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EPIC Fail:
How Below-Bid Pricing Backfires in Multiunit Auctions

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Epic Fail: How Below-Bid Pricing Backfires in Multiunit Auctions*

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PRELIMINARY DRAFT; COMMENTS VERY WELCOME!

Abstract

Ascending (or second-price) and uniform-price multiunit auctions have appealing theoretical properties if bidders are symmetric and bid competitively. However, auction designers have long been skeptical about their use in practice. First, asymmetries due to value advantage in ascending (or second-price) auctions with a large common-value component can generate asymmetric equilibria with low revenues. Second, both ascending and uniform auctions are susceptible to collusion. Sequential ascending auctions make it especially easy to form and coordinate bidding rings. Third, uniform auctions are susceptible to low-price equilibria in which bidders can commit to coordinate on high bids for initial units and low bids for final, price-setting units in equilibrium—what we call *crank-handle* bidding. All three of these patterns have been observed separately in certain settings among sophisticated and experienced bidders. We document what we believe is the first case of all three of these phenomena happening among the same, inexperienced bidders across related auctions for fishing quota in Faroe Islands. Our findings indiciate that the underperformance of ascending and uniform-price auctions are not just theoretical curiosities, but a pervasive phenomenon in practical auction design. We suggest straightforward improvements to auction design that could have mitigated these problems.

Keywords: ascending auction, uniform-price auction, collusion, bidding rings, multiple equilibria, hockey-stick bidding, crank-handle bidding, value-advantage, individual transferrable quota.

JEL Classification: D44, D47

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1 Introduction

If a seller wishes to sell a single item, many auction theorists would recommend an ascending auction.[1] If the values are affiliated (e.g. common), the symmetric equilibrium in an ascending auction raises greater revenue than the second-price sealed-bid auction and even greater revenue than the first-price sealed-bid or descending auctions (Milgrom and Weber, 1982). Moreover, when bidders have independent private values, the ascending auction is the unique strategyproof and credible mechanism i.e. it cannot be undetectably manipulated by the seller (Akbarpour and Li, 2018).[2]

If a seller wants to sell multiple units of a homogeneous goods, many auction theorists would recommend a uniform-price auction.[3] Weber (1981) showed that in the affiliated values model with unit demands, the uniform-price auction yields greater revenue than the discriminatory auction. In a general setting with symmetric bidders, Pycia and Woodward (2016) proved that the unique equilibrium in the discriminatory auction for divisible goods is revenue-equivalent to the seller-optimal uniform-price auction with optimal supply and reserve price.[4] However, Ausubel et al. (2014) pointed out that when bidders are asymmetric uniform- and discriminatory-price auctions cannot be ranked either in terms of revenue or efficiency.[5] Uniform-price auctions appear appealing both from a theoretical and practical perspective.[6] Ausubel et al. (2014) conclude that:

[1] First-price (second-price) sealed bid and descending (ascending) auctions are strategically equivalent from the bidders' point of view (Vickrey, 1961). If bidders' values are independent and private and if bidders are risk-neutral, all standard auctions yield the same revenue (Riley and Samuelson, 1981; Myerson, 1981).

[2] In fact, ascending auctions for a single item are ex-post incentive compatible (EPIC) and obviously strategyproof (Li, 2017).

[3] There are many possible formats here: simultaneous vs. sequential and sealed-bid vs. dynamic, but we will focus on simultaneous, sealed-bid formats. Revenue-equivalence with independent private values result holds (in a weaker form) for multiple object settings (Engelbrecht-Wiggans, 1988). While discriminatory-price auctions and uniform-price auctions are considered to be the natural generalizations of first-price and second-price sealed-bid auctions (Weber, 1981), the appropriate strategyproof generalization of the second-price auction is, of course, the Vickrey auction. Vickrey payments can also be obtained by running an English auction i.e. a deferred acceptance algorithm (Gul and Stacchetti, 2000; Ausubel, 2004). Uniform-price auctions are not strategyproof or even EPIC.

[4] Wilson (1979) introduced such "auctions for shares" and analyzed the common-value setting. See also Klemperer and Meyer (1989); Green and Newbery (1992); Back and Zender (2001); Wang and Zender (2002). Swinkels (2001) proved revenue-equivalence of uniform- and discriminatory-price auctions in a large market setting.

[5] However, if agents are risk-averse in a common-value model then uniform-price auctions dominate in revenue and efficiency (Wang and Zender, 2002).

[6] In the early 90s, the United States famously switched from disciminatory- to uniform-price auctions to sell debt (Bikhchandani and Huang, 1993). Today, both auction formats are popular to sell sovereign debt (Brenner et al., 2009). From a structural econometrics perspective, there is a mixed picture on the performance of discriminatory price auctions. Using a private-value model, Hortaçsu and McAdams (2010) find that the two auction formats perform simiarly in the Turkish debt market. With a common-value model, Fevrier et al. (2002) and Castellanos and Oviedo (2008) produce contradictory rankings for the French and the Mexican debt markets respectively. Using both private and common value models, Marszalec (2017) shows that disciminatory auction revenue-dominates in the Polish sovereign debt market under both sets of assumptions. Both types of auctions are also popular in many liberalised electricity markets (Fabra et al., 2002). Finally, in an experimental setting, Abbink et al. (2006) find

> Uniform pricing has several desirable properties, including: (i) it is easily understood in both static and dynamic forms; (ii) it is fair in the sense that the same price is paid by everyone; (iii) absent market power it is efficient and strategically simple ("you just bid what you think it's worth"); and (iv) the exercise of market power under uniform pricing favours smaller bidders.

But a theorist's preference for ascending and uniform-price auctions often relies on two assumptions rarely met in practice: bidder symmetry and competitiveness of the market.

1.1 Consequences of bidder asymmetry

It is well-known that when bidders are asymmetric, revenue equivalence of standard auction formats breaks down even in the singe-item, independent value setting: it is no longer possible to universally rank auctions by revenue, but in general stronger bidders prefer the ascending auction and weaker bidders prefer the first-price, sealed-bid auction (Maskin and Riley, 2000).[7]

Milgrom and Weber's beautiful result on the dominance of ascending auctions depends crucially on the assumption that all bidders are playing a symmetric equilibrium: in asymmetric equilibria their revenue ranking breaks down (Bikhchandani and Riley, 1991). Bulow et al. (1999) analyze such asymmetric equilibria in an *almost*-common-value setting of takeover battles in which one bidder exercises a small advantage by having a slighter larger "toehold" on existing company shares. They show that in this case there is a unique asymmetric equilibrium in the ascending auction in which the weaker bidder, in anticipation of aggression by the stronger bidder (who is interested in bidding more aggressively due to the value advantage), bids a very low amount. With sufficiently asymmetric value advantage, therefore, the stronger bidder can win the auction at a much lower price in an ascending (or second-price) auction than in a first-price auction (Bulow et al., 1999, Proposition 6). One may wonder whether such effects could be strong in practice, but Kagel and Levin (2002) argue that

> it would seem to require very sophisticated bidders for the explosive effect to be realized under these conditions. As such we would expect that bidders outside the laboratory would employ alternative strategies available to them in the less structured environment they operate in to press their private value advantage.

In real-world situations, therefore, bidders with an existing value advantage have an incentive to make announcements that cement their advantage, make other bidders bid even more conservatively or drive them out of the auction altogether. As a result, with

that uniform-price auctions outperform discriminatory-price and Spanish auctions.

[7] On the other hand, if either the bidders or the seller is (are) risk-averse, the seller would prefer first-price auction (Maskin and Riley, 1984).

strong value advantage asymmetry ascending auctions or second-price auctions could yield low revenue and be highly inefficient.

1.2 Consequences of uncompetitive bidding

In practice, the competitiveness assumption is often inadequate since bidders often have incentive to collude.[8] Auction design can mitigate some collusive practices (Klemperer, 2002a,b). In general, providing bidders with less information about each other and their bids and using sealed-bid formats is considered to make bidding ring formation more difficult (Robinson, 1985; Marshall and Marx, 2007, 2009, 2012).[9]

Among sealed-bid auction formats, there is little agreement on whether uniform-price auctions are more prone to collusion than discriminatory-price auctions. Friedman (1960) argued that the uniform-price auction "in any of its variants, will make the price the same for all purchasers, reduce the incentive for collusion, and greatly widen the market." Chari and Weber (1992) argued that: "Uniform-price auctions are also likely to be less susceptible to market manipulation."

However, many auction theorists have pointed out that uniform-price auctions are susceptible to coordination on low-price equilibria (Wilson, 1979; Back and Zender, 1993; Noussair, 1995; Engelbrecht-Wiggans and Kahn, 1998; Kremer and Nyborg, 2003, 2004; LiCalzi and Pavan, 2005; McAdams, 2007). In equilibrium, bidders submit high prices for the first few units and very low prices for the final units. The bids are coordinated such that the bids drop sharply as aggregate demand approaches supply. If any bidder wishes to grab more than the equilibrium share, the equilibrium price will jump sharply so he (and others) will have to pay a very high price for every unit of the good. Hence, bidders are deterred from deviating. Indeed, (Milgrom, 2004, p. 264) says that these "extreme price equilibria [are]... of great practical importance," Such sophisticated strategies have been observed experimentally when bidders have been given access to pre-play communication (Goswami et al., 1996). When these tactics are observed in procurement or supply-function settings they are referred to a "hockey-stick" bidding (since the price offered for the first units is low and price for the final units is very high). Hockey-stick bidding is often found in repeated electricity auctions (Hurlbut et al., 2004; Holmberg and Newbery, 2010). Figure 1 illustrates an empirical example of hockey-stick bidding in the Texas electricity market.[10]

[8] Che and Kim (2009) offer elegant designs of collusion-proof auctions, but they have not yet been used in practice.

[9] Milgrom and Weber's "linkage principle"—which states that on average revenues can be increased by providing bidders with more information—fails in multiunit auctions (Perry and Reny, 1999).

[10] However, Cramton (2003) argues that "such bids are entirely reasonable given reasonable assumptions about demand and supply uncertainty, forward contracts, and marginal cost curves."

