European Journal of Operational Research 226 (2013) 452–460

Contents lists available at SciVerse ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Production, Manufacturing and Logistics

# A distributed coordination mechanism for supply networks with asymmetric information

Péter Egri [a,*], József Váncza [a,b]

[a] Fraunhofer Project Center for Production Management and Informatics, Computer and Automation Research Institute, Hungarian Academy of Sciences, Kende u. 13-17, 1111 Budapest, Hungary

[b] Department of Manufacturing Science and Technology, Budapest University of Technology and Economics, H-1111 Budapest, Egry József u.1., Hungary

ARTICLE INFO

*Article history:*
Received 14 February 2012
Accepted 19 November 2012
Available online 29 November 2012

*Keywords:*
Supply chain management
Vendor managed inventory
Game theory
Mechanism design
Asymmetric information

ABSTRACT

The paper analyses the problem of coordination in supply networks of multiple retailers and a single supplier, where partners have asymmetric, private information of demand and costs. After stating generic requirements like distributedness, truthfulness, efficiency and budget balance, we use the apparatus of mechanism design to devise a coordination mechanism that guarantees the above properties in the network. The resulting protocol is a novel realisation of the widely used Vendor Managed Inventory (VMI) where the responsibility of planning is at the supplier. We prove that together with the required generic properties a fair sharing of risks and benefits cannot be guaranteed. We illustrate the general mechanism with a detailed discussion of a specialised version, assuming that inventory planning is done according to the newsvendor model, and explore the operation of this protocol through computational experiments.



## 1. Introduction

Supply networks are large and complex systems, characterised by the existence of numerous competitive enterprises, dynamic structures, uncertain knowledge, asymmetric information structure, and difficult planning and decision making problems. The uncoordinated actions in such a system lead to suboptimal performance, exemplified in a simple case by the well-known *prisoners' dilemma*. In supply networks this phenomenon is called *double marginalisation*: since every enterprise concerns its own profit when making decisions, the aggregate benefit is in general lower than if the enterprises were vertically integrated and centrally controlled. This suboptimality manifests itself in waste of materials, labour, energy and other environmental resources, and eventually causes significant financial losses, too. Hence, analysing the interactions of autonomous enterprises and designing coordination methods that are applicable and useful also in the industrial practice are some of the most compelling challenges of operations management today (Váncza et al., 2011).

In a vertically integrated supply network with multiple retailers and a supplier, centralising the replenishment and inventory management decisions at the supplier's side is advantageous compared to the situation where each retailer has to decide individually. This centralisation approach is called *risk pooling*, and it is proved to result both in lower average inventory levels and safety stocks (Simchi-Levi et al., 2000).

In order to use the idea of risk pooling in vertically non-integrated networks, the *Vendor Managed Inventory* (VMI) business model is applied frequently in the practice. In this case, the supplier takes all risks and full responsibility for managing a one-point inventory, while it tries to fulfil the demand occurring at the retailers (Simchi-Levi et al., 2000). In this situation, it is hard to decide what is the reason if a network performs poorly: were the forecasts unreliable, or was the planning inappropriate? If the retailers are not faced with the consequences of an imprecise forecast directly, they are not inspired to increase their efforts in accurate forecasting. On the contrary, they even have incentives to distort the forecasts, and tend to overplan demand and forward too optimistic values towards the supplier, in order to avoid lost sales. Alternatively, if the retailers are rewarded for overperforming the plans, then they tend to underestimate the demand, and hope that the supplier can still fulfil a higher realisation. In both cases, the selfish distortion of information introduces additional uncertainty into the demand forecasts, and leads to higher operational costs or higher lost sales.

We have observed both of the above phenomena when working on improving the performance of real supply chains. In a manufacturing domain, the supply network under study produces mass products like lighting sources and appliances. The products are marketed and sold on local markets by distribution centres throughout Europe. The distribution centres are autonomous business units with their own objectives, business plans and special

* Corresponding author. Tel.: +36 1 279 6136.
*E-mail addresses:* egri@sztaki.mta.hu (P. Egri), vancza@sztaki.mta.hu (J. Váncza).

0377-2217/$ - see front matter 
http://dx.doi.org/10.1016/j.ejor.2012.11.036

knowledge of the local markets, hence they prepare the demand forecasts. On the other hand, so as to exploit economies of scale, production is concentrated at a focal manufacturer who is responsible for cost efficient production and making inventory replenishment decisions on behalf of the distribution centres. Operations of the factory are highly complex (for a description of its production scheduling problem, see Drótos et al., 2009), the actual costs of serving the distribution centres depends on a number of factors among which the quality of received forecasts is of primary impact. Our other motivating example comes from the practice of a retail trade service, where local stores are linked to a central warehouse. The distributed stores are autonomous profit centres responsible for serving their local customers. They generate forecasts for demand of various fast moving consumer and durable goods. In contrast, the responsibility for organising supply of these goods is at the central warehouse who is connected to the suppliers and makes appropriate decisions of purchasing, replenishment and logistics. Similar to the industrial case above, processes and data of central planning are not known to the distributed retailers. The quality and reliability of their local forecasts, however, have a major impact on the efficiency of the overall system.

