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Procuring Customized Products: Integrating Contracting with Co-Design

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Abstract:

Customization is essentially a *pull* system and customers' demand for customized products is the ultimate force that drives a customization business. Research has been primarily focused on improving customizers' efficiency in eliciting and fulfilling customers' needs. This paper is concerned with customers' procurement decisions when faced with multiple competing customizers. A conceptual framework is constructed to capture the essential decisions, information, and incentives involved in procuring customized products. Procuring customized products differs from procuring standard products in that product specifications become *variable* and other contract terms like price and delivery tend to vary with product specifications. Conceptually, it's a *contracting* problem with an embedded *collaborative design* problem, with information asymmetrically distributed between customers and manufacturers in both the commercial domain and the technical domain. Based on specific information structure, different procurement scenarios for customized products are characterized and appropriate procurement mechanisms are discussed accordingly.

Keywords:

Customization, procurement, contracting, co-design

1. Introduction

Customization has been recognized as a frontier for manufacturers to gain competitive advantage in an increasingly diversified and dynamic marketplace [30]. Recent years have witnessed rapid increase in output of customized products, spanning from capital goods like airplanes, machine tools, elevators and escalators to consumer goods like computers, printers, sneakers, and watches etc. [25,35,36]. With the proliferation of customized products and spread of customization technologies, there emerges a new competitive landscape where multiple manufacturers compete on customization for customers' patronage. For example, both Boeing and Airbus customize airplane interiors for airliners; Dell, HP, and Lenovo allow customers to configure their own computers; both Adidas and Nike offer custom made sneakers, etc.

The increasing availability of customized products gives customers more choices that could potentially best fulfill their individual specific needs, which are often compromised in standard products designed for mass appeal. The escalating competition on customization among manufacturers further shifts bargaining power in customers' favor. However, to tap into the potential value offered by product customization, customers are faced with a series of difficult decisions in procurement, e.g. *which manufacturer to buy from? What specification to commit upon (given the product is not available yet)? How much (premium) to pay for it? How long to wait for the delivery? ...*

The difficulty to make these decisions comes from manufacturers as well as customers themselves. From manufacturers' side, a major motivation for manufacturers to pursue customization is to differentiate from competition. Manufacturers often have distinct customization capabilities and their offerings are often heterogeneous and resistant to

direct comparison. Consequently, a customer looking for a customized product is essentially faced with multiple *niche monopolists* and the market price for a customized product is often obscure. From customers' side, customers need to articulate their needs in terms of preferences and requirements. However, it's often difficult for customers to make informed tradeoffs and accurately articulate preferences, particularly when the product to be customized is complex. Customer requirements are often found to be either over-specified or under-specified relative to a manufacturer's capability.

Because of these difficulties, procurement of customized products could be a lengthy, costly, or even frustrating experience. In the context of industrial procurement, procuring custom made products like industrial equipments often involves painstaking preparations and back-and-forth negotiations [14]. The administrative cost of procuring customized products is often significantly higher than procuring standard products. Not surprisingly, customized products are avoided by purchasing professionals whenever possible. In the context of customized consumer goods, customers could get *confused* by the large number of options offered even by a single manufacturer [20], let along the enormous, if not infinite, possibilities offered by multiple competing manufacturers. Even worse, the value of choice implied in customization could get lost in the process [34].

There's a genuine need to look at customization from customers' perspective and to design/develop mechanisms and systems to improve their efficiency in procuring customized products. This is not only directly beneficial to customers but is also important to manufacturers that are pursuing customization as a long term strategy. Being essentially a *pull* system, customization as a business model can only succeed when customers are able to procure efficiently and consequently generate sufficient demand.

As a first step towards this direction, this paper aims to understand the nature of customers' procurement decisions for customized products when faced with multiple competing manufacturers. A conceptual framework is constructed to capture the essential decisions, information, and incentives involved in procuring customized products. Based on the framework, different procurement scenarios for customized products will be characterized and appropriate procurement mechanisms will be discussed accordingly. Given that research in product customization has been primarily focused on the supply side from manufacturers' perspective, the second objective of this paper is to call for study of customization as a procurement problem from customers' perspective. Suggestions for future research are also given.

