A Negotiation-Credit-Auction Mechanism for Procuring Customized Products

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Abstract:

Customization promises higher value creation by matching customers' individual specific needs with manufacturers' capabilities. However, difficulties in terms of information asymmetry, information stickiness, and conflicting incentives prevent customers from effectively tapping into the value of customization in procurement. This research conceptualizes procurement of customized products as a *transaction* problem with an embedded *design* problem. A Negotiation-Credit-Auction mechanism is developed to separate *design* and *transaction* into two stages and employ negotiation and auction, respectively. Bidding credits are introduced in an intermediate stage as an instrument for incentive adjustment. This hybrid mechanism proves to be socially efficient and provides necessary flexibility as well as incentives for innovation in customization.

1. Introduction

Customization has been recognized as a competitive strategy in industries that are faced with an increasingly fragmented and volatile marketplace (Tseng et al. 1996; da Silveira et al. 2001). Recent years have witnessed rapid increase in output of customized products, spanning from capital goods like machinery, network servers, and information systems to consumer goods like personal computers, cars, golf clubs, and sneakers among many others (Moser and Piller 2006). Under this trend, there emerges a new manufacturing landscape where multiple manufacturers compete on customization for customers' patronage. For example, Cisco, Huawei, and Alcatel-Lucent compete on customizing network servers; Dell, Lenovo, and HP compete to provide customized computers; both Nike and Adidas offer custom made sneakers, etc.

The increasing availability of customized products gives customers more choices that could potentially better fulfill their individual-specific needs. In the meanwhile, the escalating competition on customization among manufacturers shifts bargaining power towards customers' favor. However, to tap into the value of customization often involves a lengthy, risky, and costly procurement process (Kenczyk 2001; Shachat and Swarthout 2004). In the context of industrial products, the time and resources consumed in procuring customized products are often significantly higher than those of standard products because of extra efforts in supplier selection, specification definition, and price negotiation (Bajari et al. 2009). Not surprisingly, customized products are often avoided by procurement professionals whenever possible. In the context of consumer products, customers could get "confused" by the large number of options offered in customization (Huffman and Kahn 1998). Schwartz (2004) defines this phenomenon as "the paradox of choice" and offers a comprehensive explanation of the possible reasons. In general, difficulties in procurement translate into high burden and cost, which could offset the value of customization and consequently discourage customers from customizing.

Research in mass customization has been primarily focused on the supply side in terms of mitigating the tradeoff between customization and production efficiency (da Silveira et al. 2001; Salvador and Forza 2004). Recent developments in procurement methodologies and technologies promise potential means to improve efficiency from the demand side of customization. Mechanism design theory, auction design in particular, has been widely adopted for procurement purposes (e.g. Milgrom 2004; Chandraskekar et al. 2007; Bajari

et al. 2009). Powered by increasing computing capacity and network connectivity, various mechanism designs have been implemented within advanced information systems and have henceforth transformed the procurement functions of both private and public organizations (e.g. Aberdeen Group 2002; Panayiotou et al. 2004; Gunasekaran and Ngai 2008). However, success has concentrated on standard or commodity-type products, for which there is little ambiguity on product specification and price is the dominant factor in procurement (Carter et al. 2004; Bichler and Kalagnanam 2005).

By contrast, customized products are often differentiated and individual customers are actively involved as collaborative designers in product creation (Berger and Piller 2003). A key challenge, however, lies in that customers are often unable to accurately articulate needs in terms of concrete requirements or preferences, and in the meanwhile, it is difficult for a manufacturer to describe a customized solution in sufficient details without confusing the customer (Zipkin 2001). As succinctly summarized by von Hippel (2005), customization is essentially a type of innovation that requires integration of *need information* and *solution information*, which are usually distributed asymmetrically with customers and manufacturers respectively, and both of which are "sticky" in the sense that they are difficult to be extracted, transferred, or used in a different location.

Conceptually speaking, procurement of customized products can be taken as a *transaction* problem with an embedded *design* problem. Design is collaboration oriented that requires truthful exchange of need information and solution information; transaction, on the other hand, is competition oriented that motivates strategic withholding or misrepresentation of private information. To reconcile these conflicting incentives, this paper proposes a Negotiation-Credit-Auction (NCA) mechanism for procuring

customized products. This hybrid mechanism separates design and transaction into two stages and employs negotiation and auction, respectively. Bidding credits are introduced in an intermediate stage as an instrument for incentive adjustment. The rest of the paper is organized to present the NCA mechanism in detail by first reviewing relevant literature, and modeling pertinent decisions, and then presenting the mechanism's procedure, outcome, and discussing its performance and applicability.

