Master Thesis

Corporate Finance

Integration in the Supply Chain –

Use of Real Options to mitigate the costs of the Bullwhip Effect

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Abstract

Title: Integration in the Supply Chain – Use of Real Options to mitigate the costs of the Bullwhip Effect

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Purpose: During the last years Real Options have been established in many areas of the day-to-day business. Recent literature also tries to address Supply Chain problems with option theory, since an efficient Supply Chain increasingly gains in importance as a significant competitive advantage. This thesis tries to answer the question, if Real Options can mitigate the costs induced by the Bullwhip Effect as one of the major problems in Supply Chains.

Methodology: The authors of the thesis used a deductive approach. Based on a theoretical model utilizing Real Option contracts and under the usage of a randomly created dataset the influence of the Bullwhip Effect on the company's business and financial structure is examined and subsequently analyzed.

Conclusion: The authors showed that the Real Option approach can have some negative impact on the firm value, due to an increased risk exposure, but it is believed that the positive effects, namely the drastic increase in profits and the improvement in customer service levels, will overcompensate its drawbacks. Thus, it makes the Real Option approach a valuable tool to reduce the costs, which are induced by the Bullwhip Effect.

Affidavit

We hereby declare that the following master thesis with the title "Integration in the Supply Chain – Use of Real Options to mitigate the costs of the Bullwhip Effect" has been written only by the undersigned and without any assistant from third parties.

Furthermore, we confirm that no sources have been used in the preparation of this thesis other than those indicated in the thesis itself.

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Integration in the Supply Chain –

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1 Introduction

Chapter 1 gives a short summary of the historical development of the in this thesis addressed problem and to which extent it influences the supply chain. Furthermore, the author's motivation and the problem description are presented. The chapter closes with the outline of the thesis.

1.1 Background

The process of globalization forces companies to more and more consider the increasing complexity of their business relations. No longer can economy be seen as only the connection between just two companies, moreover, huge business networks develop, which put firms in new positions and opens new possibilities as well as responsibilities. Long gone are the times, where a firm like the Ford Motor Company® in the beginning of the 20th century incorporated all steps of the production process, beginning with the mining of the ore for the cars' necessary steel parts and ending with the distribution to its customers. In these years, the demand of the consumers for industrial goods was more determined by the usability of the products rather than by its diversity. Cars were not considered to be special because of the properties. Alone the fact of owning a car, while most of the people could not afford one by themselves, made it so exclusive that differentiation by for instance colour or performance enhancers was not yet needed. Thus, Henry Ford, known as the inventor of the flow production, achieved acceptance for his very simple, less diversified, and for that time very cheap and efficient production system of only one car type. To cite Mr. Ford in that matter: "Any customer can have a car painted any colour that he wants so long as it is black"[1]. Thus, he had the major advantage that the simplicity of the production process enabled him to benefit considerably from economies of scale.

Increasing performance of production technologies in the middle of the century led in the following years in nearly all industries to decreasing production costs and thus lower product prices. The more consumers could afford industrial products, which had been exclusive due to their rarity in the past, the less valuable they became for the company. Nobody wanted to pay a fortune for something, which everybody else already had. That made producers look for

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[1] Ford [1925]

new ways to attract their customers. They achieved it by differentiating their products by for instance offering additional services, versions or models. Companies like the Ford Motor Company® could not uphold their economies of scale by building different versions of their car. Management had to cut back its business to those areas, where it had a sustainable competitive advantage, in this case, to the car manufacturing facilities. Especially the extraction and processing of raw material were soon outsourced in order to reduce the rapidly increasing amount of the processes needed within the production. Another upside of the outsourcing process was that those elements, which were separated from the company, could better develop their core competences for themselves, thus become much more efficient. That of course is also beneficial for the former big companies, since they obtain the opportunity for cheaper resourcing.

The splitting of business units, as it mentioned above, created a major increase in the amount of companies on the market and accordingly the number of firms involved in the production process. The complexity of those newly developing manufacturing structures with its enormous amount of business linkages made it necessary to find new methods and models in order to reduce the problem to a manageable size. That was basically the beginning of the theory of supply chain management or as it was called earlier until the 1980s "Operations Management" and "Logistics". As Michael Hugos (2003, p. 4) puts it: "Supply chain management is the coordination of production, inventory, location, and transportation among the participants in a supply chain to achieve the best mix of responsiveness and efficiency for the market being served." Supply chain management has as a goal the perfect collaboration of all participants within the product development process. That means that you try to achieve a solution, which creates the highest possible customer service level and internal efficiency, i.e. the most cost efficient solution needed to produce a certain product by coordinating the contribution of every supply chain member within the production process.

In order to achieve a supply chain of optimal performance all participants have to fulfil their duties and responsibilities in a perfect manner. Unfortunately, as it is often the case, some partners can not keep up with the requirements of the chain, thereby causing inefficiencies. Even though the scientific world normally assumes the market to be efficient[2], i.e. all information is known within the economy, you will hardly find the demand market to be

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[2] Fama [1970]

perfectly efficient in reality. It is simply not the case that costumers have an equally distributed demand over the whole year and that it is independent of major non-macroeconomic impacts or changes.

The unpredictability of consumer demands causes a problem in the supply chain, known as the Bullwhip Effect[3]. "What happens is that small changes in product demand by the consumer at the front of the supply chain translate into wider and wider swings in demand experienced by companies further back in the supply chain."[4] The missing coordination between the different tiers leads to misinterpretations of the real demand. In fact, it is only natural that human beings tend to overstate unexpected occasions. Just imagine a driver of a car, who comes into the awkward position of sliding on a slippery street, not being able to control the car anymore. Most drivers will probably oversteer the car and will make the situation even worse. It takes a considerable amount of exercise or technical equipment to keep the car on the road. The same applies for supply chain management. A retailer being confronted with a sudden drastic increase of demand, which it is not able to meet with its given stock, will probably tend to order a greater amount for the next time, in order to avoid such an occasion from happening again. If the high demand was just an "outlier" and the demand will go down afterwards, that behaviour will lead to an overstocking. Unfortunately, the same problem occurs on every step in the supply chain, leading to a more and more amplified demand going up the supply chain. In the same manner as in the example of the car driver the overstating effect can be mitigated by either exercise, i.e. learning from the past, or by using techniques like real options theory.

1.2 Motivation

It is obvious that the Bullwhip Effect is of major importance for the whole supply chain: It leads not only to overcapacities and out-of-stock situations, but also increases costs and decreases the revenues of the firm. According to Carlsson and Fullér (2004, p. 1) the Bullwhip Effect has numerous negative impacts on the company. In their article they state several effects, listed in Table 1-1, which lead to a deteriorating financial performance.

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[3] Forrester [1961]
[4] Hugos, p. 104 [2002]

Characteristic of effect	Financial implication
Excessive inventory investment	Higher working capital; lower free cash flows; higher depreciation
Out of stock situations	Less revenues, profits; loss of market share
Transportation costs	Higher operating costs, less profit
Labour costs	Production peaks and lows cause expensive use of labour
Excess stockholding	costs of capital commitment

Table 1-1. Costs of "Bullwhip Effect"[5]

The authors of this thesis aim to show ways to mitigate the costs of the Bullwhip Effect in the supply chain by using real options. The main approach will thereby base on the idea to strengthen the coordination between the different firms by using contract options in the business relations between two parties. Those options are installed to create an incentive for the actual supplier of the product to uphold certain extra capacities to react more flexible on changes in demand, without having to cope with the negative effects mentioned above in a model without options. Basically, the buyer orders a certain amount based on historical research, which he is certain to be able to sell or, in case of the consumer, to use. In order to cover the potential excess demand he could face, he buys a certain amount of options, which give him "the right, but not the obligation" (Copeland and Antikarov, 2003, p. 5) to buy further products to a precommitted price. If the amount ordered under fixed conditions should turn out to be too high, i.e. the demand is lower than the supply, the buyer has the possibility to salvage it on the spot market. Additionally, an option to return excess stock back to the seller could pose a more cost efficient solution to the above mentioned problem and will also be addressed in this thesis. Given those options, there exists risk sharing between both parties, which also partly mitigates the problem of one party trying to exploit the other. Due to the set-up of the business relation, i.e. sequential design, it is only natural that one party has the advantage of the first choice; meaning that the seller as the dominant party is able to determine the terms and conditions of the trade relation, while the buyer can only react within the constraints of that environment. Heinrich Freiherr von Stackelberg (1934) addresses those kinds of business interactions in his game-theoretical approach, describing the sequential competition on quantities.

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[5] Carlsson and Fullér, p. 1 [2004]

1.3 Problem description

As mentioned in the previous sections, one problem that occurs in modern supply chains is the so-called Bullwhip Effect. Due to a lack of exchange of information and time lags, retailers often have to face uncertainty in the demand. Additionally, not every company in the supply chain faces the same amount of uncertainty, as might be expected by the uninformed reader. Uncertainty rather shows a positively sloped pattern to very high values towards the upper levels of the supply chain. Even as this so-called amplification effect, which almost every industry has to face, can be considerably small with a factor of 2, higher ratios up to 20:1 have also been observed.[6] The insufficient information exchange also complicates the detection of deviations of optimal levels and thus problems often become obvious not before costly corrections have to be done in order to correct its drawbacks. In a worst case scenario the whole supply chain could even collapse, causing massive financial damage to each firm. That could not only lead to financial distress and its associated costs, but also to bankruptcy.

A major interest of the companies is the impact the Bullwhip Effect has on the firm's financing and thus also on its future performance. The decreasing customer service level and internal inefficiencies of the supply chain worsen the financial performance of the company in the long run. As a consequence, the firm has to deal with diminishing revenues and profits, on the one hand, and with the rise of costs of capital commitment, inventory cost, labour costs, storage costs, and costs of depreciation, on the other hand. Another problem that should not be forgotten is the emergence of time lags due to missed production schedules within the supply chain.

This thesis will focus on the question, if real options can pose a solution to the Bullwhip Effect and how it will influence the firm. It is thereby of special interest, to which extent the modelling approach used in the later sections is able to mitigate the problem of the quantity fluctuations and/or its corresponding costs. Based on a numerical example it will be shown that the chosen model can in fact considerably reduce the costs inflicted by the Bullwhip Effect, but cannot reduce the effect itself.

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[6] Geary et al., p. 2 [2005]

1.4 Outline of the Thesis

The rest of the thesis is organized as follows.

Chapter 2 explains the basic theories, which are necessary to understand the following chapters. It will therefore cover the following topics. Starting with a short view on the basics of Real Option theory and its applications, it will continue by giving an insight into the theory of Supply Chain Management followed by an explanation of the Bullwhip Effect as a real life problem faced by the Supply Chain partners and the "Beer Distribution Game" as an often used illustration of that effect. The chapter closes with an introduction in Game Theory, especially focusing on Nash equilibriums and the Stackelberg competition.

Chapter 3 shows the model approach used to mitigate the costs of the Bullwhip Effect. It begins with a short literature review of models presented in scientific papers and subsequently discusses the usability and limitations of each of the models. In the following, the chosen basic model structure, the conducted necessary adjustments, its advantages and disadvantages, its limitations and data requirements as well as its mathematical set-up are explained.

Chapter 4 gives a numerical example to illustrate the advantages of the real option approach. Subsequently, a thorough analysis and interpretation of the results is conducted. The chapter closes with a short critical discussion about the usability of the model and possible improvements.

Chapter 5 concludes the main results obtained within the previous chapter.

Chapter 6 gives a list of references used in this thesis.

2 Basic theories and key contributions

Chapter 2 presents the basic theories, which are necessary to follow the theoretical framework of the later discussed model. It will therefore summarize Real Option theory, Supply Chain theory, the Bullwhip Effect, and selected approaches from the Game Theory.

2.1 Real Option Theory

Since the model approach, which is used within this thesis to mitigate the problems connected to the Bullwhip Effect, will be based on real options, the following sections give a survey of the basic real option theories. For Real Option theory is in fact the fundamental element in the option model explained in chapter 3.3.2, it will be explained at the beginning of this chapter.

2.1.1 Basics of Real Options

"A real option is the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time – the life of the option."

Copeland and Antikarov, 2003, p. 5

With the development of real options companies started to explore the opportunities presented by this approach, i.e. the valuation of flexibility of projects and services offered. This section will present an introduction in Real Option theory based on the books of Copeland and Antikarov (2003, Ch. 1-6) and Hull (2002, Ch. 1, 7-13, 28). In order to value a real option it is necessary to find the basic variables of project or investment, which are

- the current value of the underlying asset,
- the exercise price of the option,
- the time to maturity,
- the volatility of the underlying assets value,
- the risk-free interest rate,
- and the dividends paid out during life time of the option.

The value of the underlying in the world of real options is the value of projects respectively investments, whereas the exercise price is the price that has to be paid in case of the execution of the option. The time to maturity defines the maximum lifetime of an option and the volatility represents the degree of uncertainty about the development of the underlying asset's value. Furthermore, the risk-free rate is the factor that is used to discount expected future returns of the project or investment and is thus necessary to compute the value of the project for the firm. Possible dividend payments influence the value of the option and thus have to be included in the valuation process.

There are two different groups of real options mentioned in literature. On the one hand, call options are used, which give the owner the right to buy the underlying asset for a predetermined exercise price. On the other hand, there are put options, giving the right to the owner of the option to sell the underlying asset for a predetermined exercise price. A call option is said to be in-the-money, if the value of the underlying exceeds the exercise price of the option when exercised, otherwise it is considered to be out-of-the-money. The contrary is the case for put options. Thus, the value of the real option is the difference between the price of the underlying and the exercise price. Another distinction, which is made in option theory, is the point in time, in which calls and puts are allowed to be exercised. It is distinguished between European options, which can only be exercised at the exact date of maturity, and American options, which by contrast can be exercised at any point in time during the lifetime of the option.

The variety of investments and projects led to the development of different types of call and put options. All option types "are classified primarily by the type of flexibility that they offer" (Copeland and Antikarov, 2003, p. 12). The following paragraphs give a short overview of the most common options used by companies.

The abandonment option is an American put option with the project value as the underlying, which allows the owner to close down or sell the project before maturity for a fixed price. These options are exercised, if the project or investment is expected to be unprofitable.

The so-called option to defer, or deferral option, states the opposite to the abandonment option. In this case the owner has the right to delay the start of projects, which enables him to wait for better circumstances.

Expansion options are American calls, which give the owner the right to enlarge his investment in a project. Thus, the investor scales up the investment, if he faces advantageous conditions.

Contraction options, which are American puts, enable the investor to diminish his contingent in a project by selling parts of it for a predetermined price. Basically, the firm adjusts its investments to the lower requirements of the market, e.g. a product at the end of its life cycle has lower demand.

Another possibility to make use of options is the extension of projects or investments. In this case, the life span of the project is extended, if the investor chooses to exercise this American call.

Furthermore, the combination of those options is also an often used method to reach the optimal flexibility for the firm. First of all, investors can use switching options, where they switch between American puts and calls and pay a fixed price for the switch. Another combination of options are compound options. Those "are options whose value is contingent on other options." (Copeland and Antikarov, 2003, p. 163) and can be used simultaneously or sequentially.

2.1.2 Net present value approach

Before real options have been introduced in the companies' decision-making process, the net present value approach was used in order to evaluate investments and projects. The net present value is defined as the difference between net present of total future revenues and net present of total future costs, whereas the expected values are discounted with the weighted average costs of capital[7]. In contrast to the real option approach, this model is not capable of valuing flexibility and its corresponding upside opportunities, leading to a systematic undervaluation of projects. The net present value approach gives the investors an average project value by using only expected values for all possible states of nature. While the option approach includes the possibility to, e.g. abandon the project and thus avoid losses, the net present value approach is not designed to consider such changes of circumstances.

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[7] The weighted average cost of capital (WACC) is a firms measure for the cost of its capital, equity as well as debt, thus the cost of financing and often used as a discount rate for future investments

2.1.3 Real Options Analysis

In order to compute the value of real options there are different approaches. In the following, the two most common ways to compute an appropriate real option value will be presented.

On the one hand, management can utilize the replicating portfolio approach[8], which uses twin securities[9]. If it is possible to find equivalents on the financial market for the company's investments and projects, the firm can utilize these as twin securities for the underlying risky asset, under the usage of replicating portfolios and the assumption of no arbitrage. Since it is rather difficult to find exact financial equivalents, this approach lacks applicability. On the other hand, the firm can make use of the marketed asset disclaimer assumption. In this case, the company firstly computes the present value of the investment or project, i.e. without flexibility. This value is then used as the underlying asset. Basically, it is necessary to find an underlying that shows the same behaviour as the project with flexibility and "what is better correlated with the project than the project itself?"[10] Having found the value of the underlying risky asset, the value of the real option can be computed using replicating portfolios or the risk neutral probability approach. The replicating portfolio itself is a combination of x units of the underlying asset and y units of the risk-free bond for the up and down state of the project. The firm has two unknown variables, x and y, and two equations, one for each state, and thus it is possible to solve the system of equations. The risk-free interest rate is being used to discount future values of future states in this approach.