2. Procurement Mechanisms in General

Procurement is essentially trading viewed from buyers' perspective and it has been generally approached as a contracting problem. Procurement mechanisms, or the procedures and rules that buyers follow to select sellers and determine contract terms, have a direct impact on procurement performance. The advent of information technology brings new avenues and means to conduct procurement and there is growing interest in procurement mechanism design from economics, computer science, management science and operations research [15]. Despite the diversity of procurement mechanisms reported in literature, they can be classified into 3 basic categories, namely *search-based*, *negotiation-based*, and *auction-based*¹, based on the trading institution [24].

¹ In some literature, auction is taken as a special form of negotiation. This research differentiates these two concepts by emphasizing that auction is a multi-lateral trading institution with fixed procedures and rules while negotiation is a bi-lateral trading institution with flexible procedures and rules. Bargaining and negotiation are used interchangeably in the paper.

2.1 Search-Based Procurement

In search-based procurement, a customer searches for a product that best satisfies her needs from a predetermined solution space. For each product possibility, the customer is faced with a *take-it-or-leave-it* decision without haggling on price, product attributes, or whatsoever. This is the mechanism we employ when buying from shopping malls, online product catalogs (e.g. [amazon.com](https://www.amazon.com) for books, [autotrader.com](https://www.autotrader.com) for cars, etc.), or product configurators (e.g. [dell.com](https://www.dell.com) for PCs and notebooks, [121time.com](https://www.121time.com) for Swiss watches, etc.).

The advantage of search-based procurement is its transparency and simplicity. Information technology, and search engines in particular, have made it easy for customers to locate relevant product information. The disadvantage of search-based procurement is its rigidity, since the solution space needs to be determined *ex ante*. The burden is mainly on manufacturers. First, it's difficult to describe a product, especially when the product is complex, in sufficient details without confusing customers. Second, it's difficult to forecast customers' willingness to pay and price right, particularly when the product variety is high and customers are highly diversified [6]. The rigidity of search-based procurement prevents effective communication and leads to demand-supply mismatch.

2.2 Negotiation-Based Procurement

In negotiation-based procurement, a customer engages in a bi-lateral dialogue with a potential manufacturer upon product attributes, price, or anything that is pertinent to the transaction. Each party makes offers or counteroffers and collectively they search for an agreement on transaction that is mutually acceptable. Negotiation is arguably the most widely used institution in industrial procurement, e.g. purchasing of materials, industrial equipments, office supplies, or professional services [14]. Individual consumers who

have bought souvenirs at tourist sites probably also have had firsthand experience of negotiation-based procurement.

The advantage of negotiation-based procurement lies in its flexibility. With rich exchange of information, a buyer and a seller could dynamically explore all sorts of possibilities and potentially reach innovative win-win solutions [31]. There's been extensive research on electronic negotiations in recent years [7]. For example, negotiation support systems have been developed to support negotiators in decision making and finding efficient agreements [32]. Enterprise software vendors like [SAP](#), [Oracle](#), and [i2 Technologies](#) have incorporated various negotiation support functionalities in their procurement solutions [1].

However, there're inefficiencies inherent in negotiations. Myerson and Satterthwaite prove "... *the general impossibility of ex post efficiency of bargaining without outside subsidies*" [26]. Raiffa *et al* point out the so-called *negotiators' dilemma*: "... *value creation is usually inextricably linked to value claiming in negotiation and the tactics used to create a larger pie may conflict with tactics designed to claim a large slice of the pie*" [31]. The inefficiency of negotiations in practice is manifested by bluffs, threats, and traps, iterative processes, and unpredictable results. To some extent, it's more an art than a science.

2.3 Auction-based Procurement

An auction is a market institution with an explicit set of rules determining resource allocation and prices on the basis of bids from the market participants [22]. Auctions used for sales are called *forward auctions*, in which bidders bid to buy products or services, e.g. selling art collectibles through [Sotheby's](#) or [Christie's](#), and selling used books through [EBay](#). Auctions used for procurement are called *reverse auctions*, in which bidders bid to

supply a product or service, e.g. government procurement of construction service for infrastructure projects through public bidding.

