



Coordinating Contracts in SCM: A Review of Methods and Literature

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Abstract. Supply chain coordination through contracts has been a burgeoning area of research in recent years. In spite of rapid development of research, there are only a few structured analyses of assumptions, methods, and applicability of insights in this field. The aim of this paper is to provide a systematic overview of coordinating contracts in supply chain through highlighting the main concepts, assumptions, methods, and present the state-of-the-art research in this field.

Keywords: supply chain management, coordination, contracting, methodology.

JEL Subject Classification: M11 – business administration/production management.

Revised: 28 August 2010.

1. INTRODUCTION

The supply chain management paradigm asserts that when making decisions, the efficiency of the whole system should be taken into consideration. When decision making is decentralized, i.e. decisions are made by independent agents comprising the chain, optimization of system's total efficiency might be discordant with the agents' incentives. Therefore, coordinating the agents' decisions becomes a major issue.

By viewing a supply chain as nexus-of-contracts (Wang and Parlar, 1994), i.e. a group of rational agents interacting with each other according to pre-specified rules, an improved supply chain management is achieved by designing appropriate contracts coordinating the agents' decisions. This is the main objective of research on coordinating contracts. Although contracts have been studied in law, economics, and marketing disciplines, their study in SCM takes a rather different approach.

“What distinguishes SCM contract analysis may be its focus on operational details, requiring more explicit modeling of materials flows and complicating factors such as uncertainty in the supply or demand of products, forecasting

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and the possibility of revising those forecasts, constrained production capacity, and penalties for overtime and expediting” (Tsay et al., 1999).

A contract specifies mechanisms for governing the interaction contingencies among agents. It manifests the exchange of promises regarding the actions which are to be done in time. Necessarily, contracts must be *enforceable*, i.e. the agents’ refrainment from fulfilling their promises should be ruled out (or made highly improbable). For a contract to be enforceable, its terms (the mutual promises), should be *verifiable* by an enforcing body. However, the verifiability of contract’s terms is dependent on the enforcing body. If a contract’s terms are verifiable by a *court of law*, that contract would be a *legal* contract.

Supply chain contracts are not always required to be legal. Several papers in the literature consider contracts among independent agents that are divisions of the same company and a higher level manager can verify the rendition of lateral promises (e.g. Chen (1999), Lee and Whang (1999), and Zhang (2006)). Nevertheless, the process of contract design should explicitly point out the verifying ability of the enforcing agent. Two approaches to verification are detectable in the literature: direct, and indirect. In direct verification, the conditions regarding the fulfillment of contract terms must be *observed*. In indirect verification, the aforementioned conditions may be *inferred*. In reality, the verification process is a mixture of the two approaches. An example of direct verification is the delivery of the ordered products from a supplier by a retailer. The retailer can observe, i.e. count, the number of products received. Indirect verifications are achieved when a certain action is considered to be necessary (or self-enforcing) for a rational agent. For example, a manufacturer can verify that if the market selling price is greater than the total production cost and salvage value, the retailer would satisfy market demand as much as it can.

The study of supply chain contracts is an interdisciplinary research area. For the most part, it is a synthesis of inventory theory (e.g. Zipkin (2000)), game theory (e.g. Owen (1995)), and contract economics theory (e.g. Brousseau and Glachant (2002)). In spite of rapid development of research on supply chain contracting and coordination, there are only a few structured analyses of the assumptions, methods, and the implications of insights in this field. Relevant examples include Li and Wang (2007), Chan et al. (2004), and Gomez-Padilla et al. (2005).

The aim of this paper is to provide a general overview of coordinating contracts in supply chain through highlighting the main concepts, assumptions, methods, and presenting the state-of-the-art research in this field. We intend to provide a non-technical framework encompassing the most important components of these theories.

The rest of this paper is organized as follows. In Section 2, the concept of coordination in SCM contracting is elaborated. Section 3, provides a classification scheme for coordinating contract in supply chain. Some of the well-known contractual mechanisms in SCM are introduced in Section 4. Section 5 contains a review of recent literature based on the proposed classification scheme. Section 6 discusses several issues with regard to coordinating contracts in SCM and finally, Section 7 introduces some directions for future research in this area.

2. COORDINATION AND SUPPLY CHAIN CONTRACTS

As a rule of thumb, the efficiency of a centralized decision making system is superior to that of a decentralized system, all other things being equal. A well-known justification of the latter is the double marginalization conundrum (Spengler, 1950). The incompatible incentives of agents in a decentralized system make the decisions that are optimal for the agents sub-optimal for the whole chain. In the decentralized supply chain literature, coordination refers to the equivalence of agents' individually-optimal decisions with the optimal decisions of the (centralized) supply chain¹. The incompatibility of incentives in decentralized supply chains stems from the fundamental characteristic of agents, i.e. *rationality*. The rationality of individuals implies that each agent seeks to maximize its own *utility*, and moreover, each agent is able to calculate its optimal decisions, which lead to the maximization of its utility, given the information it has². As the result, the agents do not undertake the supply chain optimal decisions unless they know that those decisions are also optimal for themselves.

In order to coordinate a supply chain, a contract must transform the individuals' utility functions in a way that the supply chain optimal decisions would also be optimal for the individuals. However, this is only one necessary condition for a contract to be *coordinating*. Another necessary condition is that a contract cannot be forced upon individuals; they must willfully *accept* the contract. The literature contains at least two approaches to formulating the acceptability condition of a contract. The first approach implies that a contract is acceptable if it leads to the utility of each agent being above a certain acceptable level for that agent. These levels can be interpreted differently, e.g. reservation profits, opportunity costs, outside options, or *status quo* utilities. The second approach demands that not only should an acceptable contract guarantee minimum amounts of utilities to the agents, but it also must divide the extra utilities in a *fair* manner among them³.

