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Faculteit Bedrijfseconomische Wetenschappen

master handelsingenieur

Masterthesis

Real option contracts in supply chains: a literature review

Alexander Ricour

Scriptie ingediend tot het behalen van de graad van master handelsingenieur, afstudeerrichting operationeel management en logistiek

PROMOTOR :

Prof. dr. Inneke VAN NIEUWENHUYSE

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Real option contracts in supply chains: a literature review

Alexander Ricour
Business Engineering
Faculty of Business Economics, Hasselt University

The use of real option contracts in supply chains has increased over the years as more supply chain members are faced with demand uncertainty and production yield uncertainty. This paper provides a summary of the different choices of real option contracts available and how they work. Furthermore, we present a comprehensive overview of the available literature on real option contracts in a supply chain context. We define several characteristics in order to classify and group together the literature which focuses on similar option contract strategies and scenarios. Lastly, we present our conclusions based on the literature that was found and suggest opportunities where future research can fill in current gaps in the literature.

Keywords: real option contract, call option, put option, bidirectional option, demand uncertainty, production yield uncertainty, supply chain coordination, risk-averse, asymmetric information

1. Introduction

The increase in globalization and technological development has given businesses many opportunities and growth possibilities (Erixon, 2018). However, the business environment has also become increasingly competitive with a lot of uncertainty (Simangunsong, 2012). Uncertain demand, uncertain production yield and price fluctuations are common examples. These factors make matching supply and demand a difficult task, which can put heavy pressure on supply chains. To ensure that the optimal supply chain efficiency is realized, members of the supply chain need to align their incentives. The risks that accompany uncertainty need to be divided fairly between the different nodes of a supply chain. This is where contracts can play an important role to assist businesses in reaching their optimal performance within their supply chain. Different contracts exist that can fill this role, such as buy-back policies (Eppen & Iyer, 1997) or quantity flexibility contracts (Cachon & Lariviere, 2001). A third option which has been getting increasingly popular over the past years is option contracts. These contracts can help companies with risk management by adding a level of flexibility to their ordering strategy (Barnes-Schuster et al., 2002). The focus of this paper will be to put forth a comprehensive summary on (1) how

option contracts work, and which choices of option contracts are available, (2) which literature is available on the use of these contracts in supply chain management, and (3) where additional research is still needed.

An option contract has two distinct features: the option price (also known as the option premium) and the exercise price. The buyer of an option receives the right, but not the obligation, to buy or sell the underlying asset. The option price is the payment made by the buyer to the seller to obtain this right. If at a certain point in the future the buyer wishes to exercise the option, he will pay the seller the exercise price. Both the option price and exercise price have to be approved by both parties beforehand.

Different types of option contracts exist and can be distinguished. The most common kind is the call option. The holder of this option has the right, but not the obligation, to buy the underlying asset at the predetermined exercise price on a future date. If demand is higher than expected, the buyer can choose to exercise his call options to make sure he can meet the demand (Zhao et al., 2013). The flexibility that the call option contract provides helps companies deal with the risk that is associated with demand uncertainty. The put option can be seen as the opposite of the call option. The holder of a put option has the right, but not the obligation, to sell the underlying asset back to the supplier at the exercise price on a future date. If demand turns out to be lower than expected, the buyer can choose to exercise his put options. He then sells the underlying asset back to the seller of the put option at the predetermined exercise price. This helps prevent big losses for the buyer as he is not stuck with products he cannot sell on the market. Both call and put options can be categorized as unidirectional option contracts as the option only gives the right to either acquire more assets or sell the assets back to the supplier. A bidirectional option contract does not have this limitation. It is basically the combination of a call and put option, where the option gives the right to either buy an additional asset or sell a leftover asset. While this option gives the buyer the maximum amount of flexibility, it is more difficult to execute well in practice. A bidirectional option contract comes with more complexity, which not all option sellers are prepared to handle. Additionally, not much literature is available on bidirectional option contracts, as discussed in section 4 “Classification”.

The concept behind option contracts did not originate from the supply chain management field. Readers with some financial background or interest will know options as tools to hedge against risk when investing in financial instruments. However, this paper focuses solely on “real” options as opposed to financial options. “Real” options refer to options where the underlying asset is tangible. In the supply chain context the assets are mostly raw materials, (semi) finished goods or capacity. However, option contracts can also be used in service based supply chains. Furthermore, a real option is a contract between two parties. Both parties require an incentive to want to use an option contract. For the buyer, the biggest

advantage is the additional flexibility when placing an order. If demand uncertainty is a problem for the buyer, he can buy options from his supplier when demand is still uncertain. The moment the buyer feels like he has accurate demand information, he can choose to exercise a certain amount of options. Another advantage for the buyer is the protection against price fluctuations. The exercise price of the option is agreed upon before buying the option (Xu, 2010). For the seller of the option the main advantage is the option price he receives when an option is bought. Think of it as a non-refundable deposit: the seller thus collects a part of his revenue before any asset is sold. If options are bought but not exercised, the seller will still have received the option price. A second advantage for the seller is the additional information he has, he knows how many options he sold and thus can adjust his capacity planning accordingly (Zhao et al., 2013).

As mentioned before, the goal of option contracts is to make the total supply chain as efficient/profitable as possible. Additionally, both parties should achieve individual advantages for an option contract to be used in reality. An added bonus to using option contracts is that it can build trust and partnerships between members of a supply chain. Option contracts can be seen as a promise made between buyer and seller. The seller promises to the buyer to have at least as many assets (goods, capacity…) available as the options that were bought. On the other hand the buyer rewards that promise by paying the option price. Coordinating the supply chain by building lasting partnerships can have considerable benefits for all parties involved (Sahay, 2003).

Section 2 will explain in detail the methodology that was used find literature and select relevant publications. In section 3, we define classification characteristics that will be used to group similar studies together. Section 4 presents the total amount literature that was found and classifies it using the characteristics from section 3. Several studies will be shortly highlighted to show the impact (if there is any) of real option contracts on factors such as order quantities, risk management and expected profits. In section 5, we give our conclusions on the literature that was found and give suggestions where future research could be useful. Also in section 5, we acknowledge the people that helped create this paper. Section 6 is the appendix, which contains large tables that visualize and classify the literature we found. Lastly, the list of references is also located in section 6.

2. Methodology

This section will describe the search strategy that was used to find and select the literature on which this paper is built. We use the literature review by Cosemans (2018) as a starting point, and complement it by novel related work, published after 2018. The search strategy has remained the same and consists of four steps which will be discussed next.

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The first step was a general search in electronic databases such as Web of Science, ScienceDirect, EBSCOhost and Google Scholar. The following search terms were used to look for papers: “option contract”, “real option”, “call option”, “put option”, “bidirectional option”, “supply chain(s)”, “supply chain option(s)”, “logistics”. The initial search was done in 2018 and considered only articles published after 2000 in English-language journals. The new search looked specifically at papers published from 2018 to 2022. In the second step, we filter out the papers of suboptimal quality by only considering papers published in journals with a Q1 or Q2 ranking in the Operations Research and Management Science category of Web of Science in 2020. This ensures that we only use literature which is scientific, peer-reviewed and well structured. Conference proceedings, books and newspaper articles are also excluded. In the third step, the relevance of the papers is checked. The fourth step applies the ancestry approach; the references of selected papers are inspected to make sure that no relevant work is overlooked. Figure 1 shows the number of publications over the last 2 decades. A trend can be seen where the amount of research done on option contracts in a supply chain context has risen considerably in the last 5 years. The search for literature ended at the beginning of 2022, more literature could certainly be published throughout the remainder of 2022. Table 1 contains an overview of all the journals from which papers were selected.

This paper aims to provide a comprehensive overview of recent literature on the topic of real options in supply chains. The selected papers will be grouped together based on the specific features of the option that was researched. This will help researchers find articles related to their work, as well as show where literature is missing.