In contrast, another calculations method, namely the risk neutral probability approach, uses a hedge portfolio that consists of one share of the underlying risky asset and x units of the option utilized in the model. Apart from that is uses the same discount rate. For further information and numerical examples the authors of this thesis refer to the literature of Copeland and Antikarov (2003).

2.1.4 Put-Call-Parity

A special characteristic within the framework of option theory, which will also be mentioned in the later model discussion, is the so-called put-call-parity. This premise describes the existence of a fixed mathematical relation between puts and calls if certain requirements are

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[8] Amram and Kulatilaka, Ch. 8 [1999]

[9] The twin security has values in the same states as the project but at a different scale

[10] Copeland and Antikarov, p. 94 [2003]

fulfilled. Assume that two portfolios containing European options exist. The first portfolio is a composition of one call option and a certain amount of cash, i.e. $C + K \cdot e^{-r \cdot T}$ with C as the price of the call option, K the amount of cash, r the interest rate and T the time to maturity. The second contains a put option and one share of the underlying asset, i.e. $P + S_0$ with P as the price of the put option and S_0 as the price of one share. Furthermore, it is assumed that no arbitrage opportunities exist. As a consequence, according to Hull (2002, p. 174), "the value of a European call with a certain exercise price and exercise date can be deduced from the value of European put with the same exercise price and exercise date, and vice versa", i.e. $C + K \cdot e^{-r \cdot T} = P + S_0$. For American options the parity will not hold, but it is still possible to narrow the results such that $S_0 - K \leq P - C \leq S_0 - K \cdot e^{-r \cdot T}$. The direct mathematical connection of call and put options allows for exchanges against each other, without changes in the overall result.

2.2 Supply Chain Management

To comprehend the full extent of the model used in the next chapter of the thesis, which combines both, supply chain theory as well as real option theory, a short introduction into the basic parameters and characteristics of supply chain management is necessary. In this section the theoretical framework for the already mentioned supply chain problem, namely the Bullwhip Effect, is presented. As the discussed topic of supply chain management is non-financial, this section is more entitled to support the less logistic experienced reader.

2.2.1 Background of Supply Chain Management

"A supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customers themselves."

Chopra and Meindl, 2001, Ch.1

In contrast to the obsolete opinion that business interactions occur just between two parties, it is now more common to think of the value enhancement process in a more holistic manner. Every participant in the supply chain should be able to interact with each other and can thus contribute improvements to the overall performance of the system. The companies' value creation process should no longer be constrained by the narrow view of just feeling the urge

to perfect its own performance; moreover, the overall value should be the main goal companies should try to achieve. Is it reasonable to improve for instance the own production efficiency, if the retailer is not able to deal with the amount produced beforehand? Just imagine a manufacturer, who has a very efficient and highly modernized production facility and a retailer, being maybe the only customer of the producer, who has simply not such a high demand for those kind of products. Is that value creating? And even if the retailer should have the necessary demand, real life problems have to be taken into account, which can considerably disturb the overall performance, e.g. the transportation system are not compatible with each other, creating a huge amount of at least partly avoidable transhipment-costs. As those examples try to show, a regularity process is called for, which mitigate the problems emerging from an unregulated self-centred system like the one described above. That is, where supply chain management comes in:

"The systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole."

Mentzer et al., 2001, p. 18

Thus, the purpose of supply chain management within the whole network is to maximize the internal efficiency, which implies the reduction of costs as well as the improvement of customer service. Integration and collaboration between the participants within the supply chain can help in that matter. Especially an increased amount of computer-based networks in order to make the whole business process more transparent and the use of special contract specifications, as applied in the later explained real option model, have been proven to be beneficial in order to address that problem. Internal efficiency and better customer service can also be reached by fulfilling the six **R**'s stated by Reinhard Koether (2003, p. 37) by allocating

- the **R**ight amount,
- the **R**ight object,
- at the **R**ight place,
- at the **R**ight time,

- with the **R**ight quality,
- and the **R**ight costs.

2.2.2 Holistic view on Supply Chain Management

As mentioned above, practitioners tend to view supply management out of a more holistic point of view in modern management theory. This more general approach connects different areas of management in order to create synergies within the supply chain optimization process. Following the perception by Prof. Dr. Frank Straube (2006, p. 29) the field of tasks in a fully integrated supply chain can be displayed in a way, as it can be seen in Figure 2-1. Supply Chain management is comprised of the elements of design, plan, fulfillment, and monitoring.

Supply Chain Performance Management
Supply Chain Event Management

MONITORING	

Collaboration   **PLAN** $\longrightarrow$ Fusion of Plan and Fulfillment $\longrightarrow$ **FULFILLMENT**   Collaboration

DESIGN

Supply Chain Design
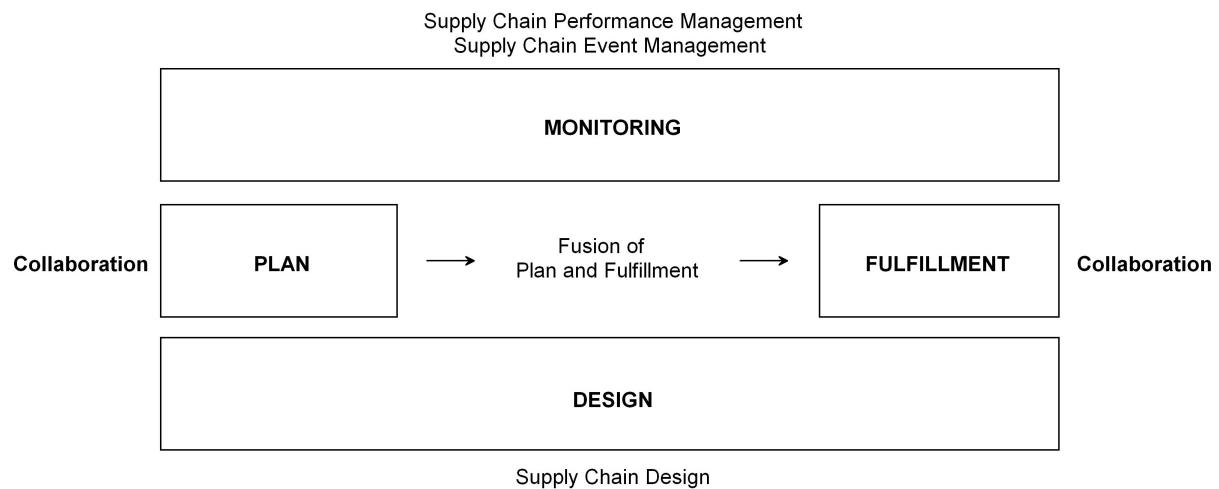
Figure 2-1. Holistic view of management tasks[11]

The first step in order to create an integrated supply chain is the designing process. According to literature[12], there exist several approaches like single-sourcing, dual-sourcing, multiple sourcing, and centers of excellence, which help to fulfil that task. Figure 2-2 gives an illustration of those sourcing strategies. As it is probably obvious for the interested reader, those strategies mainly differ in their numbers of suppliers providing the needed inputs. The choice of strategy is primarily dependent on, firstly, the uncertainty of demand and the suppliers ability to cope with those deviations and, secondly, the reliability of the supplier in general. Centers of excellence herby describe a company, which acts as an agent between supplier and producer. Thereby the company just has to deal with one partner instead of

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[11] Straube, p. 29 [2006]
[12] Zeng [2000]

coordinating with every single supplier on the next tier. Thus, the producer benefits of the variety of suppliers, but still keeps his efforts, i.e. coordination costs as well as time consumption, in a reasonable level.

Within the planning task the participants of a fully integrated supply chain coordinate their demand forecasts as well as ordering and sourcing in order to mitigate out-of-stock situations and to avoid excess stock, respectively. This includes both, the scheduling of the production and the planning of procurement, distribution and stock holdings.

The fulfillment includes the production of the good or the providing of a service within the supply chain. It thereby either describes the distribution of the good to the customer or its recycling, if the end of the product life cycle is reached.
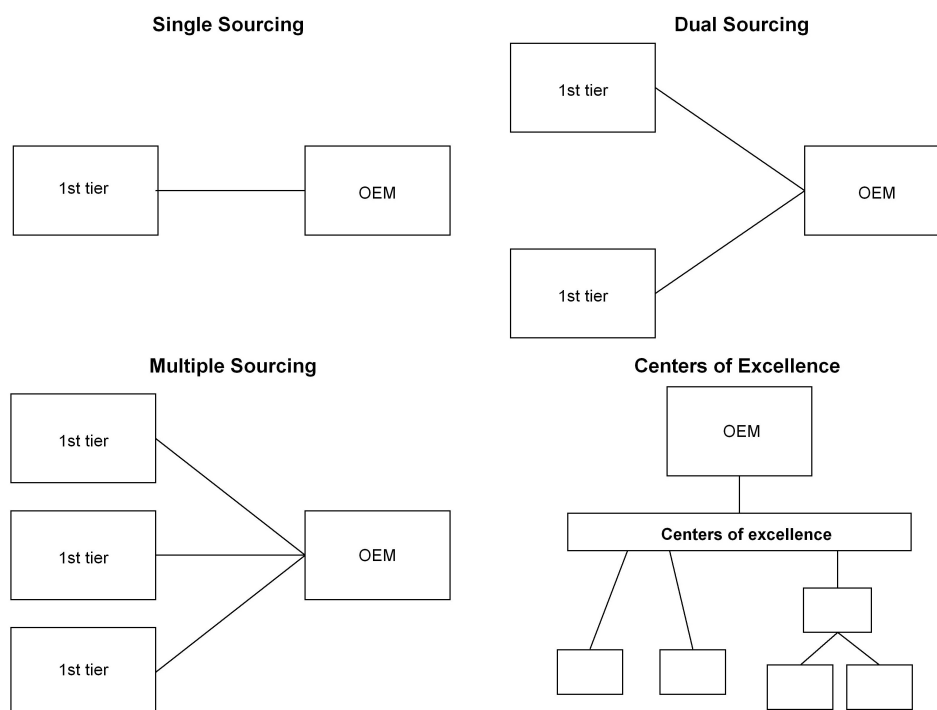
Figure 2-2. Supply chain design[13]

The task of monitoring is to assure frictionless operations in every step of the supply chain in order to be able to observe the performance and intervene if deviations from the optimal path occur. Thus, it states more or less the controlling feature of the whole supply chain.

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[13] Zhaohui [2000]

2.2.2.1 Strategic configuration of the product and network

Integration in the optimal supply chain starts with the strategic configuration of the product and the network. Depending on the considered product a supply chain has to be set up in different ways. Two types of products can be distinguished. Firstly, functional products, which are characterized by low prices and margins, constant demands, long lead times, low out of stock rates, and less variants. Often those kind of products are produced in large quantities and represent basic goods, e.g. detergents or basic clothing offered by H&M®. Innovative products, on the other hand, have a short lead time, higher stock-out rates, much shorter products life cycles, and are available in much more variants. A good example are for instance expensive cars or exclusive clothes, e.g. Ferrari® and Dolce & Gabana®; basically products, which differentiate themselves by rarity and up-to-dateness. Depending on the kind and requirements of the particular product the design of the supply chain has to fulfil different criteria. In order to reach the highest customer service level it has to be differentiated between a market responsive supply chain and physical efficient supply chain[14], depending on the type of product. Thereby physical efficient supply chains are more accepted to deal with the demands of functional products, since the main focus lies on cost reduction. Compared to the case of a market responsive supply chain it is here more important to mitigate out-of-stock situations, meaning the firm has to be able to provide the product, whenever it is needed. Table 2-1 states the main differences and important criteria concerning the structure of supply chains.

	Physical efficient	**Market responsive**
Main goal	Satisfy predictable demand in a cost efficient way	Fast reaction to avoid out-of-stock/excess situations
Manufacturing focus	High average utilization	Excess capacities to fulfil demand
Stock holding strategy	Minimizing stock, high throughput	Holding significant buffers
Lead time focus	Reduced lead-time at constant costs	Reduce lead-time with investment
Main criteria for the choice of distributors	costs and quality	Speed, flexibility, and quality
Product design strategy	Minimize costs, maximize performance	Modular design to enable product differentiation

Table 2-1. Characteristics of supply chains[15]

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[14] Fisher [1997]
[15] Ibid

The characteristics of the supply chain determine thereby also the level of integration. Depending on the product and its requirements, the needed level of involvement in the value enhancement process is set. A good example is the sudden demand increase for football shirts during the Soccer World Championship 2006 in Germany. Manufacturers like adidas®, Puma®, Reebok®, and Nike® had to provide the market with an extraordinary large amount of shirts in a very short time window, without knowing when the demand falls back to normal levels. Especially the correlation between the demand and the ongoing success of the particular nations during the tournament made it hard to forecast reasonable sales figures. Such supply chain specifications could only be fulfilled in a very reliable and integrated business environment.

2.2.2.2 Product development in the supply chain

Management should enable the business units, which are responsible for the product research and development, to address the process already in the early stages out of a cross-company point of view in order to guarantee the later frictionless operations within the supply chain. This approach will also ensure an optimal set-up.

One attempt to achieve the above mentioned set-up is the so called supply chain target costing[16], in which the supplier tries to perfectly adjust the product to the needs of the receiving company. That means that the buyer within a supply chain analyzes the price it is able to sell its products for, i.e. market-driven, and then uses this information in order to generate an operational set-up, which is able to fulfil that requirement. Those estimated costs thereby state the parameters for the supplier's necessary inputs. This process is repeatedly used on every step of the supply chain and thus creates not only a possible but also very cost efficient solution.

In connection to the first attempt, mentioned in the previous paragraph, outsourcing decisions have to be made. Every element in the supply chain has to analyze its capabilities in order to find out, if they are either able to fulfil the price, quality, and time requirements itself or if outsourcing becomes a necessary option. A usual approach to address that kind of problem is the make-or-buy analysis described for instance by Bassett (1991) or Balakrishnan (1994).

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[16] Cooper and Slagmulder, p. 204 [1999]

Due to its rather complex nature and since it is not of major importance in the later framework of this thesis that approach will not be further discussed in this paper.

A recent development is that companies try to modularize and standardize their products in order to be able to cope with the increasing demand of flexibility and complexity of the parts. That also poses the opportunity for the manufacturers to reduce the amount of suppliers and the connected transaction costs. Furthermore, that reduces the real net output ratio and thus the ability to profit from the given operations.

2.2.2.3 Configuration of the production network

In order to serve the storage costs and costs of capital commitment different types of production control methods are used. There are mainly two types used in the industry, the so-called push and the pull system. The push system has its focus on fulfilling orders with less communication within the production, which can result in an overstrain especially of the "bottlenecks"[17] of the production, resulting in backlocking and thereby causing the costs mentioned in chapter 1.2. By contrast, the pull system regulates itself by only demanding the amount explicitly required by the next step in the supply chain. Thus, the system will create a throughput, which is limited by the "bottlenecks" of the system and hence avoids backlocking and the connected costs. Figure 2-3 gives an illustration of the two concepts.
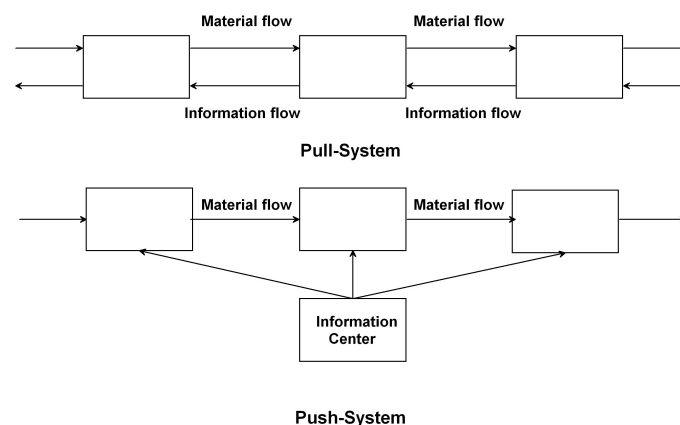
Figure 2-3. Visualization of Push and Pull concept[18]

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[17] A bottleneck of a production is in for instance a machine that impedes the system performance in the strongest manner; Chiang, Kuo and Meerkov, p. 543 [2001]

[18] Seifert, p. 5 [2002]

Another possibility to reduce and increase the customer service level is the modification of the production process regarding the point of decoupling[19]. At this point the production switches from a standardized to customized product. Thus, manufacturers are able to use cheaper non-variable parts and also increase the customer's benefits.

2.2.2.4 Process optimization

With the development of enhanced computer technologies and information systems numerous methods to improve the exchange of information have been implemented in the day-to-day business. ECR-systems[20] like vendor managed inventory[21] or collaborative planning, forecasting and replenishment[22] enhance the coordination between the companies and simultaneously improve the reaction on demand variations.

In order to both communicate and monitor the supply chain the SCOR-model[23] has been developed. It comprises the five processes plan, make, source, deliver and return. The SCOR-model is a virtual representation of reality and enables the firm to illustrate the company's performance and accordingly adjust it if necessary.