Cachon (2003) states three conditions that a coordinating contract should meet: (1) *with a coordinating contract, the set of supply chain optimum decisions should be a pure Nash equilibrium*; (2) *it should divide the supply chain profits (utilities in general) arbitrarily among the agents*; and (3) *it should be worth adopting*. The first condition is concerned with the transformation of individuals' utility functions. Although this definition does not directly specifies the acceptability condition, the second condition implies that if a contract can divide the supply chain profits among agents in any manner, at least one of those division schemes could be acceptable to all

¹ Note that in the centralized supply chain literature, coordination refers to the derivation of supply chain's optimal decisions (see Thomas and Griffin (1996) for a literature review of coordination in centralized supply chains). Therefore, in centralized supply chains, coordination is in fact a global optimization problem, while in the decentralized supply chains the latter is a mechanism design problem.

² For further discussions on the concept of rationality and proposed critiques see Osborne and Rubinstein (1994).

³ One approach to fairness is to consider it as the correspondence between the bargaining powers (yet another hard-to-define concept) and the individuals' utilities. See Nagarajan and Sosa (2008) for elaboration on this issue.

agents⁴. Unfortunately, the criteria for assessing the third condition are rather vague, but it could be taken as the combination of other qualitative acceptability conditions yet to be formalized.

Alternatively, Gan et al. (2004) define coordinating contract as *a contract which the agents of a supply chain agree upon and the optimizing decisions of the agents under the contract satisfy each agent's reservation payoff* [minimum acceptable utilities] *constraint and lead to Pareto-optimal decisions and Pareto-optimal sharing rule*. This definition formulates the acceptability condition according to the first approach stated earlier (satisfaction of minimum acceptable utilities). One drawback of this approach is that it does not indicate how one contract should be agreed by the individuals in cases where there exists multiple contracts with Pareto-optimal sharing rules which satisfy the agent's minimum acceptable utilities. Gan et al. (2004) also define *flexible* coordinating contract as a coordinating contract such that by adjustment of some parameters, it could lead to any Pareto-optimal sharing rule.

Despite the different interpretations of acceptability condition of a coordinating contract in Cachon (2003) and Gan et al. (2004), the fundamental notions in both definitions are similar. That is, with the coordinating contract, agents' optimum decisions must be the same as the supply chain's optimum decisions, and the contract should divide the resultant payoffs among them so that all agents are satisfied and as the result they would accept the contract. We provide two variations of the concept of coordination:

- Weak Coordination: If a contract could achieve the equivalence of agents' optimal decisions (pure Nash equilibrium) and the supply chain's optimal solution, and at the same time it satisfies the minimum acceptable utilities for all agents, then the contract is *weakly coordinating*.
- Strong Coordination: If a contract could achieve the equivalence of agents' optimal individual decisions (pure Nash equilibrium) and the supply chain's optimal solution, and at the same time it could divide the total supply chain payoff in any manner among the agents, then the contract is *strongly coordinating*.

The relationship between the two definitions is that if a weakly coordinating contract is also flexible, then it is strongly coordinating as well.

3. METHODOLOGY OF COORDINATING CONTRACTS

The purpose of this section is to provide a taxonomy of supply chain contracting problems and an overview of methods used in analyzing the coordinating ability of contracts.

⁴ For the cases with two agents, there is always an acceptable division schemes among all the possible divisions. However, for the cases with more than two agents, this might not hold. In particular, this definition does not address the possibility of coalition formation among the agents. We discuss this issue further in Section 3.2.2.

3.1. CLASSIFICATION OF PROBLEMS

Numerous parameters impact how contracts affect collaborative performance of supply chain agents. However, in order to retain tractability, only a few of those parameters can be abstracted and investigated simultaneously in a model. The result is a plethora of models with various combinations of parameters. Here, we present a list of the most important classes of parameters which have been considered in the literature.

3.1.1. SUPPLY CHAIN TOPOLOGY

A supply chain consists of several business entities (agents) with certain kinds of flows among them (such as material, information, and money) that can be represented by a network. Despite the complex structure of an average-sized real world supply chain, the contracting literature focuses on small chunks of such networks comprising of few nodes (representing supply chain agents, e.g. companies) and the flows between them. In many cases, supply chain contracts are considered to be centered around a focal node and the immediate predecessors and/or successors which form a hierarchy of *tiers*. We refer to this aspect as *supply chain topology*. The common topologies in supply chain contracting literature are as follows.

- **Two-tier topology with two nodes:** Majority of studies in the supply chain contracting literature consider this topology. The nodes might represent a supplier and a manufacturer, or a producer and a retailer, *etc.* This topology resembles a *bilateral monopoly*.⁵ The well-known coordinating contracts for supply chains mainly address this topology (see Section 4).
- **One-tier topology with several nodes:** The contracts with this topology deal with horizontal collaboration among several independent agents that are in the same supply chain tier (all retailers, or manufacturers for instance). The collaboration is through pooling resources in order to balance the outstanding demands and surplus resources. In *sub-contracting* literature, the flow of resources among any two agents are only in one way. However, in the *trans-shipment* literature, the flows are bilateral. Although the agents collaborate with one another, still, they may compete over some aspects of their business, e.g. order quantities (Rudi et al., 2001) or their market selling prices (Zhao and Atkins, 2009). An important aspect of the supply chain models with this topology is whether the collaboration among the agents happen prior to the realization of the demand or afterwards.
- **Two-tier topology with several nodes:** The contracts with this topology address the interactions among a focal node and several other nodes all being located in an adjacent tier. Therefore this topology is comprised of either one

⁵ A bilateral monopoly consists of two vertically-dependent agents: an upstream supplier (a monopolist) that sells all its output to a downstream buyer (a monopsonist) that acquires all its supply of an essential input from the monopolist. Their relationship is symmetric. Both have market power, and neither can survive without the other; therefore, the agents necessarily deal with each other, negotiate and conclude contracts, and settle prices and quantities (Ingene and Parry, 2004, p. 32).

upstream node that supplies several downstream nodes, or one downstream node that is being supplied from several upstream nodes. The nodes in the same tier may compete with one another over the limited capacity of the other tier's resources (as in Cachon and Lariviere (1999)), or on market prices (as in Deneckere et al. (1997)), *etc.* In more elaborate models the nodes in the same tier are assumed to pool resources, e.g. Ulku et al. (2007).

