Repeated Contracts for Supply Chain Coordination: A Review and Future Directions

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Abstract

Supply chain coordination with contracts has emerged as one of the key strategies to reduce the inefficiencies arising from conflicting objectives of agents in a supply chain. In this paper, we critically analyze the literature on repeated contracts that are designed for mitigating inefficiencies in supply chains. We also provide some directions for future research in repeated contracts for supply chain coordination.

Keywords: Supply chain coordination; Repeated contracts

1 Introduction

In a typical supply chain, there are conflicting objectives of multiple agents. These conflicting objectives reduce the overall supply chain performance. Supply chain coordination with contracts has emerged as one of the key strategies to mitigate the inefficiencies due to conflicting objectives. The current literature on supply chain coordination is predominantly limited to one-shot contracts; however, Cachon (2003) observes that most supply chain interactions are long term with many opportunities to renegotiate. If the contracting parties can “commit” to a single comprehensive long-term contract at the contract design stage, there is no significant complexity in analyzing optimal long-term contracts. These long-term contracts are complete—the terms of the contract are completely specified ex ante. These contracts assume that the contracting parties must each foresee all the relevant contingencies and can explicitly define them in the contracts. Long-term contracts, in case of non-compliance, depend on the courts for enforcement.

The above mentioned literature on complete contracts abstracts away from the fact that most long-term contracts are incomplete. Milgrom and Roberts (1990, p. 61) note, “[a]ny contract that calls for the future delivery of a good or service, the future provision of capital, or the future performance of work must be incomplete. That is, a contract can never specify exactly what actions
are to be taken and what payments are to be made in all possible future contingencies”. This is because the contracting parties cannot perfectly foresee all the future contingencies that affect the contractual commitments; and, it is costly to write unambiguous contracts. Furthermore, incomplete contracts can exist because some clauses in contracts are non-verifiable ex post like product or service quality, demand forecasting, hence cannot be enforced through courts.

The response to this incompleteness of contracts is relational contracting in which the contracting parties can rely on long-term relationship to provide sufficient incentives (or mal-incentives) for coordination. These are also called repeated contracts. Milgrom and Roberts (1992, p. 132) mention, “[i]n situations where reasonably complete contracts are too costly or impossible, actual contracts are relational”. These informal contracts are modeled as repeated games and are based on folk theorem—“repetition can yield cooperation”. In the event of non-compliance, repetition provides a credible future punishment threat which induces each party to cooperate. Levin (2003), Doornik (2006), and Samuelson (2006) provide good introduction to relational contracts.

One example of relational contracting in supply chain context is between Toyota and its suppliers. The relational contracts frame the long-term relationship between Toyota and its suppliers rather than having very specific and complete contractual terms. Only target quantities are indicated and the price is not stipulated. However, prices can be adjusted twice in a year based on cost and design changes. For further discussion on these relational contracts, we suggest the case “Johnson Controls, Inc.—Automotive Systems Group The Georgetown, Kentucky plant” (Milgrom and Roberts, 1997).

Based on the above discussion, in this paper, we critically analyze the literature on relational contracts that are designed for mitigating inefficiencies in supply chains and provide some directions for future research on relational contracts for supply chain coordination. In Section 2, we describe a model of repeated contracts for supply chain coordination where inefficiency is due to asymmetric information about the demand forecasts. The other literature on relational contracts designed for attenuating different inefficiencies in supply chain coordination is discussed in Section 3. Our review indicates that current literature on relational contracts for supply chain coordination is scant. In Section 4, we conclude this review with comments and future directions.

2 A Model of Repeated Contract

In this section, we consider canonical papers on relational contracts by Ren et al. (2006, 2010). In a supply chain, sharing forecast information of demand is a critical component for effective coordination. Ren et al. (2006, 2010) discuss infinitely repeated contracts for supply chain coordination under asymmetric information about the demand forecasts. The objective in Ren et al. (2006, 2010) is to induce truthful forecast sharing and system-optimal capacity investment in a supply chain within linear price contract framework. In these repeated contracts, they consider two different types of strategies—trigger and review strategies. They show that the trigger strategy can induce truthful forecast sharing and system-optimal capacity investment. However, the
trigger strategy involves the loss of efficiency due to the punishment phase; and, in such cases, they show that the review strategy is more efficient than the trigger strategy in achieving the desired objectives. One of the key assumption in their work is that the defection is easy to detect. In this review, we are not considering the discussion on the review strategies.

