Outsourcing vs. in-house production: a comparison of supply chain contracts with effort dependent demand

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ABSTRACT

We analyze the effort and pricing decisions in a two facility supply chain in which one of the parties can exert costly effort to increase demand. We consider an outsourcing model in which the supplier makes the effort decision and an in-house production model in which the manufacturer decides on the effort level and we compare these two models with each other. We analyze and compare several contracts for decentralized supply chain models and we aim to find which contracts are best to use in different cases. We find the optimal contract parameters in each case and perform extensive computational testing to compare the efficiencies of these contracts. We also analyze the effect of the powers of the parties in the system and the effect of system parameters on the performances of the contracts and on the optimal values of the model variables such as price, effort and demand.

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1. Introduction

In this study, we analyze a supply chain composed of two parties and we aim to increase the efficiency of this system through contracts. For this study, we are motivated by an original equipment manufacturer (OEM) that works with a contract manufacturer (CM) for the production of one of its products. The OEM (manufacturer) outsources the production to the CM and the CM invests in the technology and expends a certain amount of effort for the production of this product. A larger investment in technology or a higher level of effort improves the quality of the product and a higher quality product results in an increased market potential (demand) for the product. In this setting, the CM essentially determines the product quality. However, the OEM is worried that the CM does not exert the appropriate level of effort to produce products of the appropriate quality. Thus, the OEM is considering to use a contract in order to effect the supplier’s effort and to increase the demand and his profits. However, the OEM cannot force the CM to exert the level of effort that the OEM wants. It is assumed that the companies cannot contract directly on the effort level (or the quality level) beforehand since quality is not always verifiable for a third party such as a court to decide on. In addition, the firms cannot identify every possible contingency and define effort in advance. Thus, they cannot write a complete contract that defines what to do in every possible situation. Because of these reasons, we assume that the quality and thus the efforts of the parties are non-contractible which is a standard assumption in much of the related research (see [1–5]).

In today’s world, there might be many reasons for an OEM to outsource the production of a product to a CM, such as the OEM might not have the required technology to make that production or outsourcing might be less costly for the OEM than in-house production. In addition, as stated by Yue et al. [6], Sawik [7] and Yu et al. [8], quality, capacity restrictions, probabilities of satisfying due dates, disruption risks, discounting schemes, reliability and flexibility of the suppliers effect the outsourcing and supplier selection decisions. In this study, we mostly focus on the cost and the quality considerations of the OEM. Since the OEM is worried about the effort level of the CM and the quality of the products, instead of outsourcing, he also considers in-house production to determine the product’s quality level himself. However, since the OEM is not as experienced in the production of the product as the CM, he might need to put more effort in production and make more investment in order to produce the same quality product that the CM produces. Thus, the effort might be more costly to the OEM compared to the cost of effort to the CM. In addition, the unit production costs for the CM and the OEM might differ from each other. The cost of production for the CM might be less than the cost of production for the OEM due to various reasons like the specialization of the CM in the production of that product or the low labor costs in the geography of the CM. However, even in those cases, the OEM can still choose to make the product himself by investing in the necessary technology for...
the production and by incurring the high production costs. Also, note that the OEM still needs to buy some raw materials from a supplier for in-house production and we assume that the OEM still uses contracts in his relationship with his supplier in the in-house production case.

Several different types of contracts are analyzed in literature in different settings (see [9–13], for surveys on supply chain coordination with contracts). Major coordination mechanisms include profit or cost sharing mechanisms, linear two part tariffs and discounts. Profit sharing mechanisms are designed to share the benefit of coordination and cost sharing mechanisms are designed to share the total cost of the supply chain between the supply chain members, whereas a two part tariff is a price discrimination technique in which the price is composed of a per-unit charge and an additional fixed fee. Quantity discount is the offer of price discount in return for increased order quantity.

It is shown that, although a contract can be very efficient in some cases, it might not perform as efficiently in some other situations. Thus, the choice of the contract to implement in the supply chain also plays an important role in coordination. Companies need to determine the right type of contract to implement depending on the specific characteristics of their business structure and the parameters of their system. In literature, researchers mostly analyze contracts in isolation from each other and aim to find fully coordinating contracts that allow arbitrary profit sharing which is defined as contracts that make the total profit of the decentralized supply chain equal to the total profit of the centralized supply chain and allow each party get an arbitrary profit or loss. These non-coordinating contracts might be preferred by the supply chain members to the coordinating ones depending on the performance of the contracts, implementation costs and system characteristics.

In this study, we will analyze two different models for supply chain coordination; the supplier effort (outsourcing) and the manufacturer effort (in-house production) models. There are several papers in literature that analyze contracts considering manufacturer or retailer effort (e.g. [14–17] etc.). For the manufacturer effort case, Cachon [11] states that coordination with an effort-dependent stochastic demand model is complex when the firms are not allowed to contract on the effort level directly. He states that the supplier fails to coordinate the supply chain with buy-back, revenue sharing, quantity flexibility or sales rebate contracts. Taylor [14] shows that he can coordinate the channel by combining a sales rebate contract with a buy-back contract. However, four parameters make for a complex contract. He et al. [17] also consider a variety of contracts to coordinate a supply chain with sales effort and price dependent stochastic demand. They show that none of the traditional contracts such as a returns policy or a revenue sharing contract can coordinate the supply chain and only the properly designed returns policy with sales rebate and penalty contract is able to achieve channel coordination. Krishnan et al. [15] also analyze the manufacturer effort and discuss coordinating contracts in this setting. Cachon and Lariviere [19] show that revenue sharing contracts cannot coordinate this supply chain, but they present a simpler quantity discount contract that achieves coordination. Netessine and Rudi [18] can also coordinate this supply chain by presenting a contract that requires simultaneous revenue and cost sharing. In addition, a linear two-part tariff contract can also coordinate the supply chain in the manufacturer effort model.