Forward auctions and reverse auctions are theoretically equivalent except a sign difference [22]. We use the more familiar forward auctions to explain the basic auction types, which include English auction, Dutch auction, first price sealed bid auction, and second price sealed bid auction (also called Vickrey auction) [15]. An English auction is an iterative auction where bidders submit monotonically increasing bids. This process continues until a price is reached where there is only one bidder who remains willing to buy. The item is awarded to this buyer at the final bid price. The Dutch auction is the reverse of the English auction where the price is monotonically decreased by the auctioneer until there is a buyer who is willing to buy at the ongoing price. The first and second price sealed bid auctions are single round auctions where bidders submit sealed bids. The winner of the contract is the bidder who submits the highest bid. The payment that he makes in the first price sealed bid auction is the bid price itself. In the second price sealed bid auction, the payment is the second highest price, and this makes it a truthful auction mechanism, in which bidders bid their true values.

Despite the apparent differences among different types of auctions, they actually yield the same expected revenue for the auctioneer under some assumptions¹, a property called *revenue equivalence theorem* [22]. In practice, however, robustness, efficiency, transaction costs, and immunity to cheating are also important factors besides revenue in choosing an auction type. It turns out that first price sealed bid auctions are most popular

¹ These assumptions are: 1) The bidders are risk neutral. 2) Bidders' valuations are independent and private. 3) The bidders are symmetric. 4) Payment is a function of bids alone [22].

for trading with endogenous quantity because of *economies of scale*, and English auctions are most popular for fixed-quantity trading because they economize on information gathering and bid preparation by giving bidders a dominant bidding strategy [24].

The advantage of reverse auction for procurement is its efficiency in price discovery and economy of transaction. Companies like [GE](#) and [Motorola](#) [23] and market makers like [Ariba](#) have reported billions of dollars of cost saving in price paid to suppliers and administrative cost of procurement through online reverse auctions [4]. The downside of reverse auctions is the potential disruption of supplier relationship. Throat-cutting competition on price squeezes bid winner's profit down to zero or even negative, a dilemma called "*winner's curse*" [24]. Suppliers with differentiated solutions are particularly reluctant to participate in reverse auctions for fear of being commoditized. When participation is necessary, suppliers tend to capitalize on ambiguities in customer requirements by means of up-charges for later changes [9]. The construction industry is notoriously known for contractors bidding below cost to win a contract and make profits through customer initiated change orders. As a result, reverse auctions are mainly used for procurement of standard or commodity products where price is the king and there is little ambiguity on product specifications.

When factors like product quality, delivery lead time, etc. are also important and manufacturers' products are differentiated, the price-only auctions mentioned above may fail to identify the best overall solution. Multi-attribute auctions are proposed to include additional factors in competitive bidding. The basic idea is to convert multiple attributes into a score, or a *virtual currency*, to measure the overall utility of a bid and determine bid winners based on the score [15]. Che considers a two dimensional case (price and

quality) and designs an optimal scoring rule based on the assumption that the buyer knows the probability distribution of suppliers' cost parameters [16]. Branco extends Che's independent cost model and derives an optimal auction mechanism when the bidding firms' costs are correlated [11]. Parkes and Kalagnanam propose an iterative multi-attribute auction design based on a primal-dual algorithm to enable multiple rounds of auctions [27]. Bichler *et al* develop a mixed integer programming (MIP) model for procurement of configurable products [8].

With more factors considered, multi-attribute auctions give suppliers more flexibility to specify bids and buyers more freedom to select bid winners, hence promise higher efficiency of allocation and better supplier incentives. However, multiplicity of bidding attributes implies increase of complexity in bid preparation as well bid evaluation. A critical challenge is to determine the score function. Decision theory and techniques like multi-attribute utility theory (MAUT) and analytic hierarchy process (AHP) are often used to elicit buyers' preferences and determine the score function. Although advanced versions of MAUT and AHP can model interactions among attributes, the basic techniques use a linear, weighted value function, which assumes *preferential independence*¹ of all attributes. This assumption, however, is questionable in many situations, e.g. the importance of price in car purchasing might depend on whether it's a luxury car or a low-budget car [8].

In general, auction is efficient and transparent as a procurement mechanism. It enables the customer to "negotiate" simultaneously with multiple manufacturers. However, it is rigid because of its fixed procedures and rules, and it may disrupt supplier relationship

¹ An attribute x is said to be preferentially independent of y if preferences for specific outcomes of x do not depend on the value of attribute y [21].

because of public competition. As argued by Bajari et al., “... *auctions may stifle communication between customers and sellers, preventing the customer from utilizing sellers’ expertise*” [3]. When other factors besides price are also important in procurement, auction may become very complex and difficult to implement.

