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Channel coordination with the newsvendor model using asymmetric information

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ABSTRACT

In this paper, after surveying short-term two-echelon supply channel coordination methods, we present an extended version of the newsvendor model in which the supplier has to fulfil all demand of the customer, even if this calls for an additional setup of production. Given uncertain demand forecast, the solution is an optimal production quantity that minimises the expected total cost including setup, inventory holding and obsolete inventory costs. Then, the model is studied in a decentralised setting where the customer has private information about the demand forecast, while the supplier knows the various cost factors. We suggest such a coordination protocol and payment scheme that provides both partners the right incentive for minimising the total cost: the customer is interested in sharing her unbiased demand forecast and uncertainty, while the supplier's rational decision concurs with the overall optimum. Hence, local decisions based on asymmetric information coordinate the channel in the global sense. The results are also demonstrated by taking some real-life test cases from an industrial study that motivated our work.

1. Introduction

Because of today's continuously changing market conditions, manufacturing enterprises are facing much difficult challenges than before. In spite of the still existing uncertainties of the environment (such as demand fluctuation, resource failures, scrap production, procurement delays) customer expectations are persistently growing. Now, customers seldom accept shortages or backlogs and, in addition, they often want to customise the product characteristics themselves. In the last decades, tighter cooperation between the enterprises along the supply chains appeared to be necessary to respond to this situation. Several recent practical initiatives have taken this approach, like the vendor managed inventory (VMI) or the collaborative planning, forecasting and replenishment (CPFR) programme, to name a few examples (Choi and Sethi, 2010).

One of the most subtle challenges of production is still the appropriate management of inventory. In the last decades of the 20th century, the Just-In-Time (JIT) production paradigm became very popular, since it promised the elimination of inventories, which were considered passive elements of the business creating only expenses and no value (Chikán, 2007). However, this ‘‘zero inventory'' concept could rarely be realised in practice under the special conditions of JIT production (unvarying demand, negligible setup cost/time, and so forth). In general, inventories are necessary in order to exploit economies of scale or to hedge against various uncertainties. Due to unforeseen changes of demand, stocks of products with short life-cycles may easily become obsolete, which causes not only significant financial losses for the enterprises, but also serious waste of material, labour, energy and environmental resources.

In supply chains, where the decisions are decentralised, the inventory management is even more problematic (Tang, 2006). As previous studies have shown (see Section 2.3), the resultant of the locally optimal decisions usually leads to suboptimal performance, since the objectives of the autonomous decision makers are not aligned with any global objective. This is essentially a distributed planning problem: supply chain members would like to exercise control over some future events based on information what they know at the moment for certain (about products, technologies, resource capabilities, sales histories) and only anticipate (demand, resource and material availability). Hence, the supply chain partners need to collaborate and to take into account some of the other's decisions. However, the issues of resolving conflicts between individual interests as well as of acting for a common goal are far from being resolved (Arshinder et al., 2008).

The theory of *contracting* aims at developing arrangements for aligning the different objectives. Contracts are protocols that control

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the flows of information, materials (or services) and financial means alike. According to Li and Wang (2007), a contracting scheme should consist of the following components:

- local planning methods which consider the constraints and objectives of the individual partners,
- an infrastructure and protocol for information sharing (see also Váncza et al., 2010), and
- an incentive scheme for aligning the individual interests of the partners.

A contract is said to achieve *channel coordination* if thereby the partners' optimal local decisions lead to optimal system-wide performance. Note that there also exists a weaker definition of coordination aiming only at improving global performance compared to the default baseline solution of decomposed planning (Albrecht, 2010); in this paper however, we regard the former, strong notation.

The motivation of our work comes from an industrial research and development project, which involves a production network with a focal end-product manufacturer and several suppliers. The network produces both standardised and customised consumer goods in a large variety. Customers of the end-products tend to be impatient: the acceptable delivery times are usually much shorter than the actual throughput times. Hence, production of even customised products must be based on demand forecasts, which, in turn, are just due to the nature of the market highly unreliable. The common goal of each network partner is to provide high service level towards the customers of end-products, while, at the same time, keeping production and logistics costs as low as possible. These requirements are conflicting: high service level can only be guaranteed by inventories of components, packaging materials, and end-products. Furthermore, in mass production technology low costs can be achieved only with few setups and large lot-sizes. In contrast, the market of customised mass products is volatile: if the demand unexpectedly decreases or ceases, typically due to managerial decisions, then accumulated inventories become obsolete.

