



# Asymmetric first-price menu auctions under intricate uncertainty

Seungjin Han<sup>1</sup>

*Department of Economics, McMaster University, 1280 Main Street West, Hamilton, Ontario, L8S 4M4, Canada*

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## Abstract

This paper studies asymmetric first-price menu auctions in the procurement environment where the buyer does not commit to a decision rule and asymmetric sellers have interdependent costs and statistically affiliated signals. Sellers compete in bidding a menu of contracts, where a contract specifies a vector of characteristics and a payment required from the buyer for delivering these characteristics. The buyer does not commit ex-ante to a decision rule but rather upon observing all the menus offered by sellers chooses the best contract. This paper establishes the existence of a continuum of separating monotone equilibria in this game bounded above by the jointly ex-post efficient outcome and below by the jointly interim efficient outcome. It shows that the jointly ex-post efficient equilibrium outcome is the only ex-post renegotiation-proof outcome and it is also ex-ante robust to all continuation equilibria.

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## 1. Introduction

Procurement of goods or services is an important part of the economy. For example, public procurement by governments accounts for 10 to 15% of GDP in developed countries and up

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*E-mail address:* [hansj@mcmaster.ca](mailto:hansj@mcmaster.ca).

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to 20% of GDP in developing countries. The items acquired through procurement vary from simple stationary items to highly complex goods and services such as infrastructure projects, nuclear power plants, and military weapons. In order to model procurement, various scoring auctions where a buyer (e.g., government) can commit to a scoring rule are proposed in the literature. In scoring auctions, each seller submits a single bid (or equivalently a single contract), i.e., a vector of characteristics of the good and a payment required from the buyer for delivering these characteristics.<sup>2</sup> The scoring rule calculates each seller's score given his bid and the seller with highest score wins procurement.<sup>3</sup> Examples of scoring auctions include the first scoring auction, the second scoring auction, and the handicap auction.<sup>4</sup>

While scoring auctions generate competitive bidding in an intuitive way, scoring rules must specify scores for all possible bids that sellers may submit. This may be quite complex, especially when characteristics of the good are highly multidimensional. For example, when a government is considering awarding a contract for the construction of a tunnel in a mountainous area, the specification of the tunnel to be built would be highly multidimensional. The characteristics may include the possible route, length, and radius of the tunnel, the construction method to be utilized, the air ventilation system, the construction time, and the operating issues after the construction: the list of the specifications goes on and on. In this case, it may not be economically viable for the government to commit itself to a scoring rule that specifies a score for every possible bid. The difficulty of procurement of tunnel construction is compounded because the construction cost may not be fully known to the construction companies. The construction cost will depend on the geological characteristics of the mountain, the composition and distribution of minerals in the area in which the tunnel is to be constructed. Different construction companies may receive different signals on construction costs. Those signals have interdependent values in the sense that each company's estimate of its construction cost depends on all companies' signals and its estimate would be more precise if other companies' signals were known to the company.

This paper analyzes procurement in the environment where the buyer does not commit ex-ante to a decision rule and asymmetric sellers have interdependent costs and statistically affiliated signals. With no ex-ante commitment to a scoring rule, a buyer (e.g., government) may, in practice, simply advertise open invitations for the procurement of a highly complex good or service with a few descriptive objectives. Sellers can then submit and present their proposals, which often include multiple possible bids, i.e., pairs of characteristics of the good and payment. It may take the government a few months or years to evaluate the proposals and start negotiating with the winning seller on the characteristics of the good to be delivered and the corresponding payment. Abstracting from reality, this paper formulates the first-price menu auction in which each seller bids a menu of contracts and, upon observing all the menus offered by sellers, the buyer chooses the best contract.

This type of menu auctions is relevant and interesting for procurement particularly under interdependent values. Let  $u(x) - t$  be the buyer's payoff, where  $x$  is a vector of characteristics of

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<sup>2</sup> Che [6] and Asker and Cantillon [1] study scoring auctions in situations where sellers' signals on production costs have only private values. Branco [4] considers scoring auctions with symmetric sellers, independent signals and common values.

<sup>3</sup> We use feminine pronouns for the buyer and masculine pronouns for sellers.

<sup>4</sup> Given the scoring rule in each auction, the seller with the highest score wins procurement. In the first scoring auction, the winning seller executes the contract he submits. In the second scoring auction, the winning seller can execute any contract that matches the highest rejected score. The handicap auction can give different additional scores to different sellers on top of scores based on the contracts that they submit.

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