Table 1 summarizes the pros and cons of the 3 basic categories of procurement mechanisms. It’s worth noting the boundary between these categories is not clear-cut in practice. A reverse auction usually entails extensive negotiations on the auction procedures and rules before the auction, and another round of negotiations with on implementation issues after the auction.

Table 1 General Procurement Mechanisms

Procurement Mechanisms		Pros	Cons
Search-based (fixed price)		<ul style="list-style-type: none"> ▪ Simple ▪ Low transaction cost 	<ul style="list-style-type: none"> ▪ Fixed solution space ▪ No communication ▪ Inflexibility
Negotiation-based		<ul style="list-style-type: none"> ▪ Flexible ▪ Rich communication 	<ul style="list-style-type: none"> ▪ Inefficient ▪ Unpredictable ▪ High transaction cost
Auction-based	Price-only	<ul style="list-style-type: none"> ▪ Competitive price ▪ Relatively simple 	<ul style="list-style-type: none"> ▪ Supplier disincentive
	Multi-attribute	<ul style="list-style-type: none"> ▪ High efficiency ▪ Better supplier incentive 	<ul style="list-style-type: none"> ▪ High complexity

3. A Decision Framework for Procuring Customized Products

Although research on procurement mechanisms in general has touched upon procurement of customized products from various points of view, there’s been no study dedicated

specifically to this subject. There's no systematic approach to answer the question of *what* mechanism should be used under *what* condition for procuring customized products. There's also lack of theoretical foundation and practical guidance for designing efficient procurement mechanisms for customized products. This section aims to construct a decision framework to capture the essential decisions, information, and incentives involved in procuring customized products.

3.1 Product Customization: Customers as Co-Designers

According to Oxford English Dictionary, *to customize* is “*to make to order or to measure; to model or alter according to individual requirements*”. Based on this definition, there are two essential elements about customized products. First, from a time perspective, the product is made after an order is placed, i.e. *made to order*. In other words, there's a delay between committing on product specifications and receiving the final product; second, concerning the product features, the product is made based on customer-specific requirements. In other words, customers are integrated in the process of product creation by providing key design inputs, which are individual specific. Customer's involvement in product design has been recognized as a critical *identifier* of customization [17].

Because of the asynchrony between product commitment and product receiving, customers face a risk of “what you *think* (you will get) may not be what you *get*”. Such discrepancy could be either because the product committed is not what the customer really wanted (Type-I risk) or because the manufacturer does not deliver as promised (Type-II risk). The Type-II risk is an order fulfillment issue and the manufacturer is held fully responsible for it. Any product return or rejection is costly to the manufacturer because of the specificity of customized products. The Type-I risk is trickier since the

customer and the manufacturer collectively determine the product specification, and customers will be responsible for any changes initiated by themselves. Given the large number of choices usually implied in customization, customers are often unable to accurately articulate their needs in terms of requirements and preferences. The burden of making the right choice is diagnosed as “paradox of choice” by Schwarz [34], and may lead to “mass confusion” as explained by Huffman and Kahn [20].

Hippel treats product customization as a form of innovation [19]. He argues that successful customization requires fusion of two sources of information: *need information* and *solution information*, which are distributed asymmetrically with customers (users in his words) and manufacturers respectively. Users have better need information because they have better understanding of local environment and intended use of the product; manufacturers have better solution information because of their expertise in product design, production, etc. However, both need information and solution information are often costly to acquire, transfer, and use in a new location, a problem called “*information stickiness*”. In case of product customization, Hippel advocates user-centered innovation and proposes user toolkits to transfer solution information to users so as to enable product customization by customers.

Berger and Piller emphasize the importance of customer interaction and propose to treat customers as co-designers in customization [5]. Piller *et al.* further capture the concept of customer interaction as “*economies of customer integration*” [29]. They argue that customer integration is an important asset to increase efficiency and save cost in product customization. Similar to user toolkits, product configurators have been proposed to facilitate the customer-manufacturer co-design process [12,18,33]. With product

configurators, product design can be simplified to a sequence of attribute selections, which can be performed by customers or salespeople. However, it's worth noting that design toolkits and product configurators are developed from manufacturers' perspective and they are designated to help manufacturers to better *sell*. This is evidenced by their lack of support, sometimes intentional prevention, for customers to compare offerings of different manufacturers. In other words, they are more *sales* tools than *procurement* tools.

