An Options Approach to Enhance Economic Efficiency in a Dyadic Supply Chain

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Summary:
In this article we present a framework to analyze the efficiency-enhancing impact of contingency contracts. At the beginning of the contract, market session in period 0, the seller announces a two-part tariff applicable to obtaining options on slots of his capacity. This entitles the buyer to a non-storable good or dated service provided by the seller. The buyer in turn decides how many options to purchase. Both parties act under state-contingent uncertainty concerning demand, costs, and spot price. In the spot market in period 1, with uncertainty resolved, the buyer determines his optimal contract and spot consumption portfolio, while the seller offers potentially remaining capacity at the prevailing spot market price. The opportunity of long-term capacity trading and planning provides the seller with an instrument of efficient cost management resulting in lower marginal cost related to long-term capacity allocation as opposed to those associated with allocation on short-notice. Economic efficiency is enhanced in the options scenario as compared to the one obtained in a pure spot market.

Keywords:
Supply Chain Management, Capacity Options, Cost Management, Cost Differential Long-Term vs. Short-Term Allocation

1 Introduction

Options have attracted tremendous attention not only in the context of financial markets, fueled by the seminal article by Black and Scholes[1] who were first to provide a method to value this derivative instrument, but also recently as so called real options. Real options serve to *quantify* managerial and operational flexibility with regard to an investment project whose inherent expansion, termination or down-sizing opportunities are considered options and priced according to the Black-Scholes framework. Exogenous risks such as demand and exchange rate uncertainty can thus be modeled more accurately than traditional discounted cash-flow would allow[2].

Our article is concerned with an extension to the theory of real options by considering capacity options on non-storable goods or dated services. The introduction of options with respect to supply chain contracts aims at making both trading partners more flexible in responding to uncertain future market environments and at providing a hedging instrument against pronounced spot market volatility. As we demonstrate in the following, establishing a market scheme consisting of a long-term contract market and a short-term spot market also provides the seller with a key to exploit cost savings generated through early demand discovery in the options market enabling long-term planning. Welfare created in this market scenario grows with an increasing gap between marginal costs associated with short-term vs. long-term allocation, thus yielding an incentive for both parties to engage in this novel market set-up.

The remainder of this paper is organized as follows: in section two, the related literature is briefly presented. We go on in section three to introduce the market model and state the results for the buyer's and seller's strategy. Welfare properties are discussed in the subsequent section, linking the options scenario to the possibility of applying cost management, as is further highlighted in section five by examining an example in the air cargo business. Section six concludes with remarks on future research opportunities.

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1 Black, Scholes (1973), p. 637 – 654.

2 See Huchzermeier, Cohen (1996), p. 100 – 114.

2 Literature Review

The starting point for our analysis is Wu, Kleindorfer and Zhang[3], who determine buyer and seller strategies in a similar framework, however limited to pure spot price uncertainty. A comprehensive overview of methods and applications with regard to real options is given in Dixit and Pindyck[4]. Tsay, Nahmias and Agrawal[5] provide a synopsis of current research on modeling of supply chain contracts, where contracts with quantity flexibility are analyzed via a multi-stage newsboy model rather than via a game-theoretic as is done here. A number of papers on yield management[6] illustrate an efficient method to cope with demand uncertainty when total capacity is limited. Oren, Smith and Wilson[7] study the issue of optimal pricing for services with a specified total capacity and date of delivery. Capacity fees are demonstrated to be an important component of a tariff. Harris and Raviv[8] derive an optimal pricing scheme for a monopolist facing demand uncertainty. Newbery[9] models similar contracts as the one analyzed here, consisting of a forward and a spot market for electricity. He focuses on issues of competivity in the British electricity market. In Spinler, Huchzermeier and Kleindorfer[10] implications of an options market scenario for electronic transportation platforms are discussed. The Extension of the model from a two-state to a continuous state space is undertaken in Spinler, Huchzermeier and Kleindorfer[11].