2.1 One-Shot Contract

1. The customer faces a random market demand $\theta \cdot X$. Here $\theta$ is a demand size parameter and can take two values: High $\theta_h$ and Low $\theta_l$. The high market demand is $D_h = \theta_h \cdot X$ and the low market demand is $D_l = \theta_l \cdot X$. The probability that $\theta = \theta_l$ is $P(\theta = \theta_l) = \alpha$ and $P(\theta = \theta_h) = 1 - \alpha$. It is assumed that $\theta$ is independent of $X$ and their distributions are common knowledge.

2. The supplier, being more away from the market, has more noisy observations. In this paper, the authors model this additional level of uncertainty by adding a white noise $e$ with mean 0 and variance $\sigma^2$. Hence, the supplier’s demand are $D'_l = \theta_l \cdot X + e$ with CDF $F_l(\cdot)$ and $D'_h = \theta_h \cdot X + e$ with CDF $F_h(\cdot)$.

3. The cost of supplier’s unit capacity is $c$ and it charges the customer a price of $r$ for each unit allocated and utilized. For unused units, the supplier incurs a unit holding cost $h$.

4. The customer earns a unit revenue $p$ for each unit of capacity allocated and utilized; and, in case of unsatisfied demand, incurs a unit cost of $g$.

5. In the one-shot game, Ren et al. (2006, 2010) show that the supplier ignores the customer’s forecast information and allocates capacity $K_0$ regardless of demand state $\theta$. $K_0$ is the capacity at which the supplier maximizes his expected profit based on its noisy observation about the market demand.

6. Ren et al. (2006, 2010) conjecture that, in a repeated game, the forecasts can be truthfully shared and the supplier can be induced to allocate the system-optimal capacity.

2.2 Repeated Contract

1. Ren et al. (2006, 2010) model the long-term contract as an infinitely repeated game. In this repeated game, the same one-shot game (discussed in previous section) is repeated infinitely often. In these infinitely repeated games, the time is indexed by $t = 1, 2, \ldots \infty$.

2. In the period $t$ stage game, the value of the random variable $\theta_t \in \{\theta_l, \theta_h\}$ is realized. The customer’s action is to provide a forecast to the supplier denoted as $m_t$. The supplier’s action is to install capacity level $K_t$. Then the actual demand $d_t$ is realized and the customer

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3 The common knowledge assumption is a key assumption in games with incomplete information and is based on the work of Economics Nobel laureate John Harsanyi.
places the order \( d_t \) to fulfill the demand. If \( K_t < d_t \), the demand \( d_t - K_t \) remains unsatisfied. If \( K_t \geq d_t \), then all the demand is satisfied. Based on the linear price contract, the supplier is paid with a unit rate of \( r \) and the game moves to period \( t + 1 \).

\[ h^t \rightarrow \theta_t \rightarrow m_t \rightarrow K_t \rightarrow d_t \]

\[ h^{t+1} \rightarrow \theta_{t+1} \rightarrow m_{t+1} \rightarrow K_{t+1} \rightarrow d_{t+1} \]

**Figure 1: Infinitely Repeated Contract**

3. Figure 1 demonstrates the infinitely repeated game. Here \( h^t \) is the public history at time \( t \). It includes all possible combinations of publicly verifiable information—shared forecasts, demand realizations, capacity installed—prior to period \( t \). For each \( t \), based on \( h^t \), the customer has to choose \( m_t : h^t \rightarrow m_t \) and the supplier has to decide on \( K_t : h^t \rightarrow K_t \).

4. The objective in Ren et al. (2006, 2010) is to ensure the truthful forecast sharing and the system-optimal capacity investment as *perfect public equilibrium* strategies for the customer and the supplier, respectively. To ensue this, Ren et al. (2006) use the notion of “trigger strategies”—any deviation from the desired behavior by any agent triggers a punishment phase which lasts for \( M \) periods. After \( M \) periods, the game returns to the cooperation phase. With trigger strategies, the objective is to compute optimal punishment phase \( M \) that acts as a deterrent for deviation from the desired behavior (Kreps, 1990). Ren et al. (2010) focus on review strategies to ensure truthful forecast sharing. A common time discounting rate \( \delta \) is considered. Lower discount rate indicates time impatience.

5. Before the contract, through communication, the parties are made aware about the system-optimal capacity levels are \( K_c^l \) (low demand scenario) and \( K_c^h \) (high demand scenario).