2. Relevant Literature

This research relates to the design of procurement mechanisms for differentiated products. This problem has attracted growing research attention as companies are increasingly relying on their suppliers for value-added products and services. The large volume of publications on mechanism design can be generally categorized into *auction-based* or *negotiation-based*. Auction is treated as a special form of negotiation in some literature (e.g. Raiffa et al. 2003; Bichler et al. 2003). This research differentiates these two concepts by taking negotiation as a bi-lateral mechanism with flexible procedures and rules, but auction as a multi-lateral mechanism with fixed procedures and rules.

2.1. Negotiation-Based Mechanisms

A negotiation-based procurement mechanism can be generally described as a process of "sequential search", in which the buyer contacts prospective sellers one at a time until a mutually satisfactory solution is identified (Wolinsky 2005). The bilateral interaction during negotiation is essentially a process of joint decision making with partial information exchange. With a highly flexible structure, negotiation-based mechanisms generally have a large "bandwidth" of communication for multiple issues and have a

large tolerance for ambiguities. Multiple issues imply multiple degrees of freedom in negotiation, as different parties usually have different preferences and mutually beneficial agreements could be identified through a process of *take-and-give* over these issues (Raiffa et al. 2003). Such properties are desirable for procuring customized products as the design aspect of customization is concerned, because customized products are often multi-attribute in nature and customers are often unable to accurately articulate needs.

Although little research has been devoted specifically to negotiation-based procurement mechanism design (e.g. Bulow and Klemperer 1996; Bajari et al. 2009), there is a large volume of research on negotiation as a general mechanism for joint decision making in economics, decision science, and computer science literature. A major challenge in negotiation with multiple issues lies in the complexity of making tradeoffs with incomplete information. In this regard, various Negotiation Support Systems (NSS) have been proposed to facilitate information sharing, joint decision making, and agreement mediation (Bichler et al. 2003). Enterprise software providers have incorporated many of these functionalities in their procurement system solutions (Aberdeen Group 2002).

Although negotiation is flexible enough to handle complexity and ambiguity in procuring customized products, it is an inherently inefficient mechanism for transaction. As pointed out by Raiffa et al. (2003, page 85), "...value creation is usually inextricably linked to value claiming and the tactics used to create a larger pie may conflict with tactics designed to claim a large slice of the pie", creating a so-called "negotiator's dilemma". Bargaining is often used interchangeably with negotiation in economics literature. To be more precise, bargaining corresponds to the "distributive negotiation" as defined by Raiffa et al. (2003). Myerson and Satterthwaite (1983) have analytically proved the

general impossibility of *ex post* efficiency of bargaining without outside subsidies. In other words, there is always possibility that negotiators may fail to reach an agreement, even though mutually beneficial solutions are available. The root cause of such inefficiency lies in lack of incentives for truth-telling in negotiation. On the contrary, negotiators are motivated to strategically withhold or misrepresent private information, which results in laborious iterations as well as unpredictable outcomes.

2.2. Auction-Based Mechanisms

Auctions used for procurement are also called reverse auctions in which suppliers bid to provide a product or service according to pre-defined procedures and rules (McAfee and McMillan 1987). When the product is standard and price is the main concern, reverse auctions are efficient in price discovery by forcing suppliers to reveal private cost information through competitive bidding. Such properties are desirable as transaction is concerned, but the rigid procedures and rules of a reverse auction make it ineffective in handling multiple attributes and ambiguous information. When the product is differentiated, bidding solely on price could result in awarding the contract to the lowest bidder but with poorest specifications or quality (Milgrom 2000).

One popular approach to mitigate this problem is to establish a "quality floor" for nonprice attributes and only qualified suppliers are selected to bid on price. Although a price auction with a quality floor reduces bidding to a single dimension thus reduces complexity, it requires the buyer be able to accurately articulate requirements. Ambiguous requirements may necessitate buyer-initiated design changes and contract renegotiations, which could result in extra costs and additional charges from suppliers (Bajari et al. 2009). Furthermore, as qualified suppliers are treated as homogeneous, highquality suppliers do not have incentives to participate and participating suppliers do not have incentives to innovate. Instead, suppliers are motivated to propose solutions that are just good enough to qualify (Kwak 2002). When ambiguities abound and switching costs are high, suppliers may act opportunistically to bid aggressively on price to win the contract and recoup a profit by taking advantage of loopholes in customer requirements (Kenczyk 2001; Carter et al. 2004).