3.2 Procuring Customized Products: Contracting + Co-Design

Procurement in general can be taken as a contracting problem. Product customization involves co-design between customers and manufacturers. Conceptually, procurement of customized products can be taken as a *contracting* problem with an embedded *co-design* problem. Although both contracting and co-design can be taken as decision making activities, they focus on different *decisions*, require different *information* inputs, and they are driven by different *incentives*. This section aims to capture these elements with an integrative framework for approaching procurement of customized products.

3.2.1 Decisions

In procuring a customized product, the customer needs to select a manufacturer as the supplier and agrees upon a procurement contract, which usually includes (but not limited to) price, product specification, delivery schedule, warranty, and service terms etc. These contract items can be roughly grouped into commercial decisions (e.g. price, warranty, service, etc) and engineering decisions (e.g. product specification, delivery schedule, etc.). Generally speaking, the commercial decisions correspond to the *contracting* aspect as studied in general procurement literature; the engineering decisions correspond to the *co-*

design aspect as product customization is concerned in particular. Without loss of generality, *product specification* (s) and *price* (p) are selected as the representative decisions in procuring customized products.

Product specification is the technical description of a product. However, it has different implications to customers and manufacturers. To a customer, product specification describes, with legal authority, what product she is entitled to receive in terms of product features, functionalities, and performance etc. To a manufacturer, product specification is the legal commitment on what he needs to deliver if he wins the contract. Product specification will guide and bind a manufacturer's operations including product design, production, delivery etc.

Price is the monetary value a buyer pays in exchange for a seller's solution. There are generally two pricing schemes in procurement contracting: fixed-price and cost-plus. In fixed-price contract, the buyer offers the seller a pre-specified price for completing the project/product. A cost-plus contract does not specify the price, but reimburse the contractor for costs plus a stipulated fee. Relatively speaking, fix-price contracts provide suppliers better incentives for cost reduction, while cost-plus contracts provide customers better "insurance" against the risk of design changes and contract renegotiations [2].

Product specification and Price (p, s) can be taken as the final decisions in a procurement contract for customized products. To reach agreements on price and product specification, the customer and manufacturers need to make a series of other decisions. For example, the customer may need to decide *which manufacturers to include in competition; what information to reveal to manufacturers; how to evaluate solutions and determine contract*

winner(s) etc. Each manufacturer may need to decide, first of all, *to participate or not*; if participate, *what to offer, how to price, when to exit the competition*, etc.

3.2.2 Information

As product specification and price are concerned, customers and manufacturers are asymmetrically endowed with different sources of information in both the commercial domain and the engineering domain. In the commercial domain, customers have better information on valuation or willingness to pay, which can be represented by $V(s)$ as a function of product specification. Manufacturers are better informed of the cost of customization. Different manufacturers usually have different customization capabilities and cost structures. We use $C_i(s)$ to represent the total cost for manufacturer i to deliver the product specified by s .

In the engineering domain, customers have better need information and manufacturers have better solution information [19]. Customization can be taken as a special form of design, which can be viewed as a series of *what-to-how* mappings from customer needs (CN) to functional requirements (FR) to design parameters (DP), and to process variables (PV) [37]. CN represents a customer's real, but often hidden, needs towards a product; FR is the articulated customer need in terms of desired product functionality or features; DP represents a technical solution in terms of product architecture, component selection etc. that satisfies FR; and PV describes how the product designed can be produced. Generally speaking, the customer's need information is reflected in FR, while a manufacturer's solution information is reflected in DP and PV. Collectively, FR, DP, and PV can be interpreted as product specification viewed from different perspectives [38].

Different sources of information and the decisions upon price and product specification are interrelated. A customized product's *value* (to a customer) and *cost* (to a manufacturer) provide a price window (only when the former exceeds the latter is trading possible). In the meantime, both the *value* and *cost* of a customized product hinge upon the product specification, which results from the fusion of *need information* and *solution information* (Figure 1).

