Int. J. Production Economics 159 (2015) 137–146

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Multi-attribute procurement contracts

Zhaolin Li [a], Jennifer K. Ryan [b,*], Daewon Sun [c,1]

[a] Discipline of Business Analytics, The University of Sydney, Room 490, Merewether Building (H04), Sydney, NSW 2006, Australia
[b] Department of Industrial & Systems Engineering, Rensselaer Polytechnic Institute, ISE, RPI, 110 8th St., CII, Suite 5015, Troy, NY 12180, United States
[c] Department of Management, University of Notre Dame, Room 359, Mendoza CoB, Notre Dame, IN 46556, United States

ARTICLE INFO

Article history:
Received 16 May 2014
Accepted 19 September 2014
Available online 30 September 2014

Keywords:
Procurement
Multi-dimensional screening
Competition
Market segmentation

ABSTRACT

We consider the design of multi-attribute procurement contracts when the supplier possesses multi-dimensional private information. Specifically, we consider a buyer who must design a contract to procure a single product whose value is a function of two attributes. The potential supplier's cost structure is two-dimensional, including one component for each attribute, and is unknown to the buyer. In contrast to the existing one-dimensional models, we find that in some cases the buyer can extract all of the channel profits without distorting the specifications of the final product, and we identify conditions under which that will be the case. In other words, with more dimensions to leverage, the buyer may be able to discern the supplier's type without paying any information rents, thus reducing her procurement costs. It is also possible that the buyer can extract all the channel profits by distorting the product specifications downward. Finally, we demonstrate how our results can be extended to a setting with multiple customer classes, where the valuation for the product attributes varies across the classes. We find that greater differentiation in customer valuation leads to a setting in which the buyer is less likely to extract all of the channel profit without distortion.

1. Introduction

Optimal contract menus, also known as screening contracts, have been applied in a variety of supply chain contexts in which one supply chain entity possesses private information, such as a demand forecast, marginal cost, risk attitude, or information regarding supply reliability. The majority of these applications make the assumption that the private information can be fully captured by a single parameter. The main results of this research stream have been the following: (i) characterizing the optimal contract menu; (ii) demonstrating that the full-information solution usually cannot be implemented; and (iii) demonstrating that the high-type agent (e.g., the retailer with strong demand or the supplier with lower cost) is served with the first-best (i.e., system optimal) level, while agents of other (lower) types are served with lower than the first-best level, which is the classic result of "no distortion at the top" and "downward distortion at the bottom." In practice, however, procurement rarely relies on a single piece of information and firms often possess more than one piece of private information.

In procurement, buyers often care about multiple attributes, such as quality, cost, and delivery time. An extreme example is large-scale defense procurements, where the product generally involves many dimensions (e.g., cost, time, and technological superiority). Another example is the U.S. Highway Authorities' procurement for highway repair jobs, where the agencies care about the cost and timing of the job (Asker and Cantillon, 2010). Parkes and Kalagnanam (2005) provide examples of multi-attribute procurement in the utility and IT industries. On the other hand, suppliers can also have multi-dimensional private characteristics. For example, the marginal cost of quality or of lead time reduction is likely to vary from supplier to supplier, as is the fixed cost. Amaruchkul et al. (2011), hereafter ACG, discuss contracts between air carriers and freight forwarders and note that forwarders possess multiple types of private information, including revenue margin, cost, and demand. Therefore, when designing a procurement contract, the buyer must recognize the multi-dimensional nature of both the product (or service) attributes and the supplier's private information.

Thus, we consider a broadly applicable problem setting in which the buyer cares about multiple attributes, which may be the different aspects of product quality (e.g., reliability, design, materials, product features) and which may also include factors such as response time. The buyer cares about these attributes because the customers' willingness to pay for the product is

* Corresponding author. Tel.: +1 518 276 6486; fax: +1 518 276 8227.
E-mail addresses: erick.li@sydney.edu.au (Z. Li), ryanj6@rpi.edu (J.K. Ryan), dsun@nd.edu (D. Sun).
[1] Tel.: +1 574 631 0982; fax: +1 574 631 5127.

http://dx.doi.org/10.1016/j.ijpe.2014.09.032
0925-5273/

dependent on the levels chosen for these attributes. When choosing the levels of these attributes, the buyer must consider the supplier's cost to produce a product with the specified attribute levels. However, the buyer does not have detailed knowledge of the supplier's cost structure, e.g., the buyer does not know the supplier's cost to achieve different levels of product quality.

In this paper, we study how to design a multi-attribute procurement contract menu for this problem setting, i.e., when the supplier's private information is multi-dimensional. The buyer must design a contract to procure a single product whose value is a function of multiple attributes. The potential supplier's cost structure is multi-dimensional, including one component for each attribute, and unknown to the buyer. For analytical tractability, we focus on the two-dimensional case. However, we present numerical examples to demonstrate how the insights can be extended to settings with more than two dimensions. We analyze two scenarios that are practically relevant. In our base model, the supplier performs two tasks to produce the final product and possesses private information about the marginal cost of each task. An alternative interpretation of the first scenario is that the final product is assembled from two components, where the cost of quality is component-specific and private. In this base model, the buyer serves a single class of customers, i.e., all customers place the same value on the product attributes. In our second scenario, we consider a single buyer who serves multiple classes of customer demand, which differ in their valuation for the product attributes. We first analyze the base model in order to understand the nature of the buyer's optimal contract design. We then consider the second scenario in order to understand the impact of differentiation in customer preferences on the buyer's optimal contract design.