6. In a period \( t \), let us first consider the supplier’s equilibrium strategy:

   - If \( m_t = l \), the supplier trusts the forecast and allocates the system-optimal capacity \( K_c^l \).
   - If \( m_t = h \), the supplier allocates the capacity \( K_c^h \). However, after the realization of demand \( d_t \), a credibility check is performed by comparing \( d_t \) with a threshold \( d \).
   - If \( d_t \geq d \), the game continues in the cooperative phase.
   - If \( d_t < d \), the game enters into the punishment phase for \( M \) periods where the supplier allocates \( K_0 \) (the capacity which maximizes the supplier’s profit in the one-shot game) for each of the \( M \) periods.

7. For the customer, the equilibrium strategies are as follows:
• If $K^c_i < m_t (i = h, l)$, the supplier is not allocating the system-optimal capacity and the game moves into the punishment phase in which the customer stops sharing the forecasts information truthfully.

• Truthfully reveal the forecast information otherwise.

8. To sustain truthful forecast sharing and system-optimal capacity investment as equilibrium strategies, we need incentive compatibility conditions. The incentive compatibility constraints for the customer are:

$$V_h \geq (1 - \delta)v_h(l) + \delta V$$
$$V_l \geq (1 - \delta)v_l(h) + \delta \left[ F_l(d) \left\{ (1 - \delta^M)v^0 + \delta^M V \right\} + (1 - F_l(d))V \right]$$

In the above equations, $V_h$ and $V_l$ are the expected long-term profits when the current period demand parameter are $\theta_h$ and $\theta_l$, respectively. $V$ is the expected long-term profit in equilibrium. $v_h(l)$ and $v_l(h)$ are the one-period expected profit when the customer misrepresents the forecast information (deviation from truthful revelation). $v^0$ is the expected profit in the punishment phase.

Let us now discuss the equations. In the first of the above equations, in any period $t$, the customer with $\theta_t = \theta_h$ should prefer to tell the truth $m_t = h$ than misrepresenting the forecast information $m_t = l$ (deviation is suboptimal in the long-run). The right hand side of the first equation is computed as the sum of the series $v_h(l) + \delta V + \delta^2 V + \ldots$ which is equal to $v_h(l) + \frac{\delta}{1 - \delta} V$. This term is multiplied by $1 - \delta$ to get the average discounted payoff for the infinite horizon which gives the right hand side of the first equation.

Similarly, the second equation means that, in any period $t$, the customer with $\theta_t = \theta_l$ should prefer to tell the truth $m_t = l$ than misrepresenting the forecast information $m_t = h$ (deviation is suboptimal in the long-run). The right hand side of the second equation is based on the credibility test. When the customer with $\theta_t = \theta_l$ sends that the demand forecast is high $m_t = h$ and the supplier invests in the system optimal capacity $K^c_h$, the actual demand $d_t$ can fall below the threshold $\underline{d}$ with probability $F_l(\underline{d})$ and the punishment phase starts which lasts for $M$ periods. Otherwise, with probability $1 - F_l(\underline{d})$, the supplier cannot detect the deviation by the customer and the game continues in the cooperative phase. The term in the brackets in the second equation consider payoffs in these two possibilities.

9. Solving these incentive compatibility constraints, Ren et al. (2006) compute a condition which indicates that, to sustain a truth-telling equilibrium, $F_l(\underline{d})$ should be sufficiently large relative to $F_h(\underline{d})$. It means that the probability of correctly catching and punishing a deviating customer should be sufficiently large compared to probability of incorrectly punishing a truthful customer.
If the stated condition in the above point is satisfied, Ren et al. (2006) prove that there exists a discount rate $\delta$ and a punishment length $M$ such that $\forall \delta > \delta_0$ and $\forall M > M_0$, there is a public perfect equilibrium in which the desired behavior by the customer (truthful forecast sharing) is observed.

3 Other Literature

Plambeck and Taylor (2006) characterize an optimal relational contract when two firms engage in joint production. With imperfect observability, both sides choose private actions that affect the other firm—*double moral hazard*. In such a case, to avoid moral hazard, they show that the optimal relational contract may require that the firms terminate their relationship with positive probability following deviation by either firm.

Tunca and Zenios (2006) examine the competition between competitive procurement auctions and relational contracts in electronic market places. They use price-based reverse auction for low-quality products and relational contract for high-quality parts and identify the conditions when will these two procurement schemes compete or coexist. They suggest that if the quality premium is sufficiently high, then there exist a relational contract equilibrium which ensures supply of quality parts.