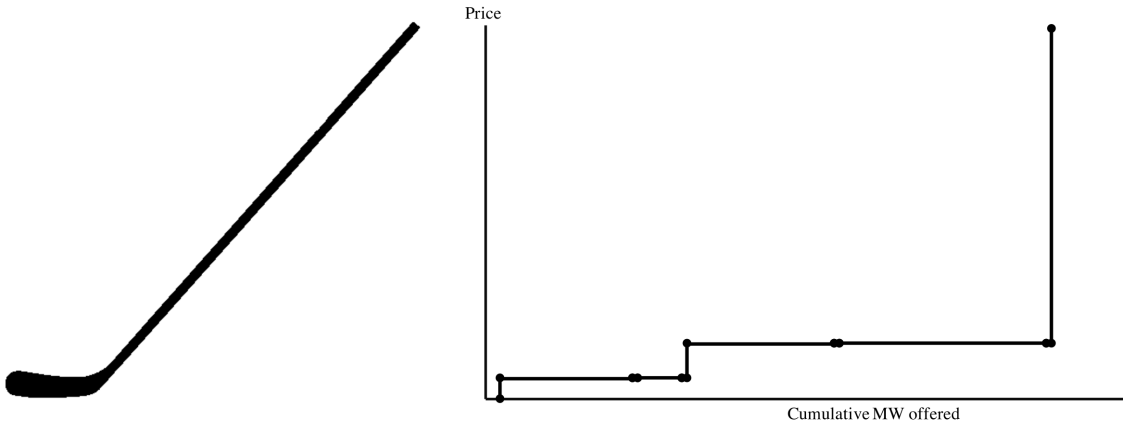


Figure 1: Hockey-stick bidding in an electricity market (data taken from Hurlbut et al. 2004, Figure 1, with numbers removed)

1.3 Contribution of this paper

In this paper, we present three examples of how inexperienced bidders who are participating in a high-stakes auction are able to exploit bidder asymmetries in an ascending auction as well as successfully coordinate on strategies that generate extremely low-price equilibria in uniform-price auctions. We present bidding data from the first three years of auctions for fishing quota in the Faroe Islands which involve overlapping sets of bidders. In one set of sequential ascending auctions, the stronger bidder pre-announced that he was willing to pay anything to get all the quota. The entrant attempted to challenge him in the earlier rounds and, having lost, dropped out in the later rounds leaving the stronger bidder to pick up the remaining quota at the reserve price. We then present an example of coordinated bidding in sequential ascending auctions in which all (but two bidders) appear to bid as if in a bidding ring. In these auctions, almost all auctions ended at the same price and the winning bidders rotated. In the final set of auctions, we present a set of striking examples of what we call *crank-handle bidding*. We explore how crank-handle bids were successfully coordinated and whether market entry can prevent low-price equilibria. We believe that these are the first real-world examples of exploiting powerful value advantage effects, enforcing nearly perfect bid rotation, and exploiting subtle low-price equilibria among fairly inexperienced bidders in high-stakes auctions.[11]

This paper is organized as follows. In Section 2, we briefly describe the context in which the auctions took place. In Section 3 we show the ascending auctions were manipulated. In Section 4, we document underpricing in the uniform auctions. In Section 5, we look into common design features that exacerbated the failure of the auctions and

[11] Our purpose is not to evaluate the suitability of auctions for allocating fishing rights in the the Faroe Islands; rather we want to analyze the design and performance of previous auctions and suggest improvements for the future.

suggest improvements. In Section 6, we conclude. Further auction information is in the Appendix. To protect company identities, we label companies with letters, altering the labeling between sections.

2 Fishing industry in the Faroes

The Faroe Islands is a small country in the North Atlantic which historically has been (and still is) heavily dependent on the fishing industry. In 2017, approximately 13 percent of GDP (Statistics Faroe Islands, 2017b)and 52.5 percent of the country's exports came from the fishing industry (Christiansen and Markná, 2018) and the fisheries sector employed 10.8 percent of the workforce (Statistics Faroe Islands, 2017a). There are three main types of fisheries in the Faroes: (i) demersal fisheries in Faroese waters; (ii) pelagic fisheries (e.g. mackerel, herring, blue whiting); and (iii) demersal fisheries (e.g. cod, haddock, rough dab) in the Barents Sea. Only the latter two are commercially lucrative.

In 2008, the Faroe Islands passed a Competition Act similar to Denmark's Competition Act. The law, which includes provisions against anti-competitive behavior, abuse of market dominance and merger control, is enforced by the Faroese Competition Authority (Faroese Competition Authority, 2007). Just three companies operate in the Barents sea (A, B, C). The pelagic fisheries industry is also concentrated: four companies (B, C, D, E) with ten vessels fish approximately 90 percent of the pelagic catch (Faroese Fisheries Inspectorate, 2017).[12] Large fishing companies are fairly homogeneous in costs and share ownership of fish factories and smaller companies in the industry. Compared with the rest of the world, the fishing industry in the Faroes is very small so Faroese firms act as price-takers with respect to world fish prices.

Since the introduction of fishing licenses in 1987, fishing rights in the Faroe Islands have been exclusively allocated based on historical fishing rights (i.e. "grandfathered") with the exception of a number of trial auctions. Meanwhile, all large companies frequently trade fishing quota through bilateral negotiations. During the last two decades, the pelagic and demersal fisheries in the Barents Sea have become increasingly profitable, following a change in legislation allowing increased transferability of fishing rights as well as increases in the total allowable catch (TAC) (Fiskivinnunýskipanarbólkurin, 2016). In 2007, the government cancelled all fishing licenses with a ten-year notice committing its future self to a complete reform of fishing rights by 2018.

In 2016, as part of the ongoing fisheries reform the new government decided to run trial auctions of 10 percent of the TAC for demersal fish in the Barents Sea, blue whiting, herring, and mackerel. In 2017, the government auctioned of between eight and 42 percent of TAC for the same species. In 2018, the Faroe Islands passed a fisheries reform which

[12]The other nine percent is caught by around forty other vessels, many of which are owned by companies B, D and E either fully or partially.

introduced auctioning of fishing rights as a permanent feature of the fisheries legislation. According to the new fisheries law, 15 percent of TAC of demersal fish in the Barents Sea, herring and mackerel in addition to 25 percent of TAC of blue whiting will be sold on auction every year, starting in 2018 (The Government of the Faroe Islands, 2018). We focus on the design and outcomes of these auctions in this paper.[13] As a fraction of GDP, these are some of the largest auctions ever held.[14]

Globally, auctioning of fishing rights is still comparatively rare. Auctions are currently implemented in some fisheries in New Zealand, Chile and Washington State in the U.S. (Cerda-D' Amico and Urbina-Véliz, 2000; Peña-Torres, 2002; Anderson and Holland, 2006; Lynham, 2014; Washington State Department of Natural Resources, 2018). Russia and Estonia have used auctions in the past, but have since moved away from this method of rights allocation (Vetemaa et al., 2002; Anferova et al., 2005; Eero et al., 2005; Vetemaa et al., 2005). Many economists believe that auction-based quota allocation can significantly improve the efficiency of operations, gives appropriate long-run incentives for innovation investment, and provides opportunities for revenue-recycling (Kominers et al., 2017; Marszalec, 2018a; Teytelboym, 2018). We do not consider broader questions of the desirability of quota auctions in the Faroese context and focus on the performance of the auctions instead.

3 How ascending auctions fail: value advantage, signaling, and coordination

3.1 Value advantage and signaling

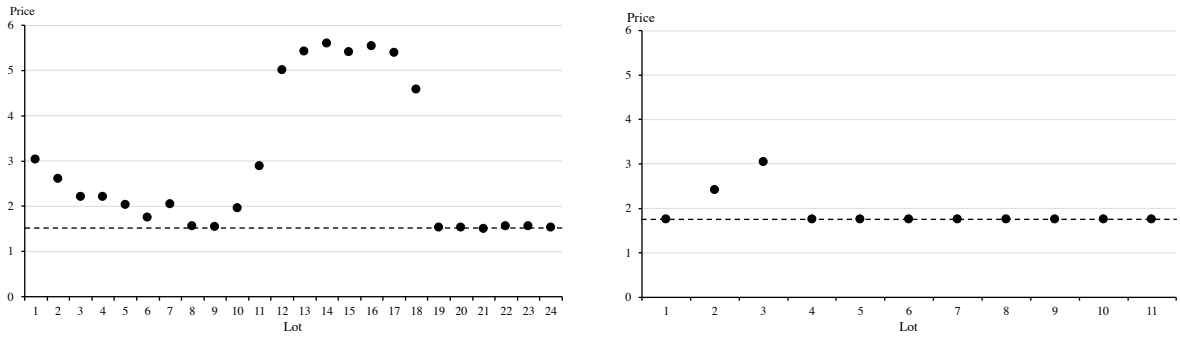
Let us first illustrate how poor auction design can exacerbate one bidder's value advantage in an almost-common-value auction setting. Consider the 2016 and 2017 auctions for quota for demersal fish in the Russian part of the Barents Sea. The auctions were run sequences of ascending auctions, with similar amounts of quota being auctioned in each round.[15] In 2016, two weeks after the auction design had been announced - and just one day before the auction was run - the dominant incumbent made an announcement on national Faroese radio claiming that they were committed to win all the quota and at whatever price necessary. Consequently, all the 24 auctions had only two bidders: the

[13] If TAC is below a certain threshold, then 15 percent (or 25 percent) will be auctioned off, but of any quota that is above the threshold 100 percent of the extra TAC will be auctioned off. Therefore, more than 15 or 25 percent of TAC may be sold on auction every year.

[14] Since the sale of the Roman Empire, the "largest ever" auction is often considered to be the 3G auction in the UK held in 2000—it raised 2.5 percent of GNP by selling 20-year spectrum licenses (Binmore and Klemperer, 2002). By contrast, the Faroese one-year quota auctions held in 2017 raised 0.8 percent of GDP.

[15] In 2016, 1200 tonnes were sold in 24 lots, and, in 2017, 1106 tonnes were sold in 11 lots.

aforementioned incumbent and one entrant.[16] The outcome of the auctions was that the incumbent won all 24 lots and the entrant was therefore the price-setter in each auction round. Figure 2a shows the final price in each auction round. The entrant competed most keenly in rounds 10 to 18, and the last six auction rounds finished marginally above the reserve price. Overall, the average price for rounds 1—18 was approximately 3.4 kr./kg but only 1.5 kr./kg for the last six rounds. It appears that in the middle rounds, the entrant was testing the incumbent's resolve, and perhaps checking whether the incumbent had bought enough quota to be willing to exit the auction . With only six lots left, the entrant stopped competing altogether: one plausible reason for such behaviour is that the remaining amount of quota would not have been sufficient for the entrant to run a profitable operation. With no serious competition on the last six lots the incumbent could buy it marginally above the reserve price. As Figure 2b illustrates, the same auction ran in 2017 continued from where the previous year's auction left off: with the incumbent showing a strong commmitment to bid whatever necessary to win everything. The entrant only bid in rounds 2 and 3 to test the incumbent's committment, but dropped out thereafter. Consequently, all lots other than 2 and 3 were sold at the reserve price to the incumbent.