Even though the approaches mentioned above can improve the performance of the supply chain and its participants they have a more logistical focus and are thus not object of investigation of this thesis.

2.3 Bullwhip Effect

In this section a major problem of supply chains is presented. A short introduction and definition followed by the reasons and characteristics will be given. Additionally, a well-known illustration of the Bullwhip Effect is presented with the "Beer Distribution Game". The section closes with a discussion of possible financial implications.

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[19] Schary and Skjøtt-Larsen, p. 423 [2001]
[20] Efficient Consumer Response (ECR) is a methodology which tries to design an efficient value creation chain with the aim to maximize the consumers benefits; Corsten and Pötzel, p. 7 [2002]
[21] Vendor Managed Inventory (VMI) is a partnership in which the supplier, usually the manufacturer but sometimes a reseller or distributor, makes the main inventory replenishment decisions for the consuming organization; Waller, Johnson and Davis, p. 183 [1999]
[22] Collaborative Planning, Forecasting and Replenishment (CPFR) is an initiative among all participant sin the supply chain intended to improve the relationship among them through jointly managed planning processes and shared information; Seifert, p. 30, [2002]
[23] Huan, Sheoran and Wang, p. 24, [2004]

2.3.1 Introduction

"[…] the bullwhip or whiplash effect refers to the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e., demand distortion), and the distortion propagates upstream in an amplified form (i.e., variance amplification)."

Lee, Padmanabhan, Whang, 1997, p. 546

The Bullwhip Effect is a well-known distortion within the supply chain and was first put into words by Jay Forrester at the Massachusetts Institute of Technology in late 1950s[24]. This effect occurs in almost every industry and is thus of major importance not only for practitioners in the supply chain, but also for researchers in the area of supply chain management. Since unexpected variations in the demand lead to fluctuations in the order process, the Bullwhip Effect can be observed in many supply chains.

Although this effect has been observed for a long time, no approach has yet been found, which can entirely cancel out the problems on hand. During the first years after the recognition of the Bullwhip Effect the scientific world struggled to explain the real reasons for the problem. Accordingly, the solutions found in that time usually lacked effectiveness. Some theories were not only ineffective, but even worsened the outcome. So it was believed that "the role of inventory is to act as a buffer to smooth production in response to demand fluctuations. [...] This argument then suggests that the variance in the production time series should be smaller than the variance in the demand time series."[25] Further research by e.g. Blanchard (1983), Blinder (1982), and Caplin (1985) shows that such an inventory policy did not solve the problem, but in fact resulted in the variance of replenishment to be higher than the variance of the demand.

Promising approaches and methods, which address the Bullwhip Effect more effectively, can be found in the modern scientific literature. For instance Lin and Lin (2006) examine the positive influence of diversifying the demand on various retailers and thus reducing the demand uncertainty in the supply chain. Another potentially useful approach in the area of the genetic algorithms is given by O'Donnell et al. (2006). They use a computational intelligence

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[24] Forrester [1961]
[25] Lee, Padmanabhan, Whang, p. 548, [1997]

approach and thus try to find an optimal order policy for all participants in the supply chain. Those theories however will not be discussed any further within this thesis.

2.3.2 Reasons and Characteristics

In theory of Lee, Padmanabhan, Whang (1997, p. 548) the Bullwhip Effect has four different sources. First of all, Demand Signal Processing is mentioned as one main reason. It is founded on the idea that demand is assumed to be non-stationary over time and that the forecasts are directly based on the observed demand. Thus, the point of order is also non-stationary for the company. In case of present unexpected high demand of the market the firm would in consequence forecast a higher demand for the following periods and adjust their orders accordingly. Long lead times tend to even amplify the above mentioned effect in a way that the company feels the urge to order even more to be able to serve the customer demand.

The second reason mentioned by Lee, Padmanabhan, Whang (1997, pp. 551-552) is the so-called Rationing Game. The idea behind that approach is a game theoretical one. Due to shortages in the supply the demand of the single firm cannot be satisfied and the supplier rations the deliveries equally between all its customers. Anticipating that, the companies will prolong their waiting time, meaning that they accumulate their order size, hoping to achieve a better bargaining position, i.e. higher delivery priority, for the next request. Since all participants in the supply chain have access to the same information, they end up in a Nash equilibrium[26] (an explanation will follow in section 2.4.1), in which every participant has a misleadingly high demand. The resulting high order sizes aggravate the demand distortions considerably.

The third source mentioned is the so-called Order Batching, which describes the phenomenon that due to the fact that the ordering process is not costless, companies tend to agglomerate their orders to achieve economies of scale, e.g. one has less order processes with full truck loads than with partly loaded trucks. Lee, Padmanabhan, Whang (1997, p. 553-554) furthermore distinguish between random, positively correlated and balanced ordering. In the first case, retailers order randomly and independent over time. The variance of demand for the supplier equals the one of the retailer. In the positively correlated case, all orders of the retailers arrive within a short time interval, creating high distortions in the demand of the

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[26] Gibbons, pp. 8-12, [1992]

supplier. Balanced ordering assumes an equally distributed demand and thus results in the lowest variance of those three theories. The effect is intensified, if bulk discounts are introduced.

The last source is given by Price Variations. In the case of price discounts companies tend to order more than necessary and thus start to accumulate the products. In times of normal or higher prices the companies no longer have an incentive to order and as a result the order, as well as the demand, shows an irregular pattern and the volatilities are increasing.

Basically, the four sources stated above are a result of unpredictable real world influences, i.e. macroeconomic uncertainties and irrational behaviour. According to Lee, Padmanabhan, Whang (1997, p. 548) the Bullwhip Effect would not occur under the assumption that

- the demand is stationary and forecasts are not based on past demands,
- there is no rationing and a fixed lead time,
- there are no fixed order costs,
- and prices are stationary over time.

The relaxation of each of those assumptions corresponds therefore to one of the above mentioned sources of the Bullwhip Effect.

2.3.3 Beer Distribution Game

The most famous example to illustrate the Bullwhip Effect is the so-called "Beer Distribution Game"[27], which was invented in the early 1960s at the MIT Sloan School of Management and was subsequently addressed by many authors, e.g. Senge (1990). The explanation of that effect will follow an article written by van Ackere, Larsen and Morecroft (1993). It is a production distribution game and is used to show managers as well as students the implications of the Bullwhip Effect in a supply chain, i.e. the appearance of demand distortions. The game has four participants, namely the retailer, wholesaler, distributor, and manufacturer. The retailer's task is to receive the orders from the customers and order the necessary amount of products from the wholesaler to fulfil that demand and thereby assure a

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[27] The "Beer Distribution Game" was developed by professors of the Massachussets Institution of Technology Sloan School of Management in the early 1960's

high level of customer service. In the next step of the supply chain the wholesaler has a similar task, namely to ship the needed goods to the retailer and to procure those goods from the distributor. The distributor itself fulfils the duty of a haulier. It is often the case that the distributor additionally provides value added services[28], e.g. commissioning or sub-assembling tasks. The last participant in the supply chain observed in the "Beer Distribution Game" is the manufacturer. It gets its orders directly from the wholesaler. Figure 2-4 shows the structure of the beer game.

Shipment delays

| Delay | | Delay | | Delay | |

| Manufacturer | → | Distributor | → | Wholesaler | → | Retailer | **Customer** |

| | Delay | | Delay | | Delay | |

Order delays
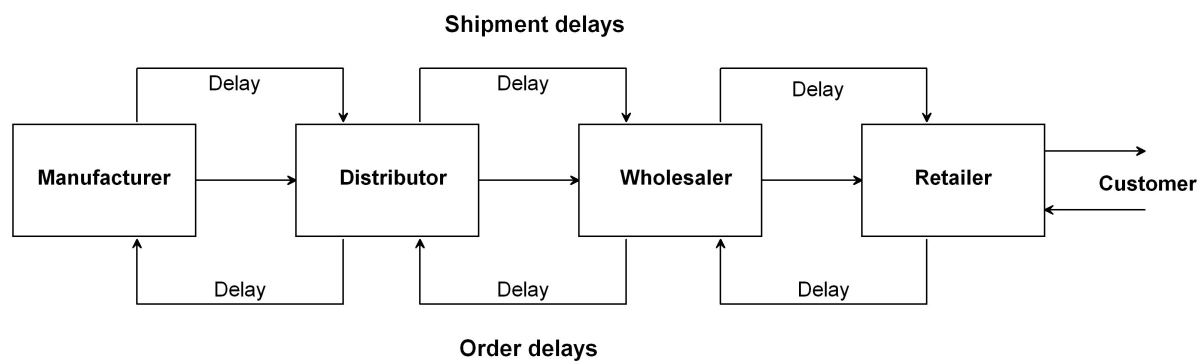
Figure 2-4. Illustration of the „Beer Distribution Game"[29]

The main focus of the "Beer Distribution Game" is to simulate the problem, which evolves in a supply chain under real world conditions, meaning that not everything can be planned as easily as theoretical approaches often tend to suggest. In order to introduce certain distortions into the set-up of the game certain assumptions are made, which try to approximate problems that can be observed in reality. First of all, the order process as well as the shipment between two tiers requires two weeks. Secondly, it takes two weeks to manufacture after receiving orders. Finally, orders may not be cancelled, once they have been given, and every participants' warehouse capacity is limited.

The basic set-up of the game is sequential, meaning that there are certain tasks, which have to be accomplished within one sequence, before the next one starts. Furthermore, the orders are represented by cards taken from a pile, i.e. they are randomly distributed. If one participant in the supply chain is not able to fill the demand of the subsequent supply chain element, the customer has to rely on its inventory or remains unsatisfied. This backlock can only be solved

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[28] Value added services (VAS) are secondary services offered and are characterized by its connection to the offered core product or service

[29] Van Ackere, Larsen and Morecroft, p. 418, [1993]

by the delivery from the previous supplier, i.e. there exists no spot market[30] for that particular good. It can take several weeks, until the problem is resolved. Furthermore, costs have to be taken under consideration. Firstly, there are the costs of holding stock, i.e. inventory costs and costs of capital commitment, and secondly, there are costs the company has to face in out-of-stock situations.

The game is played in groups over several rounds and after every sequence the stock quantities have to be reported to the supervisor of the game and are recorded for a later analysis. In the final debriefing the results of the game are shown to its participants and subsequently discussed. Especially the graphical analysis of the game results let the players have a valuable insight on the complexity of the bullwhip problem. Figure 2-5 tries to give an impression of how such graphs can look like.
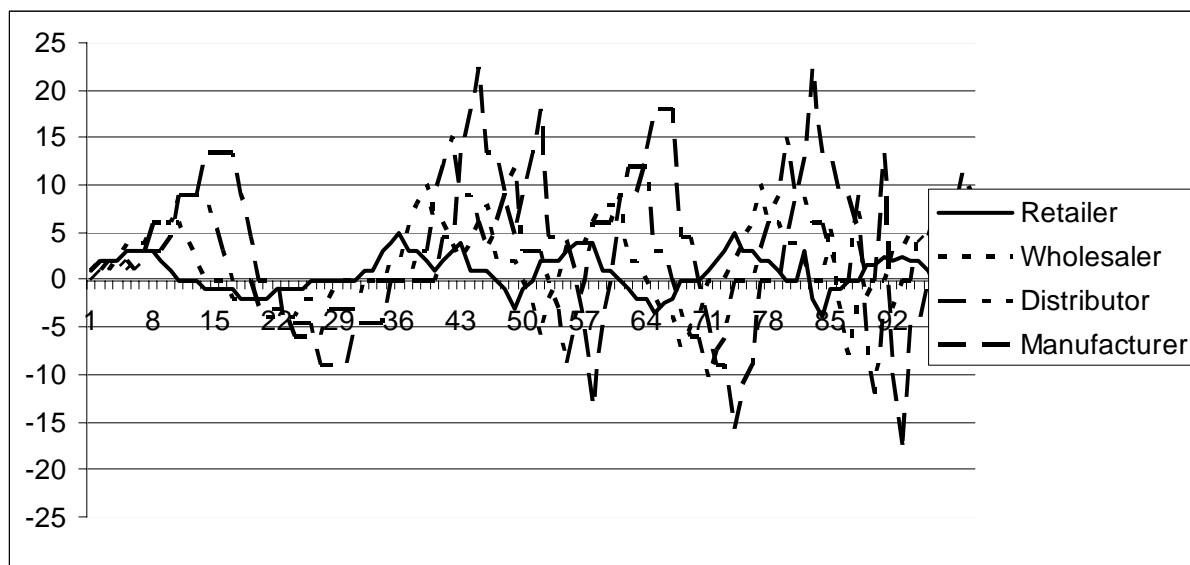
Figure 2-5. Manifestation of the „Bullwhip Effect"

It becomes obvious that the demand distortions as well as the time lag create considerably high variations in the orders within the supply chain. It has to be kept in mind though that the "Beer Distribution Game" only gives a glimpse of what has to be expected in real life. The predefinition of the order, shipment and manufacturing lead times is a very simplified approach. In real life situations those times can deviate significantly from expected values and thus even aggravate the effect. Additionally, the simplicity of the supply chain itself is nowhere near to set-ups, which can be observed in reality. The "Beer Distribution Game" is

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[30] The spot market is a secondary market where excess stock can be sold

therewith a good model to introduce managers and students to the area of supply chain uncertainty, but still considerably lacks real life applicability.

2.3.4 Financial Implications

The Bullwhip Effect is not only an interesting field of study out of a demand point of view, it moreover affects the company in several other aspects as well. In the former literature, one focus was often left out although it has a large influence on a company, namely the impact on the firm's financial performance. A first insight into possible effects is given by an article written by Carlsson and Fullér (2000, pp. 228-229). Even though the authors state the effects in a fairly general manner, they leave room for an interpretation out of a financial perspective.

In order to smooth the variations of demand and supply all members of the supply chain, i.e. retailers, distributors, wholesalers, manufacturers, and logistic operators tend to overinvest in inventory. That means that they enlarge for example their storage capacities in order to react on the irregular demand and supply. The investment in property, plant and equipment increases the capital expenditures of the firm. Beside the investment in real estate and the construction costs of the building additional costs for maintenance, insurance, labour, and taxes have to be considered. Furthermore, the increased amount of tangible assets will lead to a higher depreciation.

Another fact is caused by stock-out situations, which significantly worsen the customer service level, lower the market share, and can thus weaken the position on the market. As a consequence, the company faces not only a reduction of the revenues, on the one hand, since it is not able to fill the demand of the market directly, but also a possible lower demand in the future because of its weaker market position.

Misled by irregular peak demands management tends to believe that this growth in sales will sustain and thus adjust their capacities in the production line accordingly. When the demand of the company's product falls back to normal, i.e. lower levels, the firm has to deal with unnecessary and avoidable costs. In order to increase the production capacities the company is forced to buy new machinery and therefore has to face costs for the investment, maintenance, labour and insurance, meaning that the firm drastically increases its fixed costs. Additionally, the agglomeration of products within the supply chain generates costs of capital commitment

and intransparency, i.e. stocks blur the operations[31]. Moreover, new equipment inflicts higher levels of depreciation.

Another problem, which is caused by the demand variations, are the changes in transportation capacities and varying timetables. The participants in the supply chain have to react quickly, if they face unexpected demands and thus higher costs. For transports, which are certain in the long-term, the supply chain member can bargain with the carrier a priori and thus achieve lower rates, since the carrier gets a certain income in the future and can plan its capacities better. As a consequence, both parties gain an advantage. If the firm now needs unexpected high capacities, the carrier will be paid for this additional flexibility. Furthermore, planned capacities can be transported in optimized lot sizes and on optimized routes, which also lowers the shipping fares.

Finally, fluctuations of demand also lead to problems in the production. Beside the out of stock situations of final products, the same problem can occur in the receipt of goods. If the order is not delivered as negotiated, e.g. at the wrong time or in the wrong quantity, the production schedule cannot be fulfilled. Moreover, the inefficiency in the supply chain and the resulting varying demand can cause overproductions and unnecessary stock volumes. As a result, the costs increase for the producing firm. Stock generates cost of capital commitment; lacks of input material cause costs due to needless set-up of machines, planned transportation capacities, employment of workers, out-of-stock situations and can thus lead to a decreasing customer service level.

2.4 Game Theory

Game Theory is the trial to model the economic competitive behaviour of participants in strategic situations and multi-person decisions problems and is used within this thesis in the later discussed modelling approach. This science tries to describe the players' reactions in simultaneous or sequential games under perfect or imperfect information. According to Varian (1992, p. 260) a game is "defined by exhibiting a set of players, a set of strategies, the choices that each player can make, and a set of payoffs that indicate the utility that each player receives, if a particular combination of strategies is chosen." Furthermore, "the payoffs

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[31] High stock rates complicate the control of input/output of resources in the production; hiding real amount of stock

and strategies available to the players are common knowledge" and all players are rationally thinking, i.e. they update the actions, which maximize their utility function, if new information becomes available.