3 The Market Model

We consider a two-period von Stackelberg game to model the market interactions between the seller and the buyer. In period 0, the contract market, the seller as the Stackelberg leader first announces a two-part tariff consisting of an immediately payable reservation fee r and an execution fee e, which is due if the buyer exercises the option later in period 1. A single option entitles the buyer to a fixed portion of the total available capacity. The option is assumed to be a *European* call option. This is a standard assumption within the real options literature and it reflects reality rather well whenever high costs of repositioning, e.g., in air freight

3 Wu, Kleindorfer, Zhang (2001).
4 Dixit, Pindyck (1994).
5 Tsay, Nahmias, Agrawal (1999), p. 299 – 336.
6 See for example Gale, Holmes (1992), p. 413 – 437.
7 Oren, Smith, Wilson (1985), p. 545 – 567.
8 Harris, Raviv (1981), p. 347 – 365.
9 Newbery (1998), p. 726 – 750.
10 Spinler, Huchzermeier, Kleindorfer (2001a), p. 305 – 315.
11 Spinler, Huchzermeier, Kleindorfer (2001b).

transportation, or reconfiguration, in manufacturing environments, are incurred. The buyer then decides on the number of options Q to be purchased in the contract market. Both decisions are taken under uncertainty. The seller's marginal costs $\tilde{b}$ as well as the buyer's demand $\tilde{D}$ are state-contingent. All parameters marked by a tilde are random variables. Moreover, the spot price $\tilde{P}^s$ prevailing in period 1 is uncertain, too, and considered to be influenced neither by the buyer nor the seller, thus stemming from a competitive fringe in the spot market.

In practice, the time span between the contract market and the spot market or actual day of use would vary depending on the underlying good or service. As the day of use draws closer, the uncertainty resolves and the buyers would use a secondary market to trade options that may have turned out to be of no use in the meantime. We do not model this intermediate stage here. Rather, we directly proceed with the spot market in period 1.

The buyer now determines his optimal contract and spot market consumption portfolio, where he decides on how many options $\tilde{q}^e$ $(\leq Q)$ to execute and what quantity $\tilde{q}^s$, if any, to purchase in the spot market. The seller in turn allocates the capacity that has been contracted for in period 0 and that is now called upon, while attempting to find buyers for the remaining capacity in the spot market.

The von Stackelberg game structure enables an analysis via dynamic programming, starting with the determination of the buyer's consumption portfolio in period 1. Then expectation is being taken to compute the number of options Q the buyer contracts for in period 0 as a function of e and r. In our analysis, we use the information on $Q(e,r)$ to maximize the seller's profit by appropriately setting the execution fee e and the reservation fee r.

3.1 The Buyer's Optimal Consumption Portfolio

We make the following assumptions in modeling the buyer's behavior.

1. There are two states of the world ω in Ω, $\Omega = \{L,H\}$, with corresponding probabilities π^L and π^H, which are known to both the buyer and the seller. The state of the world may indicate the state of the economy, L representing poor conditions while H representing good ones, or a physical parameter such as temperature.
2. The spot price $\tilde{P}^s$ is state-contingent, with $\tilde{P}^s = p\ \tilde{\Psi}(\omega)$, where p is positive and accounts for a multiplicative non-state-contingent price component. $\tilde{\Psi}$ represents price uncertainty, with $\Psi^L < \Psi^H$. Thus the spot price increases with improving economic conditions. As mentioned previously, the spot price cannot be influenced either by the buyer or the seller.
3. The buyer's utility $\tilde{U}$ is affine-separable. For ease of notation, let $\tilde{U} = a\ D^{\alpha}\tilde{\Phi}(\omega)$ with demand D and the parameters $a > 0$, α in (0,1). The results

would hold for any increasing and concave function of D, as long as separability is conserved. $\tilde{\Phi}$ is uncertainty related to the buyer's utility which is increasing in ω.

4. The marginal willingness to pay for the reserved quantity Q in state H is at least as large as the execution fee, i.e., $U'^{H}(Q)>e$. Furthermore assume that the spot price in the low state and the one in the high state differ to such an extent that $P^{s,L} < e < P^{s,H}$.