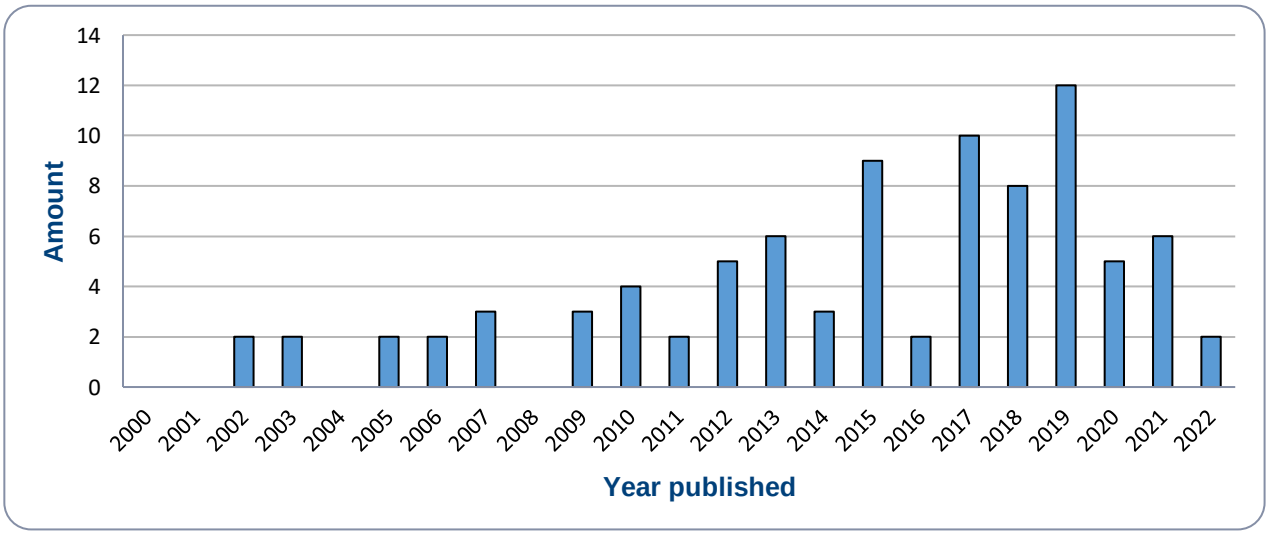

Figure 1: Number of publications per year

Table 1: journal overview

journal	#	Quartile in OR&MS category 2020
International Journal of Production Economics	23	Q1
European Journal of Operational Research	12	Q1
Omega	6	Q1
IIE Transactions	5	Q2
Annals of Operations Research	4	Q1
International Transactions in Operational Research	4	Q2
Computers and Industrial Engieering	4	Q2
Management Science	3	Q1
International Journal of Production Research	3	Q1
Operations Research	3	Q2
Production and Operations Management	3	Q2
Mathematics	2	Q1
Industrial Management and Data Systems	2	Q2
Manufacturing & Service Operations Management	2	Q2
Computers and Operations Research	1	Q1
IEEE Systems Journal	1	Q1
Journal of Manufacturing Systems	1	Q1
Journal of Cleaner production	1	Q1
Applied Mathematical Modelling	1	Q1
Expert Systems with Applications	1	Q1
Socio-Economic Planning Sciences	1	Q1
International Journal of Systems Science	1	Q2
OR Spectrum	1	Q2
IEEE Access	1	Q2
IEEE Transactions on Engeneering Management	1	Q2
Transportation Research Part E: Logistics and Transportation review	1	Q1

3. Classification characteristics

In this section the classification characteristics are discussed individually. In the following section(s) these are called on to provide the literature overview.

• **Option type** is a first important distinction between options. It describes what type of adjustment is allowed by the option contract. The two main categories are: uni- and bidirectional. Under unidirectional options we find call and put options. Bidirectional options are a combination of call and put options. In the tables in the following sections, we classify the studies as call (C), put (P) or bidirectional (B).

• **Contract strategy** explains if the option was used as the only means of acquiring an asset or if it was used in combination with another type of contract. In the first case, we refer to it as a pure strategy. We speak of a mixed strategy when an alternative exists for obtaining the asset. The spot market can

be one such alternative, here a player/party can procure or sell an asset at the current price. This price is referred to as the spot price. A second alternative we distinguish is the wholesale contract, also known as the fixed contract. As the name suggests, here the price is fixed and has been negotiated in advance.

• **# Players or parties** details if a certain study focuses on a single party (S) or multiple parties (M). The amount of parties that are considered in the study has an effect on the complexity of using options contracts and finding optimal solutions.

• **Relationship** between the above mentioned parties. Here we explain the roles of the parties, who is selling the options and who is buying them. Multiple sellers/buyers are a possibility.

• **Supply chain coordination** clarifies if a study focused on improving the total supply chain profit to the point where it is equal to the profit of the integrated supply chain.

• **# Periods** describes the amount of times an option can be used. In a single period (S) the option can be used a single time. In a multi period setting however, an option can be utilized in two or more consecutive periods.

• **Information** available between supply chain parties can differ. In case all parties have access to the same information we speak of symmetric (S) information. The opposite is asymmetric (A) information, this occurs whenever at least one member of the supply chain is missing crucial information for decision making.

• **Risk preference** describes the behavior of a player in the supply chain when risk is involved. Members of the same supply chain can have different risk tolerances and will act accordingly. In case a player has no regard for potential risk and solely seeks to maximize his expected profit, we refer to this as risk-neutrality (N). In reality being completely risk neutral is rare, most members are risk-averse (A). The degree to which they are risk-averse varies from member to member. The risk preference of players has an effect on how an option contract is set up, as well as the optimal situation.

• **Comparison** explains if the study compares one option contract to either another option contract or to a different/alternative contract.

4. Classification

In this section, the 88 selected articles will be classified using the characteristics described in section 2. The two most important characteristics for classification are option type and option strategy, as the combination of the two gives a clear view on the context of the study. Based on this logic, three main sections will follow; pure strategy (Section 4.1), mixed strategy (spot; Section 4.2) and mixed strategy (wholesale; Section 4.3). Each of these sections will begin by giving an overview of the amount of papers found for each of the different option types. It should be noted here already that most of the literature found relates to call options. A plausible explanation for this finding is that the call option has more realistic applications than the put option, while being more straightforward than the bidirectional option. Fig. 2 shows the amount of literature found for each type of option contract. Each section is accompanied by a table classifying all the relevant articles. In addition to this, some figures will be used throughout the text to visualize trends in the literature or results of studies. Within each main section, several subsections will be distinguished to discuss in more detail important characteristics such as: supply chain coordination (Section 4.1.1, Section 4.2.1, Section 4.3.1), asymmetric information (Section 4.1.2, Section 4.2.2, Section 4.3.2) and risk preference (Section 4.1.3, Section 4.2.3, Section 4.3.3).