Another popular approach for procuring differentiated products via reverse auctions is to define a score function, which converts both price and non-price factors into a single score (i.e. a virtual currency) to represent the overall value of a bid to the customer (Asker and Cantillon 2008). Given that competition is over multiple attributes, score auctions are also called multi-attribute auctions in some literature (e.g. Bichler and Kalagnanam 2005). In an early paper, Che (1993) considers both price and quality in procurement and proposes optimal auction designs that maximize buyers' utility. Interestingly, the optimal score function deviates from the buyer's utility function by systematically discriminating against quality. From a market maker's perspective, Milgrom (2000) proposes an auction design that maximizes social surplus by truthfully revealing the buyer's utility function as the score function. Recently, Bichler and Kalagnanam (2005) develop a score auction based on mixed integer programming to procure configurable products, which can be taken as customized products with predetermined solution space. Despite the increasing sophistication and ingenuity of score auction designs, a practical challenge that limits their application in procuring truly customized product lies in the difficulty of defining the customer utility function. As discussed earlier, customers are usually unable to make informed tradeoffs among competing objectives, especially when the product is complex. With an inaccurate utility function, no matter how strategically the score function is designed, it will send misleading signals to suppliers in customization.

2.3. Hybrid Mechanisms

There is ongoing debate concerning the relative superiority between negotiation and auction as a general mechanism for market transaction. Bulow and Klemperer (1996) claim that the value of negotiating skill is small relative to the value of additional competition and auction is almost always preferred, if available. Bajari et al. (2009), however, contend with empirical findings that many building contracts in the private sector are awarded through negotiations, even though competitive bidding is an available option. They point out that "auctions may stifle communication between buyers and sellers, preventing the buyer from utilizing the contractor's expertise when designing the project" (Bajari et al. 2009, page 1). Milgrom (2004) provides a more balanced view, suggesting that different mechanisms should be applied in combination to address practical market transaction problems. Up to date, however, research on hybrid mechanism design has been rare. This paper makes an original contribution by developing a hybrid mechanism that integrates negotiation and auction for procuring customized products.

3. Procurement Scenario and Decision Modeling

This paper assumes a general scenario of procuring customized products, in which a customer with individual-specific needs seeks a customized solution from multiple competing manufacturers who have heterogeneous customization capabilities. A single

manufacturer will be contracted to supply the product. A procurement contract consists of agreement over two attributes: *price* (p) and *product specification* (s), which are a scalar and a vector, representing decisions on the *transaction* and *design* aspect of procuring customized products, respectively. Other attributes like delivery lead time and service terms, although apparently important, are omitted without loss of generality (these attributes can be generally taken as extra dimensions in s).

The customer's and a manufacturer's decisions in procurement of a customized product are modeled as two interrelated mathematical programming problems that seek an agreement on (s, p) to maximize utility (u) and profit (π) , respectively (Fig. 1). Both uand π are quasi-linear functions of s and p as commonly modeled in the economics literature (e.g. Che 1993; Milgrom 2000).

$$u = v(s) - p \tag{1}$$

$$\pi = p - c(s) \tag{2}$$

where v(s) is the value function representing the customer's maximum willingness to pay for a customized product, c(s) is the cost function representing the total cost for a manufacturer to deliver the product. Individual rationality is ensured with constraints $v(s) - p \ge 0$ and $p - c(s) \ge 0$, implying that neither party will engage in a loss-making transaction. The customer's requirements and a manufacturer's solution space are modeled with inequality constraints $f(s) \le 0$ and $g(s) \le 0$, which represent the range of products that are functionally acceptable to the customer and feasibly producible by the manufacturer, respectively.