The buyer's indirect utility is represented in the following quasi-linear form:

$$\tilde{V}(\tilde{q}^{e}, \tilde{q}^{s}, \tilde{P}^{s}, Q) = \tilde{U}(\tilde{q}^{e} + \tilde{q}^{s}) - r\,Q - e\,\tilde{q}^{e} - \tilde{P}^{s}\,\tilde{q}^{s}, \qquad (1)$$

where $\tilde{q}^{e}$ is the number of options executed in the spot market, $\tilde{q}^{s}$ the capacity purchased in the spot market. The following program yields the optimal state-contingent consumption portfolio $\{\tilde{q}^{e},\tilde{q}^{s}\}$:

$$\max\ \tilde{V}(\tilde{q}^{e}, \tilde{q}^{s}, \tilde{P}^{s}, Q) \quad s.t. \quad \tilde{q}^{s} \geq 0 \text{ and } Q \geq \tilde{q}^{e} \geq 0. \qquad (2)$$

To solve this program, we need to distinguish between the two states L and H, which results in the following lemma.

Lemma 1 *In the spot market, the buyer consumes from the contract and the spot market as given in table 1.*

Contract Consumption	Spot Consumption	State
0	$(a\alpha\Phi^{L}/p\,\Psi^{L})^{1/(1-\alpha)}$	L
Q	0	H

Table 1: Contract and Spot Consumption in the Spot Market.

Proof: Apply the theorem of Kuhn and Tucker to the program given through equ. (2).

Therefore the buyer executes either all options or none; he buys from the spot market in state L only. We are now able to compute the buyer's expected utility, which results in:

$$E[\tilde{V}(Q;r,e)] = -r\,Q + \pi^{H}\,U^{H}(Q) - \pi^{H}\,e\,Q + const., \qquad (3)$$

where the *const.* term does not depend on Q.

From (3), we can derive a first order condition to determine the optimal reservation quantity $Q^*(e,r)$, quantified in the following theorem.

Theorem 1 *The optimal number of options Q^* the buyer obtains in period 0 is given by: $Q^*(e,r) = (a\ \alpha\ \pi^{H}\ \Phi^{H} / (r + \pi^{H}\ e))^{1/(1-\alpha)}$, if $r + \pi^{H}e \leq \pi^{H}p\,\Psi^{H}$. Otherwise $Q^*(e,r) = 0$.*

Proof: Differentiate equ. (3) with respect to Q and set to zero. Note that we need to require $U^{H\prime}(Q^*) > e$ and $U^{H\prime}(Q^*) < p\ \Psi^H$, conditions derived in computing the consumption portfolio provided in lemma 1, which yields the two regimes for Q^*.

We can interpret theorem 1 in the following way: The buyer is increasingly willing to pay higher reservation fee r in the contract market, the more likely state H occurs and the larger the difference between the spot price in that state and the execution fee. State H is the favorable state for the buyer, since in that case the execution fee is lower than the spot price and he therefore benefits from contracting capacity in period 0. The term $r + \pi^H e$ is the expected price the buyer is going to pay for options since he executes his options in state H only. Note that the buyer requires this price to be strictly smaller than the expected spot price, since, from theorem 1, $r + \pi^H e \leq \pi^H p\,\Psi^H < E[p\,\tilde{\Psi}]$. Traditional reasoning would suggest equality with the expected spot price.

For the seller, however, state H is less favorable, since in that case he would be able to sell his capacity in the spot market at a higher price. As a consequence, he insures himself against this case by demanding a larger reservation fee.