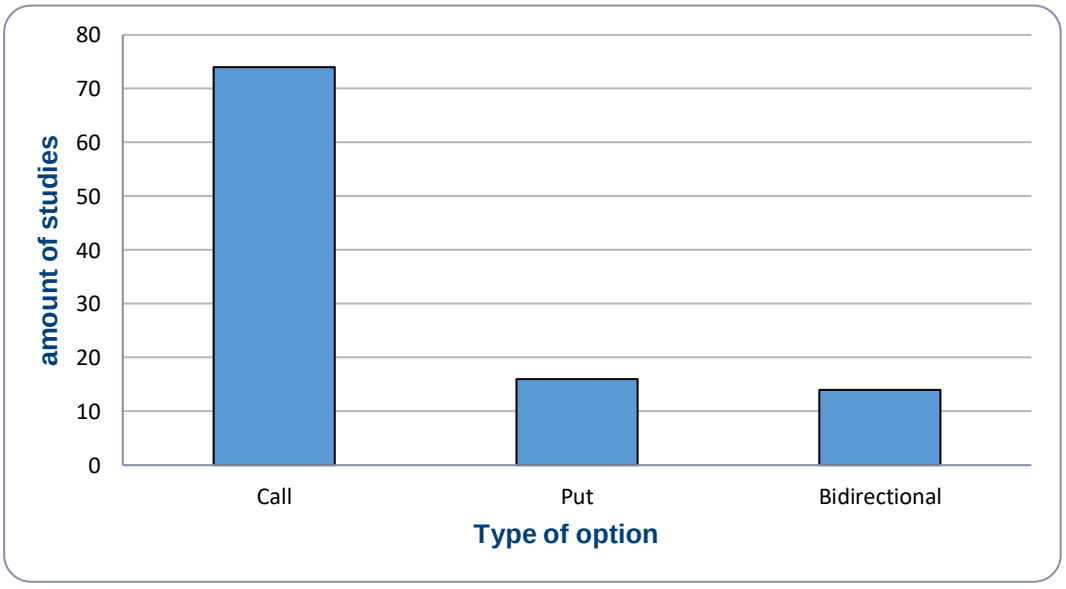

Figure 2: Amount of studies on different option types

4.1 Pure strategy

In this section, table 2 will be discussed. This is a summary of all the selected papers that study pure option contracts, classified using the before mentioned characteristics. A total of 22 publications were

found in quality journals, ranging from 2007 to 2022. All the articles focus on call options. This is no coincidence since a put option (or bidirectional option) makes little sense in a pure setting. Offering a put option, gives the buyer the right to sell the asset back to the seller, this implies that the buyer already purchased the asset at an earlier point in time via a different contract, which is not in line with our definition of a pure strategy. The majority of papers found examine the call option in a two-echelon supply chain, where one upstream party offers the options for sale and one downstream party buys the options. The sellers are usually the suppliers or manufacturers in the supply chain. The buyers are mostly manufacturers or retailers. Settings where there are multiple option sellers have been studied only a handful of times. Shamsi et al. (2018) consider two suppliers, where the option buyer will make a distinction between the main supplier and the backup supplier. Martinez-de-Albeniz & Simchi-Levi (2009) look at a situation with multiple suppliers, where each one presents the buyer with an option contract. They find that this leads to cluster behavior, where suppliers that offer similar option contracts will form smaller groups and compete with each other in order to provide the buyer with supply capacity (goods).

The majority of the papers (19 out of 22) study the impact of the option contract on all parties involved in their supply chain model. This seems logical, as the option contract remains a contract between different members and all those members need to gain some sort of advantage from using the option contract. Wang and Chen (2015), Keyvanloo et al. (2015) and Shaban (2021) are the exceptions, they solely focus on the optimal decisions of the option buyer. Nearly all papers found relate to a context where the bought options can only be used for a single period. However, there exist situations where the supplier cannot easily change his output capacity and he may force the option buyer to buy a certain amount of options that can be used to over multiple periods (Keyvanloo et al., 2015). Multi-period models for option contracts could be useful to study in that context. In the next three subsections we will look at three important characteristics: supply chain coordination, asymmetric information and risk preference.

4.1.1 Supply chain coordination

In the context of a pure strategy, 12 publications study if the option contract can coordinate the supply chain. This means that the total supply chain profit is equal to that of the integrated supply chain. In an integrated supply chain, the communication between members is at such a level that information can be shared between them effortlessly in order to have optimal operations. In a highly technological and global business environment, supply chain coordination seems to be an increasingly more important factor for companies to take into account. The literature supports this claim, as most papers from 2016 onwards

investigate the impact of the option contract on supply chain coordination.

Zhao et al. (2010) put forth a study in which they use the standard wholesale price mechanism as a benchmark to develop an option contract model. By the wholesale price mechanism we mean that a downstream party, let us take a retailer, places an order for a certain amount of units at the wholesale price with an upstream party (supplier). The order is usually placed some time in advance of the retailer's selling period and the order quantity cannot be adjusted at a later time. Zhao et al. (2010) mention that the wholesale price mechanism is commonly adopted in manufacturer-retailer supply chains, but that this can lead to conflicts of interest between the retailer and the manufacturer. When confronted with uncertain demand, a retailer craves order flexibility, as he hopes to avoid excessive inventory costs. A manufacturer, on the other hand, wants the retailer to place full orders as soon as possible, in order to hedge against the risk of over- and underproduction. Using call option contracts, the researchers look to coordinate the supply chain. For the supply chain to be coordinated, it needs to achieve the system-wide optimal expected profit. Viewing the supply chain as a single centralized entity allows them to derive the system-wide optimal expected profit, along with the optimal production quantity Q. In doing so they find two conditions for the exercise price and the option price: (i) the exercise price negatively correlates with the option price, and (ii) an increase in the option price by a single unit will induce a decrease in the exercise price by an amount larger than 1. This seems logical as the retailer would pay a larger amount of money in advance to reserve the asset (option price), so he expects to pay a slightly lower total price. They add that not all combinations of option price and exercise price that coordinate the supply chain are feasible, as some of those contracts may not be favorable for one member. Fig.2 demonstrates this visually. Without supply chain coordination, the manufacturers' profit is π_{wm} and the retailers profit is π_{wr}. So while all the points on the D-E line coordinate the supply chain, only the points on the B-C line are feasible as none of members are worse of and at least one member is better off. This concept is called *pareto improvement*. They further conclude that in the wholesale price mechanism the retailer is likely to order less than the optimal quantity Q due to *double marginalization*. This concept can be explained as follows: take two firms, one upstream and one downstream. In case both firms have market power, they both will set their price above the marginal cost. This in turn means that the retail price is larger than the optimal system-wide price, which leads to underproduction. In conclusion, when comparing the profit level of the wholesale price mechanism to the option contract mechanism, every option contract on the B-C line will coordinate the supply chain with pareto improvement.

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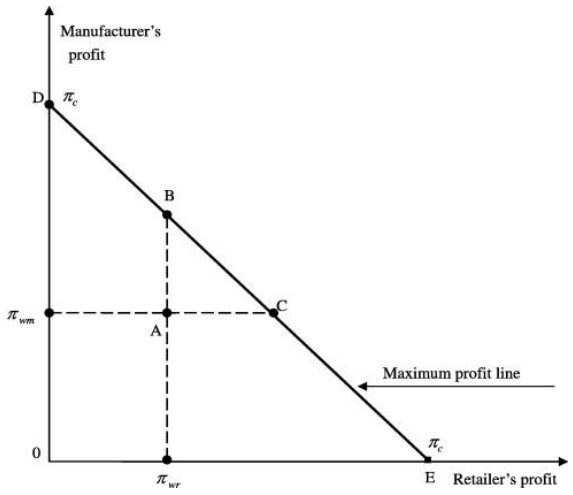

Fig.2.Allocations of the coordinating profit (Zhao et al., 2010)

Cai et al. (2016) examine the viability of a call option contract in a vendor managed inventory (VMI) supply chain. Cai et al. (2017) also look into this topic but add that the supply chain is faced with yield uncertainty. In a production setting, yield uncertainty is a phenomenon where the actual quantity produced is different from what was expected. We also speak of yield uncertainty when the quantity of goods ordered differs from the quantity received. A good example of this concept is the agricultural sector. Farmers have to take decisions concerning fertilization of their crops, but the outcome of those decisions is uncertain as factors such as diseases or the weather can heavily influence the amount of products they can eventually sell. Cai et al. (2017) consider a single supplier and single retailer, where the supplier is in charge of managing the inventory of the retailer. They look at several alternative contract strategies to try and improve the profitability of the VMI supply chain: a call option contract, a subsidy contract and a wholesale price contract. They conclude that the call option contract is the superior alternative as it coordinates the supply chain in all scenarios (deterministic demand, uncertain demand, replenishment tactic…) while being more easily applied in a VMI setting compared with a subsidy contract. This is because collaboration between supplier and retailer is an aspect that VMI and the option contract have in common.