2.4.1 Nash Equilibrium

Gibbons (1992, pp. 8-12) defines a Nash equilibrium as follows:

"In the n-player normal form game $G = \{S_1,\ldots,S_n;u_1,\ldots,u_n\}$, the strategies $(s_1^*,\ldots,s_n^*)$ are a Nash equilibrium if, for each player i, s_i^* is (at least tied for) player i's best response to the strategies for the n-1 other players, $(s_1^*,\ldots,s_{i-1}^*,s_{i+1}^*,\ldots,s_n^*)$:

$$u_i(s_1^*,\ldots,s_{i-1}^*,s_i^*,s_{i+1}^*,\ldots,s_n^*) \geq u_i(s_1^*,\ldots,s_{i-1}^*,s_i,s_{i+1}^*,\ldots,s_n^*)$$

for every feasibly strategy s_i in S_i, that is s_i^* solves

$$\max u_i(s_1^*,\ldots,s_{i-1}^*,s_i,s_{i+1}^*,\ldots,s_n^*) \text{ with } s_i \in S_i.\text{"}$$

The Nash equilibrium symbolizes the optimal choice of strategy for every player out of a set of feasible strategies in the game as in the set-up of the Rationing Game mentioned in section 2.3.2. A well-known example for a Nash equilibrium is the prisoner's dilemma shown in Figure 2-6.

		Prisoner 2	
		stay silent	betray
Prisoner 1	stay silent	-1; -1	-9; 0
	betray	0; -9	-6; -6

Figure 2-6. Prisoner's dilemma[32]

Two prisoners, who committed a crime, face the likelihood of imprisonment. Based on their testimony there are four different scenarios. If both stay silent, the burden of proof suffices only for a month-long imprisonment for each of the criminals. Since both of them have the incentive to betray the other in order to avoid the punishment, i.e. the betrayer goes free and the other one has to stay in prison for nine month, they end up in the situation that both betray each other and are imprisoned for six month. Even though that might seem to be an irrational

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[32] Gibbons, p. 3, [1992]

decision, neither of them has any incentives to leave that decision, for six month in prison are better than nine month. Therefore, the mutual betrayal is in this case the Nash equilibrium.

2.4.2 Stackelberg Competition

One of the most important models in the framework of game theory is the so-called Stackelberg competition of quantities or Stackelberg duopoly (von Stackelberg, 1934). It describes the dynamic game under complete information and has a sequential set-up. According to Gibbons (1992, pp. 61-64), the leader (dominant) makes the first move and the follower (subordinate) is able to react. The follower observes the quantity put on the market by the leader q_i and adjusts its production quantity q_j accordingly. The price is hereby determined by the overall quantity Q on the market and thus the payoff of firm i is defined as

$$\Pi_i(q_i, q_j) = q_i \cdot [P(Q) - C] \text{ with } Q = q_i + q_j, \ q_i \geq 0$$

and the market clearing price as

$$P(Q) = a - Q,$$

while a stands for the price, where the demand is equal to zero. The problem is solved using a technique called backwards reduction. Firstly, the follower's reaction has to be computed to a yet unknown quantity of the leader. The equation, which describes the reaction of the following firm, looks like follows:

$$\max_{q_j \geq 0} \Pi_j(q_i, q_j) = \max_{q_j \geq 0} (a - q_i - q_j - c) \cdot q_j,$$

which yields to quantity reaction function

$$R_j(q_i) = 0.5 \cdot (a - q_i - c).$$

with c as constant marginal costs. Thus, the reaction of the second firm in regard to the leader's quantity is obtained. The dominant company anticipates this behaviour and maximizes its profit as follows

$$\max_{q_i \geq 0} \Pi_i(q_i, R_j(q_i)) = \max_{q_i \geq 0} \left[a - q_i - R_j(q_i) - c \right] \cdot q_i = \max_{q_i \geq 0} \left[0.5 \cdot q_i \cdot (a - q_i - c) \right],$$

which yields to

$$q_i = 0.5 \cdot (a - c) \text{ and } R_j(q_i) = 0.25 \cdot (a - c).$$

This is the so-called Stackelberg equilibrium.

In comparison to the Nash equilibrium of simultaneous games, where every player can produce the same quantity and faces the same price, one obtains a higher market clearing

quantity and a lower market clearing price. Due to the complete information assumed in the game the leader has the chance to discriminate the follower by exploiting profits and it becomes obvious that perfect information disturbs the competition. In case of information asymmetry the follower cannot anticipate that the dominant firm will adjust its production and thus it will deviate from its Stackelberg solution as well and both will end up in the Nash equilibrium of a Cournot competition, i.e. simultaneous quantity competition, with a quantity of

$$q_i = q_j = (1/3) \cdot (a - c) \,.$$

3 Methodology

Chapter 3 is entitled to find an appropriate model approach to address the problems inflicted by the Bullwhip Effect. Therefore a short literature review will be given and subsequently discussed in order to decide on a model, which is able to successfully illustrate the advantages of real options. In the following, the advantages and disadvantages of the chosen model, as well as the data requirements and its limitations are explained. The chapter closes with the illustration of the modelling approach.

3.1 Literature Review

Option theory is not a particular new field of study. Many authors contributed a variety of financial models and theories that can be looked upon today; many of those are well summarized by Hull (2002, Ch. 7-14, 28). Unfortunately, financial option theory is not as easy to implement in supply chain decisions. Financial options and supply chain options have several significant differences. While financial options use the assumption of no-arbitrage and complete markets in order to find accurate prices, supply chain options as real options use the bargain process as their pricing basis. Additionally, former option theory bases on the assumption of an existing market, on which those options are traded; such a market does not yet exist for supply chain options. However, researchers as Shi et al. (2004) already initiated a discussion concerning that topic. Subsequently to the first major contribution in the field of supply chain option theory by Ritchken and Tapiero (1986) a great variety of ideas and approaches developed in the following years. Recent literature mainly distinguishes between the following option contracts:

Quantity flexibility contracts give the buying party the opportunity to adjust its previously given order, i.e. in the first period, in an predefined quantity interval. The changed quantity can be interpreted as the amount of exercised options.

In backup agreements, like in Barnes-Schuster et al. (2002, pp. 171-207), the buyer chooses a quantity of goods and simultaneously decides about the percentage of all products that should be delivered as soon as possible. In this approach the outstanding percentage can be seen as

the number of options. When the buyer receives more information about the demand it can order the remaining goods for the same price and pays a penalty for not used products.

Another approach is the capacity reservation contract. In this agreement, the buyer reserves certain capacities and pays for a part of it the wholesale price, meaning that these products are definitely delivered to the buyer. For the rest of the reservation it has to pay an option price and at a later time, if these options are exercised, a predefined exercise price. As an example of one possible application it is referred to Erkoc and Wu (2002, pp. 232-251).

Beside the above mentioned approaches, which give the buyer the possibility to design a flexible order strategy using call options, it is also possible to create return contracts. With these buy-back contracts the buyer has the opportunity to decrease existing excess stock. In this case it is a put option approach, in which the buyer receives a predefined price for every unit returned to the seller. The difference between the wholesale and the predefined price thus represents the exercise price of the option.

3.2 Choice of Model and Data

As shown in the previous section, there are several approaches to equip companies with more flexibility within their ordering process. Advantages and disadvantages of each of the models have to be compared in order to reach a set-up, which can in fact support the firm in its buying strategy.

A major flaw of the backup agreement are the penalty costs, which the buyer has to face, if it does not take the full order amount it committed to beforehand. Thus, the major part of the risk lies on the buyer's side and in the case of lower storage costs than penalty costs the buyer has an incentive to pile up stock, which can significantly increase the Bullwhip Effect and its corresponding costs. This model is therefore not particularly appropriate to address the costs of the Bullwhip Effect.

Basically, the capacity reservation contract could reflect the perfect model to address the problems induced by the Bullwhip Effect. Since the optional quantity used in that model is not produced in advance but is just reserved, it manages to reduce the stock quantities itself and not only the costs. Unfortunately, it is not particularly useful, if the demand deviations are

fairly high, especially when time lags are introduced. In this case the model will most likely not be able to satisfy the demand at any point in time, meaning that out-of-stock situations will occur. Thus, it can also amplify the Bullwhip Effect, since increased amount of out-of-stock situation support the appearance of the Rationing Game, as discussed chapter 2.3.2.

The buy-back contract and the quantity flexibility contract create basically the same result assumed that the put-call-parity holds, even if they are in itself slightly different approaches. Thus, it does not matter, which model the supply chain participants choose. The authors of this thesis use a similar approach as given in the quantity flexibility contract. In contrast to the original set-up, a single period is observed and the option price is always larger than zero. The chosen model allows for an optimization of the exercise and option prices and thus achieves the optimal profit for each of the supply chain partners. Since the appearances of out-of-stock situations are almost entirely cancelled out due to prior production, i.e. both, the precommitted and the optional quantity is manufactured at the begin of every period, the Rationing Game, as one source of the Bullwhip Effect, does not occur very often. Furthermore, the fixed mathematical framework presented by the model helps to avoid unfavourable Demand Signal Processing, since the managers can base their decision not only on their subjective opinion but also on mathematical evidence.

This thesis has a deductive set-up, meaning that a model is used on a specific dataset to show the advantageous effects of real options on the Bullwhip Effect. Due to the rather complex nature of the chosen model, the authors of this thesis abstained from the usage of a real life empirical dataset. The limited amount of time and the confidentiality of the necessary company data complicate the obtainment of applicable information and hence they enforce the usage of a randomly created dataset within the option model. In the later explained dataset the demand as well as the prices and production time lags are set. Even though those restrictions only allow for a limited comparability to the reality, it will become obvious that real options are a promising approach to mitigate the costs of the Bullwhip Effect. The simplified dataset has also the advantage that it facilitates the understandability of the calculations and it is thus easier for the reader to follow the subsequently conducted analysis.

As already explained above, the chosen model is not superior in any given supply chain. It is especially suitable in the case of high demand uncertainty. In the event of low demand a

model using capacity reservation contracts can often outperform the one with flexible quantity contracts.

The model calculations within this thesis are performed using Microsoft Excel 2003© and Microsoft Visual Basic 6.0©. The graphical illustrations are created with OriginPro 7.5© and Diagram Designer 1.18©.

3.3 Explanation of the models

An appropriate model, like the flexible quantity contract model, that can mitigate the costs between two supply chain partners is given by Cheng et al. (2003) and will therefore be explained in the following sections. Additionally, some ideas by Çinar and Bilgiç (2005), who published an extension of the model, will be used. To begin with, a non-flexible base case will be presented, followed by an unconstrained and a constrained option model. At the end of this section, an integrative model will also be stated, which acts as a benchmark case.

The text observes the business relations between two participants in a supply chain. In analogy to the articles by Cheng et al. (2003, p. 6) and Çinar and Bilgiç (2005, p. 11) a supplier and a manufacturer are chosen as market participants. By applying the different models, it will be shown, how the companies choose their prices and order quantities and how the revenues, costs, and profits are computed.

The following notation is used throughout all models presented within this thesis:

D	market demand faced by the manufacturer
μ	expected market demand (mean)
σ	standard deviation of the market demand
$F(\cdot)$	cumulative distribution function
r_m	price of one unit sold to the market
w_0	price of one unit sold to the manufacturer (charged by the supplier)
p_m	unit penalty faced by the manufacturer in out-of-stock situations
m_s	price of one unit bought by the supplier
v_m	manufacturer's unit salvage value
v_s	supplier's unit salvage value
h_m	unit handling or production cost faced by the manufacturer
Q_m	committed order quantity of the manufacturer
q_m	additional optional quantity fof the manufacturer
c	price of one option sold by the supplier
w	exercise price of one option

It is necessary to assume demand deviations to be the only source of uncertainty within the models and that the demand $D \geq 0$. The price w_o is not a result of negotiations between the two participants, but it was determined by earlier involvements of several other parties. In order to reflect realistic market behaviour three additional assumptions have to be made. Firstly, it is presupposed that the supplier sells to the manufacturer without losses and the salvage price does not cover the purchasing costs, i.e. $v_s \leq m_s \leq w_0$. Secondly, it is assumed that the manufacturer faces no profits when salvaging its excess stock, i.e. $v_m \leq w_0 + h$. Finally, w_0 must be smaller than the spot market price, which is defined as the sum of r_m and p_m, i.e. $w_0 \leq r_m + p_m$. A more detailed discussion on the inequalities can be found in either Cheng et al (2003, p. 7) or Cheng et al (2006, p. 8).

3.3.1 Inflexible model

This model is the base case used in a supply chain without flexibility[33]. The manufacturer maximizes its profits by choosing its optimal order quantity:

$$\max_{Q} \Pi_m^{\inf}(Q) = r_m \cdot E\left[D \wedge Q_m\right] + v_m \cdot E\left[(Q_m - D)^+\right] - p_m \cdot E\left[(D - Q_m)^+\right] - (w_0 + h_m) \cdot Q_m.$$

While $x \wedge y$ stands for min(x;y), meaning that $E\left[D \wedge Q_m\right]$ is the expected quantity of products sold for the price r_m. Furthermore, $(x)^+$ denotes max(x;0), which makes $E\left[(Q_m - D)^+\right]$ the expected quantity of excess stock and $E\left[(D - Q_m)^+\right]$ the expected number of out-of-stock situations. Multiplied with the salvage price v_m and the penalty costs p_m the second and the third term give the salvage value and the penalty costs. The fourth term moreover represents the manufacturer's costs for purchasing and production, which occurs whenever one unit is bought. Using the mathematical transformations proposed by Çinar and Bilgiç (2005, p. 12),

$$X \wedge Y = Y - (Y - X)^+ \text{ and } (X - Y)^+ = (Y - X)^+ - (Y - X)$$

and

$$E\left[(Q - D)^+\right] = \int_0^Q (Q - x) dF(x) = Q \cdot F(Q) - \int_0^Q x dF(x) = \int_0^Q F(x) dx$$

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[33] Throughout the thesis a flexible model describes a model using real options

the following profit maximizing equation can be obtained:

$$\max_{Q} \Pi_m^{\text{inf}} = (r_m + p_m - w_0 - h) \cdot Q_m - (r_m + p_m - v_m) \cdot \int_0^{Q_m} F(x)\,dx - p_m \cdot \mu.$$

The first order condition gives us the optimal

$$Q_m^{\text{inf}} = F^{-1}\left(\frac{r_m + p_m - w_0}{r_m + p_m - v_m} \right).$$

The demand is thereby supposed to be normally distributed with the mean μ and the standard deviation σ.

In order to calculate the corresponding profit it is necessary to compute the integral of the cumulative normal distribution function. Unfortunately, an analytical solution is not available and thus the authors use a numerical approximation, namely the trapezium rule[34]

$$\int_a^b F(x)\,dx \approx \frac{b-a}{2n} \cdot \left(F(x_0) + 2 \cdot F(x_1) + \ldots + 2 \cdot F(x_{n-1}) + F(x_n) \right),$$

which belongs to the family of the Newton-Cotes formulas[35]. In this case this results in

$$\int_0^Q F(x)\,dx \approx \frac{Q-0}{2n} \cdot \left(F(x_0) + 2 \cdot F(x_1) + \ldots + 2 \cdot F(x_{n-1}) + F(x_n) \right),$$

where $n = 40$ is used in order to get an accurate result.

The supplier will deliver the exact required amount of products for the predetermined unit price w_0. Its profit will therefore be

$$\Pi_s^{\text{inf}} = (w_0 - m_s) \cdot Q_m.$$

3.3.2 Flexible model

In this approach the manufacturer can buy options, which give the right, but not the obligation, to reorder additional products for a predetermined exercise price at a later point in time. Throughout all flexible models used in this thesis it is assumed that every optional unit is an European call option paying out no dividends, where the product is the underlying, w_0 is the price charged by supplier and w is the exercise price. Furthermore, the model does not account for time differences, i.e. the exercise price is not discounted over time, which is the

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[34] Bronstein, Semendjajew and Musiol, Ch. 19.75, [2000]
[35] Formulas of numerical analysis which are named after the mathematicians Isaac Newton and Roger Cotes

same as setting the risk-free rate r_f, as it is used in financial option theory[36], equal to zero[37]. The option price c and the exercise price w are the variables set by the supplier, while the manufacturer can choose the precommitted order quantity Q_m and the amount of additional options q_m. Since the model assumes Stackelberg competition, which is explained in chapter 2.4.2, between both parties, the supplier as a leader will set its prices first and the manufacturer can only follow by choosing its profit maximizing quantities to those prices. The options will thereby only be exercised, if the demand outnumbers the precommitted quantity. To assure the practicability of the model, certain assumptions have to be included in addition to those in the inflexible case. Firstly, the sum of the exercise price and the option price must exceed the purchasing price, i.e. c + w ≥ w₀, otherwise the manufacturer would substitute all fixed quantities with options. Secondly, it is assumed that the sum of the option and the salvage price does not outstrip the sum of the production and purchasing costs, i.e. $c + v_m \leq w_0 + h_m$. If that inequality is not satisfied, the manufacturer rather increases its precommitted order quantity and salvages the potential excess stock than buying the more expensive options, meaning that it would not buy any options. Finally, the sum of the option price and the exercise price may not exceed the spot market's price, i.e. $r_m + p_m \geq c + w$, otherwise the manufacturer would not buy its input from the supplier but from the open market.