Fig. 1. Insert here

Functions v(s) and f(s) essentially capture the customer's need information, while c(s) and g(s) capture a manufacturer's solution information. It is worth noting that v(s) and f(s) actually form a dual relationship as constraints can be converted into the objective function, and vice versa. In accordance to practical usage and convention, this paper models both of them explicitly, and similarly for functions c(s) and g(s). Need information and solution information are assumed as private to the customer and manufacturer, respectively. Effective integration of these two types of information is necessary to find a customized solution that best matches the customer's needs with a manufacturer's capabilities (Berger and Piller 2003; von Hippel 2005). The quality of codesign is measured by social surplus $\phi(s)$, which is defined as the difference between the customer's value v(s) relative to the manufacturer's cost c(s).

$$\phi(s) = v(s) - c(s) \tag{3}$$

The decision model as depicted in Fig. 1 shows that customers and manufacturers share common interest in design as product specification (s) is concerned, but they have mutually opposed interest in transaction as price (p) is concerned. As decisions on s and p are coupled, there exists conflicting incentives between collaboration and competition in terms of truthfully sharing or strategically hiding and misrepresenting private information.

Although the decision model captures the essential dynamics of decision making in procuring customized products, it is important to note that some information is often not available in practice. More specifically, customers are often unable to accurately articulate needs in customization (Zipkin 2001), meaning that functions v(s) and f(s) are usually unknown *ex ante*. It is commonly observed in practice that customers could

articulate preferences much better after receiving a product sample or prototype. Based on this observation, this research assumes that there exist hidden and consistent functions v(s) and f(s), with which the customer is able to accurately evaluate a customized solution *ex post*. Relaxation of this assumption to consider a more general case of stochastic valuation with varying degrees of accuracy will be discussed in Section 6.1. It is also important to note that formulations of u(s) and $\pi(s)$ implicitly assume there is no transaction cost. This assumption is reasonable if transaction cost is small relative to the overall value of transaction, for example in procuring capital intensive equipment. However, this assumption is questionable if the procurement process is very costly, for example when expensive product prototyping is involved. Extension of the decision model to include transaction cost will be discussed in Section 6.2.

4. A Negotiation-Credit-Auction Mechanism

Customers' ability to better articulate preferences *ex post*, not *ex ante*, suggests that it takes an iterative process to elicit customers' need information and match it with a manufacturer's solution information. It is essentially a process of joint decision making with partial information exchange. In this regard, a negotiation-based mechanism is preferred to support co-design in product customization. However, lack of incentives for truth telling makes a negotiation-based mechanism inefficient for transaction. After all, a major, if not the only, motivation for a manufacturer to pursue customization is to differentiate from competition so as to better tap into the social surplus. In this regard, an auction-based mechanism is preferred due to its leverage of competition and its efficiency in price discovery and contract allocation. However, implementation of an auction-based

mechanism runs into several practical difficulties for procuring customized products as customers are often unable to accurately articulate requirements or preferences. As discussed in Section 2.2, without accurate requirements, it is difficult to implement a price auction while ensuring quality; without accurate preferences, it is difficult to implement a score auction that conveys and fulfills the customer's actual needs.

In short, neither negotiation nor auction is sufficient by itself to support procurement of customized products in situations where both specifications and price are important but the customer is unable to accurately articulate requirements and preferences. However, it is interesting to note that negotiation and auction are effective mechanisms to support design and transaction, respectively. The rationale of mechanism design in this research is to combine the advantages of negotiation and auction in a hybrid mechanism for procuring customized products.

4.1. Mechanism Procedure

Fig. 2 illustrates the procedure of the proposed NCA mechanism. The procedure starts with the customer sending out requirements to potential suppliers requesting proposals for a customized product. Each manufacturer either responds with a technical solution or decides not to participate. The customer evaluates each solution and assigns a bidding credit based on the solution's value premium. A manufacturer then decides if he is satisfied with the assigned bidding credit. If not, the manufacturer can negotiate upon requirements and propose a different solution. The process then iterates until the manufacturer either accepts the bidding credit and proceeds to the auction stage or exits the process without any transaction. The auction is organized as a standard reverse English auction, in which manufacturers bid openly and incrementally lower on price

(with product specifications being fixed). The lowest-price bidder will be awarded the contract and receive his/her bid price plus bidding credit as the final payment, and the bid winner is contractually obligated to deliver a final product as specified correspondingly. A losing manufacturer neither makes nor receives any payment.

Fig. 2. Insert here

From a procedural point of view, the NCA mechanism differs from a negotiation-based mechanism by appending a reverse English auction for price determination and contract allocation; it differs from a price auction with quality floor by allowing customer requirements to be negotiable and differentiated instead of fixed and uniform across manufacturers; and it differs from a score auction by postponing solution valuation from announcing a score function *ex ante* to assigning bid credits *ex post*. The implications of these differences in terms of mechanism applicability will be discussed in Section 6.3.

