

NSF-SES-1247988: Market Mechanisms for Spectrum Allocation

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1 Introduction and Summary of the Project

1. Wireless Communication and Mobile Internet=General Purpose Technology. Wireless communication and mobile internet are general purpose technologies that would play the key role in

1. productivity growth
2. innovation-spillover

Their impacts have been compared to those of automobile and electricity.

2. US Incentive Auctions. Such fundamental technological innovation requires new economic infrastructure to fully realize its benefits. The FCC incentive auctions are an important step to develop the spectrum infrastructure by making the spectrum available for mobile network operators and whitespace users through voluntary relinquishments of spectrum by TV broadcasters.

3. The Objective of the Project. The research goal is to develop a prototype software of US incentive auctions as defined in the FCC NPRM Docket No. 12-268.

Expected payoff. Having prototype available on the public domain will improve public awareness of the incentive auctions, reduce uncertainties concerning the incentive auction process among policy makers, television stations, and mobile operators. It will enhance entry and competitions which in turn lead to the success of auctions by meeting the congressional mandate.

4. The Output of the Project. We have 3 papers and 1 software related to the project.

1. Kazumori, E. (2013a). "Simultaneous Heuristic Auctions," Working Paper.
2. Kazumori, E., and Y. Belch (2013a). "On the Design of Reverse Auctions with Multiple Bid Options for the US Incentive Auctions: Generalized Heuristic Threshold Auctions," Working Paper.
3. Kazumori, E., and Y. Belch (2013b). "Descending Clocks, Ascending Clocks, and Closing Rule: An Open-Source Prototype Software for Incentive Auctions," Working Paper.
4. Kazumori, E., and Y. Belch (2013c). Incentive Auctions Prototype Software.

5. Related Papers. We have worked on 6 related papers:

1. Kazumori, E. (2013b): Deleveraging, Liquidity Risk, and Asset Prices: Evidences from US and Japanese Stock Markets, 1977-2009.
2. Kazumori, E. (2013c): "What Drives Stock Returns of Apple, Google, Microsoft and Oracle? Industry Structure and Stock Returns in the US Computer Industry, 1965-2012.," Working Paper.
3. Kazumori, E. (2013d): "Double Auction Markets with Interdependent Values: An Asymptotic Equivalence Approach," Working Paper.
4. Kazumori, E. (2013e): "Optimal Auction Design for Heterogeneous Objects," Working Paper.
5. Kazumori, E. and Tchuindjo, L. (2013a): "Primary Dealers, Indirect Bidders, and Direct Bidding: A Structural Model of US Treasury Auctions," In Preparation.
6. Kazumori, E. and Tchuindjo, L. (2013b): "Treasury Inflation Protected Securities: The Role of Margin Requirements," In Preparation.

6. Referred Conference Presentations.

1. 2013 North American Winter Meeting of the Econometric Society (Presentation, Discusstant)
2. The University of Tokyo: Empirical Microeconomics Workshop (Presentation)
3. 2013 Second Cambridge Area Economics and Computation Day (Presentation)
4. 5th Israel Game Theory Conference (Presentation)
5. 2013 North American Summer Meeting of the Econometric Society (Presentation)
6. 2013 Stony Brook Game Theory Conference (Presentation)
7. 2013 Midwest Theory Conference (Presentation)
8. 2014 North American Winter Meeting of Econometric Society (Planned, Presentation, Discusstant)

7. The Contribution of the Project. The project studies the incentive auctions which are key public policy instruments to develop the spectrum infrastructure.

1. The theoretical results provide logical foundations for the design of reverse auctions with multiple relinquishment options.
2. The software is the first public implementation of the incentive auctions process.
3. The website presents background information and tutorials and lesson plans for the spectrum allocation and the role of public policy.

2 On the Design of Reverse Auctions in the US Incentive Auctions: Simultaneous Heuristic Auctions.

8. Fundamental Structure of Incentive Auctions. FCC NPRM Docket 12-268 determines that Incentive auctions consist of 3 parts:

1. *Reverse Auctions:* TV stations submit bids to voluntarily relinquish spectrum rights to the FCC in exchange for payments.
2. *Repacking:* Repacking is a reorganization of the broadcast television bands where television stations that remain on-the-air will occupy a smaller portion of the UHF band.
3. *Forward Auctions:* Forward auctions identify the prices that potential users of repurposed spectrum would pay for the new licenses

9. The Importance of Reverse Auctions. The design of reverse auction is important for 2 reasons:

1. Active participations by TV stations are important for the success of the incentive auctions in reclaiming large amount of spectrum and raising revenues.
2. TV stations going off the air or moving to the VHF band will provide spectrum for TV white space uses that are important for experimentation in new technologies, community broadband services for underserved areas, scientific uses (radio astronomy), and emerging IEEE 802.11af white-fi technologies

10. The State of the Art of the Reverse Auctions= Milgrom and Segal (2013). Milgrom and Segal (2013)'s deferred acceptance heuristics auctions

1. *Bid collection procedures.* Each seller submits one offer.
2. *Assignment procedures.* Sellers' offers are evaluated with the scoring functions. The buyer rejects the offer with the highest score. The scores are updated with the updated set of frozen sellers. The auctions end when all offers are zero scores and these offers are accepted.
3. *Procedures of determination of payments.* The payment for the winner is the threshold price.

