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A review of radio spectrum combinatorial clock auctions

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ABSTRACT

This paper surveys a decade of Combinatorial Clock Auctions (CCAs) to allocate radio spectrum licenses from their inception to 2016. Although all CCAs share a common structure (first an allocation stage and then, an assignment stage), regulators have tailored key variables depending on their spectrum policies and market structures. We identify these variables, such as: spectrum packaging policy, reserve price, demand limit, activity rule, transparency and pricing rule. We also analyze the different ways in which regulators can design them along with their implications. This theoretical work is accompanied by a review of the practical implementation decisions in each actual auction and final outcomes. Although all the information is public, it is not easy to find because it is highly disaggregated. Finally, after having identified advantages and disadvantages in this auction model, we present some proposals to improve the actual mechanism.

1. Introduction

The Combinatorial Clock Auction (CCA) was presented for the first time by Ausubel, Cramton and Milgrom, (2006). Two years later, in 2008, the communications regulator in the UK (Ofcom) adopted this mechanism for two award processes. Since then, many other countries have implemented CCAs as the mechanism to award available spectrum, displacing Simultaneous Multiple Round Auctions (SMRAs).

The CCA is a hybrid auction with two stages. First, there is an allocation stage in which the number of lots each bidder wins and the base prices are settled. Then, an assignment stage is run to determine which specific lots are awarded to each winning bidder. The allocation stage is a two-stage bidding process. First is the clock stage, composed of multiple rounds in which prices increase until there is no excess demand for any item. In each round, bidders submit a single bid for a package of items at the current prices. Following the clock phase is the supplementary phase, which is a single-round process in which bidders can submit multiple bids both to improve their clock bids and to bid for new packages. With all the clock and supplementary bids submitted, the Winner Determination Problem (WDP) is solved finding the value-maximizing combination, using the XOR bidding language in which all bids are mutually exclusive. Finally, the allocation price for each winning bidder is calculated using a second-price rule.

All CCAs recently conducted in different countries share this general structure. Nevertheless, each regulator has tailored key rules such as setting reserve prices, demand limits, and rules related to activity, transparency or pricing. These practical implementation decisions, together with the structure of each market and the spectrum packaging policies, have had a significant impact on the final outcome.

This paper surveys a decade of spectrum CCAs from their inception to 2016. While all the information is public, it is not easy to find because it is highly disaggregated. The goal in this paper is twofold: first, to gather all information about the final design in each

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country to observe how different regulators have adapted CCAs to their specific market structures; second, to compare and analyze the differences in order to understand its impact on the final outcome.

This paper is structured in the following way. Section 2 includes a brief review of the most-relevant works related to CCAs. Section 3 highlights key rules that need to be tailored in any CCA, such as spectrum packaging policies, reserve prices, demand limits, activity rules, transparency, price increments and pricing rules. The description of these practical implementations is accompanied by a historical overview of the decisions taken in the CCAs performed up to the present.

Section 4 summarizes the main features and results of the auctions analyzed. The advantages and disadvantages identified in this auction model over the years are discussed in Section 5. The paper ends with Section 6, in which the conclusions and possible future approaches are described.

2. State of the art

Due to the relevance of this allocation mechanism, there are previous works that have analyzed the CCA's advantages and limitations, proposed future improvements and included references to real spectrum auctions. A summary of the most-relevant ones is included below.

Ausubel and Cramton (2011) propose activity rules that combine revealed preference and eligibility-point monotonicity. For the clock phase, they present a hybrid revealed-preference/eligibility-point approach. Bids in the supplementary phase must satisfy the revealed preference constrain with respect to the last clock round and all eligibility-reducing rounds in which the bidder's eligibility was below the eligibility of the affected package bidding. This is known as the simplified revealed-preference cap. Section 3.4 includes a complete list of the activity rule used in each CCA. The authors' suggestion for the clock phase was implemented in four auctions and only two CCAs included the proposed activity rule for the supplementary phase.

Cramton (2013) shows how the CCA solves many of the SMRA's problems while maintaining its strengths. Among the advantages, he highlights enhanced substitution and the encouragement of price discovery and truthful bidding, given the pricing and activity rules. This paper includes references to UK CCAs.

Bichler, Shabalin, and Wolf (2013) perform a lab experiment to compare the SMRA and the CCA in terms of bidding behavior, efficiency and revenues. They highlight some important aspects regarding bidding behavior under certain activity rules. A straightforward bidding strategy in the clock round is not always possible if a simple eligibility-point rule is used. In the supplementary phase, bidders could have incentives to submit spiteful bids to increase their rival's prices without any risk if the revealed preference constrain with respect to the last clock package must be satisfied. Section 3.4 shows that all but four CCAs have used the simple eligibility-point rule in the clock phase. In the supplementary phase the activity rule with respect to the last clock package was settled only in three auctions.

Janssen and Karamychev (2013) describe a bidding behavior in CCAs in which bidders care about the price competitors have to pay and are budget constrained. They show that CCAs present many strategic gaming possibilities in both the clock and supplementary phases.

Ausubel and Baranov (2014a) review critical decisions for implementing the CCA, such as the following: treating reserve prices as a lower bound or a minimum incremental cost; accommodating technological choice; setting activity rules; price increments in the clock phase; competition policies and the bidding language. How to customize these details can prove decisive for the final result of the auction. There are references to real CCAs throughout their work. Section 3 of the present work describes some of these variables, such as: reserve price; activity rules; price increment; and competition policies. Furthermore, final implementations in each CCA are included.

Ausubel and Baranov (2014b) analyze both the advantages and limitations of CCAs and describe how these auctions have been implemented in different countries. Ultimately, the authors recommend the following improvements to be done in future: combining non-mutually exclusive bids ("OR bids") and mutually-exclusive bids ("XOR bids"); introducing activity rules based on the General Axiom of Revealed Preference (GARP); and transforming the CCA into an iterative first-price auction.

Levin and Skrzypacz (2014) describe ex post equilibria in three different scenarios. The first is focused on the standard allocation problem. In the second scenario, bidders have the incentive to make their rivals pay more. In the third scenario, bidders try to raise each other's price by relaxing the activity rule constraints on their final bids. Neither efficient allocation nor truthful Vickrey prices are achieved in any of these scenarios. These authors also include an analysis of the UK spectrum auctions in 2008 and 2013 as well as the Austrian 4G auction (2013).

More recently, Janssen, Karamychev and Kasberger (2015) explore the CCA properties when bidders are budget-constrained in two scenarios. In the first scenario, with "standard" preferences, bidders only care about the items they win and the price they pay. In the second scenario, bidders also care about the rival's price and the lots earned.

Finally, Bichler, Goetzendorff and Kroemer (2016) have analyzed bidding behavior in CCAs. These authors state that although from a theoretical point of view bidders have the incentive to bid straightforwardly, in real auctions, bidders deviate significantly from straightforward bidding. The results come from both lab experiments and real spectrum auctions analysis (the UK multi-band spectrum auction in 2013 and the Canadian 700 MHz auction in 2014). The authors conclude that a strong activity rule based on the GARP, which tests bidding consistency throughout the entire history, could be a solution. Price discovery and truthful bidding are analyzed in Section 5.2. of the present work.