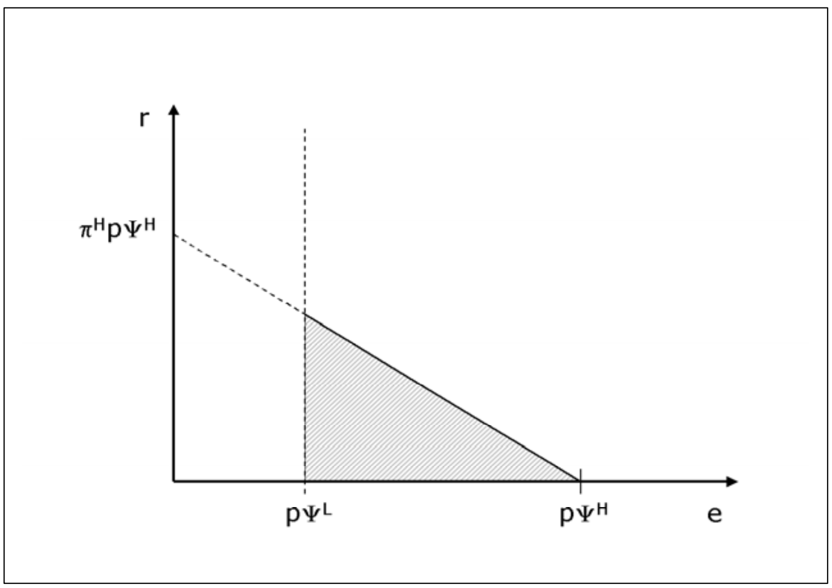

Figure 1: The Range or (r,e)-Values for Which Q > 0 is Indicated by the Triangle.

Figure 1 shows the triangular region of *(r,e)*-values for which the buyer is willing to reserve capacity in the contract market. Note that the lower limit on e is imposed by our assumptions. Thus if e is set equal to the spot price in the high state, then the acceptable reservation fee r shrinks to zero. The reservation fee is maximal for the lowest allowable execution fee.

Corollary 1 The optimal number of options $Q^*(e,r)$ the buyer obtains in the contract market decreases strictly in the reservation r and the execution fee e.

Proof: Follows immediately from theorem 1.

The corollary states the expected result that the demand for options decreases with price. We now know how the buyer reacts to any tariff (e,r) announced by the seller, who will choose the tariff relying on this information, such that his profit is maximized. This task is undertaken in the next section.

3.2 The Seller's Optimal Tariff

As we did in the buyer's case, we state a few assumptions concerning the seller's profit.

1. Total capacity K is exogenously fixed.
2. The per unit cost $\tilde{\beta}$ of holding capacity K is state-contingent.
3. The marginal cost $\tilde{b}$ of production is constant with respect to output quantity and is state-contingent.
4. Most importantly, and this is key to our options analysis in the context of cost management, we postulate a difference between the cost $\tilde{b}^c$ associated with providing capacity reserved through a long-term contract as opposed to the cost $\tilde{b}^s$, which is incurred if capacity is demanded on a short-term basis, i.e., in the spot market: $\Delta\tilde{b} \equiv \tilde{b}^c - \tilde{b}^s > 0$. We shall discuss in a later section in what industries this difference is particularly pronounced.
5. It is reasonable to assume that the marginal cost increases as the state of the economy improves, thus $b^{(c,s)L} < b^{(c,s)H}$. Furthermore let $b^{c,H} < p\,\Psi^H$, since otherwise the seller would not be able to operate profitably in state H.

The expected seller's profit then is

$$E[\Pi(r,e,\tilde{b}^c,\tilde{b}^s,Q)] = E[rQ + \tilde{q}^e\,(e - \tilde{b}^c) + m\,(K - \tilde{q}^e)(\tilde{P}^s - \tilde{b}^s)^+ - \tilde{\beta}K], \tag{4}$$

where the first two terms account for the profit generated through the long-term contract market, the third term represents the profit from selling into the spot-market. It may well be that there is a risk for the seller of not finding a buyer on short notice, which is true in particular for goods or services that are customer specific. We therefore introduced the risk factor m, with $0 < m \leq 1$. Hence, as m decreases, the risk of not finding a last-minute buyer increases. The factor m may vary substantially from industry to industry and it may also be a function of the spot price, where a higher spot price results in pronounced risk. For our purposes, however, it is sufficient to model m as a constant. Furthermore, as far as spot-market sales are concerned, we assume that no sales into the spot-market occur when price is below cost, as is evident by the $(\ldots)^+$ operator. The last term, finally, represents the cost of holding capacity K.

The seller maximizes his profit according to the following program:

$$max\ E[\Pi(r,e,\tilde{b}^c,\tilde{b}^s,Q)] \qquad s.t. \qquad K \geq Q. \qquad (5)$$

The following theorem results.

