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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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**Abstract**

Ascending single-unit 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. We present a model of collusion in multi- and single-unit auctions. Our model predicts that collusion in easier in auctions with below-bid pricing. In particular, to sustain collusion in multi-unit auctions, bidders should submit *crank-handle* bids. Our model also shows why collusion is easier when bidders have symmetric valuations and why ascending auctions are particularly vulnerable to collusion. We present empirical evidence that supports the predictions of the model in auctions for fishing quota in the Faroe Islands. Our findings indicate that the underperformance of ascending and uniform-price auctions are not just theoretical curiosities, but a pervasive phenomenon in practical auction design. Our model suggests that the discriminatory auction could have mitigated collusion and a brief trial of this design in 2019 quota auctions confirmed this prediction.

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

**JEL Classification**: D44, D47

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# 1 Introduction

One of the key insights of auction theory is that the auctioneer might find it desirable to compensate bidders to reveal their private information (Milgrom and Weber, 1982). If winning bidders have to pay their bids, they will bid below their value and will not reveal their true willingness-to-pay. Auction rules with *below-bid pricing*, such as the ascending auction or the uniform-price auction, deliberately decouple winners' payments from bids in order to incentivize bidding close to valuations. By revealing more information, these auction rules can improve the efficiency of allocations and, under certain conditions, increase the auctioneer's revenue. However, the theoretical advantages of auctions with below-bid pricing rely crucially on two assumptions that rarely hold in practice: competitive bidding and the absence of significant asymmetries among bidders.

The contribution of this paper is two-fold. First, we present a new model of collusive bidding in auctions with below-bid pricing. Our model is essentially a multi-unit generalization of Robinson (1985), who explains why collusion is sustainable in second-price and ascending single-unit auctions, but not first-price auctions. In our model, collusion can be profitably sustained using (what we call) *crank-handle bids*. We show that auctions with more below-bid pricing are more susceptible to collusion because they reduce the *collusion-enforcement premium*—i.e., the cost of enforcing a collusive equilibrium that depends on the auction format. For the two most widely-used multi-unit homogeneous-good auction rules—the discriminatory and the uniform-price auction—our results illustrate why the uniform-price auction is much more likely to sustain collusion. In particular, the collusion-enforcement premium is zero in the uniform-price auction and highest in the discriminatory auction. Additionally, we explain why incentives to deviate from collusive bidding are highest in the discriminatory auction and much lower in the uniform-price auction. Beyond these two popular formats, our model can pin down collusive incentives a wide variety format including the Vickrey auction and *mixed-price auctions* where winners pay a combination of their bids and the market-clearing price. Our insights can also explain why collusion is more likely to persist in markets with more symmetric bidders and in markets with almost-common values (even when there is considerable uncertainty about the common value itself).

Our second contribution is empirical. We present a setting in which inexperienced bidders took advantage of auctions with below-bid pricing. We analyze bidding data from auctions for fishing quota in the Faroe Islands which involve overlapping sets of bidders, and took place over three years between 2016 and 2019. The observations from these auctions support our theory in three different ways. First, we find rampant crank-handle bidding indicating attempts to collude. Second, we document a set of sequential ascending auctions, in which the stronger bidder used his value advantage to win most of the quota at reserve price. Third, we observe a successful bidding ring among incumbents in sequential ascending auctions. Finally, we illustrate the success of a brief switch to discriminatory auctions in which the same bidders that colluded in uniform-price auctions no longer engage in crank-handle bidding.

### 1.1 Relationship to previous work

If a seller wishes to sell a single item, many auction theorists recommend an ascending auction.[1] If the values are affiliated, 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. While discriminatory 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, the Vickrey auction. Uniform-price auctions are not strategyproof or even EPIC. [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 auctions cannot be ranked either in terms of revenue or efficiency.[5]

Empirical research on the revenue-superiority between discriminatory and uniform-price auctions has also not converged a definite ranking. For example, both auction formats are popular means of selling sovereign debt (Brenner et al., 2009). 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.

[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.

[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 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).

(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 discriminatory auction revenue-dominates in the Polish sovereign debt market under both sets of assumptions.[6]

Though the evidence is not entiely one-sided, uniform-price auctions appear appealing both from a theoretical and practical perspective. Ausubel et al. (2014) conclude that:

> 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.

### 1.1.1 Consequences of bidder asymmetry

When bidders are asymmetric, revenue equivalence of standard auction formats breaks down even in the singe-item, independent value setting. Maskin and Riley (2000) examine consequences of bidder asymmetry under a variety of scenarios. Although it is no longer possible to universally rank auctions by revenue, they show that for a large class of asymmetric distributions stronger bidders prefer the ascending auction and weaker bidders prefer the first-price, sealed-bid auction Maskin and Riley (2000, Propositions 4.3 and 4.4).[7] Consider the following example of a single-item auction. The weak bidder has value drawn from $U(0,1)$ and the strong bidder has value 10. In either the ascending or first-price auction, the strong bidder always wins the item. However, in the ascending auction, the expected revenue is $\frac{1}{2}$ whereas in the first-price auction the expected revenue will be nearly 1. Maskin and Riley (2000) called the the advantage of first-price auction over ascending in the presence of bidder asymmetry the "Getty effect".

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). Klemperer (1998) and Bulow et al. (1999) analyze such asymmetric equilibria in an *almost*-common-value setting. In particular, Bulow et al. (1999) focus on 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

[6]Both types of auctions are also popular in many liberalised electricity markets (Fabra et al., 2002). In a controlled experimental setting, Abbink et al. (2006) find that uniform-price auctions outperform discriminatory 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).