Zhang et al. (2017) study a pure option contract strategy in different scenarios in the presence of a capital-constrained retailer. The retailer has access to either bank credit (BC) or trade credit (TC) to help finance his operation, alternatively he can choose not to use credit financing (NC). Lastly, they also look at a situation where the retailer is capital sufficient (CS). A fitting example is a supply chain that focuses on buying/selling relief material that can be used in case of a disaster. Consider a non-profit organisation

or a government entity that has to purchase relief material to prepare for disasters that could occur. As a disaster event is rather unlikely they would prefer to order solely using options instead of placing a wholesale order. Additionally, their available budget is often limited. They consider a single-period supply chain consisting of one manufacturer and one retailer and make several findings on which scenarios impact the ordering decisions and expected profit of the supply chain members and supply chain. Fig.3 shows that the scenario with trade credit (TC) has the highest supply chain profit and so at least partially coordinates the supply chain. This can be explained intuitively as under trade credit the retailer enjoys a risk-free interest rate, while under bank credit he pays the bank's interest rate which is higher than the risk-free interest rate. The amount of money payed to the bank in turn lowers the total supply chain profit. Additionally, under trade credit the retailer has an incentive to order a larger quantity as he does not carry the default risk. Mathematical computations find that this leads to a higher supply chain profit. Hua et al. (2019) study a similar setting to Zhang et al. (2017) and find that the supplier should finance the retailer with trade credit, at the risk-free interest rate, when the retailer is faced with bankruptcy risk. Feng et al. (2014) also focus on credit financing but in a mixed strategy context with an initial wholesale order.

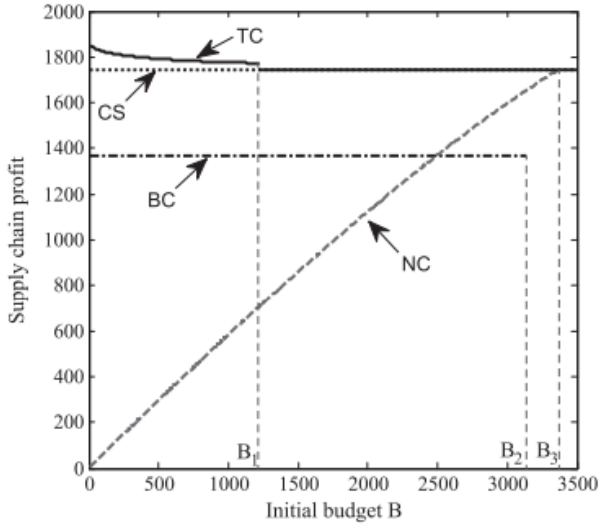

Fig.3.Supply chain profit under different scenarios (Zhang et al., 2017)

4.1.2 Asymmetric information

In order to make sound business decisions, companies need access to as much accurate information as possible. In an ideal world, members of a supply chain would have access to the same amount of information, this is called symmetric information. Most studies that focus on option contracts assume there is symmetric information (Zhao et al., 2016). In reality however, it is

uncommon that both parties (option seller and buyer) have access to the same information at the same time. Usually one party has more information on factors such as market demand and market price, because that party is closer to the end customer. In certain cases that information can give one party an advantage over the other. Three papers look into the call option setting with asymmetric information. Li et al. (2009) examine a situation where the retailer has additional information about the true price and demand on the market. They consider a Stackelberg game in which the supplier in this model is the leader, who is aware that he has less information compared to the retailer. The goal of the supplier is to create a contract which induces the retailer to make decisions that are also favorable for the supplier. Three contracts are considered and compared: (i) a forward contract (no options are included), where the retailer places his wholesale order in advance of his selling period and no adjustments can be made afterwards, (ii) a (call) option contract and (iii) the combination of the two. They conclude that in the presence of asymmetric information there is a place for both forward contracts and options contracts, depending on the kind of uncertainty that is present in the market. Forward contracts are useful when dealing with uncertainty in the retailer price (price the retailer charges his customers). The authors find that the profit of both supplier and retailer are independent of the retail price volatility, which is not the case when option, contracts are used. However, option contracts are more suited to deal with demand uncertainty.

A study by Fang & Whinston (2007) also deals with asymmetric information, but in a slightly different context. Their model considers a monopolistic supplier that has two customers, each with demand uncertainty. The customers can be one of two types: a type “A” customer or a type “B” customer. The willingness to pay for a single unit is larger for type “A” customers than for type “B” customers. This is something the supplier wants to take advantage of, the more units he can sell to type “A” customers the higher his revenue will be. The problem is that only the customer knows how much he is willing to pay for a unit, meaning only he knows his own type (asymmetric information). The supplier has limited capacity to produce units and does not know which customer is the type “A” customer. The researchers propose that the supplier use an option contract in order to discriminate between the different types of customers with the goal of maximizing his own expected revenue. The option is priced in such a way that only the type “A” customer will buy them, because when the capacity of the supplier is tight, that customer has the highest risk of suffering from demand losses. Fang & Whinston (2007) conclude that this option contract helps the monopolistic supplier in three ways: (i) the revenue of the supplier will increase as the type “A” customers will pay a higher unit price, (ii) the demand of customers with options is prioritized and (iii) when customers buy options, this reveal their type, which in turn allows the supplier to better adjust his capacity level.

Shamsi et al. (2018) present a study where they look into a relief supply chain, more specifically for purchasing vaccines to prevent the outbreak of diseases after a disaster event. Since it is unknown when and where a disaster event will occur, the demand for those vaccines/drugs is extremely uncertain. Option contracts seem to be a good fit for this kind of problem, as buying options will greatly reduce holding costs (of vaccines), while still being reliably on time in case a disaster occurs. Suppliers of the vaccines serve an important role in delivering the product efficiently and on time. At the same time, the suppliers themselves are a source of uncertainty as they too can be affected by a random disruption or event that stops their business from functioning. In order to try and prevent a situation where the supply of vaccines is jeopardized, the researchers suggest contracting with a back-up supplier in addition to the main supplier.

4.1.3 Risk preference

Much of the existing literature seems to focus on models with risk-neutral supply chain parties. As was the case with (a)symmetric information, risk-neutral parties are rather unrealistic. Being risk-averse means choosing less expected returns for a lower chance at a loss, so lowering the profit variance. Chen et al. (2014) and Zhao et al. (2010) have created models that can be adapted to fit risk-averse parties. In case both parties are risk-averse, the more risk-averse a party is, the smaller his share of the extra profit in a coordinated supply chain (Zhao et al., 2010).

Liu et al. (2020) study supply chain coordination in a supply chain where the supplier is risk neutral and the retailer is risk-averse. They look at two supply chain structures, one where the supplier is the leader in the supply chain, the other where the retailer is the leader. In case the retailer is the leader he will set the option price as low as possible. This makes that much of the stock-out and overproduction risk gets transferred to the supplier. Their results show that the risk-averse nature of the retailer lowers his order quantity. They also find that in the retailer led supply chain, the retailer will order more options, but the supplier's production quantity remains the same for both supply chain structures. Lastly, Liu et al. (2020) conclude that supply chain coordination is possible in both structures. Zhao et al. (2021) look at a supply chain consisting of a risk-neutral supplier and a risk-averse retailer where the retailer commits to a service requirement. Companies can promise a certain service level in order to promote sales, maintain their market share and keep their customers content. The results show that both the risk-averse nature of the retailer and the service requirement have an impact on order quantities and expected profit. They find that the use of a call option can improve performance for both parties and present the optimal decisions for both

4.2 Mixed strategy - spot market

In this subsection, the literature that focuses on using a mixed strategy of options and accessibility to the spot market will be classified and discussed. Where we previously looked at a pure strategy (a party of the supply chain can solely rely on using options to purchase or sell an underlying asset), here the spot market is added in the equation. The addition of this second market changes the overall structure/setting of the supply chain, as members have an extra option to buy/sell an asset outside of using option contracts. These two markets existing together will have an effect on how options are priced, and on optimal option order quantities. As was the case in the pure strategy section, we observe that solely the call option has been studied in a mixed strategy with access to the spot market. For an option buyer, the spot market is a second market where an asset can be purchased at a price that is unknown in advance. The buyer has no control on what that price will be, it can be either lower and higher than the option exercise price. Liu et al. (2014) is one notable exception to mention, they specify that the spot market price is fixed and always higher than the option exercise price. To justify this assumption, they present an example of an electronics market in China where hundreds of suppliers of electronics products sell under the same roof. In case one supplier runs out of stock for a specific product, he can buy it from a competing supplier at the spot price. The fact that he has the product immediately (very short lead time) and since he buys from a competitor, makes the spot price always higher than the option exercise price in their model. For this section, 30 publications were selected. The main difference in the research compared to the pure strategy research is the amount of papers that focus on more than two supply chain members. A total of 10 papers were found that look at either a situation with multiple option buyers or multiple option sellers.