- **More general topologies** Assuming more than two tiers in an independently owned serial supply chain system will drastically increase the complexity of analysis of coordinating contracts. To the best of our knowledge there are only a few papers which consider these topologies. As an example, Zijm and Timmer (2008) study the coordination problem in a three-tier supply chain with three nodes. However, they assume separate contracts governing the interactions between the node in adjacent tiers.

3.1.2. SUPPLY CHAIN ENVIRONMENT

The supply chain environment is the collection of external factors affecting the supply chains' decisions. Some of the most relevant dimensions of supply chain environment are as follows.

- **Certainty/Uncertainty of environment:** Usually, the uncertainty of supply chain environment refers to the market demands. Two broad categories are deterministic and probabilistic market demands. Sarmah et al. (2006) review the contracts with quantity-discount policies in deterministic demand environment. In deterministic systems, the coordination might pertain to the timing of orders (Klastorin et al., 2002). The coordinating contracts with uncertain market demand environment mostly consider continuous probability functions. An example of coordination with discrete demand distributions is Zhao et al. (2006) which consider a one-tier supply chain with two nodes and Poisson demand arrival rates. Recently, Xu and Zhai (2010) study the general properties of coordination in a two-tier, two-node topology with fuzzy demands. The other source of uncertainty about the supply chain environment is associated with the supply chain's input. The supply chain contracting literature has considered uncertain delivery times (e.g. Zimmer (2002)) and uncertain delivered quantities (e.g. He and Zhang (2008)). The latter is also referred to as *random yield*.
- **Sensitivity of environment to supply chain decisions:** In many supply chain models, market demands are assumed to be sensitive to some decision variables internal to the chain. Among others, the decision on market selling price and marketing efforts are the most addressed. For example, in addition to choosing the order size, a retailer facing price-sensitive market demand should also decide its selling price. This, in turn, affects the coordinating ability of the contract between the retailer and its supplier. Yano and Gilbert (2005) and Chan et al. (2004) review the literature on supply chain contracts with price sensitive market demands. When the market demand is affected by the

marketing effort of downstream agent – which is unverifiable by the chain – a coordinating contract should induce the supply chain’s optimal level of marketing effort. He et al. (2009) explore coordinating contracts for a two-tier, two-node topology with both price and marketing effort sensitive market demand. Another factor that could affect the market demand is the stock level. Sajadieh et al. (2010) address the issue of coordination in the setting where the amount of stock displayed to customers has a positive effect on demand.

- **Dependencies among agents in the same tier:** The individual decisions of agents who operate in the same supply chain tier may affect each other. These dependencies add another dimension to the complexity of models. Competition, and correlated market demands are among factors that amount to dependencies among agents in the same tier. Multiple nodes in a particular tier, may compete over their market shares (when they are operating in the same market), or supplier’s quotas (when the supplier’s capacity is restricted), or fill rates. Cachon and Lariviere (1999) investigate the supply chain coordination in the setting where the downstream agents compete over the limited supplier’s capacity. Hartman and Dror (2005) analyze the cooperation among many newsvendors with dependent market demands.

3.1.3. LENGTH OF CONTRACT

The length of a contract is the duration of time that the contracting agents are assumed to uphold the contract. Therefore, the contract terms are not *re-negotiated* during the length of a contract. This has a crucial effect on modeling the underlying supply chain problem. The effective length of a supply chain contract can be compared with the number of inventory replenishment periods. Accordingly, there is a close affinity between the length of a supply chain contract and the modeling approach. The two main classes are:

- **Single period models:** A large number of supply chain contracts has been devised for the single period supply chain model, i.e. the newsvendor model with its numerous variations (Khouja, 1999). This family of supply chain models is specially appropriate for the supply chains with perishable products, short selling seasons, and long procurement lead-times. Nevertheless, the analytical simplicity of single period supply chain models has given rise to the popularity of contracts with one period length. Cachon and Lariviere (2005) outline several coordinating contracts for the standard newsvendor model. Hu et al. (2007) consider a single period model with limited and uncertain supplier’s capacity. Cachon (2003) provides an excellent literature review on coordinating contracts for this family of models. Cachon (2004) addresses coordination in a single-period model with two replenishment opportunities for the downstream agent.
- **Multi-period models:** The multi-period models could simply be the combination of two consecutive newsvendor models (Barnes-Schuster et al., 2002), or they might consist of several stocking periods. The multi-period models are mainly based on the multi-echelon model of Clark and Scarf (1960). Among the

early papers that address the multi-period supply chain contracts is Cachon and Zipkin (1999) which offers a coordinating contract based on the end-of-period inventory information at different agents.

3.1.4. SUPPLY CHAIN DECISIONS

Among the numerous decision variables that are critical in managing supply chains, the supply chain contracting literature commonly concentrates on those that are related to capacity, order size, market selling price, marketing efforts, contract type, lead times, quality, review period, and stocking policy. For a more detailed analysis of supply chain decision variables see Tsay et al. (1999). Considering the multiplicity of decision makers in decentralized supply chains, an important aspect of supply chain decisions is the distribution of decision making responsibilities among supply chain agents. Although traditionally some of decision variables are attributed to certain supply chain entities, e.g. responsibility of deciding the order size to the downstream agent (buyer), many cases with less conventional approaches have also been investigated in the literature. For example, in an insightful paper Lariviere and Porteus (2001) assume that the upstream agent chooses the order size while the downstream agent picks the buying price. Hence, the distribution of decision rights among supply chain agents falls, at least partially, within the purview of the modeler.