The literature of supply chain coordination with *asymmetric information* usually assumes that either the retailers' demand forecast or the supplier's cost is private information, or rarely both (for an overview, see Egri and Váncza, 2012). In this paper, we consider that both demand forecasts and production costs are private information of rational agents, and apply the apparatus of *mechanism design* theory in order to analytically investigate supply coordination mechanisms that exhibit generic properties like efficiency, truthfulness or budget balance.[1] By exploiting the special properties of the coordination problem, we construct a truthful and efficient mechanism that can be implemented in a distributed way. The resulting VMI-type relationship specifies an appropriate information exchange and payment scheme that has a straightforward interpretation. We illustrate the general mechanism with a detailed discussion of a specialised version, assuming that inventory planning is done according to the *newsvendor* model, and explore the operation of this protocol through computational experiments.

The remainder of the paper is organised as follows: In Section 2, we review the related literature. Next, our general supply network coordination model is presented in Section 3. We demonstrate the approach for the particular case of the newsvendor problem in Section 4. Finally, Section 5 discusses potential applications and extensions of the method and concludes the paper.

## 2. Literature review

In this section we review the main topics that relate to our paper. *Coordination with contracts* aims at constructing such enforceable rules whereby the overall supply chain performance can be optimised. *Game theory* determines the possible results of strategic situations defined by a number of participants, their own goals and decision options. *Mechanism design* is a subtopic of game theory, where the aim is to influence the participants in order to achieve some preferred outcome. In fact, coordination with contracts is a special application of this approach in the field of supply chains. However, there are several achievements of mechanism design which have not been used in this context so far, thus applying them seems to be a promising research direction. Finally, *information elicitation* models such problems, where the participants have private information about the probability of a stochastic event. We utilise this approach in our model assuming that the demand forecasts are only known by the retailers.

[1] For definitions see Section 3.

Several papers discuss different contractual forms for achieving optimal supply chain efficiency, called *coordination*, both for VMI and non-VMI models; for overviews see (Cachon, 2003; Li and Wang, 2007). Yu et al. (2009) study the VMI supply between a supplier and multiple retailers assuming symmetric information. They show that the network performance can be improved with cooperative contracts, but they cannot achieve perfect channel coordination. Chen and Bell (2011) consider price-dependent stochastic demand, customer returns and a retailer-supplier pair with symmetric information. They prove that the standard buyback contract cannot coordinate the channel in this case, but a modified version with two different buyback prices can, and furthermore, it enables profit sharing between the partners. Chen and Xiao (2011) present a model for a supply chain of short life-cycle products whose prices drastically decrease in the selling season. In a retailer–supplier chain with symmetric information, they develop buyback-based contracts that coordinate the channel and provide win–win situation for the partners.

As for the asymmetric information models, Liu and Özer (2010) compare the widely used price-only, quantity flexibility and buyback supply contracts when the demand forecast information is private. They assume that the forecast is either shared truthfully or not shared at all. It is shown that in this asymmetric situation the quantity flexibility and buyback contracts are not equivalent any more, since the quantity flexibility contract may not warrant truthful information sharing and coordination. Wang et al. (2009) assume price-dependent demand and that the production cost of the supplier is private information. The paper studies several contract forms and concludes that none of them can guarantee truthful information sharing.

Recently, the game theory forums have also become interested in supply chain applications. An overview can be found in Nagarajan and Sošić (2008), which focuses on cooperative models including bargaining and coalition formation. Yu and Huang (2010) study a network with a supplier, multiple retailers and symmetric information, but assumes VMI supply. In this case, the retailers can decide about the retail prices and the advertising investments. The authors do not intend to coordinate the network, but to develop an efficient algorithm for computing the Nash equilibrium. Esmaeili et al. (2009) consider a single supplier single retailer setting with deterministic demand and symmetric information. In their model the supplier is responsible for the lot sizing decision, therefore it can be considered a VMI system. Instead of coordinating the channel, their goal is to characterise the Pareto-efficient cooperative solutions that can be used during the price negotiation between the partners. Wang et al. (2004) model a supply network with one supplier and multiple retailers, and study the setting as a non-cooperative game with symmetric information. They also consider the situation when the supplier has some strict production constraints and thus the retailers must compete for the supply. The paper also presents contracts that result in unique Nash equilibria and coordinate the network.

Mechanism design theory deals with the problem of constructing the rules of a game with incomplete (asymmetric) information in order to achieve some preferred outcome. For an overview of the classic mechanism design theory we refer to Narahari et al. (2009). One of the main achievements in this field is the Vickrey–Clarke–Groves (VCG) mechanism, which is the only one in the general model that can provide *efficient* and *truthful* behaviour, but unfortunately, it cannot guarantee the *budget balance* property. An other possibility is to apply the mechanism developed by d'Aspremont, Gérard-Varet and Arrow (dAGVA), which results in efficiency and budget balance. Unfortunately, the dAGVA mechanism offers a much weaker equilibrium concept than the VCG, and it also necessitates some common belief about the private information, e.g., a probability distribution (belief) about a