A good baseline to start this subsection is provided by Wu et al. (2002). They put forward a single-period, 1-to-1 (seller-buyer) model using call options and the spot market in a supply chain focused on non-storable/perishable goods such as electric power or other services. Furthermore, their model doesn't take into account factors such as risk tolerance, asymmetric information or supply chain coordination, which makes the model relatively easy to understand but less applicable to realistic cases. They use a von Stackelberg game with the seller as the leader to model the situation. As the leader, the seller selects the option price and exercise price to maximize his own profit. The buyer in turn decides which is his optimal option order quantity. Both these decisions are made before the exact spot price on the market is known, only a probability distribution about the spot market is available. At a later time when the spot price is known, the buyer will decide the amount of options to exercise and the amount of assets to buy from the spot market. The paper focuses on the sellers' optimal option pricing strategy and the buyers' optimal reservation level and finds the following: (i) The buyer should reserve units based on an index, which shows different combinations of the option price and exercise price the seller could set. (ii) The

seller should set the option exercise price equal to his variable cost of producing a unit and use the option price to extract value from the buyer. This way the seller has ample funds to cover his capital costs of capacity, while the buyer has the option to purchase units at a cheaper price should the spot market price in the future be lower than the option exercise price. The second half of the paper by Wu et al. (2002) generalizes the results above to cases with multiple buyers and/or multiple sellers.

Zhao et al. (2013) take a similar approach in structuring their research. They present an option pricing scheme in a setting with the spot market starting with a single manufacturer and single retailer. Additional retailers are then added to the model to examine how it performs with multiple option buyers. In situations with multiple sellers, the buyer will behave optimally by choosing a subset of suppliers that offer the best option configuration (Wu & Kleindorfer, 2005). For option sellers the results are more interesting: when competing sellers are aware of the other bids the buyer may go for, it is optimal for each seller to set their exercise price equal to his real execution cost and make profit solely of the reservation fee/option price (Anderson et al. (2017)).

4.2.1 Supply chain coordination

Zhao et al. (2018) provide insights on the use of a call option in addition to the availability of the spot market. Fig.4 shows the timeline of their model. The retailer continues to gather demand information throughout stage 1 and decides at the beginning of stage 2 how many products to order by exercising his call options and how many products to order from the spot market. The model is compared to the pure call option setting and the pure spot market setting. They find that compared with the pure spot market, the call option contract in the mixed market can push both the manufacturer to produce more and the retailer to procure more. Hence, the mixed market can alleviate the effects of double marginalization, and subsequently improve the overall performance of the supply chain.

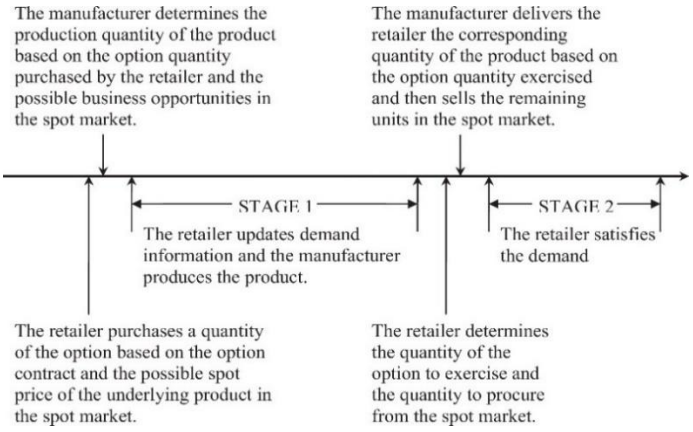

Figure 4: Timeline of the model with call options and the spot market (Zhao et al., 2018)

Wang et al. (2015) propose a strategy that involves the purchase of relief supplies immediately after a disaster (instant purchasing), as this would reduce operational cost. However, purchasing price and possible supply scarcity are high because of the time urgency. Alternatively, pre-purchasing relief supplies is a strategy that is characterized by a low purchase price. However, this approach entails a cost associated with the uncertainty of demand and an increase in inventory cost. To resolve this problem they introduce a supply chain methodology into humanitarian operations management by considering the system as a relief supply chain. Furthermore, they show that pre-purchasing relief supplies from a supplier with an option contract is superior in terms of expected to both pre-purchasing with a buyback contract and instant-purchasing with a return policy. The reason for this is the money saved on transportation costs. Relief supplies are ordered in large quantities, which makes for high transportation costs. The use of an option contract can lower the amount of transportation needed.

Luo & Chen (2017) investigate the role of option contracts in a random yield supply chain in the presence of a spot market. They consider a single-period supplier-manufacturer system where the supplier with random yield produces key components for the manufacturer and the manufacturer assembles/processes the components into end products to meet a deterministic market demand. They develop game models to derive the manufacturer's optimal ordering policy and the supplier's optimal production policy under two contract mechanisms (with and without option contracts). The results suggest that option contracts can coordinate the manufacturer's order quantity as well as the supplier's production quantity, and eventually achieve optimal supply chain performance, i.e. the random yield supply chain can be completely coordinated with option contracts in their proposed setting. However, Luo & Chen (2017) do note that a revenue sharing mechanism needs to be introduced in order to achieve pareto-improvement. Sharing the additional profit of the coordinated supply chain in such a way that both members are incentivised to want to use the option contract.

4.2.2 Asymmetric information

Only three papers were found that combine option contracts and the spot market with information asymmetry. Pei et al. (2011) study a situation where a supplier wishes to sell an industrial good to his existing business partner, a manufacturer. In most realistic cases, the manufacturer has access to multiple suppliers in the spot market, aside from his existing supplier. Each of those suppliers offer a similar product, with certain differences and varying degrees of quality. The more flexible the manufacturer's production process is in terms of product substitution, the less he is reliant on one specific supplier. In case the production process is not very flexible, the manufacturer is more reliant on the current existing supplier, as purchasing from the others suppliers brings down the overall value

of his product. The manufacturer knows his own valuation of the product of his existing supplier and that of the products from the suppliers in the spot market. The existing supplier has an information disadvantage as he does not know the willingness-to-pay of the manufacturer for his product and similar products. The authors compare different scenarios: (i) a standard wholesale contract versus option contracts, (ii) the differences in flat-price contracts versus volume-dependent contracts. Volume-dependent contracts can incorporate volume discounts or volume premia. A volume premium is the opposite of a volume discount, where the average price of the product increases when a higher quantity is purchased. This is sometimes done in practice by a buyer to incentivise his supplier to produce more. The study finds that depending on the discount rates of the buyer and the seller, different type of contracts are optimal. In case the buyer's discount rate is relatively higher than that of the seller, the optimal contract is a volume-dependent option contract with either a volume discount or volume premium, depending on if the seller or buyer respectively is the leader in the supply chain. It is mentioned that the determination of the discount rate lies beyond the scope of the study as many market factors and firm specific factors such as firm size, credit rating and the balance of assets and liabilities have an influence on the discount rate.