Another aspect of this issue is related to the right of non-compliance among supply chain agents. Generally, whenever one contracting agent requests something from another agent, the latter may have the right not to comply with the former's request. In supply chain contracting literature, the allotment of compliance rights is, in fact, the choice of the modeler. Cachon and Lariviere (2001) refer to this issue as *compliance regimen*. Accordingly, there are two classes of compliance regimes: *voluntary* and *forced*. Cachon and Lariviere (2001) use these terms with respect to the responsibility of a supplier to completely fill the manufacturer's order. In this context, if the model gives the supplier the right to decide the fraction of manufacturer's order to deliver, then the system would be under voluntary compliance regimen. In other words, under voluntary compliance regimen, an agent keeps the decision right regarding the fulfillment of it received requests. Under the forced compliance regime, on the other hand, an agent is obligated to fulfill the requests it receives.⁶ Therefore, whether explicitly or implicitly, the compliance regimens of all the mutual promises in a supply chain contract should be indicated. If a contract can coordinate a specific supply chain settings under a voluntary-compliance regime, it could coordinate under the forced-compliance regime as well. The opposite might not be the case.

3.1.5. CHARACTERIZATION OF SUPPLY CHAIN AGENTS

We have earlier alluded to *rationality* as an underlying characteristic of the agents. Two other aspects of supply chain agents' characteristics pertain to their *utility functions* and attitudes toward risk. Utility functions reflect preferences of agents which,

⁶ It is because non-compliance would be penalized. The penalties (or other forms of threats) are implicitly assumed to be large enough so that, in theory, non-compliance never occurs.

in turn, determine their decision making criteria. In the supply chain contracting literature, it is conventional to assume that the utilities of agents are solely function of monetary payoffs. That is, agents only care about the amount of profit they make. Nevertheless, there has been a recent trend in considering utility functions which reflect agents' social preferences as well. For instance, supply chain agents may also care about *fairness* in a mutual business relationship (Cui et al., 2007). Other examples include *equity aversion* and *status seeking* among agents (Loch and Wu, 2008).

In decision making in uncertain environments, the analysis of agents' decision making process requires the knowledge about their attitudes toward risk. Two types of such attitudes have been considered in the literature: *risk-neutrality*, and *risk-aversion*.⁷ For a risk-neutral agent, a certain payoff of M is equally preferred as an uncertain payoff with the same *expected* value M , while a risk-averse agent prefers the certain payoff M . Hence, the objective of a risk-neutral agent is to maximize its expected profit (or equivalently to minimize its expected cost). While there is only one measure for risk-neutrality, risk-aversiveness can be reflected in many (theoretically infinite) ways. Among the objectives studied for risk-averse agents are the minimization of variance of profits (Chen and Parlar, 2007), and the minimization of mean-variance difference (Gan et al., 2004; Choi et al., 2008). Van Mieghem (2003) reviewed the literature on capacity investments considering the issue of risk-aversion. The general characteristics of supply chain contracts with risk-averse agents are studied in Gan et al. (2004).

3.1.6. INFORMATION STRUCTURE IN SUPPLY CHAIN

Information structure pertains to the agents' knowledge in comparison to the collective knowledge of agents in the supply chain. When all the information about supply chain is simultaneously known by every agent, the information structure is said to be *complete* or *symmetric*. On the other hand, if some agents have some information that the other agents do not, the information structure is *incomplete* or *asymmetric*. The pieces of information that are known only by an agent is that agent's *private* information.

In general, coordination under incomplete information is more complex than coordination under complete information. One approach to deal with incomplete information structure is to assume certain *types* of agents each with known characteristics (c.f. Harsanyi and Selten (1972)). Although the agents do not know what types of agents they are facing, the probability that an unknown agent is of a particular type is assumed to be common knowledge. A coordinating contract in these settings is comprised of a menu of contracts designed in a way that will make the agents with private information to choose the only contract that result in the supply chain optimum decisions. Therefore, a coordinating contract in incomplete information setting will result in the truthful revelation of private information. Several papers study supply chain contracts under asymmetric information. Corbett and Tang (1999) assume a two-tier, two-node setting with deterministic and price-sensitive demand function

⁷ To the best of our knowledge, *risk-taking* attitudes have never been considered in supply chain contracting literature.

where the upstream agent does not know the exact cost structure of the downstream agent. They investigate the effect of contracts with different pricing mechanisms on the overall efficiency of the chain. Corbett et al. (2004) study a supply chain with two agents where the supplier does not know the retailer's internal cost. Cachon and Lariviere (2001) analyze a supply chain contracting problem where the information regarding the probabilistic distribution of market demand is the private information of downstream agent. Burnetas et al. (2007) introduce a coordinating quantity-discount policy in a two-tier two-node topology where the upstream agent do not have the information regarding the demand distribution of downstream agent. The risk sharing contract of Gan et al. (2005) can coordinate when the upstream agent does not know how risk averse the downstream agent is. Burnetas et al. (2007) introduce an all-unit discount policy that results in coordination of a two-tier two-node topology supply chain in one period. Sucky (2006) considers a two-tier two-node setting in deterministic environment under forced compliance regimen. Assuming that the upstream agent is uncertain about the downstream agent's cost structure, he shows that coordination can be achieved through bargaining and with the help of side payments.

3.2. ANALYTICAL METHODS OF COORDINATING CONTRACTS

The ability of a contract to coordinate a supply chain is completely context-dependent. We differentiate between contracts at two layers: the *contract template*, and the *contract setup*. At the outer layer, the contract template provides a holistic view of interactions among the agents involved in a contract and points out the variables that the contract is based upon. The second layer, i.e. the contract setup, specifies the particular setup of contract variables for a given contract template. Consider the famous wholesale-price contract as an example. The contract template declares that the buyer should pay the seller a fixed price for a unit of ordered product. The contract setup, on the other hand, specifies the exact unit price in the contract. Our goal in this section is to answer two important questions: (1) How is a contract template obtained? and (2) How is the coordinating ability of a contract analyzed?