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

### 1.1.2 Consequences of collusive bidding

In practice, the competitiveness assumption is often inadequate since bidders often have incentives 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] Graham and Marshall (1987) and McAfee and McMillan (1992) allow for the possibility that buyers collude. In particular, Graham and Marshall argue that such collusion is facilitated in an open auction, where buyers can directly inspect one another's behavior. Hence expected revenue will tend to be higher in pay-as-bid auctions.

Among sealed-bid auction formats, there is little agreement on whether uniform-price auctions are more prone to collusion than discriminatory 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; Klemperer and Meyer,

[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).

1989; 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 and everyone 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)— such bidding patterns are often found in repeated electricity auctions (Hurlbut et al., 2004; Holmberg and Newbery, 2010).[10] In this paper, we refer to analogous bidding patterns in standard auctions as crank-handle bidding.

### 1.2 Organization of the paper

This paper is organized as follows. We present our theoretical model in Section 2. In Section 3, we briefly describe the context in which the Faroese fishing quota auctions took place. In Section 4, we document crank-handle bidding in uniform-price auctions. In Section 5 we show manipulations in sequential ascending auctions. In Section 6, we look into common design features that exacerbated the failure of the auctions and describe improvements, some of which were briefly implemented, and are discussed in Section 7. Section 8 is a conclusion. Further auction information is in the Appendix. To protect company identities, we label companies with letters, altering the labeling between sections.

## 2 A model of collusion in multiunit auctions

### 2.1 Setting and auction formats

To fix ideas, we consider a simple model of multiunit auctions. There are two bidders $E$ ("enforcer") and $D$ ("deviator") and a seller who is selling a unit of a perfectly divisible good.[11] Without loss of generality, the seller's value for the good is zero. Bidders have full information about each others' valuations and are able to reach an agreement on their possible collusive strategy. We analyze whether the market can be split between

[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."

[11] The assumption of two bidders is without loss as we can label one bidder as $E$ and the remaining set of bidders as $D$.

bidders at a price of zero as a Nash equilibrium in a variety of auction formats. We illustrate four different auction formats in Figure 1. Three of these auction formats are familiar: the discriminatory auction, in which each winner pays their bids in full; the uniform-price auction in which winners pay the market-clearing price for all units won, and the Vickrey auction in which the winner pays the value of externality on the other bidder. We also introduce a *mixed-price auction* which is a general auction format in which the winners pay a weighted average of their bid and the market-clearing price on each unit. To fix notation, let $MP(\alpha)$ denote a *mixed-price auction* where $\alpha$ is the weight on the market-clearing price and $(1-\alpha)$ is the weight on the winner's own bid. Therefore $MP(0)$ recovers the discriminatory auction; $MP(1)$ recovers the uniform-price auction; and in the $MP(0.8)$ auction winners pay 80 percent of the market-clearing price and 20 percent of bids on each unit won.[12]

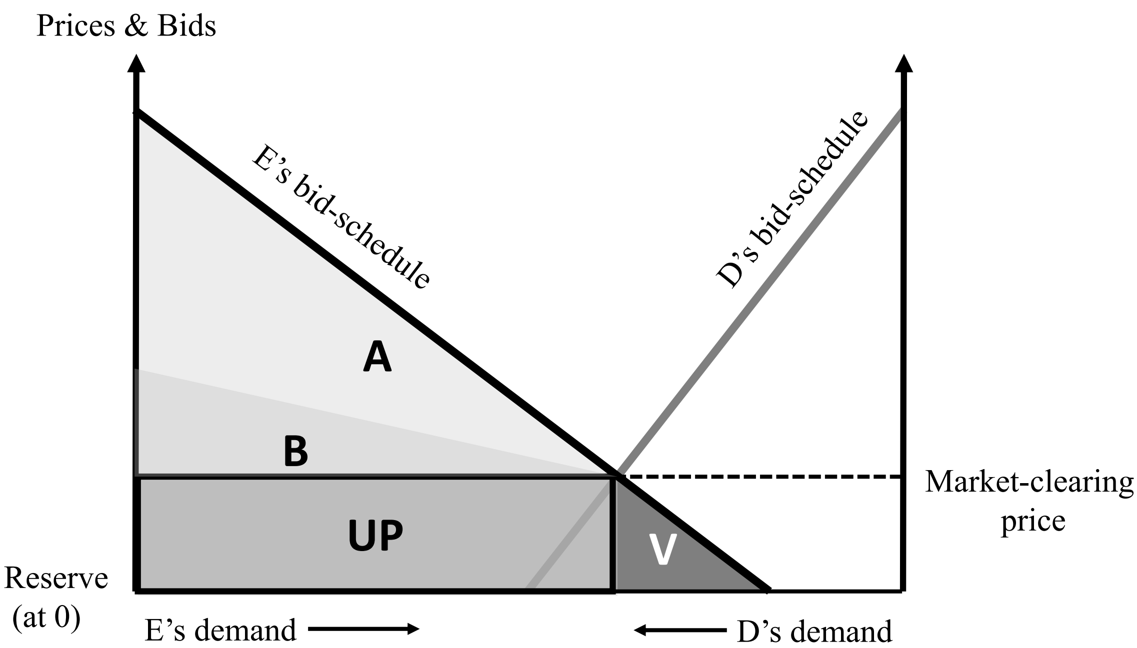



Figure 1: Auction formats. Areas denote total payments in different auction formats: in the uniform-price auction $= UP$, Vickrey auction $= V$, discriminatory auction $= A + B + UP$, mixed-price auction $= B + UP$.