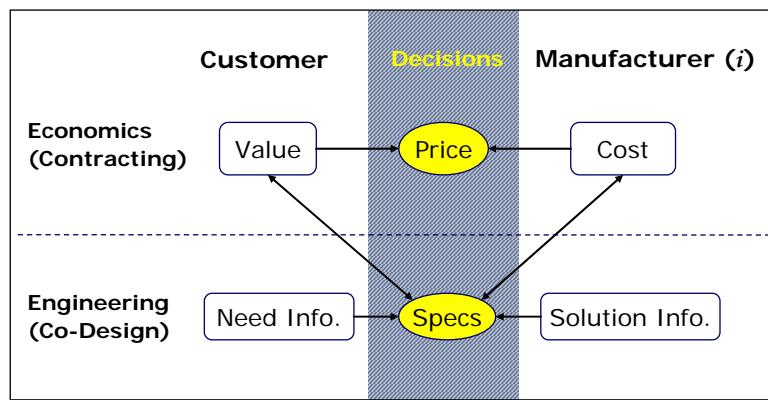


Figure 1 Decisions and information in procuring customized products

With multiple (N) competing manufacturers, different manufacturers have different solution information and cost structures. The customer may have certain information upon manufacturers' solution information and cost structure individually or collectively, and each manufacturer may have certain information about the customer and his competitors. Different information structure leads to different behaviors in a competitive procurement environment, driven by different sets of incentives.

3.2.3 Incentives

So far, *customers* are used as a generic concept for buyers without distinguishing their actual identities. *Customers* could be government agencies, industrial firms, or individual

consumers, and different types of *customers* have different priorities in procurement. For example government agencies may care more about social welfare and fairness than economic benefits; industrial firms may focus their attention on cost reduction; while individual consumers may be experience driven. This paper assumes customers' overall objective in procurement is to nail down a contract (s, p) that maximizes a general utility function [16]:

$$U(s, p) = V(s) - p - \sum_i^N Tc_i,$$

Tc_i represents the transaction cost incurred to the customer when dealing with manufacturer i . The transaction cost erodes customer utility. When deciding whether to deal with a manufacturer or not, the customer needs to tradeoff the extra transaction cost against the marginal value the manufacturer can bring to the table.

A manufacturer is assumed to be striving for winning a procurement contract that offers highest profit:

$$\pi(s, p) = p - C(s) - Tm,$$

Tm represents the transaction cost to the manufacturer. Manufacturers who lose the competition will make a loss that is equal to the transaction cost. Anticipating this, each manufacturer will calibrate his chance of winning and potential profit before entering the competition. In other words, transaction cost creates an *entry barrier* for manufacturers.

The relationship between the customer and each manufacturer in product customization can be characterized as *co-opetition*, a buzzword coined by Brandenburger and Nalebuff

to describe the coexistence of incentives for cooperation and competition in business relationship [13]. The customer and each manufacturer are aligned in terms of value creation, i.e. maximizing the product's value to the customer while minimizing its cost to the manufacturer. In the meanwhile, they are divided in terms of value claiming, particularly as price is concerned. More specifically, the customer is motivated to truthfully reveal her need and value information in order to identify the best solution, but she is also motivated to undervalue a solution in hope of driving down its price. Reversely, each manufacturer is motivated to offer a solution that gives the customer maximum value, but he is also motivated to exaggerate the cost of customization so as to boost the price.

From a domain perspective, the customer and each manufacturer are motivated to truthfully exchange need information and solution information in the engineering domain, but discouraged from sharing value information and cost information in the commercial domain. Instead, the competition for value claiming entices strategic withholding or even misrepresentation of value information and cost information. Distorted value information and cost information convey misleading signals about customer's real needs and a manufacturer's actual capabilities, and consequently prevent them from identifying efficient solutions. In general, there's an incentive conflict between design collaboration and contract competition, which poses a dilemma in procuring customized products.

3.3 A decision framework for procuring customized products

From an overall perspective, procurement of customized products in a competitive environment can be characterized as a principal-agent problem, with the principal

(customer) aims to hire an agent (manufacturer) to provide a customized product. The principal has individual-specific needs and private information on valuation (or willing to pay); each agent has distinct customization capabilities (solution information) and private information on his cost. Given the asymmetry of information, the customer is faced with an *adverse selection*¹ problem, which describes a contract situation with hidden information [10]. To overcome information asymmetry, the customer basically conducts a *screening* process, in which the uninformed party (customer) attempts to screen the different pieces of information the informed party (manufacturers) has and then make selection decisions. Reversely, manufacturers conduct a *signaling* process, in which the informed party (manufacturers) attempts to signal to the other party (the customer) his local information through his offers [10]. Summarizing the essential decisions, information, incentives, Figure 2 depicts a general decision framework for procuring customized products.