The remainder of the paper is organised as follows. In Section 2, we review the most recent results in supply chain coordination theory. We introduce a new model and its analytic solution in Section 3, which guarantees to satisfy all demand with minimal cost. In Section 4, we extend our model to a decentralised two-echelon supply chain with *asymmetric information*, and present a payment scheme with double compensation that can coordinate such a supply chain. Finally, in Section 5, we demonstrate the proposed ideas on some industrial test cases.

2. Literature review

2.1. Classification of channel coordination methods

The general method for studying coordination mechanisms consists of two steps. At first, one assumes a central decision maker with complete information who solves the problem. The result is a so-called *first-best solution* which provides a bound on the obtainable system-wide performance objective. In the second step one regards the *decentralised problem* and designs such a contract protocol that approaches or even achieves the performance of the first-best solution.

An early review of supply chain contracts can be found in Tsay et al. (1999). In this paper supply chain management is defined as the extension of the classic multi-echelon inventory theory with the ideas of decentralisation (multiple decision makers), asymmetric information and new manufacturing and logistic paradigms, such as delayed differentiation and outsourcing. The study also provides a taxonomy for classifying contracts, which consists of eight different contract types. The authors pointed out, however, that these classes are not disjoint. Therefore we present a set of aspects, which generalise their taxonomy by allowing classification along multiple viewpoints; then we review the more recent related papers according to this extended classification. The different viewpoints can be classified as follows:

Horizon: Most of the related models consider either *one-period horizon* or *two-period horizon with forecast update*. In the latter, the production can be based on the preliminary forecast with normal production mode or on the updated forecast with emergency production, which means shorter lead-time, but higher cost. These latter models are extensively discussed in Sethi et al. (2005). In addition, the horizon can consist of *multiple periods* and it can be even *infinite*.

Number of products: Almost all models regard only one product. Handling more products in gross is rational in case of technological or financial constraints, like capacity or budget limits.

Demand characteristic: Generally, the demand is considered *stochastic*, although some models assume *deterministic* demand.

Risk treatment: Focus is usually set on models where the players are *risk neutral*. This means that they intend to maximise their expected profit (or minimise their expected costs). However, some studies regard *risk averse* players who also consider risk measures, e.g., standard deviation (Choi and Chiu, in press), value-at-risk (Özler et al., 2009) or conditional value-at-risk (Wu et al., 2010).

Shortage treatment: The models differ in their attitude towards stockouts. Most authors consider either *backordering*, when the demand must be fulfilled later at the expense of providing lower price or *lost sales* which also include some theoretical costs (e.g., loss of goodwill, loss of profit, etc.). Some models include a *service level constraint*, which limits the occurrence or quantity of expected stockouts. Even the 100% *service level* can be achieved with additional or emergency production (e.g., overtime, outsourcing) for higher costs.

Parameters and variables: This viewpoint shows the largest variations in different models. The main decision variable is quantity-related (*production quantity*, *order quantity*, *number of options*, etc.), but sometimes *prices* are also decision variables. The parameters can be either constant or stochastic. The most common parameters are related to costs: *fixed* (*ordering* or *setup*), *production* and *inventory holding* and *backorder cost*. These are optional; many models disregard fixed or inventory holding costs. There exist numerous other parameters: prices for the different contracts, salvage value, shortage penalty, lead time, etc.

Basic model: Most of the one-period models apply the *newsvendor model*. On a two-period horizon, this is extended with the possibility of two production modes. On multiple period horizon the *base-stock*, or in case of deterministic demand the *EOQ* models are the most widespread.

Technological constraints: Generally, technological constraints are completely disregarded in the coordination literature. However, in real industrial cases *resource capacity* or *budget constraints* can be relevant.

Solution technique: In the basic models—and most papers study these—the optimum of the objective function can be determined with simple algebraic operations (e.g., Grubbström and Erdem, 1999; Cárdenas-Barrón, 2001). However, in case of more complex models and further constraints, more powerful solution techniques may be required, like mathematical programming, dynamic programming, constraint programming, and, in the last resort, heuristics or metaheuristics (e.g., Hop and Tabucanon, 2005; Cárdenas-Barrón, 2010).

Number of players: We focus on the *two-player* case and call the players *supplier* and *customer*. There are also extensions of this