Consider, next, what happens to bidders' payments when the deviator increases his demand at the margin. The deviator's payment increases in every auction format. The enforcer's payment depends on the auction format. In particular, the enforcer's payment decreases in the discriminatory auction (because he wins fewer units) and increases in

[12] Marszalec and Teytelboym (2020) also consider a mixed-price auction which mixes between the discriminatory auction and the Vickrey auction; therefore this format captures *variable-$\alpha$ auction* due to Tse (2004, Section 2.3) as a single-unit special case. Marszalec and Teytelboym (2020) derive optimal bidding strategies mixed-price auction under uncertain supply.

There also exist practical below-bid pricing rules, such as the Spanish auction, which are not nested by the mixed-price auction. In order to capture the Spanish auction, $\alpha$ would need to be a function of the distance between winning portion of demand the uniform price rather than a constant weight.

the Vickrey auction (because he is crowding out units that the deviator values more). However, in mixed-price or in uniform-price auctions, the enforcer's payment can go up or down depending on the shape of the demand curve: The flatter the demand curve, the more likely it is that the enforcer's payment falls.

## 2.2 Illustration: collusive crank-handle equilibria in uniform-price auctions

Let us first consider a well-known example of a collusive bidding in uniform-price auctions. The bid-schedules drop off sharply to the reserve price at the point where the colluding bidders split the market. In procurement auctions, these bid-schedules are often referred to as "hockey-sticks" (Hurlbut et al., 2004), however, as Figure 2 shows they more closely resemble crank-handles.

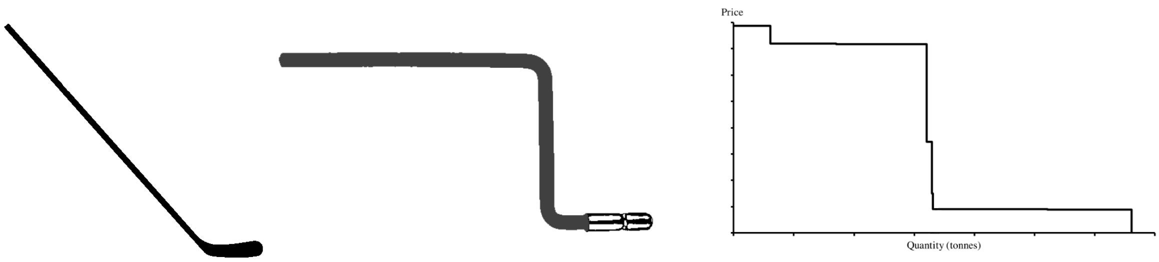
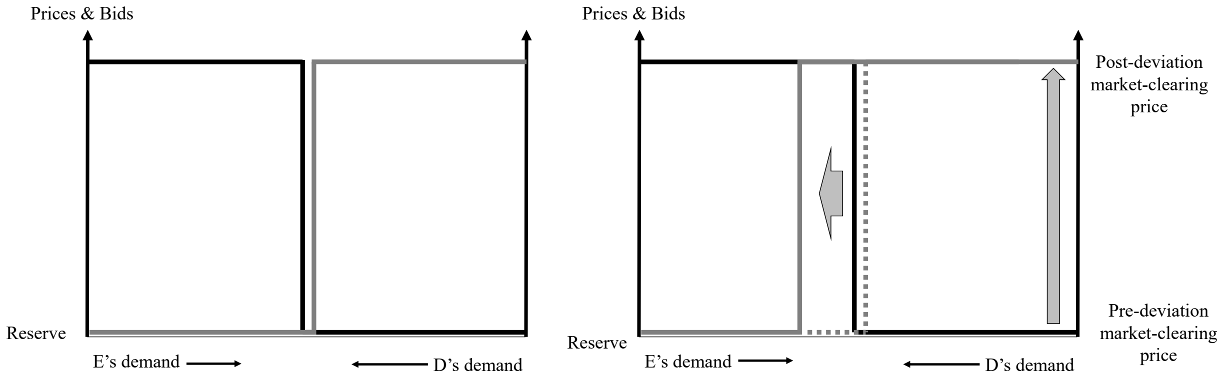



Figure 2: A hockey stick, a crank-handle, and a bid-schedule.

Now consider two crank-handle bid-schedules illustrated in Figure 3a. In this collusive equilibrium, both bidders' payments are zero.




(a) Before deviation: market split at reserve

(b) After deviation: large price rise on all units

Figure 3: Crank-handle equilibrium in a uniform-price auction.

To see why these strategies constitute a Nash equilibrium, suppose the deviator increases his demand on the margin, as in Figure 3b. The market-clearing price jumps dramatically meaning that now the deviator has to pay a positive price for *every* unit won. If enforcer's crank-handle is high enough, the increase in the market-clearing price can wipe out the deviator's profit on the marginal unit, making deviation unprofitable.

## 2.3 Collusive equilibria in general auctions with below-bid pricing

We now show that the intuition of crank-handle collusion in uniform-price auction extends generally to all auctions with below-bid pricing.[13]

For collusion to be sustainable in our setting, two conditions must be met:

- (No Deviation) the increase in the deviator's payment following his deviation must be sufficiently large to generate a loss on the additionally won units, and
- (Collusion Profitability) it must be profitable for all bidders to adhere to the collusion-inducing bid-schedules in the Nash equilibrium, i.e., when no deviation occurs.

First, consider the deviator's incentive to increase his demand. As in the uniform-price auction example, in all auction formats a high enough crank-handle bid-schedule for the enforcer can ensure that the deviator makes a loss on the additionally won units. How high the enforcer's crank-handle bid-schedule needs to be depends on the auction format. Other things equal, the closer the pricing is to a discriminatory auction (i.e. $\alpha \to 0$) the higher the enforcer's crank-handle needs to be to prevent a deviation.