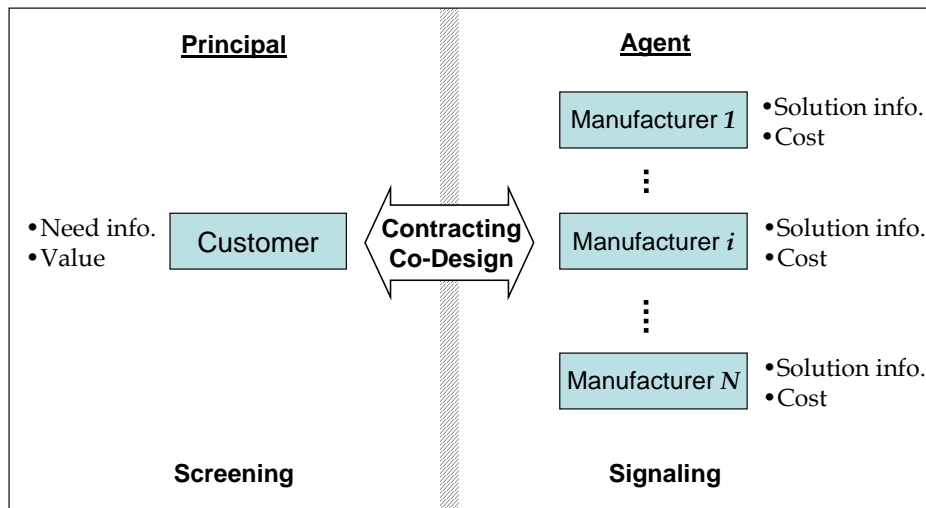


Figure-2 A decision framework for procuring customized products

¹ The term was originally used in insurance to describe a situation where the insured are more likely to suffer a loss than the uninsured, because people with higher risk are more willing to buy insurances.

4. Procurement Scenarios and Mechanisms for Customized Products

Buying customized personal computers is dramatically different from acquiring custom made industrial machinery. Different procurement situations entail different procurement mechanisms. Given the diversity of customized products, the question is *what* procurement mechanism should be used under *what* conditions. The decision framework constructed in the previous section provides a foundation to systematically answer this question. Depending on specific information structure between the customer and manufacturers, procurement of customized products can be characterized into typical scenarios, based on which appropriate procurement mechanisms can be developed.

A procurement scenario for customized products can be characterized based on the general market information, the customer's information upon her own needs, her ability to evaluate a solution, and manufacturers' customization capabilities. Along each dimension, the relative performance of *search-based*, *negotiation-based*, and *auction-based* procurement mechanisms is discussed, assuming other conditions being equal.

General market information

Above all, the bargaining power the customer has determines her freedom in choosing a particular mechanism in procurement. Without enough bargaining power, a customer can only procure in the way that is dictated by how the product is sold. With sufficient bargaining power, the customer can almost impose her way of procuring products onto suppliers at will (of course the procurement mechanism needs to be perceived fair to most of the suppliers). Generally speaking, search-based procurement requires least bargaining power and reverse auctions require highest bargaining power, with negotiation in the

middle. So before deciding which procurement mechanism to use, a customer needs to assess and should try to increase her bargaining power.

A customer's bargaining power increases with the size of her business, the competition level among manufacturers, and the information she has upon manufacturers. Correspondingly, customer can increase her bargaining power through consolidation of procurement, which can be achieved by centralized procurement for large companies like Wal-Mart and GE, or joining a purchasing consortium/group for small companies or even individual consumers [9]. Another way for a customer to increase bargaining power is to proactively develop alternative sources of supply so as to increase the competition level among manufacturers. A third way is to do market intelligence and collect as much information as possible upon manufacturers' solution information and cost information. In the rest of the discussion, the customer is assumed to have sufficient bargaining power to choose a procurement mechanism in her best interest.

Accuracy of need information (*FR*)

Customers have varying degrees of accuracy in articulating their needs, depending on the complexity of the product, customers' technical knowledge about the product, the dimension of customization, and the medium used etc. Generally speaking, the simpler the product is and the more knowledge the customer has about the product, the more accurate the need information will be. There are 3 generic dimensions of customization, namely fit/size, functionality, and (aesthetic) design/taste, with increasing difficulty for customers to articulate their needs [29]. The medium used for eliciting customers' need information could be a design sketch, an engineering drawing, a sample, or a prototype

etc. Generally speaking, the closer the medium is to the finished product, the easier it is for customers to articulate their needs.