As in the inflexible model the manufacturer maximizes its profits by choosing its optimal order quantity, but in this case the overall quantity is separated into the precommitted quantity Q_m and the optional quantity q_m.

The manufacturer's profit function looks as follows:

$$\Pi_m^{flex}(Q_m, q_m) = r_m \cdot E\left[(Q_m + q_m) \wedge D\right] + v_m \cdot E\left[(Q_m - D)^+\right] - (w + h_m) \cdot E\left[(D - Q_m)^+ \wedge q_m\right]$$
$$- p_m \cdot E\left[(D - Q_m - q_m)^+\right] - w_0 \cdot Q_m - c \cdot q_m - h_m \cdot Q_m$$

In addition to the terms, which were already explained in the inflexible model,

$E\left[(Q_m + q_m) \wedge D\right]$ describes the quantity of goods sold, $E\left[(D - Q_m)^+ \wedge q_m\right]$ gives the

amount of options exercised, and $E\left[(D - Q_m - q_m)^+\right]$ denotes the number of out-of-stock

situations.

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[36] Hull, p. 174 [2002]
[37] Cheng et al., p. 30 [2003]

The transformation of the expected quantities gives the following equation:

$$\Pi_{\mathrm{m}}^{\mathrm{flex}}\left(Q_m, q_m\right) = \left(r_m + p_m - w_0 - h_m\right) \cdot Q_m + \left(r_m + p_m - w - h_m - c\right) \cdot q_m - p_m \cdot \mu$$

$$- \left(r_m + p_m - w - h_m\right) \cdot \int_0^{Q_m + q_m} F(x) \, dx - \left(w + h_m - v_m\right) \cdot \int_0^{Q_m} F(x) \, dx.$$

After taking the first order conditions with regard to the precommitted quantity Q_m and the option quantity q_m and after reorganizing the equations, one gets

$$Q_m = F^{-1}\left(\frac{c + w - w_0}{w + h_m - v_m}\right)$$

and

$$q_m = F^{-1}\left(\frac{r_m + p_m - w - h_m - c}{r_m + p_m - w - h_m}\right) - Q_m.$$

A detailed discussion in the articles by Cheng et al. (2003, p. 12-14) and Çinar and Bilgiç (2005, pp. 14-18) shows that the manufacturer's optimal decision regarding Q_m and q_m depends on the option buying price c and option exercise price w and that the expected profit is at least as high as in the inflexible case. Furthermore, it is shown that increasing production costs h_m lead to a lower profit for the manufacturer.

In contrast to the inflexible model, the supplier anticipates the manufacturer's quantity decision function and accordingly maximizes its profit by choosing the optimal option price c and the exercise price w. The supplier's profit function looks like follows:

$$\Pi_s^{\mathrm{flex}}\left(c, w\right) = w_0 \cdot Q_m + c \cdot q_m + w \cdot E\left[\left(D - Q_m\right)^+ \wedge q_m\right]$$

$$+ v_s \cdot E\left[\left(q_m - \left(D - Q_m\right)^+\right)^+\right] - m_s \cdot \left[Q_m + q_m\right],$$

where $E\left[\left(q_m - \left(D - Q_m\right)^+\right)^+\right]$ expresses the amount of non-exercised options. The transformation gives us

$$\Pi_s^{\mathrm{flex}}\left(c, w\right) = \left(w_0 - m_s\right) \cdot Q_m + \left(c + v_s - m_s\right) \cdot q_m - \left(w - v_s\right) \cdot \int_{Q_m}^{Q_m + q_m} F(x) \, dx.$$

In order to reach the optimal values for c and w, the first derivatives of the supplier's profit function with respect to c and w are taken. Subsequently, the supplier's profit function is differentiated, likewise with respect to c and w, and solved for the prices.

The supplier's reduced equation for the first order condition with respect to *w* looks as follows:

$$\frac{\partial \Pi_s}{\partial w} = \left(v_m - h_m - v_s\right) \cdot F(Q_m) \cdot \left[F(Q_m + q_m) - F(Q_m)\right] \cdot Q'_{m,c}$$

$$+ \left[q_m \cdot F(Q_m + q_m) - \int_{Q_m}^{Q_m + q_m} F(x)\,dx\right]$$

with

$$Q'_{m,c} = \frac{1}{\left(w - v_m + h_m\right) \cdot f(Q)},$$

which is the first derivative of the precommitted quantity Q_m with respect to the option buying price *c*.

It is shown in the article by Çinar and Bilgiç (2005, p. 18) that the profit function is not concave and *w* is constrained by $w \leq r_m + p_m - h_m$, while *c* is close to zero. Since it is assumed, as stated above, that the inequality $c + w \leq p_m + r_m$ holds, the supplier tries to choose *c* and *w* so that the sum nearly reaches the spot market price. More precisely, it will charge an exercise price that is slightly lower than the spot market price with a corresponding option buying price that is only slightly higher than zero. Thus, the supplier gives the manufacturer an incentive to buy options in addition to the precommitted order quantity.

The numerical example given in a later section of this thesis will also use a constrained model, in which the option exercise price is fixed to a certain portion of the purchasing price, i.e. $w \leq a \cdot w_0$ with *a* as the limiting factor. The constraint is introduced in order to influence the profit distribution among the bargaining parties. The company, which leads the game, will normally choose the same strategy, namely setting the exercise price *w* as high as possible and the options price *c* close to zero. But if the Stackelberg-leader is constrained in the choice of the exercise price *w*, the salvage price for the leader v_s is sufficiently high, and when the purchasing price w_0 is considerably low, compared to the leader's purchasing price m_s of the product, a special case can occur. The leader has then an incentive to increase the option buying price *c* and decrease the exercise price *w* in order to exploit the maximum profit from the follower. The leader can do that, since the salvage value is high enough to compensate the foregone revenues due to not exercised but sold options. In some cases it might therefore also be necessary to restrict the option price *c* in order to achieve a favoured profit distribution. A more detailed discussion will follow in the numerical example. Beside the changes in the

financial implications, which are discussed below, the set-up of the model remains the same, meaning that all formulas are used equally.

3.3.3 Integrated model

This approach is characterized by a full exchange of information in the supply chain and market, meaning that, on the one hand, the manufacturer gives the supplier all its available data and, on the other hand, no market demand deviations occur so that none of supply chain partners has to face demand uncertainties. As a result, neither out-of-stock-situations nor excess-stock-quantities appear in the model and thus the supply chain participants do not have to take penalty-costs and salvage revenues into consideration. Additionally, supplier and manufacturer do not have to optimize their quantities, since those are exogenous variables and thereby known. The profit functions of the supplier and manufacturer look as follows:

$$\Pi_m^{int}\left(Q_{market}\right) = \left(r_m - w_0\right) \cdot Q_{market}$$

and

$$\Pi_s^{int}\left(Q_{market}\right) = \left(w_0 - m_s\right) \cdot Q_{market}.$$

3.3.4 Put-Call-Parity

Even though the put-call-parity is not explicitly used within the numerical example of this thesis it is also possible to use put options, in contrary to the call option models mentioned above, to achieve the same results and effects. In such a model the manufacturer is able to return the excess stock by using its options, meaning that it gets back a part of the purchasing price from the supplier in case of the execution of the option, i.e. the exercise price, and it is thus a buyback contract. In this case, the profit function of the manufacturer looks like follows:

$$\Pi_m^{p-c}\left(Q_{p,m}, q_{p,m}\right) = \left(r_m + p_m - w_0\right) \cdot Q_{p,m} - \left(r_m + p_m - w\right) \cdot E\left[Q_{p,m} - D\right]^+$$
$$- \left(w - v_m\right) \cdot E\left[Q_{p,m} - q_{p,m} - D\right]^+ - p_m \cdot q_{p,m} - p_m \cdot \mu,$$

where $E\left[Q_{p,m} - D\right]^+$ expresses the non-sold and returned precommitted quantity and $E\left[Q_{p,m} - q_{p,m} - D\right]^+$ the excess quantity of products, which cannot be returned due to a lack of options.

The supplier in the put-call-parity model has the following profit function:

$$\Pi_s^{p-c}(p,w) = (w_0 - m_s) \cdot Q_{p,m} + p_m \cdot q_{p,m} -$$
$$(w - v_s) \cdot \left[E(Q_{p,m} - D)^+ - E(Q_{p,m} - q_{p,m} - D)^+ \right].$$

Under the additional assumption that the put-call-parity holds, i.e. $c - p = w_0 - w$ with $Q_{p,m} = Q_{c,m} + q_{c,m}$ and $q_{p,m} = q_{c,m}$, the profits in the put option approach are the same as in the call option model, for the supplier and manufacturer. Thus, the following equations will hold:

$$\Pi_m^{p-c}(Q_{p,m}, q_{p,m}) = \Pi_m^{flex}(Q_m, q_m)$$

and

$$\Pi_s^{p-c}(p,w) = \Pi_s^{flex}(c,w).$$

Consequently, it is the supplier's decision, if it wants to use put or call options; both will give the same result. A combination of both is also possible.

4 Simulation Results and Analysis

In the following chapter numerical examples for the models, which are explained in the previous chapter, will be presented. Subsequently, the results will be discussed under a financial perspective. It is the aim of this chapter to show that the use of real options in a supply chain can mitigate the costs of the Bullwhip Effect. It is thus expected that the inflicted costs will diminish noticeably and as a consequence the profits increase.

4.1 Basic assumptions

The following section shows the application of the previously discussed models by giving a numerical example in order to point out the implication of the use of real options in the supply chain. The analysis will thereby focus on financial figures and thus highlight the influence of demand uncertainty on the company's financial performance.

It is the authors' opinion that a growth market, e.g. the high-tech industry, is an excellent example to show the advantages of an option approach. Firstly, those markets show high demand volatilities and are therefore in need of techniques and methods to either reduce those uncertainties or at least mitigate the costs the company has to face, e.g. the costs of the Bullwhip Effect. Secondly, the products traded in such a supply chain loose in value considerably fast, meaning that the companies have to optimize their stocks in order to avoid value destruction. As a consequence a market responsive supply chain is necessary to satisfy the requirements of the participants.

Growth market products tend to show short life cycles due to fast research and development and a competitive business environment. The high research costs force the firms to set the prices to high levels in the early stages of the product life cycle in order to balance out their losses due to R&D and compensate for the later price deterioration. As a consequence, some of the sources of the Bullwhip Effect, mentioned in chapter 2.3.2, will most likely not appear in the given industry. Due to the fast price deterioration of the products the companies try to avoid excess stock and the corresponding costs of capital commitment in case of an unexpected low demand. Thus, demand distortions due to Price Variations seem to be unlikely, since price discounts in the early stages can not be expected and the fall in value can

severely impair the company's profits. The next source of the Bullwhip Effect, namely the Order Batching, can also be excluded from the observation. Even though economies of scale are also an important factor in the high-tech industry, increased order quantities bear the risk of excess stock situations and can thus inflict fairly high costs for the firm. Furthermore, it is assumed throughout the model that the ordered quantities will always be delivered. Out-of-stock situations will only occur when the market demand changes unexpectedly, i.e. the market demand exceeds the expected order quantities.

In this thesis a supply chain with three participants and a single-sourcing set-up can be observed. Out of a market's perspective the first supply chain element is the retailer, which can anticipate the expected demands best due to its strategic position and experience. The next participant in the supply chain model is the manufacturer and the last element in the supply chain is the supplier. To illustrate a possible real life supply chain the authors choose the chain between Sanyo® as a supplier of displays for mobile phones produced by Nokia® and sold by Vodafone® to the customers as shown in Figure 4-1.
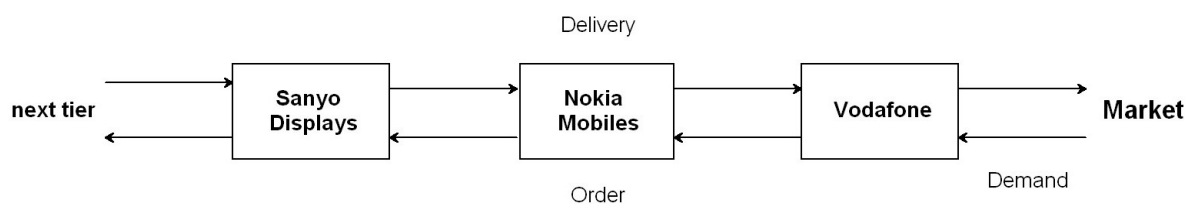
Figure 4-1. Supply chain in mobile industry

As explained in the previous section, the model has certain limitations for its input and output variables. It represents only a simplified version of reality. Unfortunately, the constraints somewhat complicate the usage of real life data due to their complexity and quantity. In order to facilitate the comprehensibility of the model a simplified randomly created dataset will be used. Even though the data will not account for every possible situation that might occur in reality, it will emphasize the advantages of Real Option theory in that business area. Additionally, the model will be constrained in the sense of assuming a constant time lag of one period for production and delivery.

Three periods for each connection between two supply chain partners will be examined, while today's period is defined as period t. The two following periods are denoted as period t+1,

respectively period t+2. The demand follows an autoregressive process, which is also a standard assumption in academic literature. Kahn (1987, p. 668) uses an autoregressive model with one time lag, which looks as follows: $D_t = d + \rho \cdot D_{t-1} + \varepsilon_t$. The variable d is the drift parameter, which describes the trend, while $d > 0$ stands for an increasing demand and $d < 0$ for a decreasing one and ρ is the correlation factor between the current and the previous demand and is constrained by]-1;1[. ε_t is the error term and is independently and identically normally distributed with a mean of zero and a variance of σ^2. In the authors' model it is also reasonable to assume d to be time varying as well, so that the demand volatility not only depends on the fluctuations of the demand itself, but also accounts for changes in market trends and can thus be written as $\sigma(D_t, d_t)$. Other models, which can be used to achieve a volatility forecast besides the model based on Kahn (1987), are GARCH models, which also account for instance for volatility clustering[38] and heteroskedasticity[39]. The explanation of these models is beyond the scope of this thesis and it is referred to more detailed literature for the interested reader.

In this case the standard deviation of market demand is assumed to be constant at 30 % for a one period forecast. The standard deviations will increase with every additional period looked ahead. An explanation for that development can be seen in the available degree of information known to the individual. The more recent the information is, the more diminishes the uncertainty in the forecast and thus the estimate becomes more precise. Additionally, it is assumed that the retailer does not put its demand forecasts through to the other companies in the supply chain, meaning that all other firms have to create their own forecasts. As they lack the advantageous position of the retailer, their estimations will most likely contain higher forecast errors. The authors tried to account for this growing amount of uncertainty by both, the disadvantageous market position and the longer forecast period, by using a multiplier of 1.25 for the second period forecast. In the used model, forecasts beyond two periods are not necessary, but would be simple to implement. The volatility multiplier is increasing exponentially with an exponent that equals to the number of forecast periods, i.e. $\sigma \cdot x^n$ with x as the multiplier and n as the number of forecast periods.

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[38] Volatility Clustering describes the positive correlation with its previous levels
[39] Heteroskedasticity describes the absence of homogeneity of variance; Brooks, Ch.4 [2002]

Today's one period demand forecast, i.e. the demand the retailer expects to have in period t+1 conditional on the information available in period t, is set to 100,000 and as explained above the standard deviation is assumed to be 30 %, meaning that the demand can deviate within an interval of [70,000;130,000]. Due to the production and delivery time constraint explained above the manufacturer faces the problem that it must forecast two periods ahead. It adds a forecasted drift to demand figures, which it obtains during the bargaining process in order to adjust for changes in the market demand. As the retailer withholds its superior forecast data and the market demand is still less predictable, the standard deviation of the manufacturer increases. In the numerical example the manufacturer predicts a demand of 110,000 including a forecasted drift of 10,000 and the demand 100,000 obtained in the bargain. Hence, the related standard deviation is calculated in the following way: $\sigma_{t+1} = D_{t+1} \cdot \sigma \cdot x^n$. With the resulting standard deviation of $\sigma = 41,250$ the demand interval is [68,750;151,250]. Since the drift itself is forecasted, deviations between the estimator and real figures can occur. Thus, in this model a real drift of 9000 units is set from period t to t+1 resulting in a more narrow interval of [76,300;141,700]. The same procedure is applied for the demands the manufacturer expects from the retailer in t-1 and t+1 for t and t+2 respectively and the retailer's market demand expectation in t+1 and t+2 for t+2 and t+3. The results are summarized in Table 4-1:

period	-1		0		1		2	
drift forecast drift real	10000 10000		10000 10000		10000 9000		10000 11000	
	mean	**std. dev.**	**mean**	**std. dev.**	**mean**	**std. dev.**	**mean**	**std. dev.**
Retailer / Manufacturer	90000		100000	30000	109000	32700	120000	36000
Manufacturer / Supplier	100000	37500	110000	41250	119000	44625		

Table 4-1. Demands and standard deviations for the numerical example

Beside the set-up of the demand and the corresponding standard deviations for all periods several other parameters of the model are fixed. Additionally, the prices for the products and materials are set. The prices, costs and values, which are valid for all models, are stated below in Table 4-2.

