Two-echelon supply chain coordination under information asymmetry with multiple types

R.B.O. Kerkkamp*, W. van den Heuvel, A.P.M. Wagelmans

Econometric Institute, Erasmus University Rotterdam, The Netherlands

1. Introduction

We consider the classical 2-echelon Economic Order Quantity (EOQ) setting with a supplier and a retailer. Both the supplier and the retailer act as fully rational individualistic entities that want to minimise their own costs. It is well known that such individualistic viewpoints are suboptimal for the entire supply chain. This loss of efficiency is often called the price of anarchy, see for example [22]. We assume that the supply chain uses a pull ordering strategy, i.e., the retailer places orders at the supplier. Therefore, the retailer's default ordering policy is optimal for herself. The supplier can decrease his costs by somehow persuading the retailer to change to a different ordering policy.

One way the supplier can do so is by offering a contract to the retailer that typically includes a side payment or discounts. If the contract is accepted by the retailer, the costs for the entire supply chain decrease and the resulting profit is divided between the two parties as agreed upon in the contract. Being selfish, the supplier wants the largest possible share of this profit. Depending on the type of contract, it is non-trivial to determine a contract that maximises the supplier’s profit and that is accepted by the retailer.

The complexity of the matter is increased significantly if the retailer has private information that is not shared with the supplier. For example, the retailer's cost structure can be undisclosed. Furthermore, private information typically leads to inefficiencies for the supply chain, see for example [12]. This partial cooperation between the supplier and the retailer leads to a principal-agent optimisation problem with asymmetric information.

In the case that the retailer holds private information, the supplier can use mechanism design or incentive theory to improve his situation, see [16]. That is, he presents a specially designed menu of contracts for the retailer to choose from. We focus on constructing the optimal menu of contracts that minimises the supplier’s expected costs, provided that the retailer is not worse off by choosing one of these contracts.

Our setting fits in the active broader research on supply chain coordination, see for example [17,18,28]. Ideally, all parties in a supply chain should cooperate fully for maximum efficiency. Such (centralised) cooperation is often difficult to achieve in practice, as parties do not want to share their private information or become too dependent on each other. However, even under information asymmetry, cooperation to improve efficiency is essential in order to be part of the increasingly competitive market.

To further specify the considered optimisation problem and our contribution to the literature, we need to introduce the economical setting.

* Corresponding author at: Postbus 1738, 3000 DR Rotterdam, The Netherlands. E-mail address: kerkkamp@ese.eur.nl (R.B.O. Kerkkamp).

http://dx.doi.org/10.1016/j.omega.2017.04.005
0305-0483/© 2017 Elsevier Ltd. All rights reserved.
1.1. Contracting model

The retailer faces external demand for a particular product with constant rate $d \in \mathbb{R}_{>0}$, which must be satisfied immediately, i.e., there is no backlogging. Placing an order at the supplier has an ordering cost of $f \in \mathbb{R}_{>0}$ for the retailer. Delivery of the order is assumed to be instantaneous (no lead times). Furthermore, the retailer has inventory holding cost of $h \in \mathbb{R}_{>0}$ per product unit and time unit.

Since we assume that the retailer minimises her own costs and can place any order, she places an order if and only if her inventory is depleted (the zero-inventory property). An order quantity of $x \in \mathbb{R}_{>0}$ units leads to an average holding cost per time unit of $\frac{1}{2}hx$ and an average ordering cost of $df \frac{1}{x}$. In total, the average costs per time unit for the supplier is given by

$$\phi_R(x) = df \frac{1}{x} + \frac{1}{2}hx,$$

which is minimised by ordering the well-known economic order quantity $x^* = \sqrt{2f/H}$ (see [3]).

The cost structure of the supplier is similar: the supplier has an order handling cost $F \in \mathbb{R}_{>0}$ and inventory holding cost $H \in \mathbb{R}_{>0}$. Procurement by the supplier takes place with constant rate $p \in \mathbb{R}_{>0}$. To minimise his own costs, the supplier follows a just-in-time lot-for-lot policy. That is, the supplier does not batch the retailer's orders and completes procurement of an order exactly on time. Note that $F$ can be interpreted as a production setup cost provided that $p > d$ and batching is not allowed.

Per time unit the supplier has average holding costs of $\frac{1}{2}H \frac{d^2}{x}$ and average order handling costs of $df \frac{1}{p}$. This leads to a total cost for the supplier of

$$\phi_S(x) = df \frac{1}{x} + \frac{1}{2}H \frac{d^2}{p}x,$$

which is minimised if the order quantity is $x^*_S = \sqrt{2fp/H}$.