Inaccuracy in need information will basically expose the customer to the Type-I risk in product customization, or the risk of product being committed is not what the customer really wanted. As a result, the customer may either need to initiate a design change and renegotiate the procurement contract or have to stick to what's been committed and settle with compromise. Both options could be costly to the customer. A general principle in procuring a customized product is to get requirements as accurate as possible. One approach is to delay the commitment on product specification (differentiation) as late as possible. However, there's a limit on how late the commitment can be delayed given the constraint of lead time and the cost of providing the medium, particularly when physical samples or prototypes are used.

When need information is inaccurate and the cost is severe, negotiation is the preferred procurement mechanism due to the flexibility and rich communication required, and cost-plus contract is preferred to fixed-price contract, since it can better hedge against the risk and cost of customer-initiated design changes.

Customers' ability to evaluate solutions (V)

Customers may not be able to accurately evaluate a customized product, particularly when the product is complex and the customer is not an expert on the technical issues. In this case, the customer will be exposed to the Type-II risk, or the risk of the manufacturer failing to deliver as promised. Although the manufacturer is contractually responsible for the under-delivery, it's the customer who will bear the risk if solution cannot be

accurately evaluated and under-delivery cannot be detected. For example, in construction industry, contractors may use inferior material for cost saving if the quality of material cannot be accurately evaluated in the final building. In economic terms, this is called “moral hazard”, which describes a contract situation with hidden actions [10].

When the “moral hazard” effect is severe, negotiation-based long-term relational contract is preferred [39]. Without clear criteria for solution evaluation, search-based mechanism is impractical while reverse auctions should be avoided since competition will almost surely drive the contract to those manufacturers who are most willing to exercise hidden actions against the customer.

Manufacturers’ customization capability (DP, PV, C_i)

The ability to provide high quality customized products with low cost is denoted as a manufacturer’s customization capability, which represents a manufacturer’s performance in value creation through customization. In some industries, manufacturers may use similar technologies and even share critical components or suppliers, for example, Dell, HP, and Lenovo on personal computers. In some other industries, manufacturers may use dramatically different technologies and hence have distinct customization capabilities, for example Boeing and Airbus on airplanes.

When manufacturers have similar customization capabilities, the competition among them is strong. As a result, search-based mechanisms are preferred if the market price is stable, and price-based reverse auctions are preferred if the market price is unstable. When manufacturers’ customization capabilities are distinct, direct comparison across different manufacturers may be difficult and manufacturers enjoy the status of *niche*

monopolists. Multi-attribute auctions are preferred if the complexity is manageable, otherwise selective negotiations with the most capable manufacturer(s) (expected) can help to locate the best solution while economizing on transaction cost.

Different procurement mechanisms are preferred along different dimensions. To make an optimal decision on *what* procurement mechanism to use under a specific scenario requires tradeoffs along different dimensions. The actual tradeoff will depend on how the mechanism will impact the overall objective of procurement (the utility function in this paper).

5. Summary and Future Research

Product customization has become increasingly pervasive in today's manufacturing industries. Research on product customization has been focused on the supply side, i.e. improving manufacturers' customization efficiency in terms of product design, production, and distribution etc. Less attention has been paid to customers' procurement decision for customized products, particularly in an environment with multiple competing manufacturers. This paper first reviews literature on procurement mechanisms in general and literature on product customization in particular. By synthesizing these two streams of literature, procurement of customized products is conceptualized as a contracting problem with an embedded co-design problem. A general decision framework is constructed to capture the essential information, decisions, and incentives involved in procuring customized products. Based on the framework, different procurement scenarios for customized products are characterized and appropriate procurement mechanisms are discussed accordingly.

This paper takes a step in systematically studying customization as a procurement problem from customers' perspective. The general decision framework proposed in this paper provides a conceptual foundation for further investigation. More specifically, future work is needed to quantitatively study the effect of transaction cost, inaccuracy in customer requirements and risk of design change, moral hazard, and manufacturer' cost correlation etc. Research efforts are also needed in designing mechanisms specifically for procuring customized products. One particular challenge is how to design a procurement mechanism that effectively supports design collaboration in a competitive contracting environment. Parallel to the research in procurement mechanism design, procurement systems need to be developed to improve the efficiency of procuring customized products, for example, to develop a procurement system that can effectively interact with multiple distinct product configurators.

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