Second, consider the enforcer's incentive to maintain the collusive equilibrium. In uniform-price and Vickrey auctions, it is costless for the enforcer to bid with an arbitrarily high crank-handle in a collusive equilibrium. If no deviation occurs, the high portion of the crank-handle is only used as a deterrent and does not affect the enforcer's payment in the collusive equilibrium.

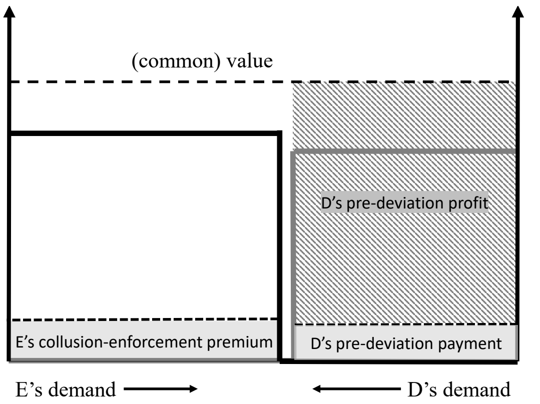
In the discriminatory auction each inframarginal winning bid is paid in full. Thus, in a collusive equilibrium, all winning bids are costly to the enforcer: the enforcer must pay a *collusion-enforcement premium* even if no deviation occurs. To collude at a minimal cost, the enforcer must submit crank-handle bid-schedule where the upper portion is very close to the reserve price. However, such flat crank-handle bid-schedules make deviation from collusion attractive: by bidding slightly more, the deviator can win more units at a slightly higher price, and therefore increase his overall profit. As a result, in the discriminatory auction, the two conditions for successful collusion are in direct conflict.

In summary, to disincentivize deviations, the market-clearing price must jump considerably after a deviation—but inducing such jump is costlier when prices are more closely tied to the enforcer's bids on inframarginal units. The extent of below-bid pricing is thus crucial to resolving the conflict between the deviator and the enforcer that would maintain collusion. The closer the prices are to the winning bids, the higher the cost of bidding in a crank-handle equilibrium that would make collusion sustainable. Conversely, below-bid pricing makes collusion-enforcing crank-handle bid-schedules easier to sustain.

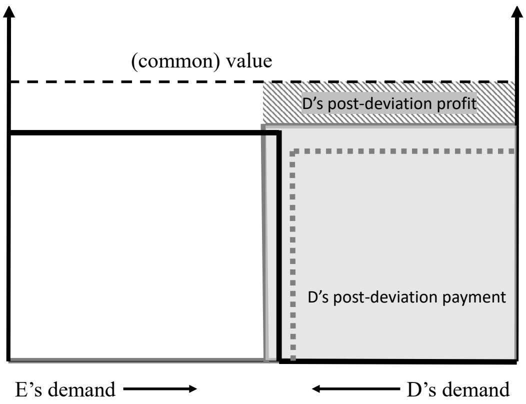
To more fully illustrate collusive incentives in *mixed-price auctions,* in Figure 4 we assume that both bidders have the same value for each unit. Figure 4a depicts collusion

[13] It is sufficient to restrict our attention to crank-handle bid-schedules in the collusive equilibria as these are the most efficient bid-schedules for any split of the market at the reserve price.

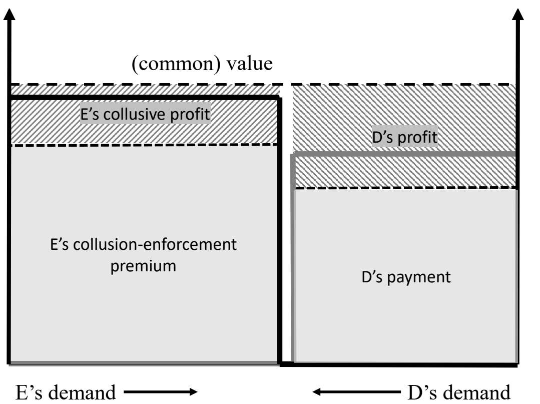
in the $MP(0.9)$ auction. In equilibrium, the price on inframarginal units is above the market-clearing price, but still relatively unresponsive to a bidder's own bid. To discourage deviation, the enforcer can submit a crank-handle bid-schedule which is only slightly higher than in the uniform-price example. But, in the collusive equilibrium, the enforcer only pays a 10 percent collusion-enforcement premium. To win a larger share, the deviator must increase their bid snough to crowd-out some of the enforcer's bids - but doing so pushes the price up considerably. Consequently - comparing Figures 4a and 4b - it is clear that deviator's profit falls if he cheats on the collusive split. From the enforcer's viewpoint, it may be worth paying the collusion-enforcement premium to deter deviation.



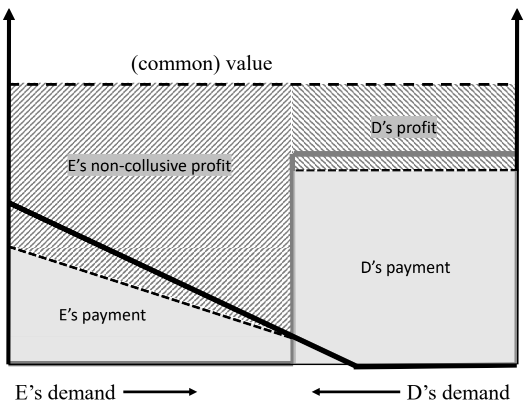

(a) MP(0.9): low collusion-enforcement premium




(b) Deviation under MP(0.9) is unprofitable




(c) MP(0.1): high collusion-enforcement premium




(d) MP(0.1): E may prefer to bid competitively

Figure 4: Lower $\alpha$ in mixed-price auction is more likely to sustain collusion.