In our supplier effort models, although the effort is not contractible, we assume that once the supplier exerts the effort, the manufacturer can observe and act upon it, which is a standard assumption in much of the related research (see [4,5]). So, when the CM exerts the effort, different from OEM-effort models, the OEM can observe the CM’s effort, and act (set the sales price) accordingly. Reyniers and Tapiero [20] and Baiman et al. [21,22] analyze the supplier effort in a quality context in which the effort defines the quality of the product. Similarly, Chao et al. [24] assume that the supplier effort effects the quality level and thus affects the amount of recalls after production. They analyze two different types of cost sharing contracts based on root cause analysis under symmetric and asymmetric information in this setting and discuss their results. Zhu et al. [25] consider an outsourcing model where the buyer and the supplier both incur quality-related costs and they show that the buyer’s involvement has a significant impact on the profits. They also investigate how quality-improvement decisions interact with operational decisions. Lal [23], Chu and Desai [2] and Gilbert and Cvsia [4] also examine supplier effort in different settings, analyzing different types of contracts. We observe in this study that coordinating the supply chain in the CM effort model is not as easy as coordinating the supply chain in the OEM effort model and more complex contracts are required to coordinate the supply chain in the CM effort model.

In this paper, different from the literature, we do not specifically look for a coordinating contract but focus on the non-coordinating contracts, as well as the coordinating ones, find the optimal contract parameters and compare the performances of different contracts with respect to each other, in a setting where the market demand is a function of the market price and the effort level of the supply chain members. We also consider the powers of the supply chain members and analyze how the power structure in the system effects the outcomes of the contracts. We compare the contract performances with each other and with coordinating ones and aim to find which contracts are best to use for the companies under different situations and if it is worthwhile to look for a complex, coordinating contract when the simpler, well-known contracts cannot fully coordinate the supply chain. We also analyze how the market variables such as market price, demand, effort and profits of the supply chain members are affected with different contracts by the system parameters such as market size, price elasticity of demand, cost of effort, unit cost of production and powers of the parties. In addition, we compare the supplier effort and manufacturer effort models with each other and aim to find under which conditions in-house production is preferred to outsourcing for the manufacturer. In this paper, we aim to answer questions such as: (i) How big is the performance difference between a coordinating contract and a simpler non-coordinating one, and among the simpler contracts, which one is the best to use for the OEM and the CM under different parameter settings? (ii) How are the efficiencies of the contracts affected by the system parameters? (iii) How do the powers of the parties affect the contracts? (iv) What are the effects of different contracts on the system variables such as the market price, quality level and demand? (v) When should the manufacturer move to in-house production, when should he continue outsourcing and which contract should he use in either case?

We start our analysis by explaining our general model in the next section. Then, we analyze the centralized supply chain model in
Section 3 and then, in Section 4, we analyze the decentralized model using different types of contracts. Finally, in Sections 5 and 6, we present our numerical examples and conclusion, respectively. We present all the proofs in the online appendix.

2. Model

In this paper, first, we consider the case in which, the OEM outsources the production to a CM. In this model, the CM produces the product at a unit production cost \( c \) and sells it to the OEM at a unit price \( w \), who then sells the products to its customers at a unit price \( p \). We assume that the unit production cost \( c \) is common information. This assumption holds when the unit production cost is insignificant, as in the software industry, or when it is mostly due to components whose price is known in the industry. We assume that the CM can exert some costly effort to increase demand. In this model, first the parties agree on a contract and then depending on the contract parameters, the CM decides on his effort level \( e \) and the quadratic form implies increasing marginal demand \( \text{Higher effort cost.} \)

The first-best solution that maximizes the expected total supply chain profit satisfies the following:

\[
\begin{align*}
\text{Sales price: } p^c & = \frac{c(bk-2)+a}{2(bk-1)} & \text{Expected quantity demanded in the market: } q^c & = \frac{bk(a-bc)}{2(bk-1)} \\
\text{Effort level: } e^c & = \frac{a-bc}{bk-1} & \text{Expected total supply chain profit} & : E_Z^c = \frac{k(a-bc)}{4(bk-1)} \\
\end{align*}
\]

Note that when the manufacturer moves to in-house production, the solution to the centralized supply chain will still be the same as above except that the effort cost \( k \) will be replaced by \( k_m \) and the unit production cost \( c \) will be replaced by \( c_e + c_m \).

3. Centralized supply chain model

The centralized supply chain can be interpreted as a single firm that both makes the production and sells the product to the customers. If the manufacturer and the supplier belong to the same firm and the whole supply chain is controlled by a single decision agent, then this agent wants to maximize the expected total supply chain profit. We call the optimal solution for the centralized supply chain model as the first-best solution as stated below.

Lemma 1. The first-best solution that maximizes the expected total supply chain profit satisfies the following:

4. Decentralized supply chain with contracts

It is commonly seen in the literature that when the supply chain is decentralized and each party tries to maximize its own profit, a considerable decrease in the total supply chain profit exists and the supply chain suffers from inefficiencies. Supply chain members use contracts to eliminate these inefficiencies in the supply chain and to achieve the first best solution. However, the optimal solutions and the efficiency of the contracts are deeply affected by several factors and the parameters of the system.