In most cases, the contract templates are inspired by the structure of contracts which are being used in practice. The alternative approach requires more creativity; that is, the modeler *invents* a contract template by specifying the hypothetical interactions among the agents. However, justifying the practicality of such a contract template is rather challenging. Some of the most well-known contract templates are introduced in the next section.

Game Theory is the fundamental tool for investigating the coordinating ability of a contract, with specified template and setup, in a given supply chain setting. For a brief review of related game theory concepts in supply chain contracts see Cachon and Netessine (2006) and Chinchuluun et al. (2008). Accordingly, one should analyze whether the contract can be setup so that it could induce all the agents to select the supply chain's optimal decision, and whether the resultant division scheme of supply chain profits are acceptable to them. We address the latter in two different cases: contracts between two agents, and contracts among more than two agents.

3.2.1. CONTRACTS BETWEEN TWO AGENTS

When there are only two agents involved in a contract, assessment of coordinating ability of a contract should concentrate on two issues: first, the negotiation process over a contract, and second, the effect of the negotiated contract on agents' decisions. The most common procedure used in the literature is the Stackelberg game. This approach simplifies the analysis of negotiation process between the agents by assuming that one agent (the leader) gives a take-it-or-leave-it offer, including the contract template and setup, to the other agent (the follower) who has the right to either accept or reject the offer. The following steps are typically taken under the assumption that the follower accepts the offer only if it results in a minimum (expected) profit for him/her; (1) derive the followers optimum decision as a function of contract setup variables; (2) check if the leader can offer a contract setup that induces the follower to choose the supply chain optimum decisions and provide the follower with its minimum acceptable profit level; and (3) if the result of the last step is positive, check if the corresponding contract setup provides the leader with its minimum (expected) profit so that it actually offers the contract. This approach is suitable for the situations where the leader has significantly more power and the interactions between the agents are restricted. In general, the idea of the follower either completely accepting the contract or wholly rejecting it without any further negotiations may seem too restrictive.

Another approach to analyzing the negotiation process over a contract is to consider an explicit bargaining process. The bargaining process shall specify the exact contract setup which leads to an acceptable split of the maximum (expected) supply chain profits. Two approaches which have been used in the literature are Strategic Negotiation (Rubinstein, 1982) and Axiomatic Negotiation (Nash, 1950). With Strategic Negotiation (Sequential bargaining), after a contract has been offered by an agent, the other agent could offer a new contract (counter-offer) if it is not acceptable to the latter. Considering the value of time (or agents' patience), this bargaining process has been proven (Rubinstein, 1982) to converge to a mutually acceptable contract setup. For a review of the implementation of strategic negotiation in supply chain contracts see Wu (2004). With Axiomatic Negotiation approach, the bargaining solution is developed by considering axioms that correspond to the desirable properties of negotiation outcomes. The bargaining solution can be thought as the suggestion of an unbiased arbitrator. Hence, a contract is proven to be coordinating if the underlying negotiation problem has a solution. A recent example of implementation of this approach is Hezarkhani and Kubiak (2010a) which uses the generalized Nash bargaining solution (Muthoo, 1996) in a transshipping supply chain. Nagarajan and Sobic (2008) review the literature of bargaining and negotiation in supply chains.

3.2.2. CONTRACTS AMONG SEVERAL AGENTS

The analysis of coordinating contracts becomes more complex as the number of participants in the contract increases. The principle approach to study the contracts among several agents is the *cooperative game theory*. The cooperative game theory approach to contracts provides mechanism for the distribution of total payoff that is generated

by the coalition of all supply chain agents, i.e. *grand coalition*. The acceptability of a contract to the agents implies that not only should it provide each agent with its minimum acceptable payoff, but also it must eliminate the incentives for the agents to form sub-coalitions and gain more profits in that way. In other words, in the N -agent case, the coordinating contract should meet some *stability* criteria with regard to the distribution of grand coalition's payoff among the agents.

One of the most natural stability concepts is the concept of *core* (Peleg, 1995). If a contract could distribute the grand coalition's payoff among the agents so that no subset of agents could be better off by forming a sub-coalition, then that distribution mechanism would be in the core of the corresponding cooperative game. However, it might be the case that no such distribution mechanism can be found. Nevertheless, there are alternative stability concepts that can be used in conjunction with other solution concepts in cooperative game theory, e.g. Shapley value, nucleus, bargaining set, *etc* (Owen, 1995). Slikker et al. (2005) study the coalitions of newsvendors who can also pool resources through transshipments and show that the core of these class of supply chain problems are non-empty. Ozen et al. (2009) provide a general framework for cooperation under uncertainty. Brandenburger and Stuart (2007) study *bi-form games*. The bi-form games are to model the supply chains wherein a set of agents face individual and correlated decision making problems followed by a cooperative stage. In a one-tier several agent topology, Anupindi et al. (2001) introduce an allocation rule in the core of the second stage transshipment game. Suakkaphong and Dror (2010) provide insights, clarifications, and strategic limitations regarding the allocation rule proposed by Anupindi et al. (2001). An alternative allocation rule has been proposed in Sošić (2006) which redistributes the extra profit generated through the transshipments according to the Shapely value. Although the resultant allocation is not necessarily in the core, it could result in the *farsighted stability* of the grand coalition, i.e. the agents do not form sub-coalitions since they take into the consideration other agents' reactions as well. Chen and Zhang (2009) approach the transshipment problem as a two stage cooperative game, and show that the problem of finding an allocation in the core of N -agent transshipment game is NP-hard. Hezarkhani and Kubiak (2010b) adopted the concept of pair-wise stability (Baiou and Balinski, 2002), a non-cooperative solution concept derived from the matching problem in two-sided markets, into the transshipment problem with many agents.

