Finding the Cost of Bullwhip Effect by the Use of Real Options in the Supply Chain

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***Abstract*— As we know real options established in many areas of the day-to-day business. Recent trends 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 paper 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.**

The 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. In this 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.

***Index Terms*— Supply Chain, Bullwhip Effect, Real Option Contracts, Stackelberg competition.**

I. INTRODUCTION

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.

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 new ways to attract their customers. They achieved it by differentiating their products by for instance offering additional services, versions or models. 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.

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, i.e. all information is known within the economy, you will hardly find the demand market to be 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. "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.". The missing coordination between the different tiers leads to misinterpretations of the real demand. 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 the overstating effect can be mitigated by either exercise, i.e. learning from the past, or by using techniques like real options theory.

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.

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II. 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.

III. SUPPLY CHAIN MANAGEMENT

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.

IV. BULLWHIP EFFECT

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. 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.

V. 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.

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 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.

VI. BEER DISTRIBUTION GAME

The most famous example to illustrate the Bullwhip Effect is the so-called "Beer Distribution Game", 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 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 services28, 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.

VII. 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.

VIII. 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 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.

IX. 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.

X. CONCLUSION

The findings 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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