Specifically, we first characterize the buyer's optimal contract design for the base model and demonstrate that, in some cases, the buyer can extract all of the channel profit without distorting the specifications of the product. This result is in contrast to the one-dimensional model, where distortion leads to positive rents for the high-type supplier. The managerial message is clear: with more dimensions to leverage, the buyer may be able to discern the supplier's type without paying any information rents, thus reducing her procurement costs. We also use the base model to demonstrate that the optimal multi-dimensional contract menu exhibits some properties that do not arise in the one-dimensional model. Specifically, it is possible that the buyer can extract all the channel profits by distorting the specification for one type of supplier downward (i.e., downward distortion without rents). We then consider our second scenario and study how the conditions under which the first-best (i.e., system optimal) product specifications are used for both supplier types, and the buyer extracts all of the channel profit, change when there are differing valuations for the product attributes across customers. We find that greater differentiation in customer preferences leads to a setting in which the buyer is less likely to be able to extract all of the channel profit without distortion. Thus, greater differentiation in customer preferences can make the buyer worse off.

2. Literature review

Our study is related to the existing literature on supply chain contracting with asymmetric information, which has grown rapidly since the late 1990s. Readers can refer to Kouvelis et al. (2006) for a comprehensive review. Table 1 summarizes the representative results on screening contracts in the OM literature.

Most of the existing studies on screening contracts (except ACG) assume that the agent's (i.e., the supplier's) information is one-dimensional. A critical difference between ACG and our model is that we allow the buyer (or the principal) to use more than one instrument in the screening contract. To derive analytical results, ACG made assumptions regarding the agent's characteristics such that the agent's ranking is exogenous, i.e., the ranking of the agents is the same on all dimensions. Hence, the agent's type can be parameterized into a single dimension. In our model, the ranking of the agent is endogenous, i.e., the ranking of the agents is not the same on all dimensions. Hence, the agent's type cannot be parameterized by a single dimension. Thus, we obtain different results. In particular, we find that with more dimensions to leverage, the buyer may be able to extract all of the channel profit by strategically distorting the product specifications either upward or downward.

The design of multi-dimensional mechanisms has gained increased attention in the economics literature. Readers can refer to Rochet and Stole (2003) for an excellent survey. One of the most well-studied problems in multi-dimensional mechanism design is the product bundling problem. Wilson (1993) and Armstrong (1996) were the first to provide closed-form solutions for this problem with continuous types. Armstrong (1996) showed that the seller always excludes a subset of low-value customers. Such a result does not always arise in the one-dimensional model. Armstrong (1996) also identified the conditions under which the optimal price is only based on the cost to produce the bundle (i.e., a cost-based tariff is optimal). As in the one-dimensional problem with continuous types, when the distribution of the agent's type is irregular (i.e., the failure rate is not monotonic), "ironing and bunching" procedures will be involved. Rochet and Choné (1998) described how the "ironing and bunching" procedures can be implemented in higher dimensions. In the product bundling problem, it is the supplier who offers a menu of contracts to elicit consumers' preference. In contrast, in our analysis, the buyer offers a menu of contracts to discern the supplier's type.

The model in Armstrong and Rochet (1999) is closely related to our first scenario, analyzed in Section 3. Armstrong and Rochet (1999) developed the optimal contract menu for four types of agents (i.e., *ll*, *lh*, *hl*, and *hh* types), whereas we consider two types of suppliers with two-dimensional characteristics. In addition, we incorporate uncertain demand and extend the model to consider two settings in which the valuation for the product attributes varies across customers. As in the previous literature (e.g., Armstrong and Rochet, 1999; Asker and Cantillon, 2010), to ensure tractability, we focus on the two attribute problem.

There is also a vast literature on supply chain contracts without screening. The most commonly studied supply chain contracts are the buy-back (see, e.g., Chung et al., 2010) and revenue-sharing contracts (see, e.g., Cachon and Lariviere, 2005). However, most of the existing literature on these contracts assumes information symmetry. One exception is Dai et al. (2012), who demonstrate that when there is information asymmetry, in some cases a one-size-fits-all buy-back contract can achieve supply chain efficiency. In other cases, this result does not hold and a screening mechanism is required.

Finally, we summarize our contributions to the existing literature. First, we consider a screening contract with multiple dimensions, where the supplier's type cannot be reduced to a single dimension, for a setting in which the buyer offers the contracts to the potential supplier. We characterize the optimal contract menu for this setting. Second, we demonstrate the robustness of our analysis and findings by relaxing the assumption that there exists just a single class of customers. Specifically, we consider a model with two customer classes, and show that our main solution procedure and managerial insights still hold for this setting.

3. The two attribute problem with a single buyer

We consider a buyer who sells a single product. Demand for that product, D, is a random variable drawn from a Uniform(0,1)