The table can be explained as follows: The retailer sells the finished product for 100 monetary units[40] at the market, while it buys the input for 70MU from the manufacturer. If the market demand is lower than expected, it is not able to sell the product with profit, since it is already too specified in its characteristics and thus the salvage value is set equal to zero. In this example, the retailer customizes the mobile phones by branding them for a cost of 10MU, e.g. usage of netlock[41], simlock[42] or labelling it with the provider logo. On the other hand, if the retailer is not able to serve the market demand it has to face penalty costs of 50MU per unit. These costs represent for instance contractual penalties or price guarantees. If Vodafone® is not able to fulfil the demand out of its own stock, it must either buy the phone somewhere else, e.g. on the spot market, or pay the price difference.

	Salvage values		*Production costs*	*Purchasing price*	*Sales price*	*Penalty price*
Supplier / Manufacturer	Supplier	Manufacturer	Manufacturer	Supplier	Manufacturer	Manufacturer
	19	20	15	25	70	25
Manufacturer / Retailer	Manufacturer	Retailer	Retailer	Manufacturer	Retailer	Retailer
	20	0	10	35	100	50

Table 4-2. Fixed Input Figures

However, the manufacturer buys its raw material, the displays, from the supplier for 35MU per unit. Beside that, it is able to salvage its output, namely the not branded and thus less specified mobile, for a higher price compared to the retailer on the open market, i.e. 28.5% of the output price, which equals to 20MU. The production costs for the manufacturer are set to 15MU. Additionally, the manufacturer faces costs of contractual penalty of 25MU, which occur in the case where the bargained amount of goods cannot be delivered to the retailer.

The last participant in this model, namely Sanyo® as the supplier of the mobile phone displays, is able to buy its input for 25MU. Furthermore, the supplier has a salvage value of 19MU, which equals to 76% of the purchasing price. This is a reasonable assumption since the product is rather unspecialized and thus the open market's willingness to pay for it is still considerably high.

Given all the assumptions mentioned above, the implications of demand uncertainty on the differently structured models will be shown in the following section.

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[40] In the following text abbreviated with MU
[41] The netlock disables the mobile's use of different net providers
[42] The simlock allows only for one user per mobile phone

4.2 Model without flexibility

First of all, the results of an inflexible model without any communication between the participants in the supply chain are analyzed. Every participant in the supply chain tries to maximize its profit and optimize its order and delivery policy individually without involving previous or following companies. The only information, which is exchanged, is the quantity the retailer or the manufacturer, respectively, estimated to be profit maximizing. That means that the manufacturer or supplier, respectively, only sees the demand and tries to fulfil the exact quantity. Due to that simple set-up unfavourable Demand Signal Processing often occurs, meaning that the company will often misinterpret the demand information. This represents the basic case in which the Bullwhip Effect occurs. The missing communication leads to imprecise estimations of future demands and as a consequence the amount of produced products often mismatches the real demand. On the one hand, this often results in costly out-of-stock situations, where the company has to face the penalty costs mentioned in the previous section. On the other hand, companies have to deal with excess inventory, which also destroys profits, since the salvage value often does not reach the purchasing costs, not to mention the price of sale. Using the demand set-up mentioned in the previous section the revenues and profits summarized in Table 4-3 and Table 4-4 can be calculated.

Retailer	w_0	$Q_{m/r,inf}$	Sales	Salvage	Production	Penalty	Purchase	*Profit*
period 2	70	116989	10408420.08	0.00	-1169885.38	-795789.96	-8189197.63	*253547.12*
period 1	70	106265	9454314.91	0.00	-1062645.88	-722842.55	-7438521.18	*230305.30*
period 0	70	97490	8673683.40	0.00	-974904.48	-663158.30	-6824331.36	*211289.26*
Manufacturer	w_0	$Q_{m/r,inf}$	Sales				Purchase	*Profit*
period 2	70	116989	8189197.63				-4094598.82	*4094598.82*
period 1	70	106265	7438521.18				-3719260.59	*3719260.59*
period 0	70	97490	6824331.36				-3412165.68	*3412165.68*

Table 4-3. Results of inflexible model: retailer / manufacturer

Manufacturer	w_0	$Q_{s/m,inf}$	Sales	Salvage	Production	Penalty	Purchasing	*Profit*
period 1	35	130306	7443280.82	479460.63	-1954584.22	-316685.42	-4560696.51	*1090775.30*
period 0	35	120451	6880343.62	443198.90	-1806758.52	-292734.42	-4215769.88	*1008279.69*
period -1	35	109501	6254857.83	402908.09	-1642507.75	-266122.20	-3832518.07	*916617.90*
Supplier	w_0	$Q_{s/m,inf}$	Sales				Purchasing	*Profit*
period 1	35	130306	4560696.51				-3257640.36	*1303056.14*
period 0	35	120451	4215769.88				-3011264.20	*1204505.68*
period -1	35	109501	3832518.07				-2737512.91	*1095005.16*

Table 4-4. Results of inflexible model: manufacturer / supplier

4.3 Model with flexibility

In contrast to the inflexible model mentioned above, this section will show an alternative and more flexible modelling approach, which is based on real options. Two different scenarios of the flexible models will be observed. The first model will be unconstrained and thus enable a perfect Stackelberg competition and the second one will allow for the different market powers within the supply chain.

4.3.1 Unconstrained model

In the unconstrained model, perfect Stackelberg competition between the particular participants on every step of the supply chain is assumed. In this case the dominant party anticipates the amount of goods ordered by the weaker one, depending on the prices chosen by the dominant. Based on this knowledge it will then maximize its expected profit function by setting its prices, i.e. the exercise price and the price of the options. The follower, i.e. the company with the weaker bargaining position, will adjust its orders to the given prices.
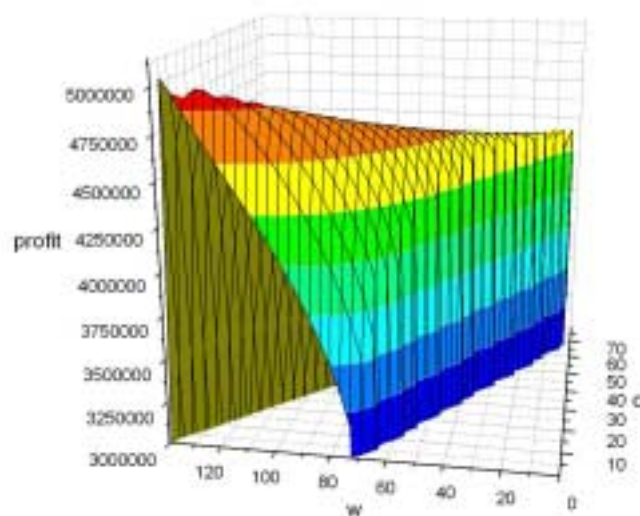
Figure 4-2. Area diagram manufacturer / retailer (unconstrained)

In the numerical example the retailer is assumed to be the company with the worse bargaining position on the first tier. Following the model description in chapter 3.3.2, the manufacturer sets the exercise and option price to $w_{m/r,u} = 139.9MU$ and $c_{m/r,u} = 0.0125MU$. Figure 4-2 shows as an example the manufacturer's profits in period t+2 depending on the choice of the exercise price w and the option price c. It can be observed that the profit increases with higher values for w and lower values for c.

The retailer as the follower in the Stackelberg competition adjusts its order quantities, both committed and optional, to the given prices. In period t+2 the retailer will order in the presented example $Q_{m/r.u} = 116,964$ directly and furthermore buy $q_{m/r,u} = 44,449$ options on additional products if necessary. The prices and quantities for period t and t+1 can be observed in Table 4-5. The option model thereby combines the advantages of push and pull production control, meaning that the precommitted quantity, as the push system, is cheaper to produce due to economies of scale and the optional quantity, as the pull system, gives the necessary flexibility to the firm.

Period	w_0	Manufacturer's decision		Retailer's decision		
		$c_{m/r,u}$	$W_{m/r,u}$	$Q_{m/r,u}$	$q_{m/r,u}$	Q+q
period 2	70	0.0125	139.9	116964	44449	161413
period 1	70	0.0125	139.9	106242	40374	146616
period 0	70	0.0125	139.9	97470	37041	134510

Table 4-5. Bargaining result manufacturer / retailer (unconstrained)

The associated revenues, costs, and profits for the retailer are given in Table 4-6 and those for the manufacturer are presented in 4-7.
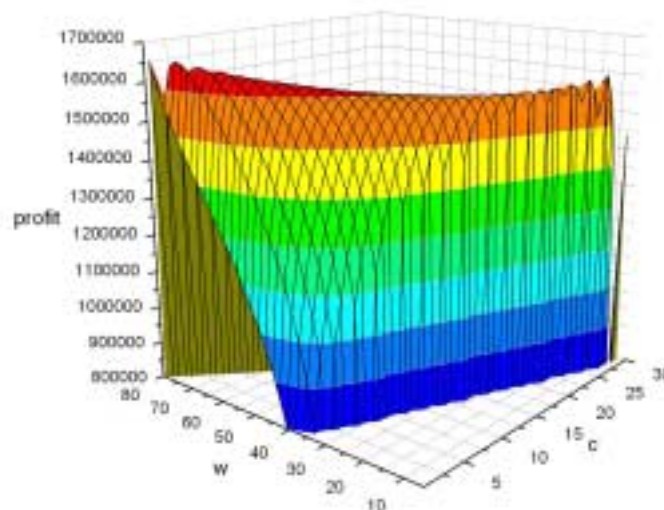
Figure 4-3. Area diagram supplier / manufacturer (unconstrained)

Retailer	Purchasing	Penalty	Option buying	Option exercise	Production	Sales	Salvage	Profit
period 2	-8187470.86	-111602.27	-555.61	-1916198.07	-1306607.82	11776795.46	0.00	254360.84
period 1	-7436952.69	-101372.06	-504.68	-1740546.58	-1186835.44	10697255.88	0.00	231044.43
period 0	-6822892.38	-93001.89	-463.01	-1596831.73	-1088839.85	9813996.22	0.00	211967.36

Table 4-6. Results retailer (unconstrained)

Manufacturer	Purchasing	Sales	Salvage	Option buying	Option exercise	*Profit*
period 2	-5649440.22	8187470.86	615035.92	555.61	1916198.07	*5069820.23*
period 1	-5131574.87	7436952.70	558657.62	504.68	1740546.58	*4605086.71*
period 0	-4707866.85	6822892.38	512529.93	463.01	1596831.73	*4224850.19*

Table 4-7. Results manufacturer leader (unconstrained)

On the second tier the manufacturer is the company, which has the worse bargaining position. As a time lag of one period is assumed, this case observes the time interval [t-1;t+1], that means that all computed figures are results of the expected supplier's demand in periods t until t+2. The supplier can set the prices and the manufacturer will adjust its quantities accordingly. Figure 4-3 shows the supplier's profits in period t+1 depending on the choice of the exercise price and the option price. The results for the price and quantity decisions between the supplier and the manufacturer are given in Table 4-8. Table 4-9 and Table 4-10 illustrate the associated revenues, costs, and profits.

Period	w_0	Supplier's decision		Manufacturer's decision		
		$c_{s/m,u}$	w	$Q_{s/m,u}$	$q_{s/m,u}$	Q+q
period 1	35	0.0025	79.975	130294	45895	176189
period 0	35	0.0025	79.975	120440	42424	162864
period -1	35	0.0025	79.975	109491	38567	148058

Table 4-8. Bargaining result supplier / manufacturer (unconstrained)

Manufacturer	Purchasing	Penalty	Option buying	Option ex.	Production	Sales	Salvage	*Profit*
period 1	-4560292.11	-51536.12	-114.74	-848582.24	-2113569.81	8185698.85	479321.98	*1090925.8*
period 0	-4215396.07	-47638.43	-106.06	-784403.76	-1953720.00	7566612.38	443070.74	*1008418.81*
period -1	-3832178.25	-43307.67	-96.42	-713094.32	-1776109.09	6878738.53	402791.58	*916744.37*

Table 4-9. Results manufacturer follower (unconstrained)

Supplier	Purchasing	Sales	Salvage	Option buying	Option exercise	*Profit*
period 1	-4404730.97	4560292.11	670407.1	114.74	848582.24	*1674665.23*
period 0	-4071600.05	4215396.07	619704.04	106.06	784403.76	*1548009.88*
period -1	-3701454.59	3832178.25	563367.31	96.42	713094.32	*1407281.71*

Table 4-10. Results supplier (unconstrained)

It instantly becomes apparent that the profit of the manufacturer (supplier) is relatively large compared to the one of the retailer (manufacturer). That is the case, since the manufacturer (supplier) is the dominant party in the business relation. In the following section a different model will be presented, which tries to balance out the profit distribution.

4.3.2 Constrained model

The model discussed in the previous section has one disadvantage. The "unfair" distribution of the profit generated by each of the two supply chain partners might complicate the business relations between them. The retailer (manufacturer) might lack an incentive to agree to the proposed option model. Especially if the market power of one of the participants in the deal is considerably higher, as can be assumed for the manufacturer, a set-up as mentioned above might appear questionable. To account for those differently allocated market powers, as it was already discussed in chapter 3.3.2, the constraining factors $a = 0.8$ for the relation between the retailer and the manufacturer and $b = 0.7$ for the one between the supplier and the manufacturer are introduced.

The reason for a being smaller than one, even though the manufacturer is assumed to inherit a lot of market power and is thereby being able to enforce good terms for itself, can be explained by the idea that the manufacturer wants to create better incentives for the retailer to think in a more holistic way. Since the manufacturer itself benefits from an accurate and maximized demand forecast coming from the retailer it might be valuable to forgo some of the profits in order to obtain a better relationship with the retailer. It is basically a trade-off between slightly less profits but therefore sustainable good business relations, which may pay off in the future.

The reason for b being smaller than one can be explained differently. Firstly, the market for the final product, in this case the cell phone displays, might be very small-sized, meaning that the supplier cannot afford to loose the manufacturer as a customer, because it will be hard to find another buyer of comparable size. Secondly, companies, which do business over a longer period of time, tend to adjust their factories on each other in different ways, meaning that they for instance synchronize their production, using compatible information systems like EDI[43] or XML[44] standards, and rely on a collaborative planning, forecasting and replenishment. Changes within those areas of the firm will most likely cause considerable high adjustment

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[43] EDI – Electronic Data Interchange; transfer of structured data based on predetermined standards between IT-systems

[44] XML – Extensible Markup Language; Meta-definition language, which defines basic format-rules for the exchange of data between companies

costs. Due to its good market position and high order quantities the manufacturer can probably find a new supplier more easily, than the supplier can find a new customer.
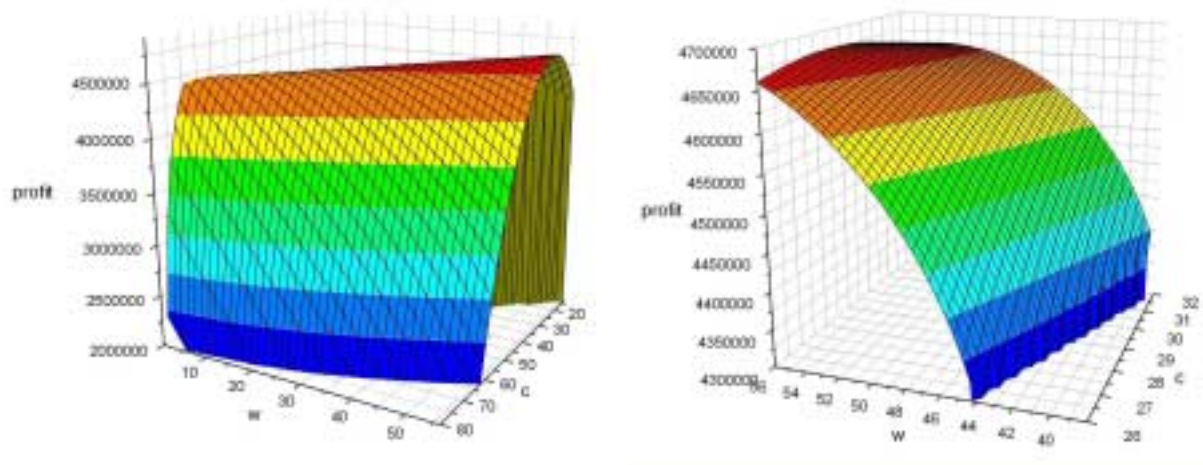
Figure 4-4. Area diagrams manufacturer / retailer constrained and detailed

Given the same basic inputs as used in the other two models, the following quantities and prices are obtained for the retailer and manufacturer as stated in Table 4-11 and for the manufacturer and supplier as shown in Table 4-12. Figure 4-4 hereby shows the profits of the manufacturer in the manufacturer-retailer game in period t+2 depending on the choice of the exercise price w and the option price c. It can be seen that the manufacturer will choose the highest possible exercise price w, which the constraint allows for, and that the corresponding option price c will be near to a value of 29.