Theorem 2 *The optimal reservation and execution fee (r*,e*) is given by:*

$$r^* + \pi^H e^* = \pi^H min[(1/\alpha)\ (b^{c,H} + m\ (p\Psi^H - b^{s,H})^+),\ p\ \Psi^H], \quad Q^* < K,$$

$$r^* + \pi^H e^* = (\pi^H a\ \alpha\Phi^H/K)^{1/(1-\alpha)}, \qquad Q^* \geq K.$$

Proof: Differentiate equ. (4) with respect to $r^* + \pi^H e^*$ to get the first order condition. Take into account theorem 1 for the case $Q^* \geq K$.

Note that in the present two-state case the reservation fee and the execution fee cannot be determined separately, contrary to the more general case of a continuous state-space which is analyzed in Spinler, Huchzermeier and Kleindorfer[12]. If we set the execution fee e^* equal to marginal cost, i.e., $e^* = b^{c,H}$ (which is possible if $b^{c,H}$ is larger than $p\Psi^L$, see our assumptions for the buyer's problem and figure 1), then we can interpret r as being the margin the seller is able to extract from the buyer. The reservation fee r contains the term $\pi^H m\ (p\Psi^H - b^{s,H})^+$, which represents the opportunity cost of reserving capacity in the contract market. This reserved capacity is going to be executed by the buyer in state H at a fixed price e, which is lower than the spot price. Thus the need for the seller to account for this case in the reservation fee.

Having computed the optimal execution and reservation fee, we can determine the equilibrium quantity.

Corollary 2 *The strategies given in theorem 1 and 2 for the buyer and the seller, respectively, lead to the following equilibrium quantity Q*:*

$$Q^* = (a\ \alpha\ \Phi^H / min[(1/\alpha)\ (b^{c,H} + m\ (p\Psi^H - b^{s,H})^+),\ p\ \Psi^H])^{1/(1-\alpha)}.$$

Proof: Combine theorems (1) and (2).

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12 See Spinler, Huchzermeier, Kleindorfer (2001b).

4 Welfare Properties

For the additional contract market to make economic sense, it should yield higher welfare than a pure spot market scenario. In this section, we shall compare the welfare generated in the two different scenarios. We define the welfare as $W \equiv E[\tilde{V}] + E[\tilde{\Pi}]$. Let W^o be the one associated with the options case, W^s the one related to the pure spot market, and let $\Delta W \equiv W^o - W^s$. We assume that transaction costs occurring in the contract market are zero, which is justified by the fact that search and information gathering costs decrease dramatically for electronic markets.

The following theorem states the superiority of the combined spot and contract market in terms of economic efficiency.

Theorem 3 *The gain in efficiency ΔW provided by the addition of the contract market to the spot market is strictly positive, i.e., $\Delta W > 0$. The welfare difference can be represented as $\Delta W = \pi^H [(1-m)(p\Psi^H - b^{s,H})^+ + \Delta b^H]$.*

Proof: Calculate ΔW with Q* given by corollary 2 and the consumption for pure spot market being in state L $X^L = (a\alpha\Phi^L/p\Psi^L)^{1/(1-\alpha)}$ and in state H $X^H = (a\alpha\Phi^H/p\Psi^H)^{1/(1-\alpha)}$.

With regard to implementing the novel market scheme, it is of interest what parameters impact the efficiency gain.

Corollary 3 *The efficiency gain ΔW increases with increasing cost difference Δb^H and with increasing risk of not finding a last-minute buyer, i.e., with decreasing m.*

Proof: Follows directly from theorem 3.

So we have obtained the key result that the efficiency gain increases (in this case linearly) with the cost differential between short- and long-term allocation. As a matter of fact, the gain is still positive even in the case of a completely riskless spot market, i.e., for $m = 1$. Thus the message is clear: Those industries where this cost difference is high are particularly suited to adoption of the spot and contract market. The implications of this important finding will be discussed in the next section.

5 Cost Management to Enhance Efficiency Gains

What factors impact the difference of marginal costs based on short-term vs. long-term allocation (to simplify notation in the following, let us denote the former, a little loosely, by "short-term costs" and the latter by "long-term costs")? This certainly depends on the industry supplying the good or service and on the time gap between the contract and the spot market.

The latter point involves a trade-off: on the one hand, the longer the period between the contract and the spot market, the more the seller is capable of making arrangements for reducing long-term costs by, e.g., optimizing his fleet and route allocation in the air cargo business or by dedicating lowest cost generators to the demand indicated early via options in the electric power business.