(a) 2016 auction (24 lots)

(b) 2017 auction (11 lots)

Figure 2: Prices in the auctions for quota for demersal fish in the Russian part of the Barents Sea. Dots: final prices. Dashed lines: reserve prices.

Let us return to theory. Clearly, the standard symmetric and competitive bidder assumption does not hold here.[17] In the bidder pool there were three incumbents (one of whom was significantly stronger than the others) and one entrant (who was definitely value-disadvantaged). In the model of Bulow et al. (1999) even a small value advantage between bidders can result in extremely asymmetric bidding strategies in ascending (or

[16]There was a third bidder in the 14th out of 24 auctions, but (as per their own explanation) this bidder entered by accident. He stayed in the auction for a very brief time, and was neither a winner, nor a price-setter. We therefore don't read much into this behavior.

[17]Indeed, if bidders were competitive and symmetric, the price path should be a martingale and different auction rules should yield revenue equivalence (Milgrom and Weber, 1982). Figures 2a and 2b show that the price path was certainly not a martingale in the 2016 and 2017 auctions for quota for demersal fish in the Russian part of the Barents Sea.

second-price) auctions. In particular, the value-advantaged bidder can credibly commit to "stay in the auction indefinitely and win at any price", and in response to this the value-disadvantaged bidder bids very conservatively. As Klemperer (2002b) pointed out:

> A strong bidder also has an incentive to create a reputation for aggressiveness that reinforces its advantage. For example, when Glaxo was bidding for Wellcome, it made it clear that it "would almost certainly top a rival bid" [...] Predation may be particularly easy in repeated ascending auctions, such as in a series of spectrum auctions. A bidder who buys assets that are complementary to assets for sale in a future auction or who simply bids very aggressively in early auctions can develop a reputation for aggressiveness (Bikhchandani, 1988). Potential rivals in future auctions will be less willing to participate and will bid less aggressively if they do participate (Klemperer, 2002a).

The above illustration offers two warnings for the auction practitioner who wishes to implement sequential ascending auctions. First, the main insights Bulow et al. (1999) can play out powerfully in asymmetric ascending auctions and appear to be strengthened if incumbents can build a reputation over time. Second, the incumbent can block entry by aggresive bidding in earlier rounds and denying the entrant the chance to win enough quota to operate at a minimum feasible scale.

3.2 Coordination

Let us now examine how poor auction design can faciliate bidding ring formation. In 2017, the quota for mackerel was sold through two different types of auction: sequential ascending auctions (analogous to the ones we discussed in the previous section) and sealed-bid uniform-price (which we discuss later in Section 4). Each type of auction offered 5,447 tonnes of quota.

The sequential ascending auctions took place on 22 August and the 5,447 tonnes were divided into 24 smaller lots ranging from 100 to 467 tonnes each.[18] Seven bidders (we label them A—G in this section) participated in the auction and all bidders except one (we refer to them as Bidder G) won a share of the quota sold. Figure 3 shows the winning bidder and the prices paid by the winning bidders for each of the 24 lots. What is striking is the stability of the prices. After three rounds, the prices settled at around 3.10 kr./kg. From the third lot onward, all but two lots were sold at prices between 3.09 or 3.12 kr./kg (the reserve price was 1.25 kr./kg).

[18] Lot 13, originally sized at 100 tonnes, was split in two because a bidder only wanted to buy half, resulting in two lots of 50 tonnes each.

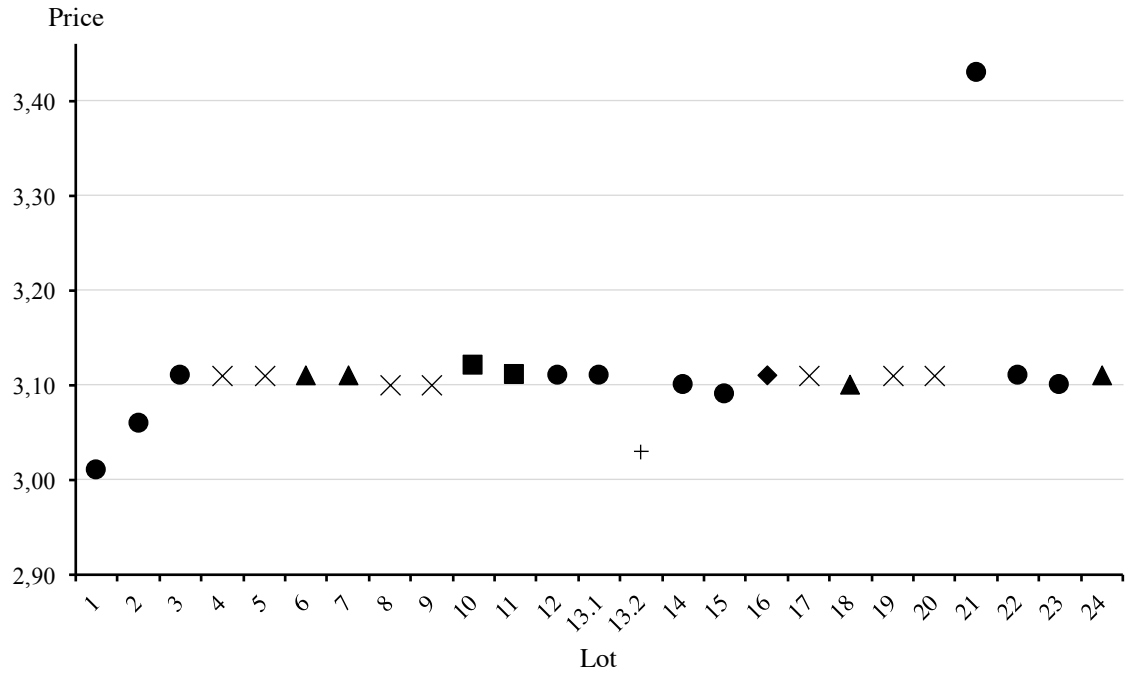


Figure 3: Final prices in the 2017 auctions for quota for mackerel (24 lots). Each shape denotes a different winner.

With the exception of lots 13.2 and 21, the prices in all these auctions were set by the same bidder – Bidder A, who exited roughly at the price of 3.10 kr./kg in 22 out of 25 rounds. The identities of the winning bidders rotated across rounds, with five bidders taking turns to outbid Bidder A suggesting that there might have been a bidding ring. In every round, with the exception of rounds 14 and 21, four non-winning ring members either did not participate or dropped out at prices much below 3.00, leaving one designated ring-member bidding against Bidder A.[19]

If the bidding ring were indeed present, then there are at least two explanations for the bidding pattern: Either Bidder A was trying to push up the price paid by all members of the bidding ring or the bidder served to commit members of the bidding ring to pay similar prices. Of course, what we present here is not conclusive evidence of an explicitly agreed bidding ring: repeated auctions, like any repeated strategic situations, naturally offer opportunities for patient players to tacitly coordinate on outcomes that are better for participants than static, one-shot equilibria (Pesendorfer, 2000; Aoyagi, 2003; Skrzypacz and Hopenhayn, 2004)

Why was bidder coordination so simple in this auction setting? As Robinson (1985) pointed out ascending auctions create ample opportunities for collusion. Moreover, sequential auction designs mean that more bidder signals can be sent (Marshall and Marx,

[19]In round 14, two non-winning ring bidders dropped out at 3.08 and 3.09 kr./kg respectively, possibly due to confusion caused by the splitting of lot 13 into two lots–13.1 and 13.2–just before this. In round 21, it appears that one ring-member (who won in round 20) forgot he was not supposed to win round 21, and stayed in until a price of 3.42. The bidder subsequently quit the auction, and did not participate in subsequent rounds.

2007, 2009, 2012). Both observations relate to the two crucial pre-requisites for successful collusion that are detection and punishment: the present auction design easily affords both. Since after each round the winning price is announced, every member of the bidding ring can detect whether a deviation has occurred. If a defection from agreement does occur at any round before the last, remaining ring members can enforce a higher price in subsequent rounds. Since each lot in these auctions was small – and the objective of most ring-members was to win multiple lots – defecting from the agreement to win one additional lot was probably of limited value, relative to the lower prices sustained in later rounds.[20]

4 How uniform-price auctions fail: crank-handle bidding

Let us finally consider the susceptibility of uniform-price auctions to low-revenue equilibria. In 2018, for example, quota for demersal fish in Svalbard was sold in a series of (sealed-bid) uniform-price auctions. In these auctions, bidders were allowed to bid entire demand curves (at most five price-quantity bids that form the individual bid schedule) and the price for all units was set at the quantity where aggregate demand intersected (fixed) aggregate supply . There were three incumbents — let us refer to them as Bidders A, B, and C.