Li et al. (2017) look at the impact of asymmetric information on an unidirectional call option and a bidirectional option. They consider a single manufacturer and a single retailer. The retailer will place an initial wholesale order, purchase an amount of options and has access to the spot market. The retailer has to determine his optimal ordering policy but only knows the random distribution of the manufacturer's production yield, while the manufacturer knows the exact value of his production yield. When comparing this information asymmetry scenario with the symmetric information scenario (both know only the random distribution), three insights were found. Firstly, the expected production quantity of the manufacturer is higher when his production yield is more variable, this is the opposite in the symmetric scenario. This can be explained since the higher yield variability does not expose the manufacturer when he is faced with deterministic demand. If the manufacturer only knows the random distribution of the production yield he is exposed to bigger risks, which most (risk-averse) manufacturers will counter by choosing a lower production quantity. Secondly, they found that the impact of production yield variability on expected profits for both players and the total supply chain are the same as in the symmetric scenario. Lastly, the manufacturer will have an advantage by having more information than the retailer. The expected profit of the manufacturer and the total supply chain would be higher if the manufacturer knew his exact product yield value, the expected profit of the retailer would be slightly lower than in the symmetric information scenario.

Wu & Kleindorfer (2005) consider a supply chain with a single buyer and multiple sellers. Each

seller has private information about their own cost of production, which no other seller or the buyer has. All the sellers will simultaneously present their option contract offer to the buyer. This paper puts forth the optimal contract structure the sellers should strive for when dealing with the competitive environment. The optimal combination between option order quantity and spot market purchases is also determined for the buyer. The combination of multiple sellers and asymmetric information looks promising for further research as it incorporates two factors that are often present in real life situations.

4.2.3 Risk preference

The amount of papers that study risk preference or risk-averse supply chain members is eight for this section. Of those eight studies, six study only one member of the supply as being risk-averse, either the option seller or the buyer buyer. Wu et al. (2002) and Wang et al. (2015) look at both supply chain members. Liu et al. (2014) use utility functions to compare the use of an option contract to that of a discount contract when the manufacturer is risk-averse. With a discount contract the manufacturer tries to incentivize the retailer to order early by offering two different wholesale prices. The results show that risk-averse manufacturer order less than risk-neutral manufacturer. When the manufacturer is riks-averse, he prefers the option contract over the discount contract as the option contract has a risk sharing mechanism.

Xu et al. (2015) show (using numerical examples) that risk-averse buyers would order a lower quantity than risk-neutral buyers for both a standard wholesale contract and option contract. They find that expected profit would decrease as risk-aversion increases, which is expected as some profit is sacrificed to prevent big losses. Additionally, they conclude that the flexibility of the option contract can make it an effective risk hedging tool the more risk-aversion increases, if the execution cost of the option is not too high. While the spot market can be a valuable source from which to order goods, it's price volatility can be too large for risk-averse supply chain members. In general, the use of option contracts seems to be beneficial for risk-averse members, as they do not have to rely solely on the spot market.

4.3 mixed strategy – wholesale/fixed

The previous section looked at combining option contracts with the spot market. This section will discuss the literature in which option contracts are combined with a wholesale order. In this case, a buyer places an initial order with the supplier for a certain quantity of assets. The price of those assets is fixed, known to both parties and stipulated in the contract. In addition to this initial order, the buyer will purchase an amount of options which he could exercise at a later date. Based on the specific option presented, the buyer can adjust the initial order upward (call), downward (put) or in either direction

(bidirectional). Table 4A and table 4B show an overview of the 49 selected papers that focus on a mixed strategy of option contracts and a wholesale order. Here we notice that there is more versatility in the option type being studied. While the majority still belongs to call options (37), 16 papers consider put options and 13 papers concentrate on bidirectional options. Most settings here are once again a 1-vs-1 supply chain. When the model contains more than one supplier, the study focuses on the optimal decisions of the buyer (Merzifonluoglu (2015) and Xu et al. (2015)).

Wang et al. (2021) investigate a scenario with yield uncertainty. The supply chain consists of one supplier and one manufacturer, who is overconfident about his yield. They look at 4 scenarios, a standard wholesale order strategy and a mixed strategy with a call option, both with and without the overconfidence factor of the manufacturer. They find that the overconfidence of the manufacturer has a negative effect on both members' expected profit, meaning the greater the overconfidence level of the manufacturer, the lower the expected profit of each company. The overconfidence of the manufacturer makes that the order and production quantities are not optimal. The results show that the option contract can improve the supply chain under specific option price and exercise price conditions. However, the situation without overconfidence will always be preferred.

Chen et al. (2020) look at a supply chain with one supplier and one retailer, where the retailer commits to a specific service level. To hedge against the risk of buying to many products when it turns out demand is actually low, the retailer can buy put options from his supplier.

Shaban et al. (2021) study the imbalance between supply and demand of capacity on cargo routes in the air transportation sector. An airlines sells capacity on cargo routes to many different freight forwarders. The cargo routes have as certain capacity limit since only a specific amount of cargo can be transported via airplane(s) on a specific cargo route. Some routes, called hot-selling routes, have a higher demand than capacity. On the other hand other routes are underutilized, meaning they have a demand lower than 50% of their available capacity. The model presented by the researchers takes advantage of the market power (ability to manipulate a higher price in the market) of the airline, which will use a wholesale contract to sell the hot-selling routes, but use a call option to sell the underutilized routes. This gives the airline the following benefits: (i) using a wholesale contract induces the freight forwarders to reveal their actual demand, without inflating their order size and (ii) the freight forwarders are more likely to purchase (reserve) more capacity on the underutilized routes, since they can do so by paying a low price (option price) and only have to pay the exercise price if their actual demand requires it. This mixed strategy is compared to a pure strategy with just the call option and to just the wholesale contract. The conclusion is that the mixed strategy is best suited to give the highest allocation of capacity to the underutilized routes compared with the other two contracts.

4.3.1 Supply chain coordination

An early contribution by Barnes-Schuster et al. (2002) presents a basic model with one supplier and one buyer. Both parties are seen as risk neutral and have symmetric information. They demonstrate how options offered by the supplier provide flexibility to the buyer in order to better adjust to market changes. In addition, they derive conditions and option prices for which the supply chain will be coordinated. They note, however, that at those prices the supplier will have zero profit and may be unwilling to cooperate to achieve coordination. To address that issue, return policies could be used in certain situations, meaning the supplier will buy back some assets at the end of the season. This could still coordinate the supply chain, while giving the supplier positive profits. Burnetas & Ritchken (2005) explore a similar 1-vs-1 supply chain, but focus on a situation where the demand curve is downward sloping. This brings an additional element to option exercise decision making for the retailer (buyer), as releasing an extra unit would lower the retail price and have a feedback effect. They conclude that when the manufacturer introduces options he will be better off. The retailer, however, could be either better off or worse off, depending on the amount of uncertainty in the demand curve. The higher the uncertainty, the worse off the retailer would be.

A study by Wang & Liu, (2007) of a 1v1 supply chain where both members are risk neutral and have symmetrical information defines two conditions for a successful supply chain coordination; (I) maintain a negative correlation between exercise price and option price and (II) the firm commitment (initial wholesale order) must be lower than the optimal production quantity in a centralized system.

4.3.2 Asymmetric information

Research on asymmetric information is very limited when it comes to a mixed strategy in combination with a wholesale order. Only five papers were found for this subsection, one by Li et al. (2009), we already discussed in subsection 4.1.2. above. The other all focus on a 1-to-1 supply chain where a call option is introduced. Basu et al. (2019) do look at information asymmetry and risk-averse in the same study, which has not been done before. They present the “option buyback contract”, a put option, and show the impact on the expected profit of the risk-averse retailer. Further research on this topic is necessary.