4.2. Assigning Bidding Credits

Assigning bidding credits is a pivotal stage in the NCA mechanism that links negotiation (a bi-lateral design process to determine product specifications) and auction (a multilateral bidding process to determine price). As manufacturers have heterogeneous capabilities, design solutions are likely to be different. Value differences among these solutions, if not properly recognized or compensated, would discourage manufacturers from innovation. The use of bidding credits is an effective tactic to encourage participation and promote competition in asymmetric auctions, in which bidders are distinguishably different (Milgrom 2004). Bidding credits can be taken as a promise of extra payment (or discount of payment in a forward auction¹). In this paper, bidding credit is assigned as the value premium of a customized solution relative to a benchmark solution s_0 , which could be thought of as the best alternative solution without customization, for example, an off-the-shelf product with similar functionalities.

$$b(s) = v(s) - v(s_0)$$
(4)

It is worth noting that the equation above implicitly assumes that the customer assigns bidding credits truthfully according to the value function. Shachat and Swarthout (2004) show that the customer could strategically assign bidding credits to handicap competent manufacturers after observing the pool of solutions so as to maximize utility. Their result, however, is derived based on the assumption that the distribution of suppliers' costs is correlated and public knowledge. Our study assumes manufacturers have heterogeneous capabilities and such information is private, hence the customer is not in a position to strategically discriminate manufacturers. Interestingly, in the same study by Shachat and Swarthout (2004), empirical findings in controlled experiments show that an English auction with bidding credits outperforms an optimal score auction, even though the game theoretical models suggest the opposite result.

Bidding credits are essentially an extra payment from the customer to a manufacturer conditional on the manufacturer wins the bidding. With bidding credits, the customer's utility function and the manufacturer's profit function, i.e. equation (1) and (2), can be modified respectively as the following:

$$u = v(s) - p - b(s) \tag{5}$$

¹ For example, the Federal Communications Commission of U.S. gave bidding credits to small businesses and minority groups to facilitate their participation in auctions for certain spectrum licenses. Upon winning, the favored bidders pay only a fraction of their winning bids (Milgrom 2004).

$$\pi = p - c(s) + b(s)$$

4.3. Mechanism Outcome

From the customer's perspective, bidding credits eliminate the value differences among the heterogeneous solutions from different manufacturers. In other words, bidding credits serve to "commoditize" manufacturers and reduce competition to a single dimension, i.e. price. From a manufacturer's perspective, bidding credits represent a source of extra revenue upon winning the contract. They can be taken as free "coupons" upon entry into the auction, which, however, can only be redeemed by winning upon exit. In this sense, bidding credits lower the actual stakes (costs) for manufacturers to be engaged in competitive bidding.

$$c'(s) = c(s) - b(s) \tag{7}$$

Assuming individual rationality, c'(s) represents a manufacturer's lower bound of price bid. c'(s) can be taken as an aggregate measure of a manufacturer's customization efficiency, as it takes into account both the cost and value (premium) of a customized solution. With change of variables, the customer's decision and a manufacturer's decision in the auction stage can be re-formulated as:

Fig. 3. Insert here

The above formulation represents a standard reverse English auction with private cost functions. In a reverse English auction, bidders have a dominant strategy to bid down to cost, and the auction concludes with the lowest cost bidder winning and price clearing at the second lowest cost (with a slight deviation due to minimum bid decrement allowed) (McAfee and McMillan 1987). To derive the outcome of the NCA mechanism, manufacturers participating in auction are indexed by *i* according to c'(s) in ascending

sequence, i.e. $c'_1(s_1) < c'_2(s_2) < ... < c'_n(s_n)$, where s_i represents the final specification submitted by manufacturer *i*. Based on these notations, manufacturer with the first order statistics $c'_1(s_1)$ wins the contract; and the clearing price is the second order statistics $c'_2(s_2)$. Thus, the final procurement contract based on the NCA mechanism can be represented as:

$$(s, p) = (s_1, c'_2(s_2))$$
(8)

5. Mechanism Performance

An economic mechanism can be evaluated along many dimensions depending on the specific context of application and the objective of design (Chandraskekar et al. 2007). This study assumes the perspective of a customer and aims to design a procurement mechanism that reconciles the conflicting incentives between (design) collaboration and (transaction) competition. The ultimate goal is to improve efficiency from the demand side of product customization. Therefore, (customer) utility maximization is by default a key criterion to evaluate the performance of the NCA mechanism. Furthermore, for a mechanism to be viable and sustainable, maximization of customer utility cannot be achieved at the expense of manufacturers (Milgrom 2000). Thus, economic efficiency and incentive compatibility are also included as criteria to evaluate the performance of the proposed hybrid mechanism.