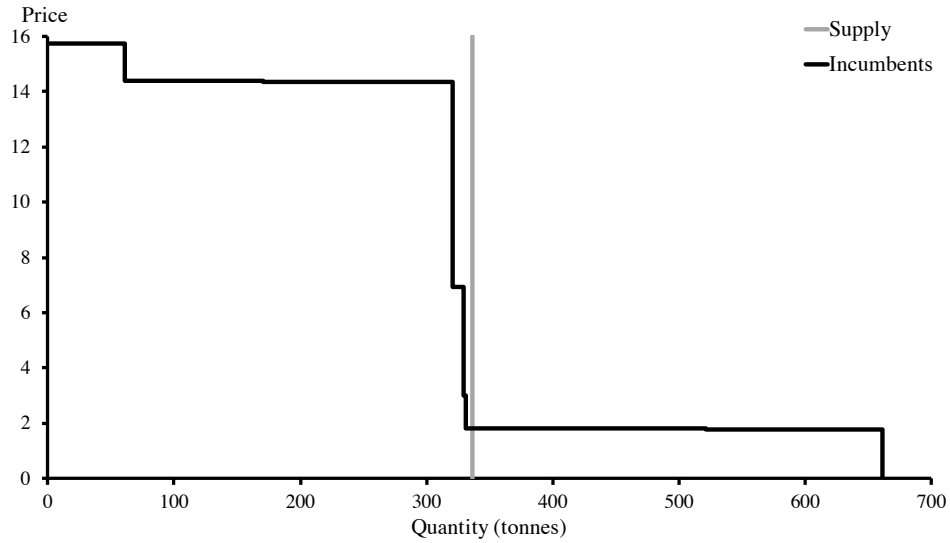
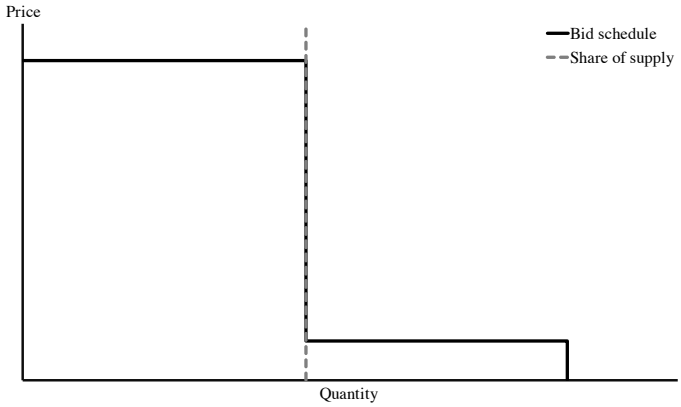


Figure 4: Aggregate bid schedule of the incumbents and the supply of quota in the 2018 auction for quota for demersal fish in Svalbard.

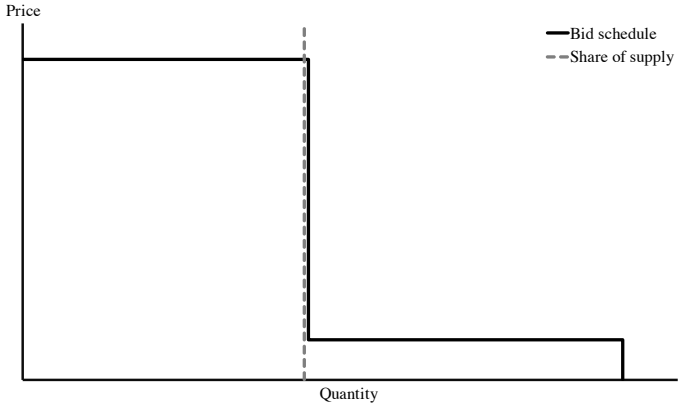
Figure 4 shows the final aggregate bid schedule and the supply in the 2018 auction for

[20] An additional reason why we did not observe deviations even towards the end of the auction could be bidder concerns for future auctions. Since the same pool of bidders will be participating in future auctions together, and it is unlikely that the identity of the deviating bidder could be concealed, deviating even in the final rounds may not be profitable for an individual bidder.

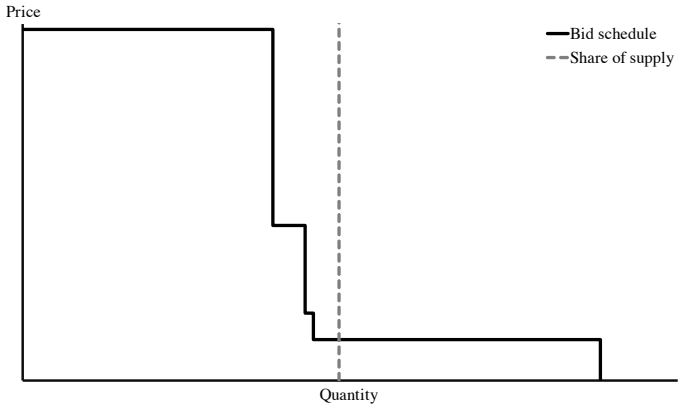
quota for demersal fish in Svalbard. A striking feature is the sharply declining portion of the aggregate bid schedule that takes place at quantities between 321 and 331 thousand tonnes. The final step decrease occurs less than 1.5 percent from where aggregate demand and supply (of 336 thousand tonnes) intersect. Even more striking are the individual bid schedules presented in Figure 5 which are flat over much of the reasonable support for all three bidders before dropping off sharply.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 5: Individual bid schedules in the 2018 auction for demersal fish quota in Svalbard and market share of grandfathered quota (prior to the auction) .

What explains this unusual bidding pattern? We call these bidding patterns *crank-handle bidding* (see Figure 6 for the visual motivation for our nomenclature).[21] While there could be many equilibria in this uniform-price auction, we believe that this is a natural, profitable, low-price equilibrium that incumbent bidders can commit to coordinating on. As we explained in Section 1, to successfully implement coordinated bidding in uniform-price auctions, the drop-off in aggregate bid schedule must happen just before the quantity at which it equals aggregate supply. Suppose that a bidder wants to increase their demand. This would push the vertical portion of the aggregate demand beyond supply and increase the price sharply for all inframarginal units. This would make the deviating bidder worse off and therefore the low-price equilibrium is, in fact, a Nash equilibrium.[22]

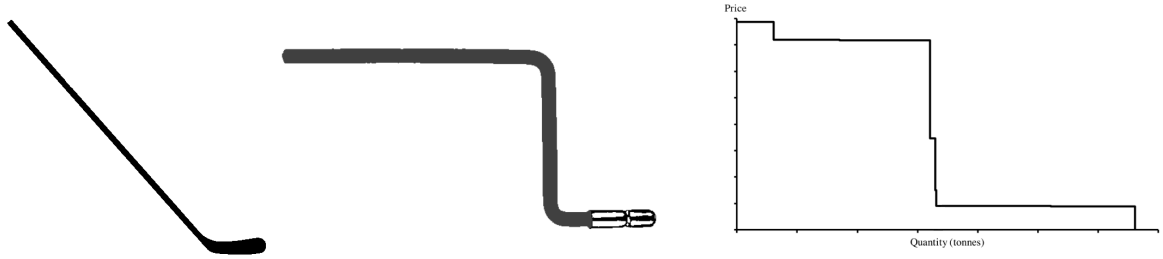


Figure 6: A hockey stick, a crank-handle, and a bidding schedule.

Without knowing exactly the bidders' motivation for submitting the crank-handle bid schedules, we cannot of course be certain that they are tacitly coordinating on a self-enforcing equilibrium; indeed it might be possible that this is genuinely what their demand functions look like. To cast doubt that these bid schedules are purely coincidental, we note that in all six of the 2018 auctions, the point at which incumbents' bid schedules drop off sharply reflect precisely the incumbents' proportional holdings of the grandfathered quota share held prior to the auction. In Figure 5, we illustrate the grandfathered quota share of the supply by the dotted line. It would be a remarkable coincidence that all three bidders' valuations of the quota would change so dramatically at exactly the grandfathered quota shares, in particular since the industry as a whole has considerable spare capacity.

There are two other notable instances of crank-handle bidding in 2018. First, consider the auction for one-year quota for demersal fish in Russian waters (Appendix 7). Here, the incumbents submitted crank-handle bids (Figure 8). However, the drop-offs in individual bid schedules were not in line with grandfathered quota shares. Nevertheless, the aggregate bid schedule still fell off dramatically just before the total quota supply (Figure 7). This indicates that bidders do not necessarily require a clear focal point to coordinate on a low-price equilibrium. Second, consider the auction for eight-year quota for demersal

[21] In the procurement context, the "hockey stick" that describes hockey-stick bidding would be horizontally reflected (e.g. Hurlbut et al. (2004) and Holmberg and Newbery (2010)). In our case, the hockey stick presented in Figure 6 only describes a portion of the individual and aggregate bid schedules.

[22] An analogous argument also applies for coordination in Vickrey auctions.

fish in the Norwegian part of Barents Sea (Appendix 8). Once again, all the incumbents here submitted crank-handle bids and for two out of the three bidders the drop-off in the bid schedule took place at almost exactly their grandfathered quota shares (Figure 10). As before, the drop-off in incumbents' aggregate bid schedule happened just before supply. However, in this case, the bidders did not succeed in coordinating on a low-price equilibrium because an entrant pushed the aggregate bid schedule out and therefore set a higher price (Figure 9). Crank-handle bidding was also observed in the three other 2018 auctions for demersal fish (see Appendix 8). In each case, we observe attempts at low-price equilibria by the three incumbent bidders. However, all these other attempts were frustrated because one of the entrants a higher price by pushing out the aggregate bid schedule. Had no entrants participated in any of the six 2018 auctions for demersal fish, the incumbents' winning shares would have reflected precisely the grandfathered quota shares prior to the auctions.

In 2016 and 2017, bidders in demersal fish uniform-price auctions were only allowed to submit one or three bids (see Appendix 10). Nevertheless, we observe a crank-handle in the aggregate demand schedule for the incumbent bidders which falls off just before supply (see Appendix 10)). As in our latter examples, whenever an entrant is present, the entrant was the price-setter in the main auction frustrating the incumbents' attempt at a low-price equilibrium. However, in each case, after the auction results were announced, price-setting entrant declined to purchase any quota since their bid was not accepted in full. This meant that, once again, the incumbents' attempt at coordination on a low price using crank-handle bidding ended successfully, at least in part. Even if the price was higher than they had coordinated on, they still had successfully excluded all entrants.

5 Discussion

Let us now review the failures of the three auctions we described and suggest an alternative design that could have ameliorated the problems.

The sequential ascending auctions for quota for demersal fish in the Russian part of the Barents Sea held in 2016 and 2017 failed because the incumbent was able to exercise his value advantage. As Bulow et al. (1999) show, in such highly asymmetric setting with a common-value component, the first-price auction is expected to perform a lot better than ascending or second-price auction. Moreover, the sequential nature of the auction allowed the incumbent to signal his commitment early on and drive the entrant out. Finally, because the quota was broken up into small lots, the entrant had little incentive to participate in the latest rounds because he could not achieve minimum viable scale.

The sequential ascending auctions for quota for mackerel in 2017 failed because bidders found a straightforward way to rotate winners and coordinate on a single price. The sequential nature of the auctions meant the bidders had a lot of information between

rounds in order to monitor the outcomes of the possible bidding ring.