Period	w_0	Manufacturer's decision		Retailer's decision		
		$c_{m/r,c}$	$w_{m/r,c}$	$Q_{m/r,c}$	$q_{m/r,c}$	Q+q
period 2	70	28.61	56	92367	42424	134790
period 1	70	28.61	56	83900	38535	122434
period 0	70	28.61	56	76972	35353	112325

Table 4-11. Bargaining result manufacturer / retailer (constrained)

Period	w_0	Supplier's decision		Manufacturer's decision		
		$c_{s/m,c}$	$w_{s/m,c}$	$Q_{s/m,c}$	$q_{s/m,c}$	Q+q
period 1	35	29.97	5.03	8249	122084	130333
period 0	35	29.97	5.03	7626	112850	120476
period -1	35	29.97	5.03	6932	102591	109524

Table 4-12. Bargaining result supplier / manufacturer (constrained)

Table 4-13 and Table 4-14 present the corresponding revenues, costs and profits on the retailer-manufacturer step, while Table 4-15 and Table 4-16 illustrate those for the manufacturer-supplier step.

Retailer	Purchasing	Penalty	Option buying	Option exercise	Production	Sales	Salvage	Profit
period 2	-6465658.22	-408024.13	-1213741.02	-1346798.36	-1164165.17	11183951.74	0,00	585564.85
period 1	-5872972.88	-370621.92	-1102481.43	-1223341.84	-1057450.03	10158756.17	0,00	531888.07
period 0	-5388048.52	-340020.11	-1011450.85	-1122331.97	-970137.64	9319959.79	0,00	487970.71

Table 4-13. Results retailer (constrained)

Manufacturer	Purchasing	Sales	Salvage	Option buying	Option ex.	Profit
period 2	-4717657.34	6465658.22	367473.86	1213741.02	1346798.36	4676014.12
period 1	-4285205.42	5872972.88	333788.76	1102481.43	1223341.84	4247379.49
period 0	-3931381.12	5388048.52	306228.22	1011450.85	1122331.97	3896678.43

Table 4-14. Results manufacturer leader (constrained)

Manufacturer	Purchasing	Penalty	Option buying	Option ex.	Production	Sales	Salvage	Profit
period 1	-288731.52	-316411.19	-3658868.68	-493623.87	-1595781.45	7444048.67	837.55	1091469.51
period 0	-266894.69	-292480.93	-3382147.52	-456290.97	-1475092.10	6881053.40	774.21	1008921.4
period -1	-242631.53	-265891.75	-3074679.56	-414809.97	-1340992.82	6255503.09	703.83	917201.27

Table 4-15. Results manufacturer follower (constrained)

Supplier	Purchasing	Sales	Salvage	Option buying	Option ex.	Profit
period 1	-3258326.18	288731.52	455004.72	3658868.68	493623.87	1637902.62
period 0	-3011898.15	266894.69	420592.6	3382147.52	456290.97	1514027.63
period -1	-2738089.23	242631.53	382356.91	3074679.57	414809.97	1376388.75

Table 4-16. Results supplier (constrained)

In contrast to the previous model, a drastic positive change in the profits for the retailer in the retailer-manufacturer game can be observed, while the changes in profit for the manufacturer are considerably moderate. The manufacturer in the manufacturer-supplier game, on the contrary, shows hardly any change in its profits, i.e. 916,744MU in the unconstrained case in period t-1 and 917,201MU in the constrained case. The fairly small profit growth can be explained by the behaviour of the supplier that occurs in case of a small difference between the supplier's purchasing price m_s and selling price w_0 and a high salvage price v_s. As already mentioned in chapter 3.3.2., the supplier gains the incentive to carry more demand risk itself, since the loss faced as a consequence of an unexpected low demand, due to excess stock, can be at least partly compensated by salvaging. It will therefore increase the option price c and reduce the exercise price w. Even though the supplier is constrained in one variable, namely in w, it can still reach an optimal point with the remaining flexibility offered by the option

price c, which enables it to exploit most of the profit and leaves the manufacturer again with a similar low profit result as in the unconstrained case. To reach a "fair" distribution of the profits the second variable, which provides the supplier with flexibility, i.e. the option price c, must also be restricted. Thus, the supplier will have to choose an optimum which leaves some of the additional profits gained by the option model to the manufacturer. Figure 4-5 shows the supplier's profits in period t+1 depending on the choice of the exercise price. One can see, that even if the global optimum can only be achieved with values for c and low values for w, a similar high profit can be reached with an option price c close to a value of 16.
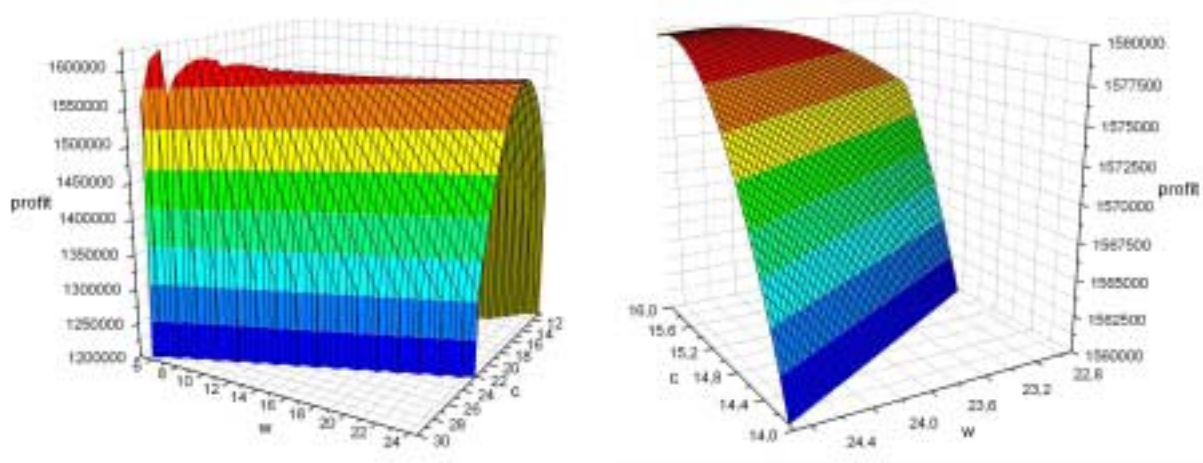

Figure 4-5. Area diagrams supplier / manufacturer constrained and detailed double-constrained

The results for the Stackelberg game with two constrained variables are given in Table 4-17, Table 4-18 and Table 4-19.

Period	w_0	Supplier's decision		Manufacturer's decision		
		$c_{s/m,c}$	$w_{s/m,c}$	$Q_{s/m,c}$	$q_{s/m,c}$	Q+q
period 1	35	15.748	24.5	91536	52978	144514
period 0	35	15.748	24.5	84613	48972	133584
period -1	35	15.748	24.5	76921	44520	121440

Table 4-17. Bargaining result supplier / manufacturer (add. constraint on c)

Manufacturer	Purchasing	Penalty	Option buying	Option ex.	Production	Sales	Salvage	*Profit*
period 1	-3203748.91	-195702.24	-834304.15	-659638.44	-1776895.51	7782033.73	145755.81	*1257500.3*
period 0	-2961448.57	-180901.23	-771205.51	-609749.82	-1642508.46	7193476.56	134732.26	*1162395.23*
period -1	-2692225.97	-164455.66	-701095.92	-554318.02	-1493189.51	6539524.14	122483.87	*1056722.94*

Table 4-18. Results manufacturer follower (add. constraint on c)

Supplier	Purchasing	Sales	Salvage	Option buying	Option ex.	Profit
period 1	-3612849.91	3203748.91	495031.61	834304.15	659638.44	1579873.2
period 0	-3339609.16	2961448.57	457592.25	771205.51	609749.82	1460386.99
period -1	-3036008.33	2692225.97	415992.95	701095.92	554318.02	1327624.53

Table 4-19. Results supplier (additional constraint on c)

An extended analysis and interpretation will follow in a later section. In the supplier-manufacturer game this thesis will primarily focus on the results with two constrained variables, since the single constrained case cannot distribute the profits adequately. In the manufacturer-retailer game however a single constraint is sufficient.

4.4 Model under full information

Even though a model under full information is impossible to find in real life, it is nevertheless interesting to observe it as a benchmark for the other models. It is assumed that every demand is known in advance and no uncertainty exists. That means, that every company on every step on the supply chain can forecast the right production amount, even if the forecaster has to anticipate several periods. Another definition for this model is simply a supply chain without the occurrence of the Bullwhip Effect. The results for the participants in the supply chain on each step are given in Table 4-20 and Table 4-21.

Retailer	w_0	$Q_{m/r,int}$	Sales	Purchasing	Profit
period 2	70	120000	12000000	-8400000	3600000
period 1	70	109000	10900000	-7630000	3270000
period 0	70	100000	10000000	-7000000	3000000
Manufacturer	w_0	$Q_{m/r,int}$	Sales	Purchasing	Profit
period 2	70	120000	8400000	-4200000	4200000
period 1	70	109000	7630000	-3815000	3815000
period 0	70	100000	7000000	-3500000	3500000

Table 4-20. Results integrated Supply Chain manufacturer / retailer

Manufacturer	w_0	$Q_{s/m,int}$	Sales	Purchasing	Profit
period 1	35	120000	8400000	-4800000	3600000
period 0	35	109000	7630000	-4360000	3270000
period -1	35	100000	7000000	-4000000	3000000
Supplier	w_0	$Q_{s/m,int}$	Sales	Purchasing	Profit
period 1	35	120000	4800000	-3000000	1800000
period 0	35	109000	4360000	-2725000	1635000
period -1	35	100000	4000000	-2500000	1500000

Table 4-21. Results integrated Supply Chain supplier / manufacturer

As it was expected, the profits considerably outnumber those of the other models. That is of course the result of non-existing stock-out situations and the connected costs. A further discussion will follow in the next section.

4.5 Analysis and Interpretation

The following section discusses the main results of the previously listed models. Firstly, a closer look on the out-of-stock and salvage quantities and the corresponding inflicted costs will be conducted. The section will continue with an analysis of the companies' overall profits followed by an observation of the risks and resulting process structure within the firms. Finally, all implications are brought together and interpreted coherently.

The inflexible model hereby acts as a base case, meaning that it will set the lower boundaries for the profits. As already mentioned in chapter 3.3.1, this is the case, where the Bullwhip Effect typically carries most weight, in the sense that the costs induced by stock-out and excess stock situations are expected to outnumber those of the other models. The missing linkages between the supply chain partners lead to misinterpretation of the expected demand and its uncertainty. The failure especially becomes apparent in the out-of stock quantities, as illustrated in Table 4-22. The results in the flexible constrained case for the manufacturer in the supplier-manufacturer game are separated in two numbers within the table. While the first figure represents the case, where both variables, the option price c and as well as the exercise w, are constrained, the number in brackets is the result of only one constraint, i.e. a constraint on w. The single-constrained case will not be discussed in detail and should only show the oddity of the results in this case.

Model	inflexible	flexible unconstrained	flexible constrained	integrated
Retailer				
period 2	15916	2232	8160	0
period 1	14457	2027	7412	0
period 0	13263	1860	6800	0
Manufacturer				
period 1	12667	2061	7828 (12556)	0
period 0	11709	1906	7236 (11699)	0
period -1	10645	1732	6578 (10636)	0

Table 4-22. Out-of-stock quantities

In the inflexible model, where there is hardly any coordination between the two supply chain partners, the quantity is by far the highest, while it diminishes considerably with the degree of integration used in the bargaining process. Thus, the out-of-stock quantity of the retailer in the inflexible case is approximately seven times higher, for the manufacturer even more than eight times higher, than in the flexible unconstrained case. The deviation can be explained by the option model used. The retailer and the manufacturer, respectively, benefit as the particular purchaser from the flexibility offered by the option, namely that they are able to reorder a specific amount of the product at a later point in time. What still needs explanation are the results of the flexible constrained model. Even though the quantities are still considerably smaller than those of the inflexible case, they exceed those of the unconstrained flexible case. The reason for that is that in the totally unconstrained model the manufacturer (supplier) is willing to share some of the demand risk faced by the retailer (manufacturer). The manufacturer's respectively supplier's incentive to face that amount of risk is an increase of its profits. A discussion on that subject will follow further down in this section. As constraints are implemented in the decision problem, the profits of the supplier and manufacturer, respectively, would shrink under the same price settings. Therefore, they will share a lower amount of demand risk, which leaves again more risk to the ordering party. As a consequence of the increased risk taking by the ordering party, the out-of-stock quantities will also rise, leading to the results observable in Table 4-22. The integrated model thereby acts as a benchmark model, since it assumes that all demands are certain, i.e. there are no uncertainties. It is reasonable that there are no more out-of-stock situations in this case.

Another interesting fact occurs, when you observe the development of the out-of-stock and the salvage quantities, given in Table 4-23, simultaneously.

	inflexible	flexible unconstrained	flexible constrained	integrated
Retailer				
period 2	12904	12893	4577	0
period 1	11721	11711	4157	0
period 0	10754	10744	3814	0
Manufacturer				
period 1	23973	23966	7288 (42)	0
period 0	22160	22154	6737 (39)	0
period -1	20145	20140	6124 (35)	0

Table 4-23. Salvage quantities

An increase in both, the out-of-stock as well as the salvage quantities, would be expected with rising uncertainties. Unfortunately, a view on the quantities for the retailer in period t and the manufacturer in period t-1 reveals that this is not the case. Both companies face the same expected demand in those periods, namely 100,000, but they differ in their standard deviations, which are 30,000 for the retailer and 37,500 for the manufacturer decision (see Table 4-1). The explanation for that is that in this example salvaging is always cheaper for the companies than running out-of-stock, which means they will decrease the probability of running out-of-stock by increasing the probability of having excess stock. In the example for the inflexible case this means, that even though the absolute quantity of either out-of-stock or excess situations increases with the higher uncertainty from approximately 24,000 for the retailer in period t to 31,000 for the manufacturer in period t-1, the out-of-stock quantity for the manufacturer is lower than that for the retailer, due to the shifting within the quantity distribution to salvage situations. This effect is even amplified in the case of the flexible unconstrained model, which enables the retailer and manufacturer, respectively, to even better shift away its risk from out-of-stock to salvage situations. By imposing the constraint, the advantage mentioned in the previous sentence is considerably reduced and thus the risk can not be shifted away that easily. As a direct consequence the retailer (manufacturer) will lower the overall quantity it orders from the manufacturer (supplier), compared to the unconstrained model, in order to reduce the costs it has to bear. In the integrated model salvaging does not occur for the same reason as in the out-of-stock case.

A comparison of the ratios between out-of-stock and excess related quantities, in period t for the retailer and t-1 for the manufacturer, points out the utility of the option model to reduce the downsides of the Bullwhip Effect. The following ratios are calculated with the numbers from Table 4-22 and Table 4-23. A ratio of 1:0.81 (1:1.89) for the inflexible model, 1:5.78 (1:11.63) for the unconstrained flexible model and 1:0.56 (1:0.93) for the constrained flexible model has been obtained for the retailer (manufacturer). This clearly shows the expected result that the companies are most successful in shifting the risk to salvage situations in the unconstrained flexible model, while the ratio, and thus the capability to shift from out-of-stock to salvage situation, in the constrained flexible model lies beneath the other two. But since the overall quantity in the constrained model is adjusted accordingly, it still outperforms the inflexible one, if you observe the accumulated costs for out-of-stock and excess situations. The overall costs for the two effects are given in Table 4-24.

Total	inflexible	flexible unconstrained	flexible constrained	integrated
Retailer				
period 2	3290673	1237305	1544462	0
period 1	2989028	1123885	1402887	0
period 0	2742228	1031087	1287052	0
Manufacturer				
period 1	1563000	555329	852985 (1202991)	0
period 0	1444790	513329	788474 (1112008)	0
period -1	1313445	466663	716794 (1010917)	0

Table 4-24. Absolute costs of out-of-stock and excess situations

The relative costs, i.e. costs per unit, of out-of-stock situations are defined as the sum of the market price and the penalty costs, since whenever the company runs out of stock it not only looses the opportunity to sell that particular good, i.e. earning the market price, but also pays a contractual penalty for not being able to serve the demand. In this example, out-of-stock costs of 150MU for the retailer and 95MU for the manufacturer are obtained. Furthermore, the salvage costs are defined as the difference between the purchasing and salvage price, i.e. 70MU for the retailer and 15MU for the manufacturer.