The theorem: *when sellers are single-minded and make only one offer, the auction mechanisms are strategy-proof.*

11. Research Question of the Paper=Extension and Implementation of the Milgrom-Segal Auctions.

The research question is to consider a generalization the Milgrom-Segal design to accommodate the requirements of NPRM:

1. Spectrum Act 6403(a)(2) states that reverse auctions shall provide 3 bid options for participants such as going off the air, switching to the VHF band, and channel sharing.
2. The reverse auctions should take into account of the issue of coexistence and interferences with whitespace and other uses of spectrum.

12. Simultaneous Heuristic Auctions.

1. *Bid collection procedures.* Each bidder, for each relinquishment options, offers the payment that the bidder is willing to accept in exchange for relinquishing the good through the option.
2. *Scoring procedures.* In heuristic auctions, bids are evaluated with the scoring function. In the process of assignment, let A_j be the set of active bidders in the auction for the j th option.
 - (a) In the auctions for going off the air, the scoring function checks interferences with already repacked stations at the UHF band. If there are interferences with existing UHF stations, then the score would be zero, the offer would be accepted, and the station would go off the air.
 - (b) In the auction for moving to the VHF band, the scoring function checks interferences with stations already assigned to the VHF band. If there are interferences with existing VHF stations, then the score would be high, the offer would not be accepted, and the station cannot be assigned to the VHF band.
 - (c) Furthermore, the feasibility checker examines coexistence and interferences with whitespace and other uses of spectrum.
3. *Auction phase:* We conduct the heuristic auctions of Milgrom and Segal (2013) for auctions for each option to determine the provisional winners and threshold prices for each auctions.
4. *Supplementary phase.* If there are sellers who are provisional winners in multiple auctions, then the buyer buys through the option that provides the highest profit for the seller.

13. Example. The buyer wishes to procure goods. Each station has 2 ways (going off the air or moving to the VHF band) to relinquish the good. Suppose there are 3 potential sellers.

Costs	Relinquishment by Going Off the Air	Relinquishment by Moving to the VHF Band
Seller 1	10	8
Seller 2	7	2
Seller 3	4	3

Suppose that the interference constraints are such that

1. The buyer can accommodate at most 2 stations in the new UHF band plan. That is, the buyer can buy 1 unit by letting the station go off the air.
2. The buyer can accommodate at most 1 stations in the VHF band. The buyer can buy 1 unit from this option by assigning the station to the VHF band.

Suppose that the cost structure is

Costs	Relinquishment by Going Off the Air	Relinquishment by Moving to the VHF Band
Seller 1	10	8
Seller 2	7	3
Seller 3	4	2

Seller 3 has low costs and expenses for both options. Then the threshold prices are:

Threshold Price	Relinquishment by Going Off the Air	Relinquishment by Moving to the VHF Band
Seller 1	4	2
Seller 2	4	2
Seller 3	7	3

Then the profits are:

Threshold Price - Cost	Relinquishment by Going Off the Air	Relinquishment by Moving to the VHF Band
Seller 1	-6	-6
Seller 2	-3	-1
Seller 3	3	1

Then the seller 3 has a largest profit from going off the air. Thus the final assignments are as follows: seller 1 stays in the UHF band, seller 2 stays in the UHF band, and seller 3 goes off the air. The final assignment respects the interference constraints.

14. 5 Advantages of Simultaneous Heuristics.

1. *Strategy-Proofness.* It provides a seller an incentive to bid true costs. In the simultaneous deferred acceptance heuristics auctions, sellers have multiple options to sell. Since the buyer would buy through the options that would provide the highest payoff for the seller and the seller's offer cannot affect the threshold price, the seller's best response is to make offers truthfully.
2. *No Seller Switching Across Options.* A seller does not need to switch across options in the auction phase. It is important since switching could complicate interference constraints.
3. *Respect Interference Constraints.* Simultaneous heuristics does not violate interference constraints. That is, the buyer does not run the feasibility checker multiple times.
4. *Implementation with Simultaneous Clock Auctions with the Supplementary Phase.* For any simultaneous heuristic auction with a finite set of bids, there exists an equivalent simultaneous clock auctions with cutoff strategies.
5. *Simultaneous Clearing.* In contrast to sequential clearing, simultaneous auctions have theoretical advantages in (1) maximizing the amount of information available to bidders, (2) permitting bidders to pursue efficient backup strategies as more information became available during an auction, (3) are also likely to be perceived as fair, and (4) experimental results show that simultaneous auctions were more efficient.

15. The Contribution of the Paper. This paper develops a generalization of deferred acceptance heuristics for multiple options.

1. By providing sellers more options to sell, the sellers are more likely to participate.
2. Simultaneous clearing has advantages over sequential clearing since it will provide more information and also backup strategies for sellers. These points were made in previous auction design for the nationwide PCS auctions (FCC (1994)).
3. This paper generalizes the scoring function to take into account of interferences with TV whitespace uses (machine-to-machine communication, community broadband services, wireless medical technology, radio astronomy, and wireless microphones).