]
\[\text{max}_S = \text{PV}_\text{EP}_\text{S};\]
\[\text{results}(2,1) = w;\]
\[\text{results}(2,2) = q;\]
\[\text{results}(2,3) = \text{PV}_\text{EP}_\text{R};\]
\[\text{results}(2,4) = \text{max}_S;\]
\[\text{results}(2,5) = \text{PV}_\text{EP}_\text{SC};\]
\[\text{end}\]
Numerical example risk-averse buyback contract

The Matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-averse buyback contract.

```matlab
1 clear all
2 mu = 10000; %Mean demand
3 sigma = 2500; %Standard deviation demand
4 pd = makedist('Normal',mu,sigma); %Demand distribution
5 cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution
6 r_f = 0.06; %Risk-free rate per year
7 r_f_1 = (1+r_f)^(0.25)-1; %Risk-free rate for moment 1
8 r_f_2 = (1+r_f)^(0.75)-1; %Risk-free rate for moment 2
9 v = 30; %Salvage value
10 c_s = 50; %Cost supplier
11 c_r = 20; %Cost retailer
12 c = c_s+c_r/(1+r_f_1); %Cost Supply chain
13 g_s = 5; %Goodwill penalty supplier
14 g_r = 20; %Goodwill penalty retailer
15 g = g_s + g_r; %Goodwill penalty Supply Chain
16 p = 200; %Retail price
17 lambda_m = 0.4; %Market risk premium
18 rho_dm = 0.05; %Correlation coefficient Demand and Market
19 sigma_m = 100; %Market deviation
20 cov_dm = rho_dm * sigma_m; %Covariance demand and market
21 i = 0;
22 max_R = 0;
23 max_S = 0;
24 result = ones(1,6); %Is used to get all data in one table
25 for b=1:p-1 %b is the buyback price
26     w = ((p-v-b+g_r)/(p-v+g))*(c-v/(1+r_f_2)) - (c_r/(1+r_f_1) - (b+v)/(1+r_f_2)) * (1+r_f_1); %Wholesale price
27         if (b+v)/(1+r_f_2) <= w/(1+r_f_1) && w/(1+r_f_1) > c_s %Satisfying constraints
28             critical_f fractile = (p+g_r-((w+c_r)/(1+r_f_1))*(1+r_f_2))/(p-v+b+g_r); %Critical fractile
29         end
30     end
31     z = vpasolve(equation,x,[0,20000]); %Find value of x
32     q = double(z); %Get a ‘double’ value for q
33     S_Q = q - integral(cdf_demand,0,q); %Amount of expected sales
34     m = p-v+g; %Multiplier of covariance for supply chain
35     m_r = p-v-b+g_r; %Multiplier of covariance for retailer
36     m_s = b+g_s; %Multiplier of covariance for supplier
37     PV_EP_R = (1/(1+r_f_2)) * (m_r*S_Q + (b+v)*q-g_r*mu)/lambda_m*m_r*cdf(pd,q)*cov_dm - (w+c_r)*q/(1+r_f_1); %Present value of Expected profit for the retailer
38     PV_EP_S = (w+q)/(1+r_f_1) - (1/(1+r_f_2)) * ((b+q-(b+g_s)*S_Q+g_s*mu)+lambda_m*m_s*cdf(pd,q)*cov_dm)-c_s*q; %Present value of Expected profit for the Supplier
39     PV_EP_SC = (1/(1+r_f_2)) * (m*S_Q+v*q-g*mu-lambda_m*m*cdf(pd,q)*cov_dm)-c_s*q; %Present value of Expected profit for the Supply Chain
40     if (PV_EP_R >= 310919) && (PV_EP_S >= 334557) %Members should have no incentive to deviate
41         i = i + 1;
42         result(i,1) = w;
```

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Numerical example risk-averse revenue-sharing contract