4. WELL-KNOWN CONTRACT TEMPLATES IN SUPPLY CHAIN MANAGEMENT

The typical solution to incompatible incentives in a supply chain is for the agents to agree to a set of transfer payments that modifies their incentives, and hence modifies their behavior (Cachon, 1999). Additionally, the flow of goods and materials might also be the subject to modification (as in a *buyback* contract). In this section, we address some of the well-known contract templates in supply chain coordination. We start with one of the most basic supply chain contracts, i.e. wholesale-price contract, in a basic setting (single-period model with risk-neutral agents, independent

demands, and symmetric information structure) and address the coordinating components which can be added to it in order to achieve coordination in various settings.

4.1. WHOLESALE-PRICE CONTRACTS

In the simplest setting, the wholesale-price contract requires the buyer to pay a fixed and quantity-independent price to the seller for each units purchased. Although the wholesale-price contract fails to coordinate supply chains in a simple two-tier topology with two nodes, it is the most common contract in practice – perhaps because of its simplicity.

In the standard newsvendor setting, two types of wholesale-price contracts are possible. First, the downstream agent has to place orders *before* the realization of uncertain market demand and the upstream agent provides products accordingly. Second, the downstream agent can place the order *after* observing the actual market demand while the upstream agent should prepare itself for meeting it in advance. Although in both cases the integrated system is a standard newsvendor model, they are different with respect to allocation of risk between the two agents. Cachon (2004) calls the first type *Push* and second type *Pull* wholesale-price contracts. Lariviere and Porteus (2001) analyze the properties of push wholesale-price contracts where the upstream agent can satisfy all the downstream agent's orders and it acts as the Stackelberg leader offering the wholesale price to the downstream agent who determines the order quantity. Note that with this contract, the seller gets a risk-less sum of money before realization of market demand and the buyer faces all the risk associated with the uncertainty market demand. Cachon and Netessine (2004) analyze the pull contract where the upstream agent has to decide its capacity level before receiving the downstream agent's orders. As the authors conclude, both types of wholesale price contracts fail to coordinate the supply chain. In fact, the only wholesale-price in the push setting which induces the downstream agent to place the optimal centralized order size, leaves the upstream agent with no profit, thus, the wholesale price contract cannot satisfy the acceptability condition of coordination, i.e. it cannot be setup to provide arbitrary division of supply chain profits.

4.2. CONTRACTS WITH DISCOUNT POLICIES

Discount policies, i.e. quantity-dependent unit prices, are well-known coordinating components in supply chain contracts. There are several forms of discount policies; see Dolan (1987) for a review. Discount policies are the main coordinating components in supply chains with *deterministic* demand. Jeuland and Shugan (1983) address the problem of coordination in the two-tier two-node topology and propose a coordinating quantity-discount contract. As they show, there are several coordinating quantity discount contracts which lead to different split schemes for extra profits generated through cooperation. Klastorin et al. (2002) consider a two-tier supply chain with one upstream agent and several downstream agents and show a discount policy that can coordinate the ordering times of downstream agents so that the supply chain can save holding costs at the upstream level. Cachon (2003) incorporates the quantity discount

component in a standard newsvendor setting and demonstrates its coordinating ability in a two-tier topology with two nodes. In his model, the mutually acceptable division of supply chain profits is determined by a Nash bargaining mechanism between the two agents.

4.3. CONTRACTS WITH RETURN POLICIES

With the return policies the seller promises to compensate the buyer for unsold quantities. One might ask why contracts with return policies are needed while quantity discount contract are just as well coordinating. First, “buy-back payments play a very important role in channel coordination when the multi-retailer setting is considered. When retailers serve markets of different sizes, the manufacturer can attain the profits of a coordinated channel only if he can charge different wholesale prices to each outlet. However, in the US such a practice is restricted by the Robinson Patman Act which protects the retailers against price discrimination by the manufacturers. It is shown that the buy-back payments for used products provide a second degree of freedom for the manufacturer to differentiate the average wholesale price charged to each retail outlet, and thereby attain the coordinated channel profits in a decentralized setting” (Debo et al., 2004). Second, with the return policies the upstream agent is also bearing the risk associated with the market demand so the downstream agent prefers it to a quantity discount contract with the same expected profit.

The variations of return policies depend upon the amount of leftover inventory which can be returned and the amount of compensation—the ratio of unit compensation fee to the original purchase price. Pasternack (1985) shows that in a newsvendor setting with risk-neutral agents, the return policies that allow for full leftover return and partial compensation can coordinate the supply chain.

Other variations of return policies are (1) unlimited return and full compensation, (2) limited return and full compensation, and (3) limited return and partial compensation. In the newsvendor setting, Pasternack (1985) also proves that the return policies that allow for full return and full compensation cannot be coordinating. In the same setting, Cachon (2003) shows that partial return and full compensation cannot coordinate either, while partial return and partial compensation can. Su (2009) study the impact of full returns policies and partial returns policies on supply chain performance.

4.4. REVENUE SHARING CONTRACTS

In revenue sharing contracts, the downstream agent commits to return a pre-negotiated portion of its realized profits to the upstream agent. The successful implementation of these contracts are reported in the video rental industry (Cachon and Lariviere, 2005).

The revenue sharing contract can also coordinate the price-sensitive newsvendor setting (Cachon and Netessine, 2004). Qin and Yang (2008) consider a two-tier, two-node topology and analyze the revenue sharing contract as a Stackelberg game and conclude that in order to achieve coordination, the agent that keeps more than half the

revenue should serve as the leader of the Stackelberg game. Yao et al. (2008b) study a two-tier, three-node topology where the downstream agents compete over setting the market selling prices. They combine the Stackelberg game among the upstream and downstream agents and the Bayesian Nash game between the two downstream agents and investigate the effect of different revenue-sharing contracts on supply chain performance.

A particular case of the revenue sharing—widely known as *consignment* contracts (Wang et al., 2004) – is the instance where the *ownership* of goods do not change with their delivery to the downstream agent, i.e. the upstream agent remain the owner of them. Then, the upstream agent pays the downstream agent a commission for each sold item. Wang et al. (2004) investigate the performance of consignment contracts when the demand is sensitive to the market selling price.