Note that a contract that maximizes the total supply chain profit might not be in the best interest of one of the parties. We assume that the manufacturer and the supplier have reservation profits \( R_{pm} \) and \( R_p \), respectively, and they reject to participate in any contract that causes them to get a profit less than their reservation profits. Note that the reservation profits of the supply chain members depend on their powers in the industry and other business opportunities that they have in the market.

For both the outsourcing and the in-house production models, there are mainly three decision stages. In the first stage, the OEM designs a contract and needs to determine the optimal contract
parameters. In the second stage, the CM needs to decide whether to accept the contract or reject it. For the outsourcing model, in the second stage, the CM also needs to decide on the optimal effort level if she decides to accept the contract. Finally, in the last stage, the OEM needs to decide on the market price. For the in-house production model, the OEM also needs to decide on the effort level in the last stage. For all the contract types that we consider in the following sections, to determine the optimal solutions in these three stages, we solve the problems going backwards and solve the third stage problem first. We find the optimal price that the OEM should set as a function of the contract parameters and the effort level \( e \). Then, using this optimal price function, we determine the optimal value of the effort level \( e \) in terms of the contract parameters. In this model, we assume that the OEM is the Stackelberg leader and designs the contract. Thus, finally, we determine the optimal contract parameters that the OEM should set using (4.1), where \( Z_m \) denotes the expected profit of the OEM and \( Z_s \) denotes the expected profit of the CM. Note that, if the objective function of (4.1) is less than \( RP_{cm} \), no contract will be signed.

Max \( Z_m \)

s.t. \( Z_s \geq RP_s \) \hspace{1cm} (4.1)

In this study, different from the literature, we also investigate the effects of the powers of the parties on the resulting contracts using varying \( RP_s \) values. Note that for a more powerful CM in the supply chain, the OEM needs to solve the problem (4.1) using a higher \( RP_s \) value since a powerful CM can extract more profit from the OEM. In this study, we analyze how the efficiency of the contracts will be affected by the powers of the parties and which contracts would be better to use for each party depending on their powers and the parameters in the system. Note that if a contract can fully coordinate the supply chain with arbitrary profit sharing, the solutions to the problems (4.1) for different \( RP_s \) values all result in the same market price, effort, demand and total supply chain profit and they are all equal to their values in the first best solution independent of the powers of the parties and the values of the reservation profits. But the profit of the OEM will be affected by the reservation profit. However, if the contract cannot fully coordinate the supply chain, then the results of the problem (4.1) for different \( RP_s \) values might be very different from each other and the powers of the parties play a much more important role in the determination of the final solution.

Observe that, due to Lemma 1, if there exist fully coordinating contracts with arbitrary profit sharing for both the outsourcing and in-house production cases, the OEM prefers outsourcing to in-house production if

\[
\frac{k(a-bc)^2}{4(bk-1)} - RP_{CM} \geq \frac{k_m(a-b(c_s+c_m))^2}{4(bk_m-1)} - RP_s
\]

where \( RP_{CM} \) denotes the reservation profit for the CM in the outsourcing case and \( RP_s \) denotes the reservation profit for the supplier in the in-house production case. For example, a simultaneous revenue and cost sharing contract, in which the OEM shares both the cost of effort and the revenue with the other party can coordinate the supply chain. We consider a contract such that the OEM pays a portion \( 0 \leq \beta \leq 1 \) of the effort cost and gets \( \alpha = \beta \) of the revenue, while the other party pays the remaining \( 1-\beta \) of the effort cost and gets the remaining \( 1-\alpha \) of the revenue. If the OEM also pays a unit wholesale price \( w = \alpha c \) to the CM in the outsourcing case and \( w = \alpha c_s + (1-\alpha) c_m \) to the supplier in the in-house production case, then such a contract coordinates the supply chain and allows arbitrary profit sharing with a suitable choice of \( \alpha \) for both the outsourcing and in-house production models. However, note that such a contract would mean sharing everything among the parties and this type of a contract might not be preferred by the supply chain members. In addition, the implementation of this contract might be very costly or hard due to the need to new information technologies, control systems and the trust issues.

Note that it is not always possible to find coordinating contracts and even if it is found, it might not be preferable by the supply chain members due to the complexity, implementation costs and the risks of the contract and a simpler contract might be preferred if the simpler contract does not cause too much decrease in the profits compared to the more complex but coordinating contracts, if they exist. In the following sections, we analyze several types of contracts, and compare the efficiencies of these contracts with each other. We note that some of these contracts are studied in the literature in similar settings in isolation from each other. For the brevity of the paper, we only present the results related to the efficiency and the comparison of contracts rather than presenting the optimal contract parameters and the solution values.

### 4.1. Wholesale price only contract

A wholesale price only contract (WPC) is one of the simplest and widely used contracts in the literature. In this contract, only the unit wholesale price \( w \) is determined in the contract.