The uniform-price auctions for demersal fish in 2016—2018 failed because bidders found a low-price equilibrium in which they submitted crank-handle bidding curves. This equilibrium was only possible because in the uniform-price auction only the marginal unit was setting the price for all quota therefore the bidders did not need to worry about bids on inframarginal units (except to enforce the equilibrium). As Klemperer (2002b, p. 171) argued:

> Since, with many units, the lowest winning bid in a uniform-price auction is typically not importantly different from the highest losing bid, [the uniform-price] auction is analogous to an ascending auction (in which every winner pays the runner-up's willingness-to-pay). The "threats" that support collusion in a uniform-price auction are likewise analogous to the implicit threats supporting collusion in an ascending auction.

One auction design that could potentially improve all these auction is the first-price sealed-bid package auction. In this design, bidder could submit bids for packages of quota (divided into sufficiently small lots) in a sealed-bid manner and the winner would pay the price that she bid for the winning packages. This design has several advantages. First, package bidding would allow bidders to express preferences over operational scale which would make it harder to lock out entrants. Second, sealed-bid auctions transmit little information to bidders making the formation of bidding rings less likely. Third, pay-as-bid auctions reduce the value advantage of incumbent bidders compared to ascending or second-price auctions as well as any incentives for crank-handle bidding in uniform-price auction. Therefore, pay-as-bid auctions are more likely to generate higher revenue and efficiency compared to ascending or second-price auctions in our setting. Fourth, although the first-price sealed-bid package auctions have complex Bayes-Nash equilibria, it is often easier to explain a first-price auction to bidders than an auction with more subtle core-selecting pricing rules (see, for example, Prendergast, 2017, footnote 4 and Marszalec, 2018b).

There are two possible variations on the first-price, sealed-bid package auction. First, one could run a single auction for all the species at the same time, allowing bidders to express package bids across different species. However, this is likely to become complicated for the bidders as the bidding space would increase very quickly. Second, the government could also run an auction with uncertain supply of quota, which is most easily achieved by permitting the auctioneer to reduce supply if the stop-out price is too low for their liking. This design mitigates the ease with which bidders could coordinate on a crank-handle equilibrium and is used in practice in many Treasury Bill auctions (Back and Zender, 2001; LiCalzi and Pavan, 2005; McAdams, 2007).[23] However, uncertain supply might not

[23] Mariño and Marszalec (2018) find that the Department of the Treasury in Philippines uses active

be feasible in the fishing quota context since the annual TAC is usually set by a political and scientific consensus.

6 Conclusion

Economic theory based on realistic assumptions about the auction setting can be extremely informative for auction design (Klemperer, 2002b). However, models that do not take into account bidder asymmetry and possibility of collusion could offer very misleading predictions of market behavior and result in disastrous auction outcomes. In this paper, we showed that the underperformance of ascending and uniform price auctions, which is predicted by various models of auctions with asymmetric bidders and collusive behavior, is borne out in practice even among bidders who have had little experience of bidding in such auctions. While fishing companies in Faroese auctions did not (as far we know) hire dozens of auction consultants, their experience of running profitable businesses in a tightly-knit industry allowed them to easily implement profitable bidding strategies that surprised the policymakers

We believe that we have documented the first example of such a plethora of interesting bidding strategies occurring simultaneously among a group of overlapping bidders. Our examples of crank-handle bidding are probably the most exciting as we know of no other such clear example from the field (except in electricity markets). However, it is worth noting that the underpricing equilibrium in this case was particularly easy to achieve since the supply of quota was fixed and known. With some uncertainty in supply (as is frequent in electricity and Treasury Bills auctions), such equilibria may be more difficult to achieve.

We therefore caution any auction designer who considers running (sequential) ascending or uniform-price auctions without flexible supply wherever there is serious bidder asymmetry and opportunities for industry coordination. We suggest that first-price sealed-bid package auctions may be more efficient and raise higher revenue in such settings. Meanwhile, the majesty of ascending and uniform-price auctions walks on theoretical stilts.

supply restriction frequently, and on occasion cancels the entire tender if prices seem too low. As a result, the market clearing price – whenever the auction is completed – is never pathologically low.

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Appendix

7 One-year quota for demersal fish in the Russian part of the Barents Sea

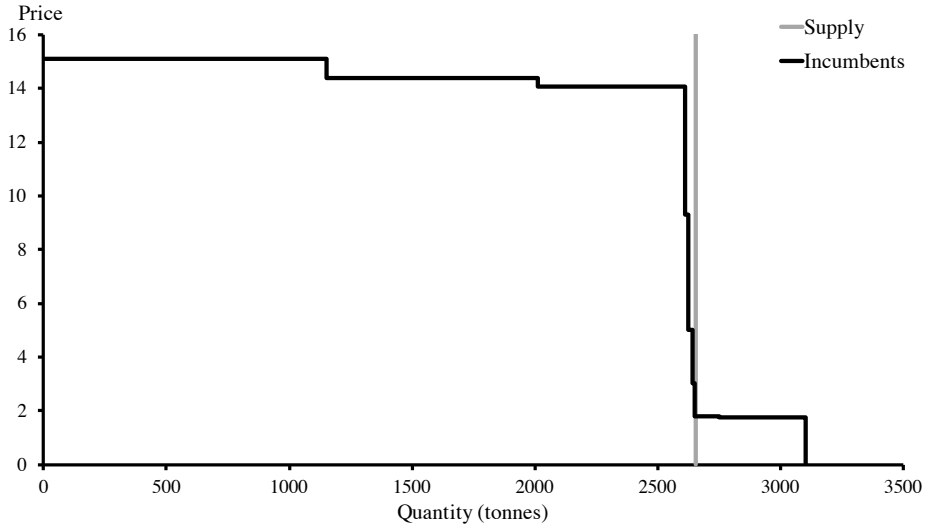
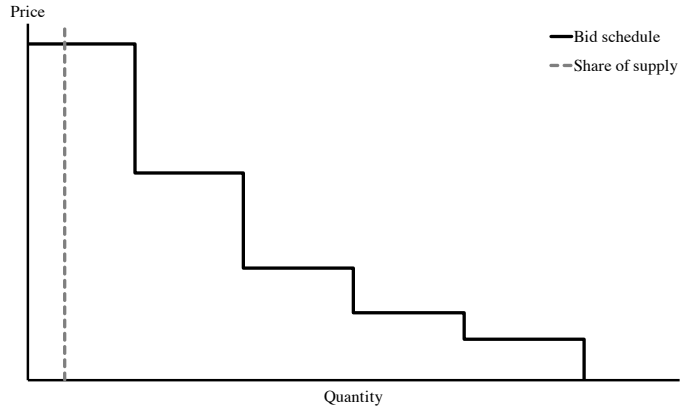
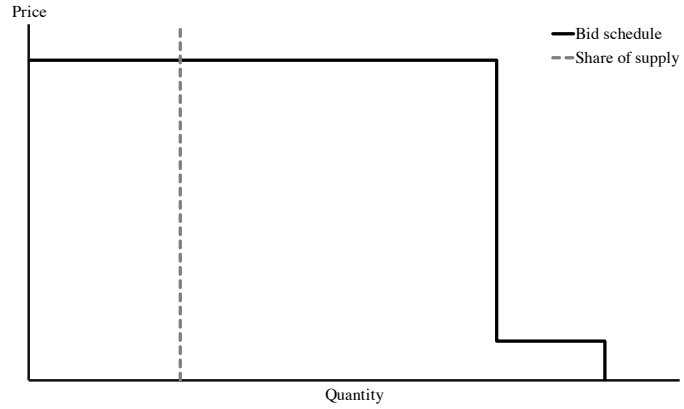


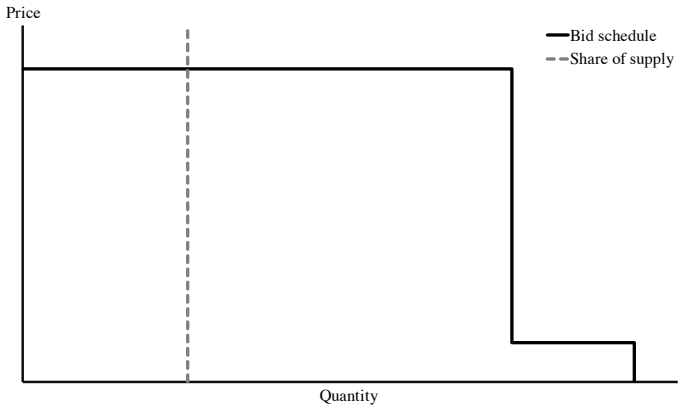
Figure 7: Aggregate bid schedule in the 2018 auction for one-year quota for demersal fish in Russian waters.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 8: Individual bid schedules in the 2018 auction for one-year quota of demersal fish in Russian waters and grandfathered quota share of supply (prior to the auction).