5.1. Economic Efficiency

The efficiency of a mechanism in the economic sense generally consists of two concepts: *social efficiency* and *allocation efficiency*, which are measured respectively by optimality conditions of social surplus (i.e. whether maximum social value is created) and resource

allocation (i.e. whether the most competent supplier is contracted) (Milgrom 2004). The social surplus created with a transaction based on the NCA mechanism can be derived as:

$$\phi(s) = v(s_1) - c(s_1) = v(s_0) - c_1'(s_1)$$
(9)

As s_0 is a constant, s_1 is the value-maximizing solution in co-design and $c'_1(s_1)$ is the minimum out of $\{c'_i(s_i)\}\)$, the social surplus $\phi(s)$ is maximized. Hence, the NCA mechanism is socially efficient. Furthermore, as c'(s) measures a manufacturer's overall customization efficiency, selection of manufacturer with lowest overall cost, i.e. $c'_1(s_1)$, as the bid winner also implies that the NCA mechanism is efficient in terms of allocation.

5.2. Utility Maximization

As the NCA mechanism is designed from a customer's perspective, its performance in serving the customer's interest is a key criterion to justify its viability and practical implementation. As the customer cares about both product functionality and price in product customization, utility maximization, rather than price minimization, is a more appropriate performance metric. The customer's realized utility based on the NCA mechanism can be derived as:

$$u = v(s_1) - c'_2(s_2) - b(s_1) = v(s_0) - c'_2(s_2) \le v(s_0) - c'_1(s_1)$$
(10)

The above result shows that the NCA mechanism is not generally optimal in utility maximization as it fails to extract the entire expected social surplus for the customer. Optimality only holds when manufacturers (theoretically the top two most competent) have equivalent customization efficiencies, i.e. $c'_1(s_1) = c'_2(s_2)$. In case there is a dominant manufacturer (i.e. $c'_1(s_1) \ll c'_2(s_2)$), the winning manufacturer will capture the lion's share of the surplus. This result suggests that the NCA mechanism is preferably adopted in

procurement situations where there is genuine competition among manufacturers. It is worth pointing out that pursuit of utility maximization could backfire as squeezing suppliers' expected profit down to zero could disrupt supplier relationship, which has been recognized as a key drawback of optimal mechanism design (Kwak 2002; Milgrom 2000, 2004). In comparison, the NCA mechanism leaves the winning manufacturer a profit that is equal to its efficiency advantage over its strongest competitor, i.e. $c'_2(s_2) - c'_1(s_1)$. This result could be generally perceived as fair, hence be conducive in cultivating long term supplier relationships.

5.3. Incentive Compatibility

With information asymmetry and information "stickiness" in customization, it is critical to provide right incentives for manufacturers to truthfully share private information and to innovate in problem solving. This section introduces the concept of *incentive compatibility* to evaluate the incentive structure underlying the NCA mechanism. A mechanism is incentive-compatible if it is a dominant strategy for each self-interested participant to report his/her private information truthfully (Milgrom 2004).

From a manufacturer's perspective, the NCA mechanism gives manufacturers a dominant bidding strategy in the reverse English auction. Knowing that the contract will be allocated to the manufacturer with highest overall customization efficiency, manufacturers are motivated to search for a solution that best matches the customer's needs with their capabilities, thus truthfully revealing their solution information in the negotiation stage of the NCA mechanism. From the customer's perspective, however, incentive compatibility depends on the availability of information on manufacturers' capabilities and costs. In case that manufacturers share common technologies and have correlated costs, a self-interested customer would strategically distort need information when assigning bidding credits (Shachat and Swarthout 2004). In this case, the focus of competition will be more on price rather than customization. In case manufacturers compete on customization with heterogeneous solutions, as assumed in this study, information upon manufacturers' capabilities and costs are generally not available and it is in the best interest of the customer to truthfully assign bidding credits and reveal private utility information (Milgrom 2000). Hence, the NCA mechanism is incentive compatible and effectively reconciles the conflicting incentives between (design) collaboration and (transaction) competition in procuring customized products.

6. Model Extension and Mechanism Applicability

The decision model depicted in Fig. 1 makes two simplifying assumptions: first, the customer is able to accurately evaluate a customized solution *ex post*; second, transaction costs are negligible. This section relaxes these assumptions to consider more general procurement scenarios for customized products and discusses the consequent impact upon the NCA mechanism. The applicability of the NCA mechanism is subsequently discussed in comparison to other mechanisms.

6.1. Uncertainty in Valuation

Postponing valuation of a customized product until after receiving a solution proposal can significantly reduce, but cannot eliminate uncertainty. The true value of a customized product may take a long time of actual usage to be accurately assessed. Thus, it would be more general to model v(s) as stochastic with varying degrees of accuracy instead of deterministic. The NCA mechanism can be adapted to cope with this scenario by

assigning bidding credits based on *certainty equivalent*, which is a deterministic value that gives the same utility as a stochastically distributed value stream based on the decision maker's risk attitude (Keeney and Raiffa 1993). Assuming the value of a customized solution follow a normal distribution and the customer is risk averse with a mean-variance utility function (Jia and Dyer 1996), its certainty equivalent can be calculated as:

$$\hat{v}(s) = \mathbf{E}[v(s)] - \mathbf{Var}[v(s)]/\gamma \tag{11}$$

where γ is a positive constant that measures the customer's degree of risk aversion. The equation above indicates that the actual value of a customized solution is negatively related to the variance of its value distribution. If the variance, i.e. Var[v(s)], is significantly large, $\hat{v}(s)$ could be very small. This result offers an explanation of why customers refrain from customizing when they cannot accurately articulate their needs and preferences. As negotiation is essentially a process of partial information exchange that gradually removes uncertainty concerning the final solution, it reduces Var[v(s)] thus enhances $\hat{v}(s)$. In this regard, the negotiation stage in the NCA mechanism contributes to value creation by means of risk reduction. By substituting v(s) with $\hat{v}(s)$, the stochastic scenario is converted into a deterministic one and the procedure and performance of the NCA mechanism remain intact.

6.2. Transaction Cost

Both negotiating product specifications and participating in an auction could be time and resource consuming, resulting in significant transaction cost for both customers and manufacturers. Transaction costs incurred during negotiation and auction in the NCA mechanism are denoted as C_N^c and C_A^c for the customer, C_N^m and C_A^m for a manufacturer,

respectively. From a process view, negotiation costs (C_N^c and C_N^m) can be taken as variable costs that are proportional to the effort invested. They create barriers in the search process in co-design, which limit the customer and a manufacturer's ability to identify a globally optimal solution. Auction costs (C_A^c and C_A^m) can be taken as semifixed costs in the sense that there is a fixed cost to participate in an auction and there is also a variable cost that depends on the time or number of rounds in the auction. From a partisan perspective, C_N^c and C_A^c represent the customer's investment in procurement while C_N^m and C_A^m represent the "ticket" price for a manufacturer to participate. As a single manufacturer will be contracted, manufacturers losing out will register a net loss and the customer's efforts invested in dealing with these manufacturers will be "wasted", even though inclusion of more manufacturers may help promote competition. Anticipating such consequences, the customer need to screen manufacturers and manufacturers may refrain from participating. This result has been empirically confirmed by many studies on supplier qualification and selection (e.g. Carter et al. 2004; Hur et al. 2006). Recently, Wan and Damian (2009) have developed a quantitative model to study the impact of supplier qualification upon procurement cost. However, despite its necessity from a risk and cost perspective, qualification inevitably excludes some potential suppliers and thus reduces the solution space and competition in procurement. In general, transaction cost compromises the efficiency of the NCA mechanism and erodes the customer's utility. As transaction cost can be generally taken as sunk cost, it does not affect assignment of bidding credits, which measure the relative values of different customized solutions. Thus, the basic procedure of the NCA mechanism remains intact. Furthermore, depending on the relative costs of negotiation and auction,

the NCA mechanism can be flexibly "configured" to mitigate its effect by adjusting the relative efforts on negotiation and auction. When the cost of negotiation is significantly higher than that of auction (i.e. $C_N^c + C_N^m \gg C_A^c + C_A^m$), the NCA mechanism can be tilted towards more auction (e.g. by means of reducing iterations in negotiation), and *vice versa*. The NCA mechanism can also be extended to incorporate decision analysis tools to help customers and manufacturers assess their respective selection and exit conditions, thus improving overall efficiency.

6.3. Mechanism Applicability

As discussed in Section 3, the nature of decision making in procurement of customized product can be characterized as a transaction problem with an embedded design problem. The key challenge in design lies in information asymmetry and stickiness (von Hippel 2005) and the consequent uncertainty concerning product specification. The key challenge in transaction lies in the inherent differentiated features of customized products and the consequent uncertainty concerning price. Therefore, the applicability of a procurement mechanism for customized products can be generally delineated based on its effectiveness in handling these two types of uncertainties (Fig. 4).

Fig. 4. Insert here

Relatively speaking, when uncertainty on product specification is high, negotiation-based mechanisms are preferred due to the necessity for rich information exchange and joint problem solving; when uncertainty on price is high, auction-based mechanisms are preferred because of their efficiency in contract allocation and price discovery. More specifically, if the customer is able to articulate requirements f(s) with high degree of accuracy, a price auction with quality floor is preferred; and if the customer is able to

articulate metrics of solution valuation v(s) with high degree of accuracy, a score auction will be a viable option. Situations where both types of uncertainties are low basically correspond to a degenerate case that approximates standardization, for which posted prices with catalogs are sufficient and efficient. Situations where both types of uncertainties are high are the primary area of application of the NCA mechanism. By adjusting the relative weights between negotiation and auction, the NCA mechanism can be configured to cover a large spectrum of procurement scenarios for customized products. The NCA mechanism is tilted towards more negotiation (auction) if uncertainty concerning product specification (price) and the cost of auction (negotiation) are relatively high.

7. Conclusion and Future Research

This research views customization from the demand side and models customers' procurement decisions for customized products as a *transaction* problem with an embedded *design* problem. A hybrid Negotiation-Credit-Auction (NCA) mechanism is developed to separate collaboration activities (i.e. design) from competition activities (i.e. transaction) into two stages and employ *negotiation* and *auction*, respectively. Bidding credit is introduced in an intermediate stage to recognize the value premium of a customized solution. Based on a general decision model that considers both design and transaction, the NCA mechanism is proved to be efficient in value creation and contract allocation. It also provides necessary flexibility to handle information ambiguities and right incentives for manufacturers to innovate in customization. The NCA mechanism

can also be extended to cope with stochastic valuations and configured to minimize the negative effects of transaction costs.

Maximization of the customer's utility, however, is not guaranteed and the customer could strategically discriminate against manufacturers when assigning bidding credits. This study circumvents this problem by focusing on the scenario where manufacturers have heterogeneous solutions and private capability/cost information. In a more general situation with correlated cost information, strategic handicap becomes a viable option and it is in the discretion of the customer to decide whether to exercise that option. The NCA mechanism itself can be thought of as a balanced result of social efficiency and utility maximization, as negotiation serves to remove uncertainty and risk concerning product specification in search of a value maximizing customized solution while auction serves to leverage competition among manufacturers in order to minimize price. From this perspective, the NCA mechanism fills in the gap between traditional negotiation-based mechanisms and auction-based mechanisms with a hybrid design.

This paper is limited in a number of aspects that deserve future research. First, this paper considers a rather simplified procurement scenario by assuming private need information and solution information. It would be more general to assume customers and manufacturers have correlated estimations of each others' private information with different degrees of accuracy. As a result, strategic decision making concerning bidding credit assignment will become an important dimension in the NCA mechanism. Second, this paper has only qualitatively discussed the configuration of negotiation and auction in the NCA mechanism. Future research is needed to quantitatively analyze the optimal composition between negotiation and auction in the NCA mechanism, taking into account

factors including, but not limited to, uncertainties concerning product specification and price, transaction costs in negotiation and auction, market conditions in terms of the number of manufacturers and level of competition etc. In other words, questions remain to be answered concerning which suppliers should be selected to progress in negotiations and when to switch to auction. There are certainly many other dimensions to extend this research towards building a coherent set of methodologies, mechanisms, and systems for procurement of customized products, which will ultimately advance mass customization research by improving efficiency from the demand side.

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Fig. 1. Decision modeling in procurement of customized products



Fig. 2. A Negotiation-Credit-Auction procurement mechanism

Customer			Manufacturer		
Maximize	$u = v(s_0) - p$	▶ p ◄	(Maximize	$\pi = p - c'(s)$
Subject to	$v(s_0) - p \ge 0.$			Subject to	$p-c'(s)\geq 0.$

Fig. 3. Price bidding with bidding credits



Fig. 4. Procurement mechanisms for customized products