4.5. REBATE CONTRACTS

In rebate contracts, the upstream agent rewards the downstream agent for every sold unit. Therefore, in some sense, the rebate policies are commensurate with the return policies: while in buyback contracts the downstream agent is compensated for unsold units, in rebate contracts the latter is rewarded for the sold units. Accordingly, different rebate policies can be implemented: (1) policies that reward for all sold units, and (2) policies that reward for sold units only above a threshold. In a newsvendor settings, Taylor (2002) shows that the second class of rebate policies can achieve coordination. Chen et al. (2007) consider the rebate contract in a two-tier, two-node topology with price-sensitive demands and find that the mail-in rebates (which is paid upon request) may benefit the upstream agent while instant-rebates (which includes every interaction) may not.

4.6. CONTRACTS WITH SIDE PAYMENTS

Although the notion of side payment has a clear definition in game theory⁸, its use in supply chain contracting literature is some what inconsistent.⁹ We define side payments as the lump-sum monetary transfers among the contracting agents which are independent of amount of trade and used as compensation and incentive alignment mechanisms. In order to clarify the issue consider two contracts introduced earlier: the wholesale-price, and the revenue sharing contracts. In the wholesale-price contract, the amount of money transferred from buyer to seller is a linear function of units purchased. On the other hand, in the revenue sharing contract the downstream agent pays the upstream agent a lump-sum of money after the realization of its profits. According to our definition, the latter is a side payment while the former is not.

Examples of side-payment contracts among two agents include two-part tariff (where limited side-payments are allowed, e.g. Zaccour (2008)) and option contracts (e.g. Barnes-Schuster et al. (2002)). In general, the contracts that rely on allocations

⁸ In game theory terminology, side payment is defined as the exchange of a perfectly divisible common good that is capable of transferring utility (Aumann, 2000).

⁹ For instance compare Rubin and Carter (1990) and Taylor (2002).

of realized profits, take advantage of side payments. Hence, almost all the contracts with more than two contracting agents, which utilize profit-allocation mechanisms, are contracts with side payments. Although the inclusion of side payments in supply chain contracts could facilitate the coordination, they may be infeasible in some situations, e.g. in some cases they might be prohibited by law (Leng and Zhu, 2009).

5. LITERATURE REVIEW AND DISCUSSION

In this section, we classify the recent literature on coordinating supply chain contracts. The classification scheme has been explained in earlier sections. We have not considered the papers wherein the analysis does not result in coordination. The literature review has been done through the extensive tables (Tables 1 and 2). In order to summarize the information in the tables, we have used the following notations. In the Topology column, the xT/yN represents the number of tiers and nodes of the topology. For instance, $2T/2N$ represents two tiers with two nodes topology. In the Contract Length column, $x-p$ shows the number of periods in the model ($n-p$ stands for multiple-periods). In the Agent Characteristics column, Risk-N and Risk-A respectively represent risk-neutral and risk-averse agents.

The large number of variables that can be included in analyzing the contractual situation limits the comprehensiveness of this classification scheme. Moreover, several other important aspects of supply chain contracts cannot be quantitatively analyzed. Some of those aspects are: *applicability*, i.e. the possibility of implementation of a contract in a given real world context, *verifiability*, i.e. availability of mechanisms for verifying the lateral promises stated in the contract, and *ease of implementation*, i.e. the effort which is required to apply a contract in real world settings. In fact, there is no known measure to compare among several coordinating contract for specific settings. Hence, although we have addressed several papers in the literature in Tables 1 and 2, it is not straightforward to compare the contracts that are proposed to coordinate in similar situations.

One of the weak points of coordinating supply chain contracts is their sensitivity to the context. In this respect, the over-simplification of problem may result in serious flaws. In fact, the supply chain contracts which coordinate in a particular theoretic setting (under certain simplifications), may lead to very different results when implemented in real world situations. Cachon and Kok (2010) show that well-known coordinating contracts such as quantity-discount and two-part tariffs could worsen the performance of supply chain when applied in a two-tier topology with multiple competing suppliers. Accordingly, one should be very cautious when implementing these insights into practice.

A common assumption in the supply chain contracting literature is that the process of contracting does not have any significant costs. However, there are several costs associated with the contracting process, e.g. costs related to writing down the contracts and their monitoring and enforcements costs. In addition, the literature does not consider the costs that the contracting agents incur in order to collaborate with each other.

Table 1. Literature Review

Reference	Supply Chain Problem					Coordinating Contract	
	Topology	Contract Length	Decision Variables	Agents Charact.	Environment		Information Structure
Cachon and Netessine (2004)	2T/2N	1-p	Order size, Selling price	Risk-N	Probab. & price-sensitive demand	Complete	Revenue-sharing contract
Taylor (2002)	2T/2N	1-p	Order size	Risk-N	Probab. demand	Complete	Rebate contract
Tsay (1999)	2T/2N	1-p	Order sizes	Risk-N	Probab. demand	Complete	Quantity-flexibility contract
Bernstein and Federgruen (2005)	2T/2N	1-p	Order size, Selling price	Risk-N	Probab. & price-sensitive demand	Complete	Price-discount sharing contract
Tomlin (2003)	2T/2N	1-p	Order size, Capacities	Risk-N	Probab. & price-sensitive demand	Complete	Quantity-Premium price only contract
Gan et al. (2005)	2T/2N	1-p	Order size	Risk-A & Risk-N	Probab. demand	Complete	Risk sharing contract
Wei and Choi (2010)	2T/2N	1-p	Order size	Risk-A	Probab. demand	Complete	Profit sharing contract
Hanany et al. (2010)	1T/2N	1-p	Order sizes	Risk-N	Probab. demand	Complete	Transshipment fund mechanism
Hezarkhani and Kubiak (2010a)	1T/2N	1-p	Order sizes	Risk-N	Probab. demand	Complete	Implicit pricing
Chakravarty and Zhang (2007)	1T/2N	1-p	Order sizes	Risk-N	Probab. demand	Complete	Return policies contract
Leng and Zhu (2009)	1T/2N	1-p	Order sizes	Risk-N	Probab. demand	Complete	Side payments
Anupindi et al. (2001)	1T/ <i>n</i> N	1-p	Order sizes	Risk-N	Probab demand	Complete	Side payments
Donohue (2000)	2T/2N	1-p (2 production stages)	Order sizes	Risk-N	Probab. demand	Complete	Wholesale-price with <i>ex ante</i> return option
Cachon (2004)	2T/2N	1-p (2 production stages)	Order sizes	Risk-N	Probab. demand	Complete	Advance-purchase discount contract
Barnes-Schuster et al. (2002)	2T/2N	2-p	Order sizes	Risk-N	Probab. demand	Complete	Option contract
Yao et al. (2008a)	2T/2N	1-p	Order size	Risk-N	Probab. and price-sensitive demand	Complete	Return policy contract
Ha and Tong (2008)	2T/2N	1-p	Capacity, Service level, Effort	Risk-N	Probab. and effort-sensitive demand	Complete	Revenue sharing contract