Conversely, in an $MP(0.1)$ auction, depicted in Figure 4c, the enforcer needs to submit a higher crank-handle bid-schedule to prevent deviation, but the collusion-enforcement premium might make this unsustainable.[14] The enforcer may be better off submitting a downward-sloping demand bid-schedule, as illustrated in Figure 4d.

[14]Our conditions for collusion outlined in this paper are sufficient, but usually stronger than necessary for collusion. To find the exact conditions under which collusion is sustainable, one needs to compare the profits in the collusive equilibrium to the profits in the competitive bidding equilibrium which depend on the distribution of valuations and the uncertainty of market supply (Marszalec and Teytelboym, 2020).

## 2.4 Crank-handle collusion in more general settings

**Multiple and asymmetric bidders** Our illustrative example, above, considers a two-bidder model, with one deviator and one enforcer—but this assumption is without loss of generality. With more than two bidders, incentives to collude must align for every pair. In practice, it is sufficient to check the incentive of only one pair of bidders. First, we must check the No Deviation Condition for the bidder who has the highest value on the marginal collusive unit. Second, we must check the Collusion Profitability Condition for the bidder for whom the collusion-enforcement premium is the highest. If collusive incentives do not align for these two key bidders, then collusion will break down whenever there are more bidders present.

Our model therefore also explains why collusion is more likely to be sustainable in markets in which bidders have similar preferences, rather than in markets with large asymmetries in valuations. For example, if the bidder pool contains one strong bidder with high valuations, and one weak bidder with low valuations, collusion is less likely: the profit derived from deviating on marginal collusive units is high for the strong bidder (No Deviation Condition fails), while the weak bidder's ability to pay for a high enough collusion enforcement premium is limited (Collusion Profitability fails).

**Uncertainty and value advantage** While our model in this paper assumes full information, the intuition it captures carries over to models with elements of uncertainty.[15] In the general case, if supply is uncertain, knife-edge collusion may not be possible, and in equilibrium some fraction of the goods may go unsold: with uncertain supply, there is a trade-off between how precise the market split can be, and the possibility that a low realization of supply will accidentally lead to bidders' crank-handles intersecting at the higher portion. Nonetheless, in expectation the same intuition still holds: the collusion-enforcement premium must be weighed against the expected gain from deviation on the marginal collusive units. Depending on the amount of trust, asymmetry, and uncertainty among the bidders – this may be a premium worth paying.

Our notion of the collusion-enforcement premium can also explain the results of Bulow et al. (1999) on toe-holds and almost-common values. In their model, one bidder has a small, but certain, value-advantage over his rivals. The authors point out that in an ascending auction, the value-advantaged bidder always wins, so other bidders have no incentive to participate; the first-price auction, on the other hand, does not result in such asymmetric outcomes. The toe-holds result therefore holds because in the ascending auction the collusion-enforcement premium is zero, while in the first-price auction the *expected* collusion-enforcement premium is positive. This intuition persists so long as bidders know their valuation relative to others, even if the absolute value of the good for sale is very uncertain: the most value-advantaged bidder can costlessly commit to

[15] Marszalec and Teytelboym (2020) perform an analysis in a model with uncertainty.

out-bidding everyone else in an ascending auction. However, commitment to outbidding is not credible in the first-price auction because in equilibrium even the value-advantaged bidder must bid high enough not to be outbid by other bidders with more optimistic estimates of the common value.

**Truth-telling vs. collusion** A key argument in favor of strategy-proof auctions, such as the Vickrey auction for multiple units, or the ascending-auction for a single unit, is that the competitive-bidding equilibrium bidding strategies are straightforward. Similarly, some arguments, champion uniform-price auctions over discriminatory due to their closeness to the strategy-proof Vickrey auction (Friedman, 1960; Ausubel et al., 2014). There is therefore a deep-rooted intuition that de-coupling winners' prices from their bids would lead to simple (near)-truthful bidding resulting in efficient allocations, accurate information about bidder values, and outcomes that favor weaker bidders.

Our results urge caution on these implications: while in a competitive-bidding equilibrium such desirable results may hold, once we expand our considerations to include collusive equilibria, the results may be reversed: rather than bidding truthfully, it may become optimal to bid using crank-handles, which convey inaccurate market-price signals. Moreover, in collusive equilibria it is hard to conclude anything about efficiency. Furthermore, since deviation benefits are likely to be highest for stronger bidders, and collusion enforcement premia relatively more expensive for weaker bidders, below-bid pricing may favor strong bidders over weaker ones.

# 3 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 (P/F Enniberg, Sp/f Framherji and P/F JFK Trol). The pelagic fisheries industry is also concentrated: four companies (P/F Christian í Grótinum, Sp/f Framherji, P/F JFK Trol and P/F Varðin) with ten vessels fish approximately 90 percent of the pelagic catch

(Faroese Fisheries Inspectorate, 2017).[16] 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 canceled 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 8 and 42 percent of TAC for the same species. In 2018, the Faroe Islands passed a fisheries reform which 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.[17] As a fraction of GDP, these are some of the largest auctions ever held.[18]

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,

[16]The other 10 percent are caught by around forty other vessels, many of which are owned by Framherji, JFK Trol and Varðin either fully or partially.