In the supplier effort model, for any given \( RP_s \) value, we find the optimal wholesale price for the OEM and the resulting system variables and we observe that when the OEM exerts effort, the expected total supply chain profit with a wholesale price only contract is up to 25% less than the expected total supply chain profit in the centralized model and the OEM exerts only half the effort and the mean demand will be half the mean demand of the first best solution. The efficiency loss, in terms of the expected total supply chain profit, is even more when the CM exerts the effort. However, when the OEM is more powerful than the CM, he can negotiate with the CM and can persuade him to a lower wholesale price \( w \). In that case, the OEM’s expected profit will increase and the CM’s expected profit as well as the efficiency loss will decrease. In addition, in the manufacturer effort model, when \( w = c_m \), the supply chain will be coordinated and the first best solution will be achieved, but the supplier might not agree to such a contract since the manufacturer gets everything and the supplier’s profit will be zero in that case. Also note that the OEM will exert a higher level of effort and mean demand in the market increases as the OEM gets more powerful and as the wholesale price decreases. In addition, the market price set by the OEM increases if \( bk_m \leq 2 \) and decreases otherwise as the OEM gets more powerful. However, in the supplier effort model, as the wholesale price decreases as a result of the OEM being more powerful, the CM will exert a lower level of effort, the OEM will set a lower market price and mean demand in the market increases.

We also observe that when a wholesale price only contract is used, then both the supplier and the manufacturer would get a higher profit when the OEM moves to in-house production and exerts the effort himself instead of outsourcing the production to the CM, if all the parameters were the same in both cases. This is due to the fact that in the OEM effort model, the OEM can coordinate the effort and the price decisions in a much better way to obtain a higher profit than the supplier effort case in which the CM makes the effort decision and the OEM makes the price decision. As a result, both the CM and the OEM get a higher profit due to the increase in the supply chain’s total profit in the OEM effort model. However, as the difference \( k_m - K \) or \( c_t + c_m - c \) increases, the profits with in-house production would decrease.
and outsourcing might become more profitable. As a result, if the OEM could make the production at the same costs as the CM, he would choose to make the production himself instead of outsourcing. The difference between the effort costs and the unit production costs for the CM and the OEM constitutes the main reason for outsourcing the production.

4.2. Linear two part tariff contract

A linear two part tariff (fixed fee) contract (LC) is a widely used tool in franchising industry. In this contract, in addition to the wholesale price, there is a side payment that one of the parties commit to pay to the other. Recall that, in the wholesale price only contract, the supplier charges a wholesale price higher than his unit cost to the manufacturer which effects the manufacturer’s decisions and causes the inefficiencies in the supply chain. The motivation for this contract is to persuade the supplier to decrease the wholesale price in exchange for the side payment. We denote this contract as \( (w, t) \) where \( w \) is the unit wholesale price and \( t \) is a one-time fixed fee. So, if the manufacturer orders \( q \) units from the supplier, he has to pay an amount equal to \( wq + t \).

**Theorem 1.** In the supplier effort model, a linear contract can not fully coordinate the supply chain. The optimal wholesale price and the resulting effort level, market price and the total supply chain profit are independent from the powers of the parties and the total supply chain profit can be shared in any way by a suitable choice of \( t \).

We see that the total supply chain profit, effort, price and demand values are unaffected by the powers of the parties in the contract negotiations and the value of \( R_{P_e} \). However, the parties negotiate on the value of \( t \) to extract more from the total supply chain profit and use their powers to set the value of \( t \).

**Corollary 1.** The efficiency of the linear contract in the supplier effort case, that is the ratio \( Z_{P_e}^L / Z_{P_e}^C \), increases as the value of \( b_k \) increases and goes to \( 1 \) as \( b_k \to \infty \).

Due to the above corollary, we can state that linear contracts can be very beneficial to use in industries where the cost of effort is high, (e.g. if it is very costly to produce high quality products) or the demand is very sensitive to price (e.g. very competitive markets). However, in other cases, the efficiency of this contract might be very low.

**Theorem 2.** In the manufacturer effort model, independent of the powers of the parties, the linear two part tariff contract with contract parameters \( (w, t) \) can coordinate the supply chain.

For the manufacturer effort model, the above contract can be thought as selling the production to the manufacturer at a price \( t \) where the parties negotiate on the selling price \( t \). However, note that selling the production to the manufacturer might not be an implementable strategy for both the supplier and the manufacturer and the parties might not be willing to use this contract in their business even though it can coordinate the supply chain. Thus, we also look for other contracts that might be more suitable for the companies to implement.

4.3. Quantity discount contract

With a quantity discount contract (QDC), the supplier charges different prices for different quantities ordered by the manufacturer to induce the manufacturer take actions that will increase the demand. In a quantity discount contract, we define \( w(x) \) as the unit wholesale price which is a function of the quantity ordered. We consider both “all unit quantity discounts” (i.e. the transfer payment is \( w(x)x \) when demand is equal to \( x \)) and the “marginal unit quantity discounts” (i.e. the transfer payment is \( \int_{y}^{x} w(y) \, dy \) when demand is equal to \( x \)).

For the manufacturer effort case, Cachon and Lariviére [19] analyze a similar model and for their model, they present an all unit quantity discount contract in which the wholesale price has the form \( w(x) = A - Bx \). They show that for appropriate values of \( A \) and \( B \) the quantity discount contract can coordinate the supply chain with arbitrary profit sharing. For our setting, in addition to a quantity discount contract that is similar to the one in Cachon and Lariviére [19], we show that there are several types of quantity discount contracts that can coordinate the supply chain in the manufacturer effort model as stated in the following proposition.