On the other hand, the further away the actual day of use when the contracting takes place, the less precise the initial forecast of demand on the buyer side. This may lead to reduced willingness to trade in the contract market, in particular, if, as was assumed for our modeling purposes, there were no secondary market enabling options trade among the buyers at an intermediary point of time. In practice, however, such a secondary market would be essential for a well functioning market set-up. By the time the secondary market takes place, the buyer will have updated his prior conditional demand probability distribution.[13] As a consequence, the buyer may find it in his interest to purchase additional options, if available, or sell them into this market. Thus the secondary market partially mitigates the downside of opening the contract market early with respect to the day of use.

Let us take a look at an example in the air cargo industry to see how the procedure of capacity allocation currently applied there works and how it could be modified upon implementing contingency contracts to aid cost management in the sense discussed above.

Lufthansa Cargo AG (LH Cargo) belongs to the Deutsche Lufthansa AG Group and is considered market leader in the global air cargo sector with a global market share of 7%[14]. Hellermann[15] points out that LH Cargo currently finalizes its long-term capacity planning process about 15 months prior to actual use. Thus if one wanted to keep the planning cycle, it would be reasonable to have the contract market take place that long before the spot market. LH Cargo, at this point in time, bids reservation fees for each route, which may differ depending on potentially more profitable opportunities of selling into the spot market (see Theorem 2), and the corresponding execution fees. The buyers, having learned the tariff, would then purchase options according to their likely demand. It is important to recognize that the level of options purchase provides LH Cargo with more accurate information on future demand levels than the current practice of relying on historical demand data. This early demand indication now allows LH Cargo to optimize their network supporting the various destinations and their fleet on a given route and thereby reduce the long-term marginal cost.

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13 Models analyzing this updating process are generally referred to as Bayesian Models in the literature, see Sengupta (1985).

14 See Lufthansa AG (2001).

15 Hellermann (2001).

Then, six months before use[16], the secondary market for options trading among the buyers would take place, where corrections could be made with regard to the now fixed schedule or with regard to the quantity needed. Finally, a few days prior to the transportation date, spot market interactions would occur: The buyer decides whether or not to execute the option or to satisfy his demand from a back-stop technology in the spot-market. LH Cargo in turn allocates pre-contracted capacity now called and attempts to sell remaining capacity into the spot market. Note that the remaining capacity will entail higher marginal costs than the pre-contracted capacity, as discussed earlier.

This new type of contract would replace or complement the currently used Guaranteed Capacity Agreement (GCA), which entitles the buyer to a specified quantity of capacity for the next six months and the right to return excess capacity at certain points in time. From the seller's point of view, enhanced cost savings potential could be exploited because demand data utilized for long-term capacity planning would no longer be based on historical demand but on actually materializing options sales. From the buyer's point of view, he would gain flexibility in terms of usage of capacity, thus being able to tailor capacity to his needs in the secondary and spot market. The opportunity for LH Cargo to reduce marginal costs thanks to the long-term contract market yields a benefit accruing to *both* parties. This stems from the larger welfare generated through the combination of an options and a spot market when compared with a pure spot market or a fixed contract, as has been discussed in section 4.

6 Conclusion

We have provided a game theoretic market model to value contingency contracts under demand, cost *and* price uncertainty, which demonstrates that economic efficiency can be enhanced in a market set-up consisting of a contract and a spot market versus a pure spot market. The efficiency gain is positively correlated with the marginal cost difference between capacity allocated on short notice, i.e., through the spot market, and that allocated on a long-term basis. Thus the novel market scheme we propose makes it possible to exploit this cost difference and thereby link cost management on the seller side provided by long-term planning to efficiency gains in the supply chain. We have sketched an example in the air cargo industry of how the type of contingency contract analyzed here could be implemented.

Our research lays the foundation for future work in this area: The trade-off alluded to in section 5 between marginal cost difference and the timing of the contract and the spot market is worth being incorporated explicitly into the model. Empirical

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16 Which is the lifetime of a current schedule, see Hellermann (2001).

research will shed light on further industries where the type of cost management discussed here could be put into practice via contingency contracts.

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