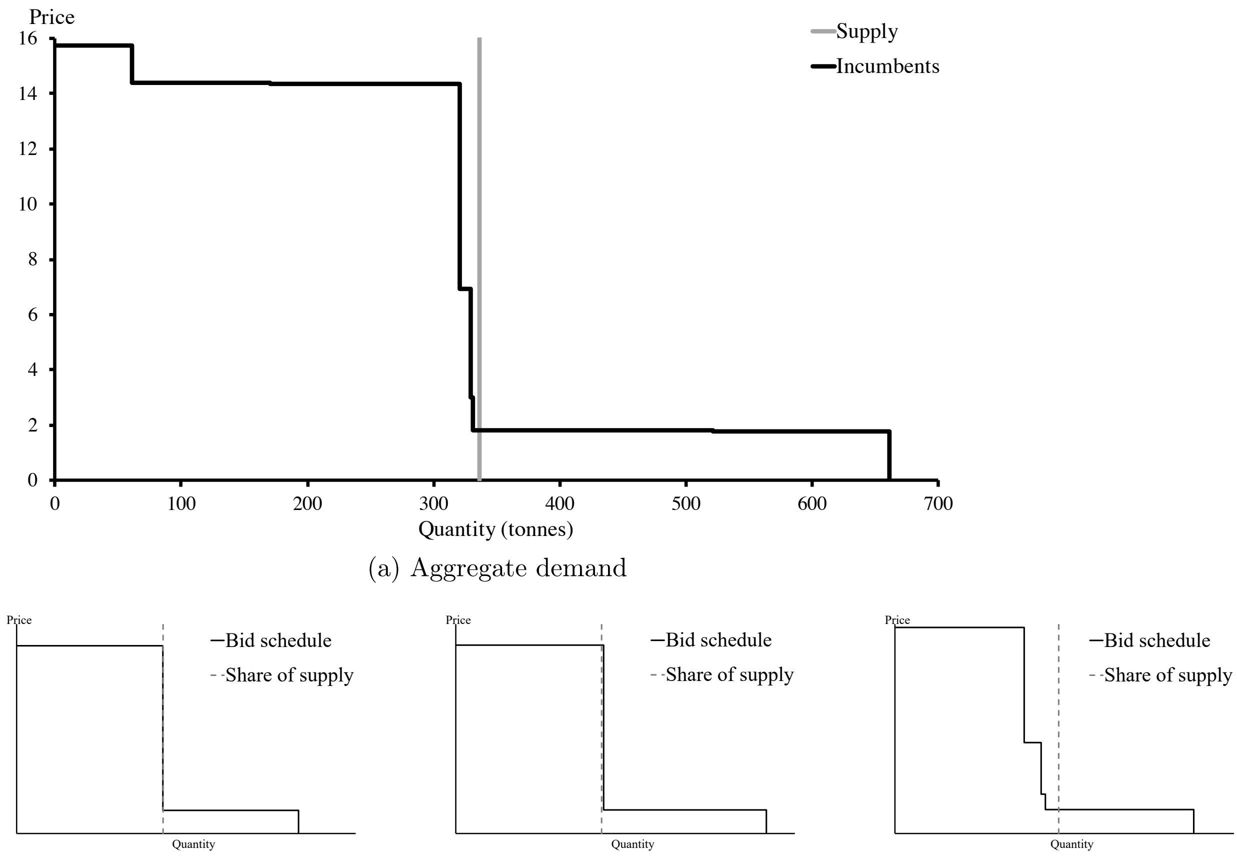
[17]If TAC is below a certain threshold, then 15 percent (or 25 percent) will be auctioned off, but of any quota that is above the threshold 100 percent of the extra TAC will be auctioned off. Therefore, more than 15 or 25 percent of TAC may be sold on auction every year.

[18]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.

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.

# 4 How uniform-price auctions fail: collusion with crank-handle bidding

Let us 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 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— we refer to them as Bidders A, B, and C.




(a) Aggregate demand

(b) Bidder A (c) Bidder B (d) Bidder C

Figure 5: Aggregate and individual bid-schedules of the incumbents and the supply of quota in the 2018 auction for quota for demersal fish in Svalbard.

Figure 5a shows the final aggregate bid-schedule and the supply in the 2018 auction for quota for demersal fish in Svalbard. The bid-schedule has a pronounced crank-handle shape: the sharply declining portion of the aggregate bid-schedule takes place at quantities between 321 and 331 tonnes. The final step decrease occurs less than 1.5 percent from where aggregate demand and supply (of 336 tonnes) intersect. Indeed, individual bid-schedules presented in Figures 5b to 5d also have a crank-handle shape—they are flat over much of the reasonable support for all three bidders before dropping off sharply—exactly as our theoretical model of collusion in uniform-price auctions suggests.

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 Figures 5b to 5d, 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 (Leo, 2018).

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 9). Here, the incumbents submitted crank-handle bids (Figure 10). 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 9). 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 fish in the Norwegian part of Barents Sea (Appendix 10). 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 12). 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 11). Crank-handle bidding was also observed in the three other 2018 auctions for demersal fish (see Appendix 11). In each case, we observe attempts at low-price equilibria by the three incumbent bidders. However, all these other attempts were frustrated because of entrants setting 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 12). Nevertheless, we observe a crank-handle in the aggregate demand schedule for the incumbent bidders which falls off just before supply (see Appendix 12)). 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 How ascending auctions fail: value advantage and collusion

In this section, we describe two more reasons for poor performance of EPIC auctions that have been noted in other contexts.