**Theorem 3.** In the manufacturer effort model,

(i) an all unit quantity discount contract with the unit wholesale price function

\[
w(x) = (1-x) \left( \frac{a(1+\delta^2) + 2\delta \sigma x}{(1+\delta^2)b} + \frac{a-b(c_1+c_m)}{b(bk_m-1)} \right) + z(c_1+c_m)-c_m
\]

can coordinate the supply chain with arbitrary profit sharing by a suitable choice of \( 0 \leq x \leq 1 \), assuming that the standard deviation of demand, \( \sigma \) is in the form \( \sigma = \gamma + \delta(a-bp + e) \) where \( \gamma \) and \( \delta \) are some known constants,

(ii) a marginal unit quantity discount contract can coordinate the supply chain,

(iii) a wholesale price function with a single price break point (i.e. the wholesale price is \( w_1 \) when the demand is lower than a certain level \( x \) and the wholesale price is \( w_2 < w_1 \) when the demand is higher than \( x \)), which is simpler and more common in practice, can also coordinate the supply chain.

Even though we can find several types of quantity discount contracts that can coordinate the supply chain in the manufacturer effort model, we observe that similar types of quantity discount contracts cannot coordinate the supply chain in the supplier effort model. However, we observe that the efficiency of a quantity discount contract increases as the supplier gets more powerful.

4.4. Revenue sharing contract

According to a revenue sharing contract (RSC), the manufacturer commits to share a portion of his revenue with the supplier, in addition to the wholesale price per unit that he pays to the supplier. Since the supplier gets a portion of the manufacturer’s revenue with this contract, the supplier is motivated to decrease the wholesale price or to exert more effort to increase the revenue of the manufacturer. Cachon and Lariviére [19] provide an analysis of these contracts in a more general setting. Mortimer [26] and Dana and Spier [27] are other papers that analyze revenue sharing contracts.

We denote this contract as \((w, z)\) where \( w \) is the unit wholesale price and \( 0 \leq x \leq 1 \) is the portion that the manufacturer gets from the revenue. The supplier gets the remaining \( 1-x \) of the revenue. We observe that a revenue sharing contract cannot coordinate the supply chain and achieve the first best solution in either the supplier effort or the manufacturer effort models. However, note that, in an extreme case, when \( R_{P_e} = 0 \), using contract parameters \((w = c, x = 1)\), the revenue sharing contract results in the same solution as the first best solution in the manufacturer effort model, but this contract does not allow arbitrary profit division and the supplier ends up with 0 profit while the manufacturer extracts all the profit. Thus, when \( R_{P_e} > 0 \), the supplier would not
agree to such a contract. Similarly, for the supplier effort model, the revenue sharing contract approaches the first best solution when the reservation profit of the supplier approaches the expected total supply chain profit in the centralized case, that is when \( R_{P} = -E[Z_{SC}^{eff}] \). In that case, using contract parameters \((w = c, \alpha = 0)\), the supplier can extract all the profit while the manufacturer gets nothing. However, the manufacturer would not agree to such a contract when \( R_{P} > 0 \). We state the effect of the powers of the supply chain members on the efficiency of the revenue sharing contract in the following theorem.

**Theorem 4.** The total supply chain profit with a revenue sharing contract increases as the manufacturer gets more powerful in the manufacturer effort model, that is the efficiency of the revenue sharing contract increases as \( R_{P} \) decreases. On the other hand, in the supplier effort model, the efficiency of the revenue sharing contract decreases as the manufacturer gets more powerful.

4.5. Cost sharing contract

With a cost sharing contract (CSC), the manufacturer and the supplier share the cost of effort and we denote this contract as \((w, \beta)\) where \( w \) is the unit wholesale price and \( 0 \leq \beta \leq 1 \) is the portion of the cost that the manufacturer pays. The supplier pays the remaining \( 1 - \beta \) of the effort cost.

We observe that a cost sharing contract cannot coordinate the supply chain and achieve the first best solution except in the case when \( R_{P} = 0 \). In this extreme case, when \( R_{P} = 0 \), the cost sharing contract can achieve the first best solution using contract parameters \((w = c, \beta = 1)\) for both the manufacturer effort model and the supplier effort model. However, such a contract will not be implementable when \( R_{P} > 0 \) since the supplier gets nothing with this contract. In addition, different from the revenue sharing contract, with a cost sharing contract, the total supply chain profit increases as the manufacturer gets more powerful in both the manufacturer effort and the supplier effort cases as stated in the following theorem.

**Theorem 5.** The total supply chain profit with a cost sharing contract increases as the manufacturer gets more powerful in both the manufacturer effort and the supplier effort models. In other words, the efficiency of the cost sharing contract increases as \( R_{P} \) decreases.

5. Computational analysis

In this section, we compare the contracts in Section 4 through numerical analysis.

5.1. Supplier effort model

In this section, we analyze the outsourcing model in which the CM makes the production and exerts the effort. For this analysis, we use the parameters \(a = 100, b = 3, c = 5\) and \(k = 1\). In addition, we assume that the demand is a random function with mean \( a - bp + e \) and standard deviation \( \sigma = \delta(a - bp + e) \) where \( \delta = 0.3 \). For this case, the optimal solution for the centralized supply chain model will result in a sales price of \( p^{seWPC} = 26.25 \) and an effort level of \( e^{seWPC} = 42.5 \). As a result, the expected demand in the market is \( q^{seWPC} = 63.75 \) and the expected total supply chain profit is \( E[Z_{SC}^{eff}] = 903.125 \). We will use the expected total supply chain profit as our base level to compare the efficiency of the contracts.