8 Eight-year quota for demersal fish in the Norwegian part of the Barents Sea

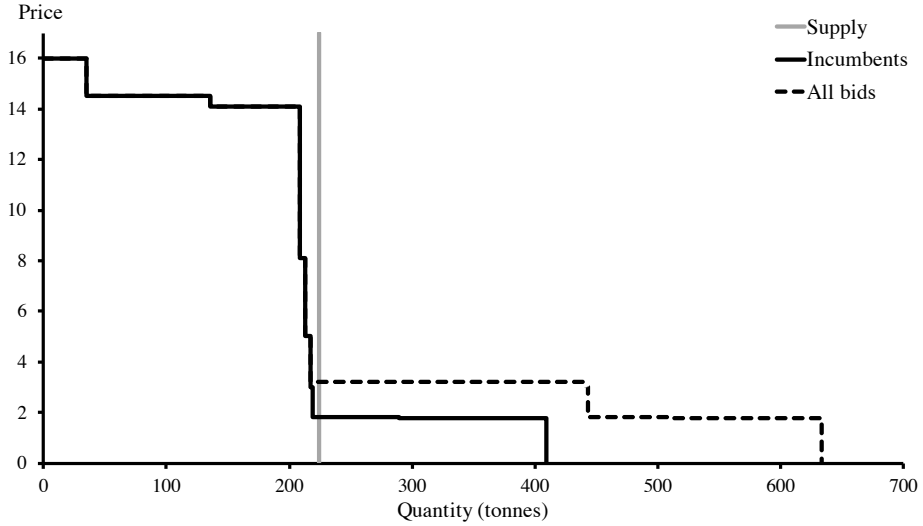
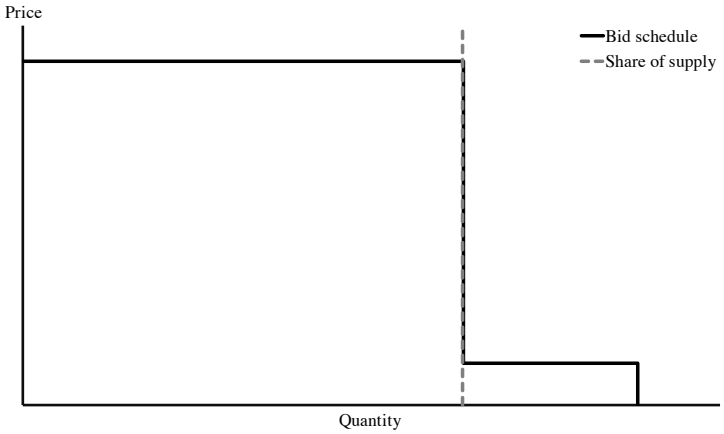
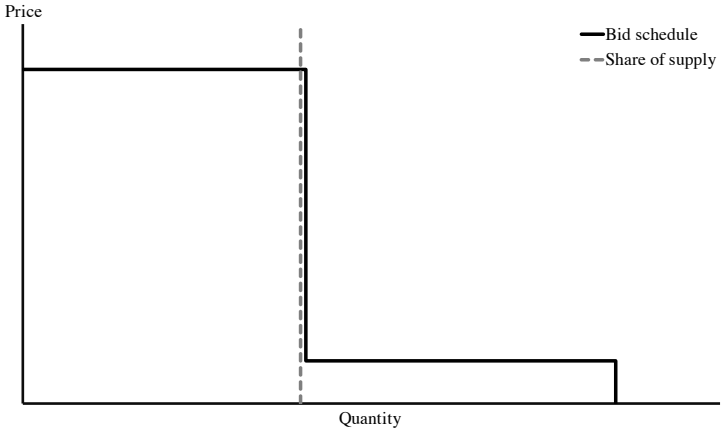


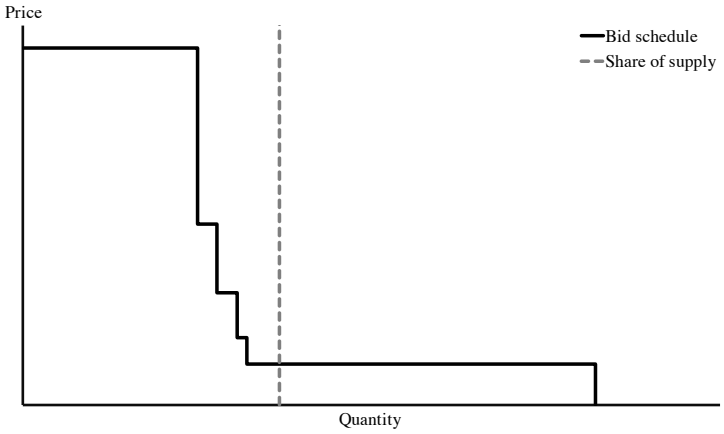
Figure 9: Aggregate bid schedule in the 2018 auction for eight-year quota for demersal fish in the Norwegian part of the Barents Sea.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 10: Individual bid schedules in the 2018 auction for eight-year quota of demersal fish in the Norwegian part of the Barents sea and grandfathered quota share of supply (prior to the auction).

Other 2018 demersal fish quota auctions

9 Other 2018 demersal fish quota auctions

9.1 Three-year quota for demersal fish in the Russian part of the Barents Sea

In this auction there was a total of 9 bids submitted by the three incumbents and one entrant (bidder D). If looking at the bids of the incumbents only, the sharply declining portion of the aggregate demand takes place at quantities between 212 to 224 tonnes, with an aggregate supply of 227 tonnes. The final step occurs 1.3% from where aggregate demand and supply would have intersected with only the incumbents' bids. The price without an entrant would have been 1.82 kr./kg. However, with the entrant's bid the price was pushed up to at 3.20 kr./kg. The entrant did buy the remaining 7 tonnes even though it was significantly less than the 227 tonnes demanded. The individual level inverse demand curves for all incumbent bidders drop of sharply very close to the intersection of the individual demand and the share of supply - for bidder A and C the drop off is just before and for bidder B just after.

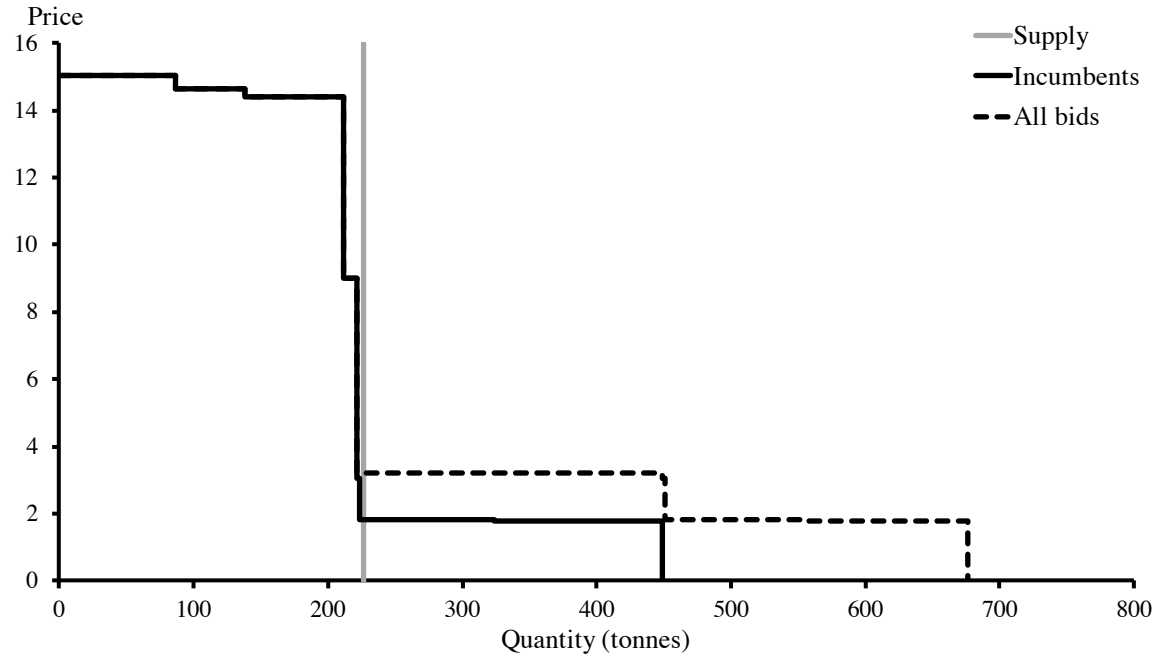
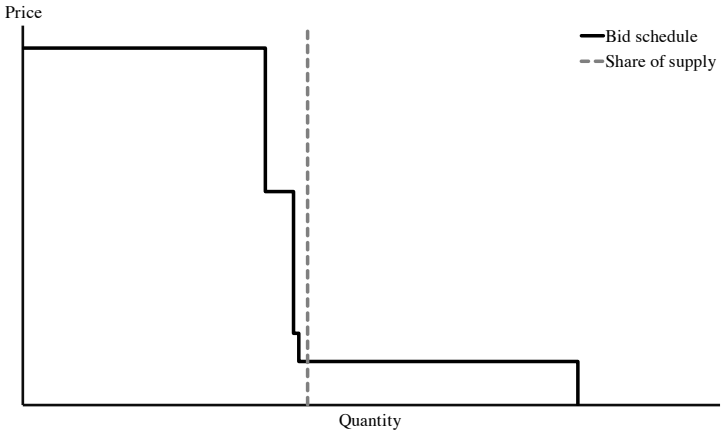
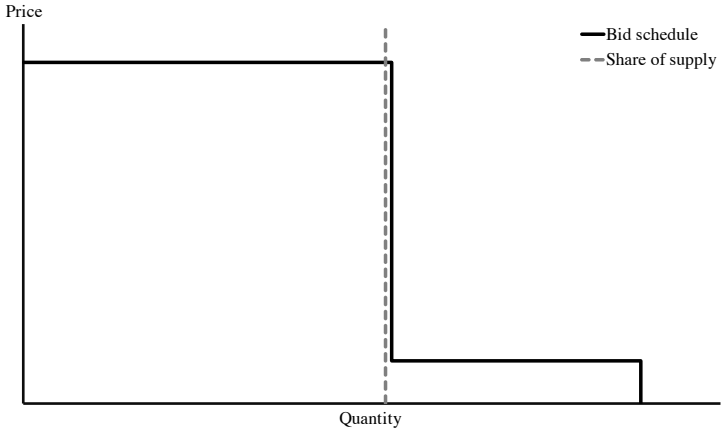


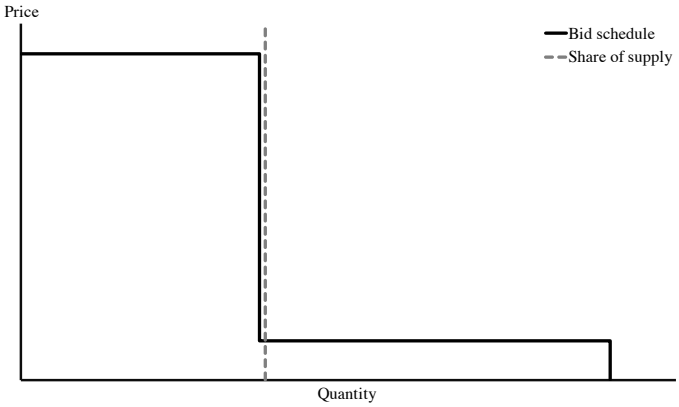
Figure 11: Aggregate bid schedule in the 2018 auction for three-year quota for demersal fish in Russian waters.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 12: Individual bid schedules in the 2018 auction for three-year quota for demersal fish in Russian waters and grandfathered quota share of supply (prior to the auction).