4.3.3 Risk preference

The risk preference of supply chain members in the mixed wholesale setting has been studied in seven papers. Chen and Parlar (2007) investigate the value of a put option for a risk-averse newsvendor

and find several interesting conclusions. We mentioned before that put options are not examined nearly as much as call options, so this study requires some more context. We know already that option contracts are mostly used to help deal with uncertain demand, reduce inventory cost and coordinate the supply chain. Aside from these, option contracts are also popular with risk-averse supply chain members. Consider the following situation: a newsvendor (let us take a retailer) wants to reduce his risk of suffering high losses in the case of low market demand. The retailer can then buy put options from his supplier (the option writer). In this paper, the put option works as follows: the *strike quantity* is the predetermined level for which, if demand falls below this level, the supplier will pay the *strike price* to the retailer for each unit of difference between the strike quantity and actual observed demand quantity. The strike price is similar to the option exercise price, in this context it is the amount of dollars (compensation) that the supplier will pay to the retailer per unit. Using a simple numerical example, these concepts are easily understood. Let us say the retailer places an initial order of 300 units with the supplier and also buys a put option where the strike quantity is 250 units and the strike price is $10. Say that the cost of this option is $400 for the retailer. In the case that the actual demand of the retailer is just 150 units instead of the expected 300 units, the value of the put option for the retailer is calculated as follows: (250-150) x $10 = $1000, minus the cost of the option ($400) leaves the retailer with a net profit of $600. In the case that the retailer's demand is more than 250 units, then the option has no value for the retailer and simply costs him $400.

Wu et al. (2010) study a single-period 1-to-1 supply chain where the manufacturer is risk-averse and has the option to purchase call options from his supplier. They use the conditional value-at-risk objective function (CVaR) to reveal the relationship between the manufacturer's risk preference and his optimal order decisions. Aside from that, they also show that not only the risk preference has an impact on optimal order decisions. Factors such as the demand distribution, the option price, exercise price and market sales price influence the amount of units bought at wholesale price, and the amount of options bought.

Xu et al. (2015) use the CVaR method to examine the impact of a put option on the optimal order decisions of a risk-averse retailer. They conclude that the optimal order quantity is higher when the strike quantity is a decision variable, meaning the retailer can decide on it, instead of a low and predetermined amount. Additionally, the more risk-averse the retailer is and the more uncertain the demand is, the more value the option contract will have for the retailer. As discussed in Wu et al. (2010), the effect of risk aversion on the put option value depends on system parameters (market demand and market price) and option parameters (option price and exercise price). Fan et al. (2020) consider an option contract in a buyer-led supply chain where both the buyer and supplier are risk-

averse. Using a Stackelberg game model and the CVaR method they determine the benefits and risks for both buyer and supplier when the option price and exercise price are adjusted. They formulate some interesting conclusions: (i) when the risk preference of both members is the same, changing the option price or exercise price has no effect on the total risk of the supply chain, (ii) in case the buyer has a lower (higher) risk-aversion, increasing the option price will decrease (increase) the total supply chain risk, and (iii) the supply chain can be coordinated under CVaR minimization, unless the buyer is more risk averse than the supplier.

5. Conclusions and insights

The interest in real option contracts has grown over the last decade as a way to deal with factors such as demand and yield uncertainty, that are becoming more common in many supply chains. The goal of this paper is to summarize and cluster all the available literature on option contracts in a supply chain setting. We put forward a framework to categorize the option contracts based on different characteristics. The main characteristics focused on are: the type of option studied, the chosen strategy (pure versus mixed), the presence of supply chain coordination, the presence of information asymmetry and the risk preference of the members. Furthermore, we looked at the number of buyers/sellers considered and the number of periods the option can be used. The following conclusions can be made from this literature review:

- The amount of research on real options has seen an increasing trend over the last 20 years and will likely continue on this path in the future.

- The call option has been studied most compared with the put option and bidirectional option.

- Both mixed and pure strategies using real option contracts can coordinate the supply chain and benefit both the seller and the buyer.

- Real options are being studied more and more under specific conditions which can alter ordering quantities and production quantities, such as: a service level commitment, inflation, existence of bankruptcy risk of a member, etc…

- Research considering settings with multiple option sellers and/or buyers is rather small. This is an area where more research should be done, as it applies to many realistic situations where

companies have multiple supplier and customers.

- There exists a gap in the research, in the sense that most settings being studied are not realistic. Many papers assume information symmetry, risk neutrality, single-period options and 1-to-1 supply chains. Settings that combine asymmetric information with risk aversion in supply chains with more than two members have not been found.

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6. Appendix

Author(s)	Year	Type of adjustment			Relationship	single or multiple parties		Supply Chain Coordination	comparison with other type of contract	symm (S) or asymm (A) information		Single (S)- or multi (M) - selling period		Risk?	
		Unidirectional		Bidirectional											
		call (up)	put (down)			Single	Multiple			Symm	Asymm	Single	Multi	neutral	averse
Fang and Whinston	2007	x			1 supplier - 2 customers		x		x	(x)	x	x		x	
Li et al.	2009	x			1 supplier - 1 retailer		x		x		x	x		x	
Martinez-de-Albeniz and Simchi-Levi	2009	x			1 buyer - multiple suppliers		x			x		x		x	
Zhao et al.	2010	x			1 manufacturer - 1 retailer		x	x	x	x		x		x	x
Jörnsten et al.	2012	x			1 manufacturer - 1 retailer		x		x	x		x		x	
Liang et al.	2012	x			1 buyer - 1 supplier		x			x		x		x	
Chen et al.	2014	x			1 supplier- 1 retailer		x	(x)	x	x		x		x	x
Wang and Chen	2015	x			1 supplier - 1 newsvendor	x			x			x		x	
Chen and Xiao	2015	x			1 buyer - 1 supplier		x	x	x	x		x		x	
Keyvanloo et al.	2015	x			1 supplier - 1 buyer	x			x				x	x	
Cai et al.	2016	x			1 supplier - 1 retailer		x	x	x	x		x		x	
Zhang et al.	2017	x			1 manufacturer - 1 retailer		x		x	x		x		x	
Cai et al.	2017	x			1 supplier - 1 retailer		x	x	x	x		x		x	
Hu et al.	2018	x			1 supplier - 1 retailer			x	x	x		x		x	
Shamsi et al.	2018	x			1 buyer - 2 suppliers		x				x	x		x	
Davis and Leider	2018	x			1 supplier - 1 retailer		x		x	x		x		x	
Biswas and Avittathur	2019	x			1 supplier - multiple buyers		x	x	x	x		x		x	
Hua et al.	2019	x			1 supplier - 1 retailer		x	x	x	x		x		x	
sharma et al.	2019	x			1 supplier - 1 retailer		x	x		x		x		x	
Liu et al.	2020	x			1 supplier - 1 retailer		x	x	x	x		x			x
Zhao et al.	2021	x			1 supplier - 1 retailer		x	x		x		x			x
Shaban et al.	2021	x			1 supplier - multiple buyers	x		x	x			x		x	x