The supplier and retailer both have their own optimal order quantity and either policy is suboptimal for the entire supply chain (unless $x^*_R = x^*_S$), see [3]. From the perspective of the supply chain, the supplier and retailer can cooperate to lower the total joint costs. The joint costs are given by

$$\phi_J(x) = df(f + F) \frac{1}{x} + \frac{1}{2} \left( h + H \frac{d^2}{p} + \frac{d^2}{p} \right)x,$$

with optimal joint order quantity $x^*_J = \sqrt{2(f + F)(h + H \frac{d^2}{p})}$. It is not difficult to verify that $x^*_J$ always lies between $x^*_R$ and $x^*_S$ (see Lemma 10). Therefore, lower joint costs can be achieved by deviating from the individually optimal order quantities. Whether such coordination takes place depends on further assumptions on power relations and market options.

As mentioned before, we assume that both the supplier and the retailer behave rationally and want to minimise their own costs. Furthermore, we assume that the retailer has the market power to enforce any order quantity on the supplier. Consequently, the retailer chooses her own optimal order quantity $x^*_R$ by default, called the default ordering policy or default option. By using incentive mechanisms, the supplier can persuade the retailer to deviate from the default policy. We analyse using a side payment $z \in \mathbb{R}$ to the retailer as an incentive mechanism for cooperation. Note that side payments can be realised, for example, via contract-dependent quantity discounts. The pair $(x, z)$ of an order quantity $x$ and a side payment $z$ is called a contract.

The presented contract $(x, z)$ must be constructed such that the retailer is not worse off than with her default option: $\phi_R(x) - z \leq \phi_R^*$. This condition is called the Individual Rationality (IR) constraint or participation constraint. If the offered contract leads to the same costs for the retailer as her default option, we assume that the retailer is indifferent and that the supplier can convince the retailer to choose the contract preferred by the supplier. By assumption, the supplier can do so without any additional costs. Hence, the retailer always accepts the presented contract if it satisfies the IR constraint.

If the supplier has complete information of the supply chain, it is straightforward to determine that the optimal contract offers the joint order quantity $x = x^*_J$ and minimal side payment $z = \phi_R(x^*_J) - \phi_R^*$. The resulting ordering policy leads to perfect supply chain coordination: it is optimal for the entire supply chain, as if there is a central decision maker.

However, we study the case that the retailer has private information on her cost structure: either the ordering cost $f$ or the holding cost $h$ is private (but not both). We consider the case that the supplier is uncertain about the retailer's holding cost, which is without loss of generality as will be shown in Section 2.1. The supplier has narrowed the retailer's real holding cost down to $K \in \mathbb{N}$ possible scenarios. Each scenario corresponds to a so-called retailer type. Type $k \in \mathcal{K} = \{1, \ldots, K\}$ has cost function

$$\phi_k^S(x) = df \frac{1}{x} + \frac{1}{2}h_kx,$$

where $0 < h_1 < h_2 < \cdots < h_{K-1} < h_K$ are the possible holding costs. This affects the retailer's individually optimal order quantity, which now depends on the retailer's type. Consequently, the retailer's default option is type dependent, since it is her own optimal order quantity by our assumptions. As such, we add the index $k \in \mathcal{K}$ to our notation to discern between retailer types. For example, for type $k \in \mathcal{K}$ the default order quantity is $x^*_k = \sqrt{2fp/H_k}$ with corresponding costs $\phi_k^R = \phi_k^S(x^*_k)$. Note that type-independent default options can be used if, for example, logistical operations can be outsourced to a third party for a fixed fee. We do not consider this option.

The supplier designs a menu of $K$ contracts for the retailer to choose from, one for each retailer type. For each type $k \in \mathcal{K}$, the supplier constructs a contract $(x_k, z_k)$ that is individually rational for that specific type, similar to before. However, the retailer can lie about her type and choose any of the presented contracts if it is beneficial for her to do so. This situation is also called a contracting or screening game in the literature, see [16].

Furthermore, the supplier assigns an objective weight $\omega_k \in \mathbb{R}_{>0}$ to each type $k \in \mathcal{K}$, indicating its likelihood, and minimises his expected costs. Without loss of generality, $\omega$ is a probability distribution ($\sum_{k \in \mathcal{K}} \omega_k = 1$), but this is not required for the model and our results.

This leads to the following non-linear optimisation problem:

$$\begin{align*}
\min_{x, z \in \mathbb{R}^+} & \sum_{k \in \mathcal{K}} \omega_k (\phi_R(\tilde{x}_k) + \tilde{z}_k) , \\
\text{s.t.} & \phi_k^S(x_k) - z_k \leq \phi_k^R, \quad \forall k \in \mathcal{K}, \quad (\tilde{x}_k, \tilde{z}_k) \in \{(x_1, z_1), \ldots, (x_K, z_K)\}, \quad \forall k \in \mathcal{K}, \quad \phi_k^R(\tilde{x}_k) - \tilde{z}_k \leq \phi_k^S(x_l) - z_l, \quad \forall k, l \in \mathcal{K}, \quad x_k > 0, \quad \forall k \in \mathcal{K}.
\end{align*}$$

The designed contracts $(x_k, z_k)$ must satisfy the IR constraints (2). The pair $(\tilde{x}_k, \tilde{z}_k)$ denotes the chosen contract by retailer type $k \in \mathcal{K}$, which must be one of the presented contracts, see constraints (3).
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات