



## Decision Support

## Efficiency of electronic service allocation with privately known quality



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## ABSTRACT

We characterize how a social planner can design electronic service allocation when the desired service quality of customers and the actual service quality of providers are private information. Because private information is present in our analysis, we derive a second-best allocation mechanism that satisfies incentive compatibility, individual rationality and budget balance. While using the first-best outcome as a benchmark, we study the efficiency properties of the associated optimal allocation rules. In a set of simulation experiments with uniformly and normally distributed private information, we find that the asymptotic efficiency of the second-best mechanism is bounded away from 100 percent even for a large number of customers and providers. This finding indicates that the agents in our model do not become informationally small as the market size increases.

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## 1. Introduction

The increasing number of third-party vendors offering electronic services has stimulated the growth of information technology (IT) outsourcing in many organizations (Chang & Gurbaxani, 2012). Firms outsource their applications to these vendors that provide access to computing resources at a specified quality of service (QoS) such as availability, throughput, and execution time (Gartner, 2014). Advances in IT facilitate the substitution of traditionally static and long-term relationships by flexible contracts of shorter duration, with Cloud computing being the most recent manifestation of these advances (Armbrust et al., 2010). Recently, marketplaces for Cloud services have emerged, for instance, the Avnet Inc. (2016). Such marketplaces might be administrated by government authorities or large corporations, who aim at a socially optimal allocation. The overall objectives are to serve the customers and to best utilize geographically remote data centers. This scenario dates back to grid computing, a predecessor of Cloud computing, for which the social welfare properties have been studied in prior research (e.g., Schnizler, Neumann, Veit, & Weinhardt, 2008; Stösser, Neumann, & Weinhardt, 2010).

On markets for electronic services, multiple providers offer their services to multiple customers, who attempt to agree on an exchange of the services for money. However, for electronic services it is not viable to solely account for the price as the

single non-functional property because customers usually have different requirements for the quality characteristics (O'Sullivan, Edmond, & ter Hofstede, 2002). On the other hand, service providers use the QoS for differentiation from the competition. Under consideration of the QoS, determining the optimal service allocation is difficult for two reasons. First, each customer's desired QoS is known only to that customer and each provider's actual QoS is known only to that provider. The social planner observes no one's desired or actual QoS and no trader observes the QoS of any other trader. Second, the allocation mechanism must guarantee four specific economic properties, which are common in optimal auction design (Myerson, 1981): (i) the mechanism must provide adequate incentives for the participants because strategic individuals may misreport their true preferences (incentive compatibility), (ii) the mechanism must not force individuals to participate in the market (individual rationality), (iii) the mechanism must omit any independent intermediary but facilitate distributed decision-making among the participants (Egri & Váncza, 2013); this requirement implies that all payments must be distributed among the participants (budget balance), and (iv) the mechanism must maximize the social welfare (ex post optimality). Standard impossibility theorems from mechanism design assert that meeting all four requirements simultaneously is not attainable (Laffont & Maskin, 1979; Myerson & Satterthwaite, 1983). Therefore, the social planner must decide about a viable tradeoff of these requirements. One compromise in the presence of private information is to derive a second-best mechanism and compare its outcome to the associated first-best outcome that would arise if all information were publicly known (e.g., Arya, Löffler, Mittendorf, & Pfeiffer, 2015; Babich, Li, Ritchken, & Wang, 2012). A second-best mechanism is

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one that maximizes the *expected* social welfare among all incentive compatible, individually rational, and budget-balanced mechanisms (Börger, 2015).

Current approaches for integrating QoS into electronic service allocation use auction mechanisms to elicit QoS and price attributes for determining the optimal allocation (Bapna, Das, Garfinkel, & Stallaert, 2008; Blau, Conte, & van Dinther, 2010). However, classic auction theory is based on two assumptions: first, private information about reservation values exists on the customer side of the market only, while double-sided information asymmetry is generally not considered (Myerson, 1981). Second, the offered quality is fixed prior to provider selection (Bichler & Kalagnanam, 2005). Online auctions that use quality attributes apart from the price also affect the auction's outcome throughout the allocation process (Bockstedt & Goh, 2011). In settings with double-sided private information, it is not clear that the QoS actually offered by a provider will match the desired QoS of the customer. More specifically, when every provider offers a service of distinct QoS and every customer has distinct needs, facilitating allocations between the right pairs of traders is critical for maximizing the total welfare of a market. Therefore, the privately known desired QoS of customers and the privately known actual QoS of providers must be internalized into the allocation mechanism. However, how this integration affects the allocation outcome is still not known.

We address the problem of optimal service allocation on double-sided markets with private information. We draw on mechanism design to derive a second-best allocation mechanism for electronic services. We analyze a market where gains from trade that can be generated depend on the privately known QoS of the matched customers and providers. While deriving the optimal allocation rules from the perspective of a social planner, we study the efficiency properties of the set of mechanisms that satisfy incentive compatibility, individual rationality and budget-balance. To identify these optimal rules, we focus on direct revelation mechanisms by invoking the revelation principle (Myerson, 1979) in a first step. Then, the issue of real-world relevance is addressed by the implementation through position auctions. Afterwards, we report on a set of simulation experiments.

The objectives of this research are to: (i) derive a second-best mechanism for allocating electronic services with private information about QoS and (ii) evaluate this mechanism in a set of experiments to study its efficiency properties. Our proposal is informed by the work of Johnson (2013), who derived a profit-maximizing matching mechanism with double-sided private information. While the approach examined by Johnson (2013) focuses solely on mechanisms that maximize the expected profit of the auctioneer, we derive the optimal allocation rules from the perspective of a social planner that seeks to maximize the expected social welfare. We are particularly interested in studying the efficiency properties of the second-best allocation mechanism. In our prior research (Widmer, Premm, & Karaenke, 2013), we designed a mechanism for a specific allocation problem in a Cloud computing scenario by integrating energy efficiency as a particular QoS into the preferences of market participants. We advance this mechanism by (i) making customers' desired QoS and providers' actual QoS intrinsic parts of the mechanism and (ii) accounting for the four economic properties in the presence of double-sided private information.

The remainder of this paper is organized as follows. In Section 2, we discuss the approaches to QoS-aware electronic service allocation. In Section 3, we describe our mechanism for service allocation with private information and study its efficiency properties (Section 4). In Section 5, we report on the experimental evaluation and discuss our findings. We provide our conclusion in Section 6.

## 2. Literature review

We discuss extant literature on mechanism design and examine the integration of QoS as an intrinsic part of the mechanism. The field of mechanism design studies how privately known preferences of multiple individuals, also called agents, can be aggregated toward a social choice (Nisan & Ronen, 2001). For making customers' desired QoS and providers' actual QoS an intrinsic part of the mechanism, research concerned with multidimensional auctions and matching mechanisms is of particular interest.

A basic procurement auction with two dimensions, namely price and quality, was proposed by Che (1993). In this auction a single customer announces a publicly known scoring rule to multiple providers that are competing for winning a project. Price and quality preferences are aggregated into the utility function of each participant. The outcome is optimal for the customer if she can commit to a scoring rule in her best interest. This model was extended by Branco (1997) by integrating correlated cost types of the providers into the utility functions. The objective function of the single customer is the maximization of the social welfare instead of the customer's pay-off as in Che's model. Branco's approach shows that the customer needs to use a two-stage auction to implement the optimal outcome: the customer (i) selects one provider, and (ii) bargains to readjust the level of quality to be provided. However, their models are concerned with a single provider only and do not consider double-sided competition.

Specific auctions for the procurement of electronic services with multiple attributes have also been studied. Bichler and Kalagnanam (2005) proposed solutions to winner determination problems in multidimensional auctions with multiple sourcing and configurable offers. They examined the impact of several business rules such as propositional logic for knowledge representation, that need to be imposed on the winner determination problem in order to obtain an acceptable supply from multiple providers. Although this mechanism maximizes the customer's utility in experimental settings, their approach does not examine the effect of double-sided competition under private information on both sides of the market.

A multidimensional combinatorial auction mechanism for trading electronic grid services among multiple providers and customers was presented by Schnizler et al. (2008). The proposed auction maximizes the social welfare and satisfies incentive compatibility in equilibrium but requires an outside subsidization because it runs a permanent deficit in budget. In our approach, we resort to mechanisms that maximize the expected social welfare to the extent that budget balance can be achieved.

The mechanism designed by Blau et al. (2010) is a multidimensional procurement auction for trading so-called composite electronic services. A composite service is a set of several elementary services and thus represents a domain-specific bundle. Multiple service providers offer composite services to a customer who specifies requirements through a bidding language that considers multiple QoS attributes. The proposed mechanism is incentive compatible in weakly-dominant strategies, individually rational, and optimal ex post, but limited to a single-sided market environment.

Mechanisms of double-sided private information have been subject of inquiry in economic theory. A seminal piece of work stems from Myerson and Satterthwaite (1983), who studied efficient market mechanisms for bilateral trading when reservation values are private information. This model was then extended by McAfee (1991) by integrating a continuous quantity parameter into both traders' private reservation function. Efficiency requires the mechanism to decide when and how much of a certain commodity shall be traded. The approach of Myerson and Satterthwaite (1983) is similar to our work, though limited to bilateral

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