Other important literature in repeated contracting for supply chain coordination under asymmetric information are Taylor and Plambeck (2007b) and Taylor and Plambeck (2007a). Taylor and Plambeck (2007b) discuss a scenario when the product is in development phase and the production should start as soon as the development phase is over; hence, in the mean time, the upstream supplier invests in capacity. As the product is ill defined, the firms cannot write court-enforceable contracts; and, due to the possibility of *hold-up* by buyer, the supplier underinvests in capacity. For such cases, Taylor and Plambeck (2007b) also use relational contracts with trigger strategies in the infinitely repeated game framework to implement the desired behavior by the supplier and the buyer.

Taylor and Plambeck (2007a) extend the previous paper with simpler relational contract: price-only relational contract—the buyer promises to pay a specified price per unit; and price-and-quantity relational contract—the buyer promises to purchase a specified number of units for a specific price. They compute the conditions under which each type of relational contract is optimal.
4 Comments and Future Directions

The above discussed literature on supply chain coordination is based on the *folk theorem*—“repetition can yield cooperation”. The literature considers folk theorem under noisy observations; however, any deviation by any player is publicly observable. The objective is to compute equilibrium strategies based on publicly observed information—public perfect equilibrium—that induces the agents (the customer and the supplier) to implement desired behavior.

In Ren et al. (2006, 2010), one of the assumptions is that a new demand forecast parameter \( \theta \) is realized in each time-period. This is related to the literature on dynamic adverse selection when the informed party’s type changes over each time-period discussed in Bolton and Dewatripont (2005, p. 396-414). Other key assumption is that, in each time-period, the supplier must make a new capacity investment or, at least, can vary the allocation of the capacity for the customer’s requirement. This possible variable allocation in each time-period by the supplier is used as a strategy to punish the customer from deviating from truthful forecast sharing.

Based on this discussion, we discuss few future directions:

1. The assumption that, in each time-period, the supplier must make a new capacity investment or, at least, can vary the allocation of the capacity for the customer’s requirement appears restrictive in nature. In some contexts, the product is extremely specific and the supplier’s capacity investment is customer-specific. Hence, in such contexts, the possibility of variable allocation to punish the deviating customer does not exist. Foreseeing the possibility of customer-specific investments by the supplier, a customer with low demand forecast \( \theta_l \) will act as a customer with high demand forecast \( \theta_h \) and can hold-up the supplier for the rest of relationship. This phenomenon is called *pooling* in contract theory literature. This problem also exists in the one-shot screening contract designed in Porteus and Whang (1999); and, can be more critical when the demand forecast parameter \( \theta \) does not vary with time. To mitigate this hold-up problem due to customer-specific investments, one possibility is that the supplier must offer *renegotiation-proof* screening contracts.

2. Another interesting research problem would be to treat demand uncertainty as endogenous and as a function of customers effort. A key argument here is that an action of the customer (R&D effort, marketing effort, etc.) has influence on the demand. The customer’s problem in this case is to choose his optimal effort, which may not be the optimal effort for the overall supply chain—a moral hazard problem. In addition, the customer can still send an incorrect signal to the supplier about the demand forecast—an adverse selection problem. Supplier would like the customer to 1) invest in the effort optimally, and 2) truthfully reveal the demand forecast. In a relationship-specific investment scenario, customer

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2This is called folk theorem as it belongs to the folk literature on game theory. The folk theorem formally states that, for sufficient patient players, any feasible payoff above their minimax values can be implemented in a Nash equilibrium.

3It is optimal for the parties not to renegotiate the contracts in future.
will initially reveal incorrect forecast information and then hold-up the supplier. Hence, the problem lends into the design of renegotiation-proof contract that addresses the moral hazard, the adverse selection, and the hold-up problems.

3. As mentioned earlier, one of the key assumptions in the existing literature is that any deviation by any player is publicly observable. However, in supply chain coordination, there exist cases—especially in globally disbursed supply chains—when there are no public signals; and, individual agents observe only private signals. With private signals, the agents cannot decide whether the cooperation is to be continued or a punishment is to be started. Hence, coordinating in the games with private monitoring require significantly different techniques (Mailath and Samuelson, 2006). This leads to the objective of designing relational contracts for supply chain coordination when agents have private signals about the deviation by the other players.

4. The existing literature discusses predominantly two agent coordination problems. Multiple buyers is a very common situation in real life supply chains. Hence, repeated contracts for supply coordination with multiple agents deserve attention.

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