When the CM and the OEM use a wholesale price only contract, the CM will ask for a wholesale price of \( w^{seWPC} = 22 \) which will lead the CM get an expected profit of \( E[Z_{SC}^{eff}] = 361.25 \) which is the highest expected profit that the CM can get with this contract. Then, the OEM will get an expected profit of \( E[Z_{SC}^{eff}] = 216.75 \) with this \( w \) and the expected total supply chain profit will be \( E[Z_{SC}^{eff}] = 578 \) which is 36\% less than the expected total supply chain profit in the centralized case. The market price, effort level and the mean demand in the market will be \( p^{seWPC} = 30.5, e^{seWPC} = 17, q^{seWPC} = 25.5 \) in this case.

However, note that, if the OEM is more powerful compared to the CM in this industry, then he can persuade the CM to work with a lower wholesale price which will increase the OEM’s profit and decrease the CM’s profit. It is also the case for the other types of contracts and different \( R_{P} \) values result in very different solutions for the contracts. In Fig. 1, we present the efficiencies of the contracts (i.e. ratios of the expected total supply chain profits with different contracts over the expected total supply chain profit in the centralized case which was calculated to be 903.125), as the supplier’s power increases and as the supplier needs to get a higher profit in order to participate in the contract. The OEM’s profit can also be deducted from this figure, and it is the difference between the total supply chain profit and the supplier’s profit. Using Fig. 1, we compare the efficiencies of different types of contracts and we also analyze how these efficiencies will change as the supplier’s reservation profit changes.

We observe from Fig. 1 that if the supplier has little power and the manufacturer is the powerful party in the system, a cost sharing contract would benefit the manufacturer the most assuming that the supplier gets the same profit under all contracts. However, as the supplier gets more powerful, we observe that the efficiency of the cost sharing contract decreases while the efficiency of the revenue sharing contract increases. Thus, when the supplier becomes the powerful party in the system, a revenue sharing contract gives the best results and the manufacturer’s optimal strategy will be to use a revenue sharing contract.

When we analyze the other contracts in this case, we observe that there is an efficiency loss of more than 25\% in the total supply chain profit with a wholesale price only contract and a linear contract cannot improve this performance very much. In addition, quantity discount contract and revenue sharing contract cannot benefit the system very much when the CM has little power. However, as the CM gets more powerful, the efficiency of both the revenue sharing contract and the quantity discount contract increases and they can improve the total supply chain profit significantly. Contrary to the revenue sharing and the quantity discount contracts, a cost sharing contract has the highest efficiency when the CM has little power in the system and the efficiency of this contract decreases substantially as the CM gets more powerful. Thus, cost sharing contract would be the best contract to use for a powerful manufacturer. In real life, when the supplier is the one making the necessary investments for the production, we observe that powerful manufacturers help their suppliers by sharing some of their costs and helping them in their investments while powerful suppliers are offering quantity discounts or some revenue sharing mechanisms that include a lower wholesale price, in order to increase the demand and increase their profits, which seems consistent with our results.

Note that the choice of the best contract to use might also depend on some other factors like the implementation costs of the contracts, technology required for implementation, trust issues among the supply chain members and the risks involved with the use of the contracts. Although we do not consider these factors explicitly in our models, observe that we can account for them, by updating the profit levels in our models. For example, recall that when the manufacturer is the powerful party in our model, a cost sharing contract under the supplier effort model gives the best results as seen in Fig. 1. However, if this contract has a certain implementation cost, we can decrease the resulting total supply
chain profit to cover the implementation cost and then observe if the cost sharing contract is still the best one to use or not. Similarly, if there is a risk factor involved with this contract, the manufacturer might decide if the extra profit with this contract is worth the extra risk or not. In addition, some of these factors can be captured by the reservation profits of the companies and different reservation profits might be required in comparing different contracts. In that case, we can still compare the efficiency of the contracts by looking at Fig. 1 and comparing the total supply chain profits at different supplier profit levels for different contracts. For example, the supplier might require a higher profit with a revenue sharing contract \((RPs_{RSC} = 400)\) for the revenue sharing contract than he requires with a cost sharing contract \((RPs_{CSC} = 300)\) since the supplier might see the revenue sharing contract as riskier. So, even in such cases, we state that our models can still be a valuable tool for managers to choose the best contract to implement.

We also note that the solutions obtained with the contracts are deeply affected by the values of the system parameters. Thus, we also analyze the effects of the parameters on the results of our models. We observe that the market size \((a)\), and the unit cost of production \((c)\) in the supplier effort model have no effect on the efficiency of the contracts, assuming that the CM’s portion of the total supply chain profit remains constant when \(a\) or \(c\) changes, and we obtain the same graph as Fig. 1 for varying \(a\) and \(c\) values. In addition, we observe that the efficiency of the quantity discount contract is independent from \(\delta\) (the coefficient for the standard deviation of the demand function).

We observe that, contrary to the effects of the market size or the unit cost of production, the price sensitivity of demand \((b)\) and the cost of effort for the CM\((k)\) have significant effects on the efficiency of the contracts. In Fig. 2, we show the changes in the efficiency of the contracts when we increase the value of \(b\) to 10. When \(b=10\), the expected total supply chain profit in the centralized case will decrease to \(E[Z_{sc}^{RSC}] = 69.44\) and thus we use this value in the calculation of the efficiency of the contracts.