In order to demonstrate the superiority of the real option approach a more detailed view on the profits generated in each model will be given in following paragraphs. As expected, the profits of the options models lie within the range spanned by the inflexible and the integrated model. That means that no firm using options is worse off than in the inflexible case and that all profits are also bounded by the profits generated in the integrated model by each company. Since the options models use a Stackelberg set-up, the same theory has to be applied to the integrated approach; otherwise it is possible that for instance the leader in the unconstrained case generates a higher profit, by exploiting the follower's profit, than it could in an integrated model without the usage of the Stackelberg model. The upper boundary for the leader's profit is therefore on each step set to the sum of the integrated profits of both participants, while that for the follower will never exceed the profit of the non-Stackelberg approach. The corresponding figures are stated in Table 4-20 and Table 4-21.

An interesting observation is that the retailer's (manufacturer's) profit in the first observed period – that is period t for the retailer and period t-1 for the manufacturer – in the unconstrained case, i.e. 211,967MU (916,744MU), is almost as high as in the inflexible model, i.e. 211,289MU (916,618MU). The reason for the fairly small difference lies in the Stackelberg game. Since the manufacturer (supplier) is the leader in the game, it can choose

its prices in order to exploit as much profit from the follower as possible. Basically, the leader will thus improve the ratio, which it will get of the overall profit. Since the total profit, which is defined as the sum of the profits of the particular bargaining supply chain partners, increase from 3,623,454MU to 4,436,818MU for the first observed period, on the first step in the supply chain, and from 2,011,623MU to 2,324,026MU, on the second step, under the usage of the unconstrained option approach, the retailer (manufacturer) can uphold its profit, even though its absolute ratio of the total profits sinks. The total profits are stated in Table 4-25.

Total Profit	inflexible	flexible unconstrained	flexible constrained	integrated
Manufacturer / Retailer				
period 2	4348145.93	5324181.07	5261578.97	7800000
period 1	3949565.89	4836131.14	4779267.56	7085000
period 0	3623454.94	4436817.56	4384649.14	6500000
Supplier / Manufacturer				
period 1	2393831.45	2765591.03	2837373.49 (2729372.13)	5400000
period 0	2212785.37	2556428.69	2622782.22 (2522949.03)	4905000
period -1	2011623.06	2324026.08	2384347.47 (2293590.03)	4500000

Table 4-25. Total profits

While the Stackelberg leader will always loose some profits, if the optimization process is constrained, the follower will always benefit from it. In fact, in some cases the total profit will even increase with implementation of constraints. This is for instance the case for the supplier-manufacturer competition, where the gains of the manufacturer outnumber the losses of the supplier.

The previous paragraphs mainly focuses on the reduction of costs to explain the increase in profits, but it should be kept in mind that there is always a second component, which has a significant impact on the profits, namely the revenues. Since the prices, except for the exercise and option prices, are not changed throughout the model, the increase in sales revenues must have a different source. As revenue is defined as the multiplication of price and quantity it is necessary to have a closer look on the development of the order quantities. A comparison of the $Q_{m/r,inf}$ given in Table 4-3 with the committed quantities $Q_{m/r,u}$ given in Table 4-5 reveals that the retailer will choose almost the same amount of fixed quantity, meaning that the manufacturer can at least sell the amount of $Q_{m/r,u}$ in both cases. For example in period t the retailer buys 97,490 products in the case of the inflexible model, while it commits itself to a quantity of 97,470 products in the unconstrained flexible case. Thus, the additional revenues can only be caused by the option purchased on top of the committed

quantity. In the example the retailer will therefore purchase 37,041 options, which will increase the manufacturer's profit by the sum of the option purchased and the amount of options exercised. The retailer would also benefit of the increased amount of products it can put up for sale, but since the manufacturer can choose the option and exercise prices as the Stackelberg leader, almost all the profit will be transferred to the dominant party. The same phenomenon can be observed between the supplier and the manufacturer.

It is questionable however, why the retailer (manufacturer) should increase its order quantity, even though the expected demand and the standard deviation stay the same. By ordering increased amounts of products the retailer (manufacturer) would normally increase its probability of excess stock at the end of the period. That is the point, where real options have their advantage. The retailer gets the opportunity to reorder products at a later point in time, but it is not committed to actually take the full amount, it purchased options on in advance. Thus the demand risk, which is normally carried by the receiving institution alone, is shared between the two bargaining parties. Since the non-option based orders, i.e. $Q_{m/r,inf}$ and $Q_{m/r,u}$, are almost equally-sized in the inflexible and the flexible unconstrained model, the base risk can assumed to be similar. The risk sharing becomes relevant for the purchasing of the additional options. By buying options the retailer (manufacturer) will take up financial risk, namely the risk that the options turn out to be worthless in the case of an unexpected low demand, i.e. the retailer (manufacturer) will loose the invested option price. In the unconstrained case of the Stackelberg competition the retailer (manufacturer) is not compensated with higher profits for the additional risk taking, which puts up one question. What are the retailer's (manufacturer's) incentives for such a deal? The opportunity to reorder assures a high customer service level by reducing the probability of out-of-stock situations. A higher customer service level is valuable for a firm for two reasons. Firstly, the firm does not loose customers and thus revenues, and secondly, if the customer service level outperforms those of their competitors, they might even increase their future demands.

It is not very unlikely though that the increase in customer service level is not enough of an incentive for the firm to agree to the model set-up mentioned in the previous paragraph. The constrained model approach can pose a solution to that problem. Within the constrained model the profits are balanced out more even and thus they represent an incentive for the retailer to take up the financial risk imposed by the options. It has to be kept in mind though that the financial risk connected to the options will be higher in this case, since the option

prices are fairly high as a consequence of the manufacturer's (supplier's) adjustment to the new situation.

The real advantage of the modelling approach with flexible contracts can be seen in the business and financial structure of each company. As already stated above the inflexible model is considered to be the base case for the observation, meaning that it is the model, where the most demand deviations in connection to the Bullwhip Effect, for instance due to unfavourable Demand Signal Processing, occur.

Companies, which use either the inflexible or the flexible model for their order processing, will try to configure their value-added processes in an adjustable manner to satisfy the deviating demand. However, due to its advanced demand anticipation methods, firms that use the real option approach can reach a better set-up in their processes, which itself allow for a level of flexibility. Adjustable processes means that the company will already incorporate overcapacities in its factors of production, namely input of labour and machines, which enables the firm to align the product development process to the real demand. Furthermore, companies often make use of logistic service providers like carriers in order to react on sudden deviations from its forecasts.

Flexible working contracts allow the company to increase or decrease the working hours and thus the corresponding wages of its employees. Overtime hours are thereby often more expensive than regular ones. Contracts of temporary employment are another good example of how companies achieve such flexibility, but also carry higher costs for the firm. Unfortunately, temporary employment agencies give only limited access to a qualified working pool and thus fixed working contracts are sometimes preferred and necessary. The advanced demand anticipation methods mentioned above give the firm a smaller or at least more stable range of uncertainty it has to plan for. That means that it can reach the more optimized choice between overtime hours and its corresponding costs and temporary employment contracts. A firm using inflexible contracts might have underestimated the real demand deviations and accordingly has to adjust its labour capacities at a later point in time. Firstly, the level of qualification on the market of temporary employment might not satisfy the demands of the firm, forcing it to use fixed contracts to gain the necessary qualification. That will of course raise the labour costs. Secondly, the firm, which lacks exact demand deviations forecasts, will have to design the fixed working contracts in a more flexible

manner, meaning that it must compensate the inferior forecasts with a higher degree of flexibility within the working contracts. That will increase the costs for overtime hours, not to mention the additional personnel, that the company might be forced to hire, when the working hour demand exceed the maximal possible overtime hours. Finally, the firm using inflexible contracts has to face higher costs in case of an unexpected low demand. While a company, which uses the real option approach, will design contracts that will enable it to easily reduce personnel, even if that means paying slightly higher wages, the inflexible firm has to deal with either continuing wage expenses or severance payments. The above mentioned discussion can be supported by the observations of the numerical example. The absolute order quantities in the flexible case, which are defined as the sum of Q and q, are always higher than the committed quantity Q in the inflexible model. Since the supplier (manufacturer) always has to be able to fulfil the full demand, either committed or optional, it will hold a higher level of capacity than the company in the inflexible case. Thus, it has the advantage of already including the excess capacity in its contract design in contrast to the inflexible firm, which has to react more spontaneously.

Reconfigurable Manufacturing Systems[45] are often used to deal with deviating demand in the production. Even though flexible machines usually impose higher fixed costs, they normally have reduced set-up costs and times, which thus reduce the overall costs a company has to face under high demand fluctuations. Basically, the following discussion is similar to the personnel discussion mentioned in the previous paragraph. The firm using the real option approach can better optimize its machines in terms of capacity and flexibility beforehand. If the real demand should deviate from the expected, it can easily adjust the systems and still reach optimized lot sizes and cost structures after taking set-up costs and times in consideration. On the contrary, the inflexible firm might have to deal with the situation, in which its machines are not optimally adjusted to the real demand risk, meaning that it must eventually face suboptimal lot sizes and cost structures or in a worst case scenario even has to buy new machines.

The same reasoning can also be applied for the transportation costs. The flexible firm will hold higher overcapacities in order to be able to adjust accordingly if necessary, while the

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[45] Reconfigurable Manufacturing Systems (RMS) can simultaneously manufacture a large variety of product types in unpredictable quantities while maintaining mass production efficiency; Du, Jiao and Jiao, p. 1202 [2006]

inflexible will have to face considerably higher transportation fees for additional not in advanced planned shipments. In contrast to the two other cost factors explained above, the here mentioned problem can more easily be mitigated by using logistic service providers, which charge a relatively constant fee for transportation. The lower costs are achieved by economies of scale, since logistic service providers work for different firms and thus assure a high degree of utilization.

As shown above, flexible contracts influence the business structure and financing in many different ways. The main focus was so far the observation of the companies' cash flows under flexibility and inflexibility, i.e. the possible usage of option contracts. It became obvious that flexible contracts will never reduce profits, but will rather always have a positive influence on them. Depending on the choice of either an unconstrained or a constrained flexible contract the increased profits were differently distributed between the supply chain partners, but it was argued that nobody will be worse off than in the inflexible case. The increased profits are a result of increased amount of risk exposure, which is differently distributed among the supply chain partners. The retailer (manufacturer) increases its risk exposure by taking up the additional financial risk incorporated by the options to reorder, while the manufacturer (supplier) increases its risk by taking up the demand risk of the additional produced, i.e. option based, goods. It was also shown that the order quantities in the flexible model deviate from those in the inflexible model and that they influence the labour, machine and transportation factors differently.

The increase of free cash flows in the real option approach enables the firm to act in a more flexible manner. Firstly, it will have more excess cash, which it can use to conduct profitable investments within and outside the company and thus strengthen its future performance. If the firm is able to hold or enlarge its free cash flow to firm in the long run it can thereby increase the company's market value. Secondly, the higher free cash flow to firm enables the company to pay out increased dividends and other premiums, on the one hand, and to reduce potential liabilities, on the other hand. While the former payment can show the firm's believe in its own future ability to create value and thus can lead to a higher market value, the latter indicates the company's solvency, thus becoming a more favourable debtor, which also results in better credit conditions.

In contrast to the positive influence of the increased cash flows the company also has to deal with a higher risk exposure in the real option approach, as explained above, which influences for instance the company's cost of equity and cost of debt. Both stakeholders, namely the shareholders and the creditors, will demand a higher return on the money, which they put into the firm. Thus, the weighted average costs of capital will increase with the amount of risk taken by the company. Since the weighted average costs of capital are used to discount the expected future profits to calculate the firm's market value, the higher risk will have a negative impact on the company's share value.

The higher quantities handled in the real option model lead to an increased asset base compared to the inflexible case. Since asset values are often used as collateral for creditors, the strengthened asset base increases the willingness of the creditors to invest money into the firm and therefore reduce the costs of debt. Even though it was shown that the real option approach can have some negative impact on the firm value, due to the company's increased risk exposure, the authors believe that the positive effects, namely the drastic increase in profits and the improvement in customer service levels, will overcompensate its drawbacks. Thus, it makes the real option approach a valuable tool to reduce the costs, which are induced by the Bullwhip Effect.

4.6 Improvements and Criticism

Even though the chosen option approach poses promising results to address the problems inflected by the Bullwhip Effect, there is still space for criticism and enhancements. The simultaneous usage of reorder options and return options, i.e. a combination of call and put options, could enable the follower to hedge not only against out-of-stock situation, but also against excess stock. Thus, the company could decrease the amount of demand uncertainty it has to face and could thereby reduce its costs. It would therefore be a valuable improvement to the model.

Another drawback in the author's model can be seen in the way it handles the Bullwhip Effect. Instead of reducing the amplification of the demand distortions within the supply chain, it rather balances out the risk exposure between the supply chain partners and thus leads each company to a favourable financial position by lowering the costs they have to face. Thus, only the costs of the Bullwhip Effect are mitigated, but not the effect itself. The leader

will still have to produce the full amount of products. A solution could be seen in reservation options contracts, but as already discussed in chapter 3.2 the applicability depends on the extent of the demand fluctuations. The manufacturing company could thus defer the production of a certain amount of products, until it gains better knowledge of the real demand it has to deal with. That would reduce the probability of excess stock situation for the manufacturer and the corresponding cost would decrease accordingly.

The assumption that all price information between two supply chain partners is distributed equally tends also to be unrealistic in real life situations. Çinar and Bilgiç (2005, pp. 24-42) present a model approach with asymmetric information concerning the production price *h*. It is assumed that the leader only knows the probability distribution of *h*, but not the exact value. Thus, the determination of the exercise price and the option price would be less optimal for the leader, representing a much more realistic illustration of the real world.

In order to keep the model and the calculations manageable all prices and lead times are assumed to be constant throughout all periods and the order costs are set to zero. That is of course not reasonable. An extension of the model could therefore be seen in the relaxation of that constraint. Especially in globally operating supply chain networks price changes due to for instance changes in exchange rates or foreign inflation rates can have a considerable strong impact on the firm's contract structure.

Furthermore, the usage of the spot market could also be seen as an improvement for the model. Spinler, Huchzermeier and Kleindorfer (2002) present a model how the follower can use the spot market as an option to fulfil additional demand and how the company could thus reduce its risk exposure to demand risk.

Another improvement could be seen in a model that also allows for more than one company on a single step in the supply chain, e.g. one supplier delivers to two manufacturers. That would have two major advantages. Firstly, the demand uncertainty for the supplier would decrease due to diversification. It would thus be able to reduce its risk exposure, which could also pose the opportunity to take up even more of the manufacturers' demand risks, leading to an even better total profit. Depending on the set-up of the option contracts that would either be beneficial for just the supplier or for all three companies. Secondly, the increased amount of firms on one tier in the supply chain would be the first step for the establishment of a

secondary market, in which the flexible contracts can be traded. First research has been conducted in that field of study by Wu, Kleindorfer and Zhang (2002) and Marquez and Blanchar (2004).

5 Conclusion

The findings of the simulation in chapter 4 show that it is possible to positively influence the costs of the Bullwhip Effect with a Real Option approach. Even though the option model does not succeed in lowering the Bullwhip Effect itself, it was demonstrated that the inflicted costs can be diminished considerably.

One way of achieving the cost reduction could be the use of the unconstrained option model, which in contrast to the inflexible model, allows for an adjustment of the order quantities if necessary. Thus, the selling companies within a supply chain can reach different levels of risk sharing with the buyer by choosing optimized exercise and option prices and find a set-up, which grants them optimal profits. It was also shown that the buyer might lack an incentive to accept the contractual set-up in the unconstrained case, since it might not feel sufficiently compensated for the increased amount of financial option risk it exposed to.

To account for this drawback, the authors of this thesis present a modified version of the option approach, which constrains the range in which the seller can set its prices in. Thus, a "fairer" profit distribution between the two business partners can be reached. The restrictions can even lead to an increase in the summed profits of both parties compared to the unconstrained case.

The additionally integrated model acts as a benchmark case for the other two models in the simulation. As expected, the profits obtained in the option models lie always between those of the inflexible and the integrated one. That means, that the company using option contracts will at all times be better off than in the inflexible case, but will never reach the almost utopian results of the integrated model.

Due to the reason that the profits in the flexible case are increasing or at least constant for both, for the seller as well as for the buyer, they are also willing to take up more risk. In fact those two variables have a correlative relationship, meaning that higher risks also enable higher profits and vice versa. It was shown in chapter 4 that the option approach often gets the companies to configure their processes in a more flexible manner, even if they have to face higher capital expenditures as a consequence. While the slightly increased asset base can act

as collateral for the firm and hence reduce the costs of capital, the increased risk exposure can have the exact opposite effect. Because of the overall growth in profits the firm value will most likely rise in spite of the potential negative effect on the costs of capital. It is the authors' believe that the increased customer service level and the gain in process flexibility is enough of a reason to consider the usage of Real Option Theory in supply chains to be an important contribution, which should be further developed in future literature.

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