9.2 Eight-year quota for demersal fish in the Russian part of the Barents Sea

In this auction there was a total of 10 bids submitted by the three incumbents and one entrant (bidder D). If looking at the bids of the incumbents only, the sharply declining

portion of the aggregate demand takes place at quantities between 433 to 448 tonnes, with an aggregate supply of 453 tonnes. The final step occurs at 1.1% from where aggregate demand and supply would have intersected with only the incumbents' bids. The price without the participation of the entrant would have been 1.85 kr./kg. However, with the entrant's bid the price for the quota was 3.20 kr./kg. The entrant did buy the remaining 10 tonnes even though it was significantly less than the 453 tonnes demanded. Also in this case the individual level inverse demand curves for all incumbent bidders drop of sharply very close to the intersection of the individual demand and the share of supply - the drop off for bidders B and C is just before the intersection of their individual demands and share of supply whilst for bidder A the drop off happens 150 kg after this intersection.

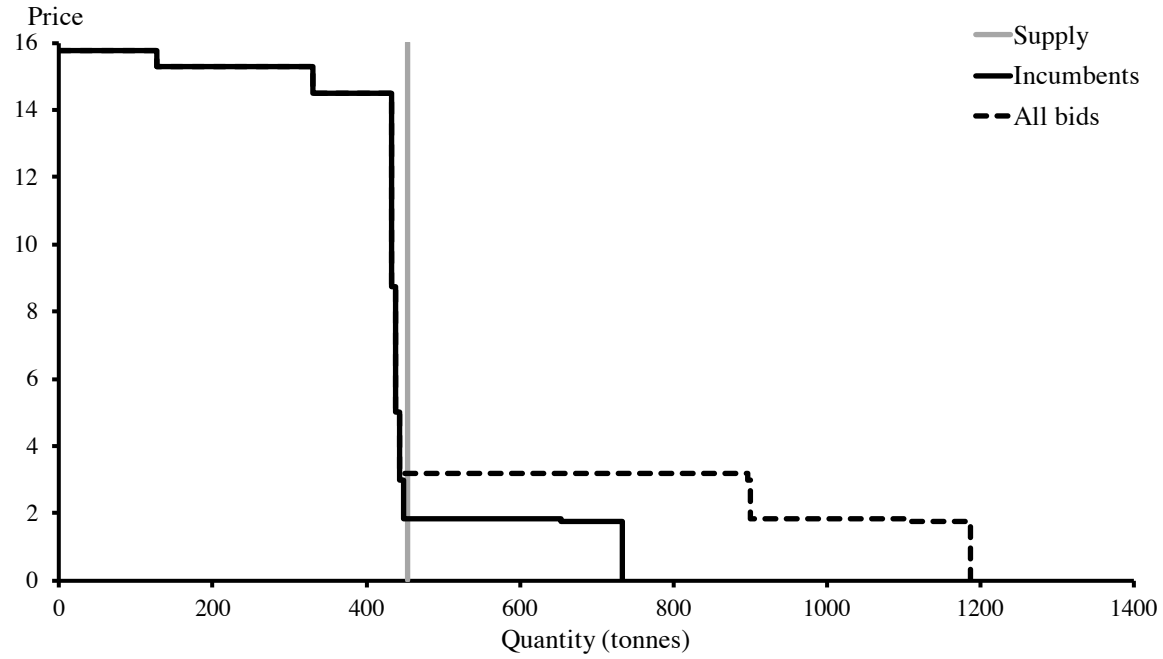
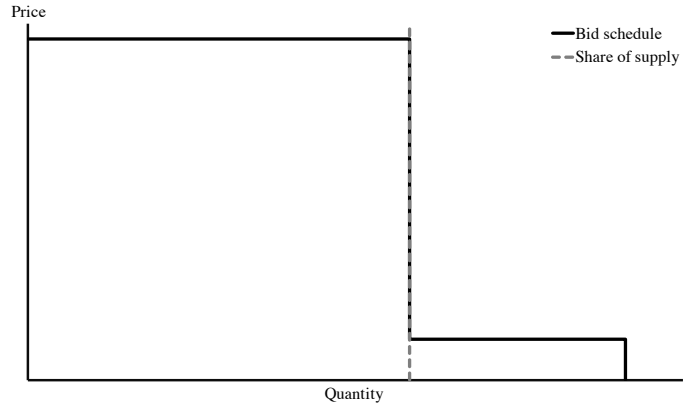
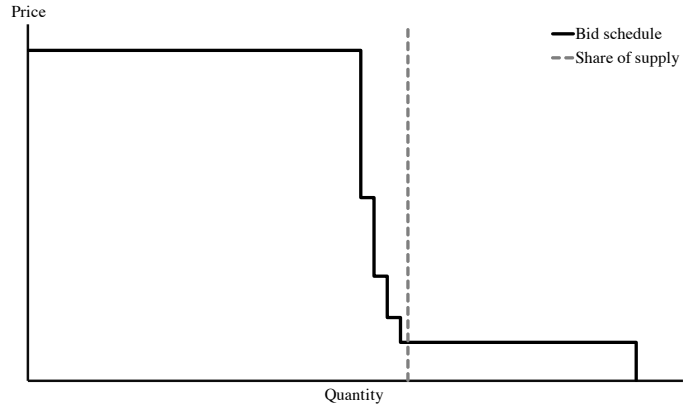


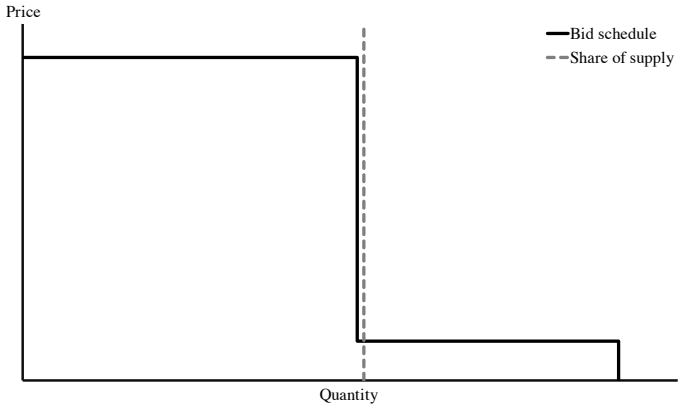
Figure 13: Aggregate bid schedule in the 2018 auction for eight-year quota for demersal fish in Russian waters.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 14: Individual bid schedules in the 2018 auction for eight-year quota for demersal fish in Russian waters and grandfathered quota share of supply (prior to the auction).

9.3 One-year quota for demersal fish in the Norwegian part of the Barents Sea

In this auction there was a total of 9 bids submitted by the same three incumbents and one entrant (bidder E). If looking at the bids of the incumbents only, the sharply declining portion of the aggregate demand takes place at quantities between 844 to 869

tonnes, with an aggregate supply of 874 tonnes. The final step occurs less than 0.6% from where aggregate demand and supply would have intersected with only the incumbents' bids. The price without the participation of the entrant would have been 1.85 kr./kg. However, with the entrant's bid the price settled at 3.10 kr./kg. The entrant did not buy the remaining 20 tonnes as this was short of the 437 tonnes demanded. Interesting about this auction are the individual level inverse demand curves who all drop off sharply right before the grandfathered quota share of the supply.

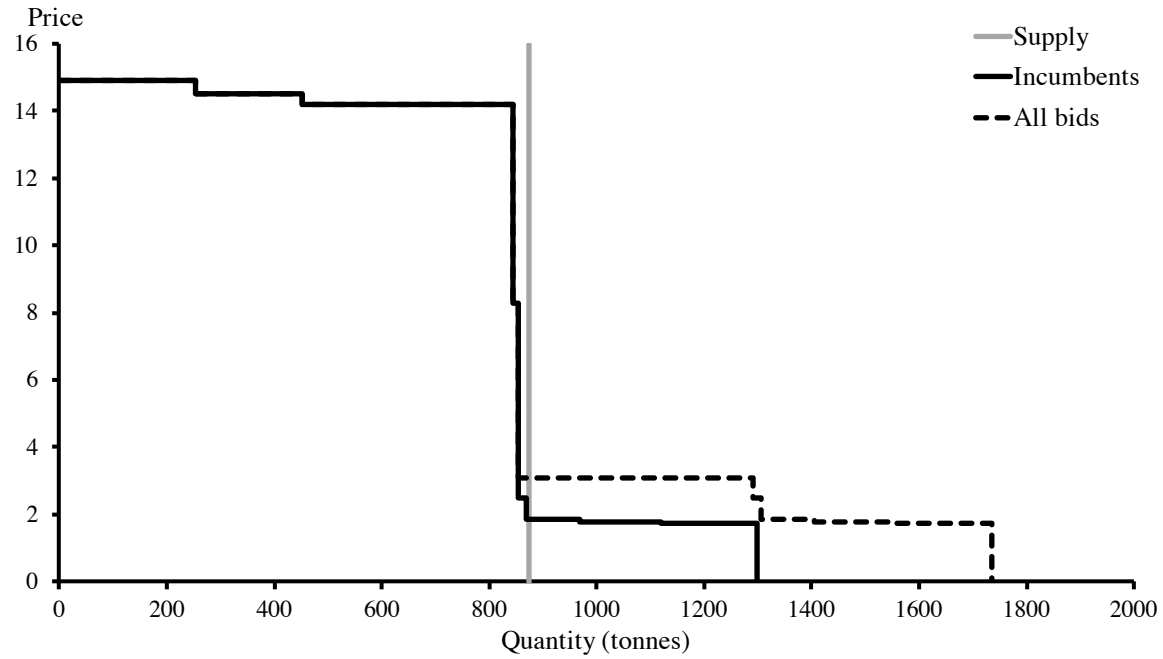
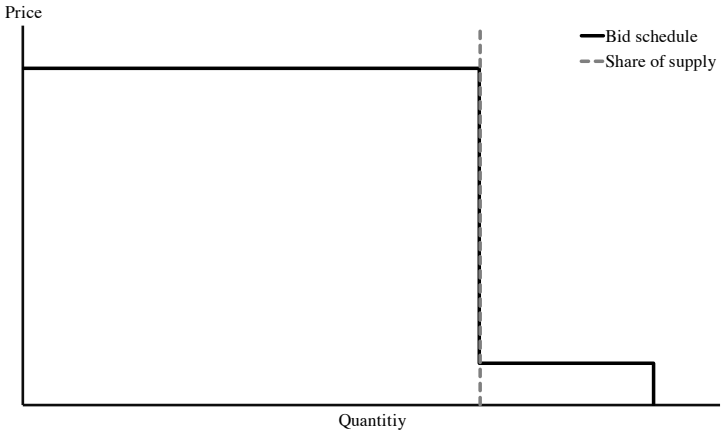
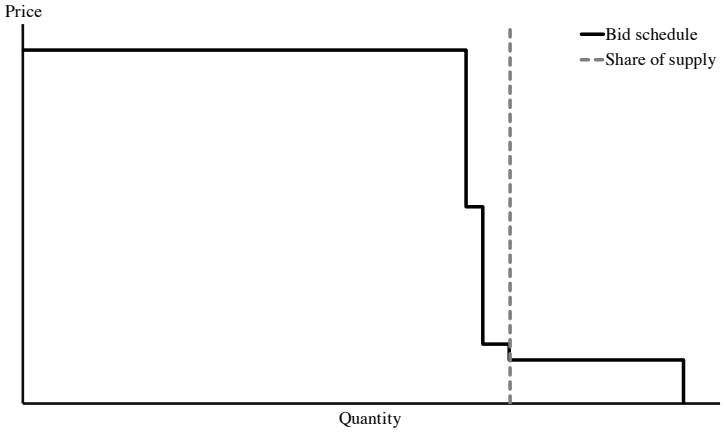