Table 2. Literature Review (continued)

Reference	Supply Chain Problem					Coordinating Contract
	Topology	Contract Length	Decision Variables	Agents' Characteristics	Environment	Information Structure
Cachon (2003)	2T/nN(1 upstream & n downstream)	1-p	Order sizes, Selling prices	Risk-N	Probab. & price-sensitive demand	Complete
Cachon and Zipkin (1999)	2T/2N	n-p	Order sizes	Risk-N	Probab. demand	Complete
Zhang (2006)	2T/3N (2 upstream & 1 downstream)	n-p	Order sizes	Risk-N	Probab. demand	Complete
Zijm and Timmer (2008)	3T/3N	n-p	Order sizes	Risk-N	Probab. demand	Complete
Ding and Chen (2008)	3T/3N	1-p	Order size	Risk-N	Probab. demand	Complete
Caldentey and Wein (2003)	2T/2N	n-p	Order sizes	Risk-N	Probab. demand, Make-To-Order Queue	Complete
Burnetas et al. (2007)	2T/2N	1-p	Order size	Risk-N	Probab. demand	Incomplete
Sucky (2006)	2T/2N	N/A	Lot sizes	N/A	Deterministic demand	Incomplete
Burnetas et al. (2007)	2T/2N	1-p	Order size	Risk-N	Deterministic demand	Incomplete
Shin and Benton (2007)	2T/2N	1-p	Order size	N/A	Deterministic demand	Complete
Zou et al. (2008)	2T/3N (2 upstream & 1 downstream)	2-p	Order size	Risk-N	Probab. demand	Complete
He and Zhang (2008)	2T/2N	1-p	Order size	Risk-N	Probab. demand, Random yield	Complete
Krishnan and Winter (2010)	2T/3N(1 upstream & 2 downstream)	1-p	Order size, Selling price	Risk-N	Probab. & price-sensitive demand, Competition over selling prices and fill rates	Complete
Ryu and Yucesan (2010)	2T/2N	1-p	Order size	Risk-N	Fuzzy demand	Complete
						Buyback Contract & Resale price maintenance Contract
						Linear transfer payment contract
						Linear transfer payment contract
						Side payments
						Return policy contract
						Linear transfer payment contract
						All-unit discount policy
						Side payments
						Side payments
						Quantity discount contract
						Buyback contract
						Risk-sharing contract
						Buyback contract
						Buyback, Quantity-discount, Revenue-sharing contracts

Many studies have shown that cooperation among supply chain agents requires costly infrastructure for information sharing, process and resource coordination, and performance measurements (c.f. McLaren et al. (2002)). Therefore, without considering such realistic costs, the practical benefits of coordinating contracts would be unclear and inconclusive. The research must find the conditions under which additional profits which result from implementing a coordinating contract are actually significant.

Despite the growing number of analytical studies on supply chain contracts, there are only a few empirical studies aiming at validation of the theoretical predictions in this area. In a laboratory study, Katok and Wu (2009) show that the effect of coordinating contracts on supply chain efficiency is smaller than what is predicted analytically. On the other hand, the small number of empirical research papers in this area is almost unanimously indicating that the actual decision making process in supply chains are hugely influenced by bounded rationality, anchoring, experience, and insufficiently adjusted heuristics (e.g. Schweitzer and Cachon (2000), Bolton and Katok (2008), and Benzion et al. (2008)). Additionally, the empirical studies of supply chain contracts do not reach beyond the laboratory tests—perhaps due to the sensitivity of necessary information.

6. DIRECTIONS FOR FUTURE RESEARCH

The opportunities for research on supply chain contracting and coordination are numerous. In fact, the research on supply chain contracts is still in its infancy and there is plenty of room for building upon the current research and expanding it. The analysis of the literature reveals that most of the coordinating contracts require the following preliminary conditions to start with: (1) rationality of the players, (2) absence of contracting costs, (3) complete knowledge structure, (4) risk neutrality, and (5) profit orientedness. However, most of these assumptions, if not all, do not provide an adequate realistic picture of the settings in which they ought to be applied. Agents might not know how to optimize or they may not have the sufficient computational power. The information sharing among the agents is very limited. Agents' behavior is opportunistic and there are various types of agents with regard to their utilities. Therefore, unless the gap between the theory and the practice does not close, the insights achieved from the research will be questionable. Among the possibilities for future research in this area are: (1) incorporating the under-analyzed aspects of supply chain contracting, e.g. verifiability, compliance, *etc*; (2) refining the definition of acceptability in coordinating contracts; (3) considering more general utility functions of supply chain members in order to capture realistic decision making criteria; (4) investigating more complex supply chain topologies; and (5) strengthening the usefulness of theoretical insights through empirical and case-based studies.

ACKNOWLEDGMENTS

This research has been supported by the Natural Sciences and Engineering Research Council of Canada Grant OPG0105675 and the Canadian Purchasing Research Foundation.

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