The Matlab script that is used to analyze the decisions that the members of the supply chain make in a risk-averse revenue-sharing contract.

```matlab
1 clear all
2 mu = 10000; %Mean demand
3 sigma = 2500; %Standard deviation demand
4 pd = makedist('Normal',mu,sigma); %Demand distribution
5 cdf_demand = @(x) normcdf(x,mu,sigma); %Cumulative demand distribution
6 r_f = 0.06; %Risk-free rate per year
7 r_f_1 = (1+r_f)^0.25 - 1; %Risk-free rate for moment 1
8 r_f_2 = (1+r_f)^0.75 - 1; %Risk-free rate for moment 2
9 v = 30; %Salvage value
10 c_s = 50; %Cost supplier
11 c_r = 20; %Cost retailer
12 c = c_s + c_r/(1+r_f_1); %Cost Supply chain
13 g_s = 5; %Goodwill penalty supplier
14 g_r = 20; %Goodwill penalty retailer
15 g = g_s + g_r; %Goodwill penalty Supply Chain
16 p = 200; %Retail price
17 lambda_m = 0.40; %Market risk premium
18 rho_dm = 0.05; %Correlation coefficient Demand and Market
19 sigma_m = 100; %Market deviation
20 cov_dm = rho_dm*sigma_m*sigma; %Covariance demand and market
21 i = 0;
22 result = ones(1,6); %Is used to get all data in one table
23 for perc = 0:0.01:1 %Shared percentage
24 w = ((perc*p-perc*v+g_r)/(p-v+g)) + (c-v/(1+r_f_2)) - (c_r/(1+r_f_1)) - (perc*v)/(1+r_f_2)) + (perc*v)/(1+r_f_2); %wholesale - price
25 if (w/(1+r_f_1) + (1-perc)*p/(1+r_f_2) > c_s) & (w+c_r)/(1+r_f_1) < perc*(p/(1+r_f_2)) & (w/(1+r_f_2) > perc*(v/(1+r_f_2))) %satisfying assumptions
26 critical_frtile = (perc*p+g_r-(w+c_r)/(1+r_f_1)+(1+r_f_2))/(perc*p-perc*v+g_r); %Critical fractile
27 syms x; %Introducing variable x
28 equation = cdf(pd,x) + lambda_m*cov_dm*cdf(pd,x) == critical_frtile;
29 z = vpasolve(equation,x,[0,20000]); %Find value of x
30 q = double(z); %Get a 'double' value for q
31 S_Q = q - integral(cdf_demand,0,q); %Amount of expected sales
32 m = p-v+g; %Multiplier of covariance for supply chain
33 m_r = perc*p-perc*v+g_r; %Multiplier of covariance for retailer
34 m_s = (1-perc)*p - (1-perc)*v + g_s; %Multiplier of covariance for supplier
35 %Present value of Expected profit for the retailer
```
PV_EP_R = (1/(1+r_f_2)) * (m_r * S_Q + perc * v * q - g_r * mu) - lambda_m * m_r * cdf(pd, q) * cov_dm - ((w + c_r) * q) / (1 + r_f_1);

PV_EP_S = (w * q) / (1 + r_f_1) + (1/(1+r_f_2)) * (m_s * S_Q - (1 - perc) * v * q - g_s * mu - lambda_m * m_s * cdf(pd, q) * cov_dm - c_s * q);

PV_EP_SC = (1/(1+r_f_2)) * (m * S_Q + v * q - g * mu - lambda_m * m * cdf(pd, q) * cov_dm - c * q);

if (PV_EP_R >= 310919) && (PV_EP_S >= 334557) %Members should have no incentive to deviate
    i = i + 1;
    result(i,1) = w;
    result(i,2) = perc;
    result(i,3) = q;
    result(i,4) = PV_EP_R;
    result(i,5) = PV_EP_S;
    result(i,6) = PV_EP_SC;
end
## Appendix D

### Consensus mechanisms

A summary of the most well-known consensus protocols is presented in the following figure:

<table>
<thead>
<tr>
<th>Type of a Consensus Protocol</th>
<th>Analysis of Algorithms for Determining the Priority of a Participant during Generating a New Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proof-of-stake</td>
<td>The priority of a participant during generating a new block in a chain of blocks depends on the size of the portion of the distributed valuable resource that he owns. The generation of a block increases the portion of the valuable resource of the corresponding participant. The question concerning the distribution of portions between participants at the protocol initialization stage is not considered.</td>
</tr>
<tr>
<td>Proof-of-activity</td>
<td>The priority of a participant during generating a new block in a chain of blocks depends on its computational resources, the portion of the valuable resource, and “activities” in the network. The larger is the portion and sojourn time in the network, the higher is the priority. An example of practical implementation, a definite measure may be considered to be the DASH cryptocurrency.</td>
</tr>
<tr>
<td>Proof-of-burn</td>
<td>The priority of a participant during generating a new block in a chain of blocks depends on the size of the portion of the distributed valuable resource that was destroyed by the participant at the previous protocol stage.</td>
</tr>
<tr>
<td>Proof-of-capacity</td>
<td>The priority of a participant during generating a new block in a chain of blocks depends on the size of the portion of the distributed valuable resource that is the volume of the data storage space.</td>
</tr>
<tr>
<td>Proof-of-delegated stake</td>
<td>The priority of a participant during generating a new block in a chain of blocks is formed in two stages. At the first stage, a subset of participants is chosen by the results of a voting procedure. The number of votes of each participant depends on the portion of possession of the valuable resource. At the second stage, only the participants elected at the first stage take part. The priority of a participant at the second stage depends on the presence of the participant in the network and its computational resources. This type is used in the Bitshares and Steem systems.</td>
</tr>
</tbody>
</table>