When we compare Fig. 1 with Fig. 2, we observe that, as \(b\) increases, the efficiency of all the contracts will increase and the values will shift upwards. However, note that the actual profits will decrease with an increase in \(b\). As we increase \(k\), we obtain similar results to Fig. 2 and we observe that the efficiency of the contracts increases with \(k\), too. We also observe that a linear contract and quantity discount contract might result in very poor performances, especially for small values of \(b\) and \(k\). However, their performances improve as the value of \(b\) or \(k\) increases and for very high values of \(b\) or \(k\), they perform very close to the first-best solution. A revenue sharing contract performs better than a linear and quantity discount contract. A cost sharing contract is not affected as much as the other contracts with a change in \(b\) or \(k\).

Recall that the efficiency loss in the expected total supply chain profits with any contract except the cost sharing contract, is...
mostly due to the CM’s not having the required incentive to exert the optimal level of effort. However, observe that when b or k increases, the optimal effort level in the first best solution decreases, that is exerting a low level of effort is the best policy in the centralized case. Effort becomes, comparatively, a less important and more costly tool than the price, in the systems with high values of b or k and thus, the efficiency losses due to not being able to achieve the right level of effort with contracts, except the cost sharing contract, will decrease as b or k increases. However, with a cost sharing contract, since the supplier already exerts a higher level of effort than the first best solution, the increase in b or k does not improve the efficiency of the cost sharing contract.

5.2. Manufacturer effort model

In this section, we analyze the case when the manufacturer moves to in-house production and decides on the effort level himself. For this study, we use the values $c = 3$, $c_m = 2$ and $k_m = 1.2$ in addition to the parameters used in Section 5.1. Observe that the total unit production cost for the in-house production and outsourcing are the same and the only difference is the cost of effort for the CM and the OEM. The OEM’s cost of effort is assumed to be 20% higher than the CM’s cost of effort since the CM is assumed to be more experienced in the production of this product.

In this case, the optimal solution for the centralized model will be $p^{wpc} = 24.6$, $e^{wpc} = 32.7$, $q^{wpc} = 58.85$ and $E[Z_{mc}] = 833.65$. Observe that when the production is done in-house, there is about an 8% decrease in the expected total supply chain profit compared to the expected total supply chain profit in the supplier effort model, due to the increase in the cost of effort for in-house production.

When the companies use a wholesale price only contract, the supplier will ask for a wholesale price of $w^{wpc} = 17.17$ which will lead the supplier to get an expected profit of $E[Z_{mc}] = 416.83$ which is the highest expected profit that the supplier can get with this contract in this case. Then, the OEM will get an expected profit of $E[Z_{mc}] = 208.41$ with this $w$ which is less than the OEM’s profit with a wholesale price only contract in the outsourcing case. Thus, moving to in-house production would not benefit the OEM if he uses a wholesale price only contract. Also, observe that the expected total supply chain profit will be $E[Z_{mc}] = 625.24$ with a wholesale price only contract, which is 25% less than the expected total supply chain profit in the centralized case for this model. The market price, effort level and the mean demand in the market will be $p^{wpc} = 28.97$, $e^{wpc} = 16.35$, $q^{wpc} = 29.4$ showing that lower quality products are produced and sold at a lower price than the outsourcing case when a wholesale price only contract is used due to the increasing cost of effort.

However, note that similar to the outsourcing case, if the OEM is more powerful compared to the supplier, then a lower wholesale price could be used, which will increase the OEM’s profit and decrease the supplier’s profit. In Fig. 3, we present the efficiencies of the contracts for the manufacturer effort model as the supplier’s reservation profit increases. In this Figure, the horizontal axis shows the supplier’s expected profit and the vertical axis shows the ratio of the expected total supply chain profit under different contracts over the expected total supply chain profit for the centralized case. Using Fig. 3, we compare the efficiencies of different types of contracts and also analyze how these efficiencies will change as the supplier’s reservation profit increases. Since the linear contract and the quantity discount contract can coordinate the supply chain in this case, the efficiencies of these contracts are equal to 1 and unaffected by the powers of the companies. However, we observe that the efficiencies of the other contracts decrease as the supplier gets more powerful in this system. In this case, since the manufacturer is the one that exerts the effort, as the supplier’s power increases and the manufacturer’s power decreases, the manufacturer exerts less and less effort due to its costs, which decreases the total supply chain profits. We also observe that the wholesale price only contract and the cost sharing contract have similar performances and they have the lowest efficiencies. Sharing the effort costs cannot improve the profits very much over a wholesale price only contract. A revenue sharing contract has a higher efficiency than a cost sharing contract for any supplier power level and the difference increases as the supplier gets more powerful. Observe that the efficiency loss with any of these three contracts can be up to 30% as the supplier gets more powerful.

We also note that the reservation profit of the supplier might be different for each contract or different contracts might require different implementation costs and these differences also have an important effect on the choice of the right contract for the manufacturer. For example, even though the linear contract or the quantity discount contract can coordinate the supply chain, the manufacturer might choose the revenue sharing contract, especially when the supplier has little power, if the linear contract or the quantity discount contract has high implementation costs or the supplier requires high reservation profits under these contracts due to the risks in these contracts.