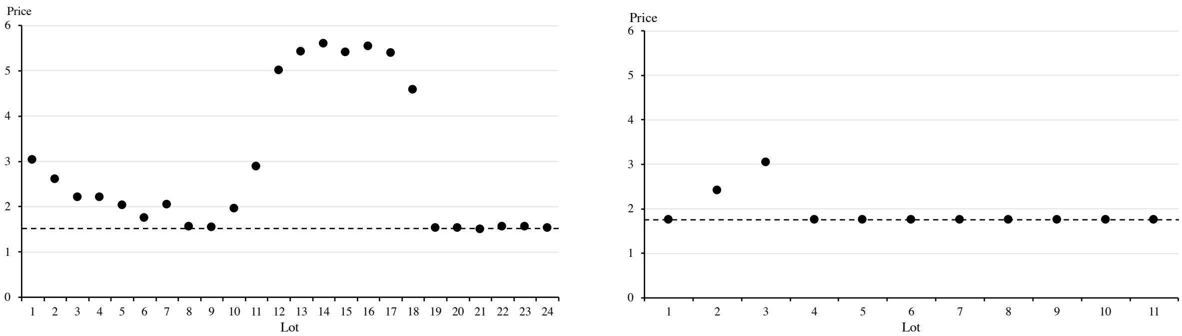
## 5.1 Consequences of value advantage

The 2016 and 2017 auctions for quota for demersal fish in the Russian part of the Barents Sea illustrate how poor auction design can exacerbate one bidder's value advantage in an almost-common-value setting. The auctions were run as sequences of ascending auctions, with similar amounts of quota being auctioned in each round.[19] 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 aforementioned incumbent and one entrant.[20] 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 6a 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 behavior 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 6b illustrates, the same auction ran in 2017 continued from where the

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

[20] 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.

previous year's auction left off: with the incumbent showing a strong commitment to bid whatever necessary to win everything. The entrant only bid in rounds 2 and 3 to test the incumbent's commitment, but dropped out thereafter. 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 6: Prices in the auctions for quota for demersal fish in the Russian part of the Barents Sea. Dots: final prices. Dashed lines: reserve prices.

Clearly, the standard symmetric and competitive bidder assumption does not hold here.[21] 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 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 of Bulow et al. (1999)

[21]Indeed, if bidders were competitive and symmetric, the price path should be a martingale and different auction rules should yield revenue equivalence (Weber, 1981; Weber and Milgrom, 2000). Figures 6a and 6b 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.

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 aggressive bidding in earlier rounds and denying the entrant the chance to win enough quota to operate at a minimum feasible scale.

## 5.2 Bidding rings

We now examine how poor auction design can facilitate 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 (discussed 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.[22] Seven bidders (labelled as A–G in this section) participated in the auction and all except one (Bidder G) won a share of the quota. Figure 7 shows the winning bidder and the prices paid by the winning bidders for each of the 25 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).

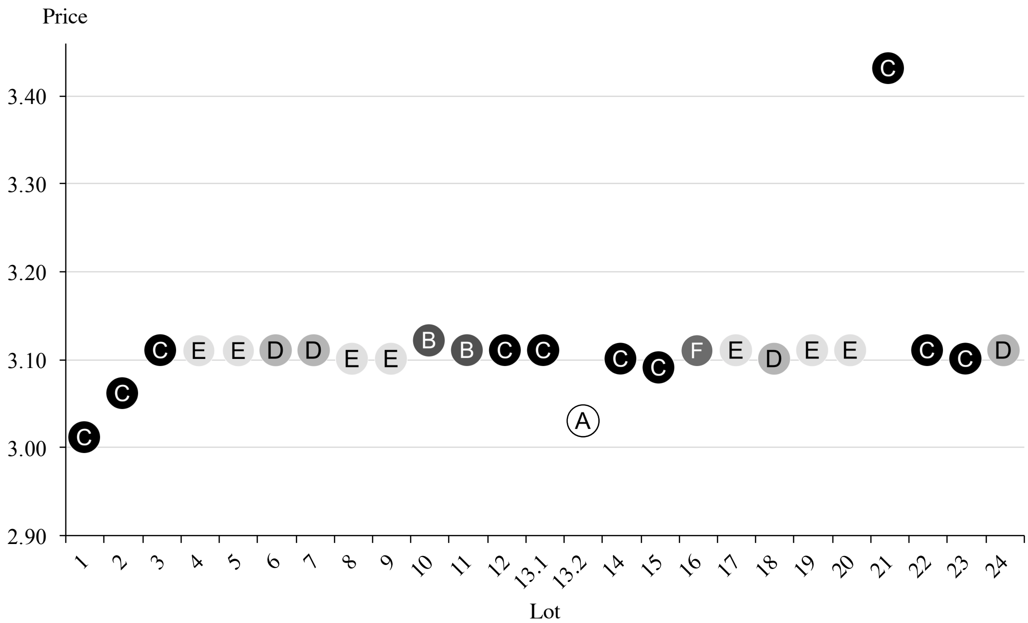



Figure 7: Final prices in the 2017 auctions for quota for mackerel (25 lots). Each letter denotes a different winner.

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

[22] 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 and 25 lots in total.

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.[23]

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; Ishii, 2009; Kawai and Nakabayashi, 2014).

Why was bidder coordination so simple in this auction setting? As Robinson (1985) pointed out ascending auctions create ample opportunities for collusion - similarly, our model in Section 2 showed that the collusion-enforcement premium in ascending auctions is zero. Moreover, sequential auction designs mean that more bidder signals can be sent (Marshall and Marx, 2007, 2009, 2012). Both observations relate to the two crucial perrequisites 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.[24]

# 6 Discussion

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

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

[23] Bidder A unexpectedly won lot 13.2. One explanation might be that the designated winner on that lot (Bidder C) dropped out early in an attempt to identify who the price-setter was: a deviating ring-member or an outsider. 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 kr./kg. The bidder subsequently quit the auction, and did not participate in subsequent rounds.

[24] 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.

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.

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 much 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.