Figure D.1: Different consensus mechanisms (Kudin, Kovalenko & Shvidchenko, 2019)
Appendix E

Validation (blockchain) contract process

Semi-structured interview current situation

The semi-structured interview is held with an employee of Atos that initiated the blockchain project with Company A. At the moment of initiating the project, she had the function Sales & Marketing at Atos Blockchain Factory. In this role, she was responsible for blockchain consulting, sales and business development. She helped (several) customers out, by exploring the possibilities in which blockchain could add value to the customer. As she worked with several companies and in different projects, she gained a broad knowledge of blockchain opportunities. In addition, she initiated the blockchain project with Company A. Thus, she has a good understanding of how the contract process is executed by Company A. Since the current process is described by literature and white papers as well, it is presumed that one interview session suffices the needs of this research.

The goal of the interview was to get an overview of the current design of contract processes. Furthermore, the inefficiencies and problems faced by the process have to be found as well. Therefore, the following questions were asked. As a result of the answers, a discussion started to gain a better understanding of the process.

- What kind of companies are involved in the contract process?
- What role does each company play in the contract process?
- Which steps have to be executed?
  - How is the step executed?
  - How much time does it take to execute the step?
  - Why is the step executed?
  - What value does the step add to the participating companies?
  - Which problems arise in the process step?
- What problems do arise in the contract process?
- Do you have any remarks with regard to the contract process?

Explanation focus group

Instead of interviewing the participants individually, a focus group is developed. A focus group is an effective method of eliciting data and of generating broad overviews of issues of concern to the cultural groups or subgroups represented (Mack, 2005). The aim of the focus group is to validate the value that blockchain has for contract processes in a supply chain. The focus group consisted out of the following persons:

- A Student. A master student that is currently graduating at Atos. The graduation project is about the implementation of a blockchain-based supply chain contract.
• A Client Executive Telecom employee. She is working at Atos for almost 4 years. At the moment of the focus group, she fulfilled the role of Sales & Marketing at Atos Blockchain Factory. In this role, she was responsible for blockchain consulting, sales and business development. She helped (several) customers out, by exploring the possibilities in which blockchain could add value to the customer. As she worked with several companies and in different projects, she gained a broad knowledge of blockchain opportunities. In addition, she initiated the blockchain project with Company A.

• A Blockchain Lead BTN employee. She is working at Atos for almost 3 years. In this role, she is responsible for strategy, business development and delivery within Atos BTN. She has a large experience in Blockchain advisory, business development, project design and project management. Currently, she is the first contact person for customers to share knowledge, develop new business cases and to collaborate.

• A Senior Developer employee. He works at Atos for almost 3 years. In this role, he is responsible for the development and delivery of software and all challenges in between. Working closely with business interests in combination with his technical knowledge and skills, he is able to explore the value that blockchain technology brings for the customers.

Each member of the focus group has a good understanding of blockchain technology, no one needs additional information related to blockchain. Therefore, the process started by providing each member information related to the traditional contract process (as described in section 7.1). This way, each member of the group has a good understanding of how processes are currently going and what inefficiencies and problems arise in this process. Then, a reference version for the blockchain solution is developed. This reference version is developed based on knowledge gained by reviewing literature, knowledge gained through the analysis of other applications, and own-thinking. In addition to the reference version, each member is provided with a set of questions. Based on this information, the members of the focus group were able to give feedback on the reference solution. With this feedback, the final version of the blockchain solution (as described in section 7.2) is developed. The set of questions that are used are divided in questions related to the blockchain solution and related to the comparison with the traditional process.

Questions related to the blockchain solution

• Why do you think blockchain is a beneficial solution for contract processes?

• How will the traditional process be affected by the implementation of blockchain?

• Which process steps have to be adjusted to suit the blockchain implementation?
  – How will this process step be adjusted?
  – What requirements does the system need to fulfill?

• Which issues and inefficiencies will be solved with the implementation of the blockchain solution?

• Which issues and inefficiencies will arise/are still occurring in the blockchain solution?

• Do you have any other remark with regard to the implementation of blockchain?

Questions related to the comparison between the traditional process and blockchain solution

• What are the positive effects of using blockchain for the contract process?

• What are the challenges of using blockchain for the contract process?
- How difficult are these challenge to solve (in the near future)?

- What are the limitations of using blockchain for the contract process?
  - How much does the limit influence the contract process?
  - How much does it cost to make the blockchain solution (a rough estimate)?

- Do you have any other remark with regard to the benefits and drawbacks of blockchain?