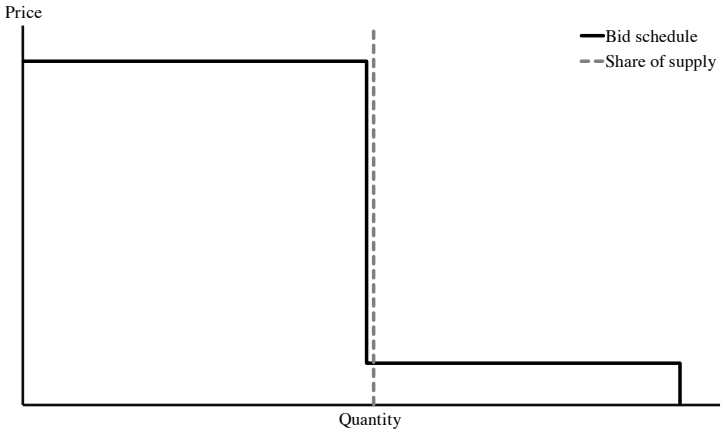
Figure 15: Aggregate bid schedule in the 2018 auction for one-year quota for demersal fish in the Norwegian part of the Barents sea.



(a) Bidder A



(b) Bidder B



(c) Bidder C

Figure 16: Individual bid schedules in the 2018 auction for one-year quota for demersal fish in the Norwegian part of the Barents Sea and grandfathered quota share of supply (prior to the auction).

10 Demersal fish quota auctions in 2016 and 2017

10.1 Quota for demersal fish in the Russian part of the Barents Sea 2016

The first example is from the demersal fish auction of one-year quota in the Russian part of the Barents Sea. The sealed bid auction took place on 21 July 2016 and bidders were allowed to submit one bid per vessel. Five bids were submitted by four companies – the three incumbents and one entrant. If looking at the bids of the incumbents only, the sharply declining portion of the aggregate demand takes place at quantities between 550 to 575 tonnes, with an aggregate supply of 600 tonnes. The final step occurs less than 4.2% from where aggregate demand and supply would have intersected with only the incumbents' bids. The price in this case would have been 2.03 kr./kg. However, with the entrant's bid the price was pushed up to 3.06 kr./kg. The entrant did not end up buying the remaining 50 tonnes as this was short of the 385 tonnes demanded.

Vessel	Company	Price kr./kg	Amount kg	Aggregate demand	Leftover
Enniberg	P/F Enniberg	8.31	300,000	300,000	
Gadus	P/F JFK Trol	8.12	250,000	550,000	
Sjagaklettur	P/F Jókin	3.25	385,000	935,000	50,000
Sjúrðarberg	P/F JFK Trol	3.06	25,000		
Akraberg	Sp/f Framherji	2.03	300,000		

Figure 17: All bids in the 2016 auction for one-year quota for demersal fish in the Russian waters

Vessel	Company	Price kr./kg	Amount kg	Aggregate demand	Leftover
Enniberg	P/F Enniberg	8.31	300,000	300,000	
Gadus	P/F JFK Trol	8.12	250,000	550,000	
Sjúrðarberg	P/F JFK Trol	3.06	25,000	575,000	
Akraberg	Sp/f Framherji	2.03	300,000	875,000	275,000

Figure 18: Incumbents' bids in the 2016 auction for one-year quota for demersal fish in Russian waters.

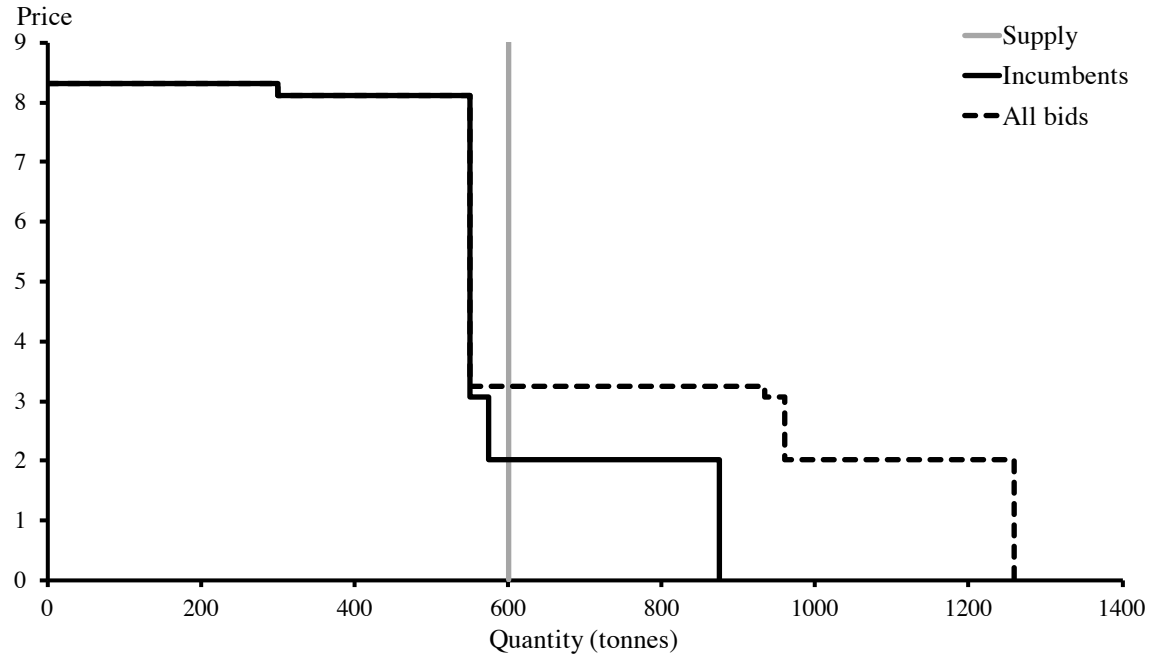


Figure 19: Aggregate bid schedule in the 2016 auction for one-year quota for demersal fish in Russian waters.

10.2 Quota for demersal fish in the Russian part of the Barents Sea 2017

The second example is from the auction on 24 August 2017 of demersal fish one-year quota in the Russian part of the Barents Sea. Companies were allowed to submit three bids per vessel in 2017 following a change in the executive order concerning the auctions of fishing rights. A total of 8 bids were submitted by 4 companies – the three incumbents and one entrant. The sharply declining portion of the incumbents' aggregate demand takes place at quantities between 1,055 and 1,095 tonnes, with the aggregate supply being 1,107 tonnes. The final step occurs at less than 1.1% from the intersection of aggregate demand (of incumbents) and supply. In the absence of the entrant the price would have been 1.75 kr./kg which was the reserve price set by the government. However, with the entrants bid the price was pushed up to 3.01 kr./kg. The entrant did not buy the 52 tonnes offered as this was significantly less than the demanded quantity of 450 tonnes.

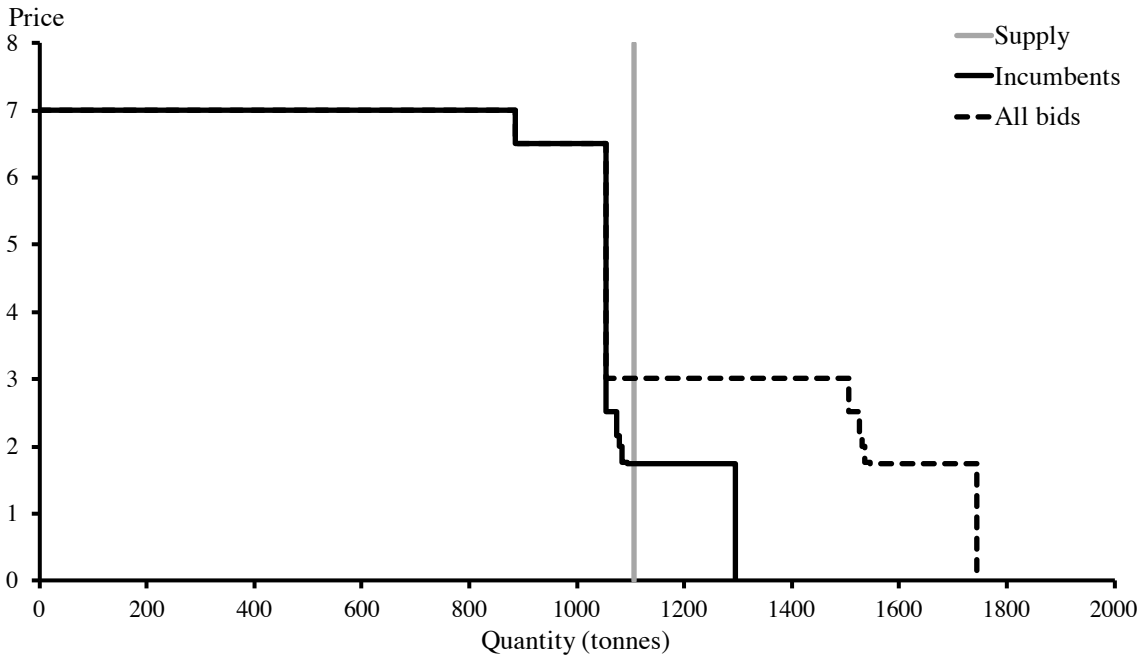


Figure 20: Aggregate bid schedule in the 2017 auction for one-year quota for demersal fish in Russian waters.