Table 2: Pure strategy

Author(s)	Year	Type of adjustment		Relationship	single or multiple parties		Supply Chain Coordination	comparison with other type of contract	symm (S) or asymm (A) information		Single (S)- or multi (M) - selling period		Risk?	
		Unidirectional	Bidirectional											
		call (up)	put (down)		Single	Multiple			Symm	Asymm	Single	Multi	neutral	averse
Wu et al.	2002	x		1 seller - 1 or more buyers		x			x		x		x	x
Kleindorfer and Wu	2003	x		1 seller - 1 buyer		x			x		x		x	
Spinler et al.	2003	x		1 seller - 1 buyer		x			x		x		x	
Wu and Kleindorfer	2005	x		1 buyer - multiple sellers		x				x	x		x	
Spinler and Huchzermeier	2006	x		1 buyer - 1 seller		x		x	x		x		x	
Fu et al.	2010	x		1 buyer - 1 seller	x						x	x	x	
Xu	2010	x		1 supplier - 1 manufacturer		x			x		x		x	
Pei et al.	2011	x		1 supplier - 1 manufacturer	x			x		(x)	x		x	
Fu et al.	2012	x		1 buyer - multiple suppliers	x						x	x	x	
Zhao et al.	2013	x		1 manufacturer - 1 or multiple retailers		x	(x)		x		x		x	
Lee et al.	2013	x		1 buyer - n suppliers	x						x		x	
Inderfurth et al.	2013	x		1 buyer - 2 suppliers	x							x	x	
Liu et al.	2014	x		1 manufacturer - 1 retailer		x	(x)	x	x		x		x	x
Wang et al.	2015	x		1 purchaser - 1 supplier		x	x	x	x		x		x	x
Keyvanloo et al.	2015	x		1 supplier - 1 buyer	x			x				x	x	
Merzifonluoglu	2015	x		1 buyer - multiple suppliers	x			x			x		x	x
Fu	2015	x		1 buyer - n suppliers	x			x			x		x	x
Xu et al.	2015	x		1 buyer - multiple suppliers	x						x		x	x
Breiter and Huchzermeier	2015	x		1 retailer - 1 manufacturer		x	x	x	x		x		x	
Luo and Chen	2017	x		1 supplier - 1 manufacturer		x	x	x	x		x		x	
Li et al.	2017	x		1 manufacturer - 1 retailer		x		x	x	x	x		x	
Anderson et al.	2017	x		1 buyer - n suppliers		x			x		x		x	
Merzifonluoglu	2017	x		1 seller - 1 buyer	x						x		x	
Wan and Chen	2018	x		1 supplier - 1 retailer			x	x	x		x		x	
Wan and Chen	2018	x		1 supplier - 1 buyer	x			x			x		x	
Zhao et al.	2018	x		1 manufacturer - 1 retailer		x	x	x	x		x		x	
Zhao et al.	2018	x		1 supplier - 1 buyer			x	x	x		x		x	
Xu et al.	2019	x		1 supplier - 1 retailer				x			x			x
Liu et al.	2020	x		1 retailer - 1 supplier		x	x		x		x			x
Luo et al.	2021	x		1 supplier - 1 manufacturer		x	x	x	x		x		x	

Table 3: Mixed strategy (spot)

In combination with wholesale contract

Author(s)	Year	Type of adjustment			Relationship	single or multiple parties		Supply Chain Coordination	comparison with other type of contract	symm (S) or asymm (A) information		Single (S)- or multi (M) - selling period		Risk?	
		Unidirectional call (up)	put (down)	Bidirectional		Single	Multiple			Symm	Asymm	Single	Multi	neutral	averse
Barnes-Schuster et al.	2002	x			1 buyer - 1 supplier		x	x	x	x		x		x	
Burnetas and Ritchken	2005	x	x		1 manufacturer - 1 retailer		x	x	x	x		x		x	
Wang and Tsao	2006			x	1 supplier - 1 retailer	x						x		x	
Chen and Parlar	2007		x		1 newsvendor - 1 option writer	x						x			x
Wang and Liu	2007	x			1 manufacturer - 1 retailer		x	x	x	x		x		x	
Li et al.	2009	x			1 supplier - 1 retailer		x		x		x	x		x	
Xu and Nozick	2009	x			1 buyer - multiple suppliers	x							x	x	
Wu et al.	2010	x			1 downstream manuf - 1 upstream supplier	x						x			x
Xia et al.	2011	x			1 buyer - 1 supplier		x		x	x		x		x	
Chen and Shen	2012	x			1 supplier - 1 retailer		x	x	x	x		x		x	
Wang et al.	2012	x			1 buyer - 1 supplier	x			x			x		x	
Liu et al.	2013	x	x	x	1 seller - 1 buyer	x			x			x		x	
Feng et al.	2014	x			1 supplier - 1 buyer	x						x		x	
Xue et al.	2015		x		1 manufacturer - 1 retailer	x			x	x		x			x
Wang and Chen	2015	x			1 supplier - 1 newsvendor	x			x			x		x	
Keyvanloo et al.	2015	x			1 supplier - 1 buyer	x			x				x	x	
Merzifonluoglu	2015	x			1 buyer - multiple suppliers	x			x			x		x	x
Xu et al.	2015	x			1 buyer - multiple suppliers	x						x	x	x	(x)
Breiter and Huchzermeier	2015	x			1 retailer - 1 manufacturer		x	x	x	x			x	x	
Nosoohi and Nookabadi	2016	x	x	x	1 supplier - 1 manufacturer	x			x			x		x	
Chen et al.	2017			x	1 supplier - 1 retailer		x	x	x	x		x		x	
Luo and Chen	2017	x			1 supplier - 1 manufacturer		x	x	x	x		x		x	
Wang and Chen	2017	x			1 supplier - 1 retailer		x	x		x		x		x	
Li et al.	2017	x		x	1 manufacturer - 1 retailer		x		x	x	x	x		x	
Wang et al.	2017	x			1 supplier - 1 firm	x			x			x	x	x	
Merzifonluoglu	2017	x			1 seller - 1 buyer	x						x		x	
Yeng et al.	2017	x	x	x	1 supplier - 1 retailer		x	x	x	x		x		x	
Luo et al.	2018		x		1 supplier - 1 manufacturer	x		x	x	x		x		x	
Wan and Chen	2018	x	x	x	1 supplier - 1 retailer		x	x	x	x		x		x	
Wan and Chen	2018	x	x	x	1 supplier - 1 buyer	x			x			x		x	

Table 4A: Mixed strategy (wholesale/fixed)

In combination with the spot market

Author(s)	Year	Type of adjustment			Relationship	single or multiple parties		Supply Chain Coordination	comparison with other type of contract	symm (S) or asymm (A) information		Single (S)- or multi (M) - selling period		Risk?	
		Unidirectional call (up)	put (down)	Bidirectional		Single	Multiple			Symm	Asymm	Single	Multi	neutral	averse
Fan and Feng	2020	x			1 supplier - 1 buyer		x	x		x		x			x
Bakshsi and Heydari	2021	x			1 buyer - 1 supplier		x	x		x		x		x	
Zhao et al.	2020	x			1 retailer - 1 supplier		x			x		x			x
Luo et al.	2021	x		x	1 supplier - 1 manufacturer		x	x	x	x		x		x	
Pathra and Jha	2022			x	1 supplier - 1 buyer		x	x	x	x		x		x	
Zhao et al.	2019	x			1 retailer - 1 supplier		x	x	x	x		x			x
Wang et al.	2020	x			1 seller - 1 buyer		x	x	x	x	x	x		x	
Nosoohi and Nookabadi	2019	x	x	x	1 manufacturer - 1 retailer		x		x		x	x		x	
Chen et al.	2020		x		1 supplier - 1 retailer		x	x	x	x		x			x
Shaban et al.	2021	x			1 supplier - multiple buyers	x		x	x			x		x	(x)
Wang et al.	2019			x	1 supplier - 1 manufacturer	x						x		x	
Wang et al.	2021	x			1 supplier - 1 manufacturer		x	x		x		x		x	
Li et al.	2022	x			1 supplier - 1 retailer		x	x	x	x		x		x	
Hu et al.	2019		x		1 supplier - 1 buyer		x	x	x	x		x		x	
Basu et al.	2019		x		1 supplier - 1 retailer		x	x	x		x	x			x
Eriksson	2019	x			1 supplier - 1 manufacturer		x	x	x	x		x		x	
Guo et al.	2021		x		1 supplier - 1 retailer		x	x	x	x		x		x	
Chen and Wan	2019	x	x	x	1 supplier - 1 buyer	x			x			x	x	x	
Wan and Chen	2019		x		1 supplier - 1 retailer		x	x	x	x		x		x	

Table 4b: Mixed strategy (wholesale/fixed)

In combination with the spot market

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