![Fig. 3. Comparison of the efficiencies of the contracts as the supplier power increases for the manufacturer effort model.](image-url)
We also present Fig. 4 to compare the total supply chain profits in the outsourcing and in-house production models. For the clarity of the figure, we only show the contracts that have the best performances in each model and plot the expected total supply chain profits with these contracts as the supplier’s profit level increases. We observe from Fig. 4 that when the CM has little power in the industry, outsourcing while using a cost sharing contract would benefit the manufacturer the most. However, when the parties have similar powers in the industry, in-house production with a linear or quantity discount contract gives the best results. On the other end, when the supplier is the powerful party in the system, the manufacturer’s optimal strategy will be to continue outsourcing while using a revenue sharing contract.

When we analyze the effects of the parameters on the results of our models, similar to the supplier effort model, we observe that the market size \( a \), the unit cost of production for the supplier \( c_s \), the unit cost of production for the manufacturer \( c_m \) and \( \delta \) (the coefficient for the standard deviation of the demand function) have no effect on the efficiency of the contracts and we obtain figures very similar to Fig. 4 for varying \( a, c_s, c_m \) and \( \delta \).
values. However, note that as the unit cost of production for the supplier \( (c_s) \) or the unit cost of production for the manufacturer \( (c_m) \) increases while everything else remains constant, the values in Fig. 4 related to manufacturer effort will shift downwards since the actual profits will decrease with an increase in the production costs even though the efficiencies of the contracts remain the same.

Next, we look at the effects of the price sensitivity of demand \( (b) \) and the cost of effort \( (k_m) \) on the efficiency of the contracts. In Fig. 5, we show the efficiencies of the contracts when we increase the value of \( b \) from 0 to 10. When we compare Fig. 5 with Fig. 3, we observe that, as \( b \) increases, the efficiencies of all the contracts increase and all the values shift upwards. We also observe that the cost sharing contract gives lower results to the wholesale price only contract and it does not have much gain over the wholesale price only contract when \( b \) gets higher. Also note that as \( b \) increases, the supply chain profits will decrease and even though the efficiency of the contracts increase with \( b \), the supply chain members obtain lower profits for high levels of \( b \). Similar to Fig. 4, we also present Fig. 6 for \( b = 10 \) and observe that as \( b \) increases, in-house production is desirable in a wider range of the expected supplier profit values. In addition to a linear contract or a quantity discount contract, a revenue sharing contract for the manufacturer effort model also gives better performance than all the contracts in the supplier effort model when the supplier and the manufacturer have similar powers. Similar to the effect of \( b \), as \( k_m \) increases, the profits in the system will decrease in the manufacturer effort model, even though the efficiencies of all contracts increase with \( k_m \). We obtain a similar graph as in Fig. 5 for high levels of \( k_m \). Thus, as \( k_m \) increases while \( k \) remains constant, in-house production will become less desirable than outsourcing.

We also analyze the values of the system variables such as market price, effort level and mean demand in the market and present the results in Appendix B in the online supplement for both the outsourcing and in-house production cases.

6. Conclusion

In this paper, we consider a two facility supply chain in which one of the parties can exert costly effort to increase demand. We analyze the effort and pricing decisions in the supply chain to maximize the profits of the supply chain members. We consider centralized and decentralized versions of the model and for the decentralized setting, we analyze and compare several different contracts with each other.

We observe that there are some contracts that can fully coordinate the supply chain and achieve the profits of the centralized model when the manufacturer makes the effort decision. Namely, a linear contract, a quantity discount contract and a simultaneous revenue and cost sharing contract can coordinate the supply chain in the manufacturer effort model. However, when the supplier is the one exerting the effort, only a simultaneous revenue and cost sharing contract can coordinate the supply chain. However, the supply chain members might not prefer to use these coordinating contracts due to their complexities, risks, implementation costs and special circumstances of the relations in the supply chain. Thus, we also focus on the other contracts and observe that, when the supplier exerts effort, a linear contract and a quantity discount contract result in very poor performances in most cases, especially for small values of price sensitivity of demand, \( b \) and cost of effort, \( k \). We observe that, when the supplier is exerting the effort, a revenue sharing contract is preferable to a cost sharing contract in industries with powerful suppliers while a cost sharing contract would perform much better in industries with powerful manufacturers. However, when the supplier and the manufacturer have similar powers, moving to in-house production and using a linear contract or a quantity discount contract might also give the best result for the manufacturer depending on the extra cost of effort and the unit costs of production. We also observe that the market size and the unit cost of production do not have any effect on the contract performances.

Of course, real world situations have many more and complex characteristics that are not captured by the model in this paper. There might be different system characteristics than we study in this paper. For example, it might be possible for the OEM to commit to the decision on the market price prior to the CM’s decision on effort level to gain first mover’s advantage. In such a setting, we can show that the OEM can coordinate the supply chain using a linear contract or a cost sharing contract which cannot coordinate the supply chain in our supplier effort model. However, we also observe that a wholesale price contract, a quantity discount contract and a revenue sharing contract are still not able to coordinate the supply chain even when the OEM commits to market price before the supplier’s effort decision. In addition, the structure of the demand function might affect the efficiencies of the contracts and demand functions other than the linear case can be analyzed. In the future, we also suggest evaluating models where the parties have asymmetric information about each other or where the effort of the supplier cannot be observed by the manufacturer even though they have symmetric information. Also, contracts in competitive markets in which there exists multiple suppliers or manufacturers can be analyzed. In all these models, the parties need to develop good strategies and contracts to coordinate the supply chain and to increase their profits.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.omega.2010.06.002.

References