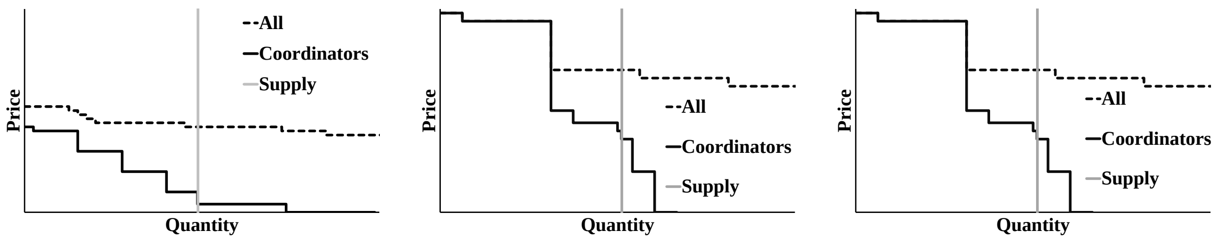
The sequential ascending auctions for quota for mackerel in 2017 failed because bidders found a straightforward way to rotate winners and coordinate on a single price. The sequential nature of the auctions meant the bidders had ample information between rounds in order to monitor the outcomes of the possible bidding ring.

One auction design that could potentially improve all these auction is the first-price sealed-bid package auction. In this design, bidders could submit bids for packages of quota (divided into sufficiently small lots) in a sealed-bid manner and the winners would pay the price that they 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.[25] However, uncertain supply might not be feasible in the fishing quota context since the annual TAC is usually set by a political and scientific consensus.

# 7 Recent evidence from uniform-price and discriminatory auctions

We publicly shared a version of this paper in October 2018. Following discussions with officials, industry experts, and civil servants, the Faroese government decided to trial discriminatory auctions to sell one-year blue whiting quota in March 2019. The discriminatory auction is a special case of the first-price package auction that we recommended for the case of a homogeneous good in the working paper. Uniform-price auction continued to be used for three-year and eight-year quota. Results from the auctions are summarized in Figure 8. Scaling on the vertical axis is the same for all auctions, and the quantity axes have been scaled proportionately.[26] For each auction, we show the full aggregate demand function, and a separate demand function for a subset of bidders who attempted to coordinate on a lower-price equilibrium. Overall, the data patterns are consistent with our predictions.




(a) One-year quota: discriminatory auction.

(b) Three-year quota: uniform-price auction.

(c) Eight-year quota: uniform-price auction.

Figure 8: Bidding functions in blue whiting auctions, March 2019.

First, aggregate demand in the discriminatory auction for one-year quota is more elastic (flatter) and does not have a pronounced crank-handle shape. The higher elasticity

[25] Mariño and Marszalec (2020) observe an extreme example of such strategic supply adjustment in the Philippines, where the Department of the Treasury restricts supply frequently, and on occasion cancels the entire tender. As a result, the market clearing price – whenever the auction is completed – is never pathologically low. Earlier discussions of strategic supply choice include Back and Zender (2001), LiCalzi and Pavan (2005), and McAdams (2007).

[26] Price and quantity numbers have been removed for confidentiality reasons.

of demand suggests that the auction was more competitive and that incumbent bidders no longer attempted to coordinate on a low-price equilibrium. The aggregate demand in the uniform-price auctions for three-and eight-year quota more closely resembles the familiar crank-handle shape observed in previous years. The aggregate demand for the coordinating bidders has an even more pronounced crank-handle shape.

Second, aggregate demand in the discriminatory auction intersects supply at a price which is strictly above the highest bid of the coordinating bidders; in this auction, a non-coordinating bidder would have won the entire supply. As outlined in Section 2, bidders attempting to coordinate in a discriminatory auction submit a flat bid-schedule—however, this strategy is vulnerable to deviation by a non-coordinating bidder who can win the entire supply.[27] By comparison, non-coordinating bidders would have won around a quarter of the three-year quota, and 40 percent of the eight-year quota. While these are not *ceteris paribus* comparisons, our results support the observation that weaker bidders prefer the discriminatory auction. These preliminary results are therefore also consistent with our theoretical model in Section 2.4.

Unfortunately, this is also where the story on the Faroese quota auctions ends. The use of auctions for the allocation of fishing quota became a major campaign issue in the August 2019 elections and the 2015—2019 coalition government was voted out of office. As of January 2020, the present government has no plans to run further fishing quota auctions.[28]

# 8 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 constructed a model which shows that below-bid pricing may facilitate collusion, and undo many of the desirable properties that such auctions may exhibit in a competitive-bidding equilibrium. The model covers the Vickrey and uniform-price auctions, as well as the entire family of *mixed-price auctions*. The intuition established in our base model also generalizes widely. Our results cast doubt on the notion that de-coupling winners' payments from their own bids is a good recipe for robust practical auction design. To the contrary: in our analysis, rules close to pay-as-bid are more robust.

Using recent evidence from the Faroe Islands, we showed that the underperformance of ascending and uniform price auctions, which is predicted by our model and various other

[27] In this particular auction, the non-coordinating bidder did not, in fact, win: due to a technical mistake, the bidder submitted their bids using incorrect formatting and their bids were canceled. Nonetheless, the bidder's intended demand function was clearly indicated, so we have retained it for our analysis.

[28] The legal document outlining the relevant policy can be found at: https://logir.fo/Logtingslog/152-fra-23-12-2019-um-sjofeingi

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 (insofar as we know) hire 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. Recent experience in the Faroes appears to support our recommendations. Meanwhile, the majesty of ascending, uniform-price, and other below-bid pricing auctions continues walking on theoretical stilts.

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# Online appendix

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

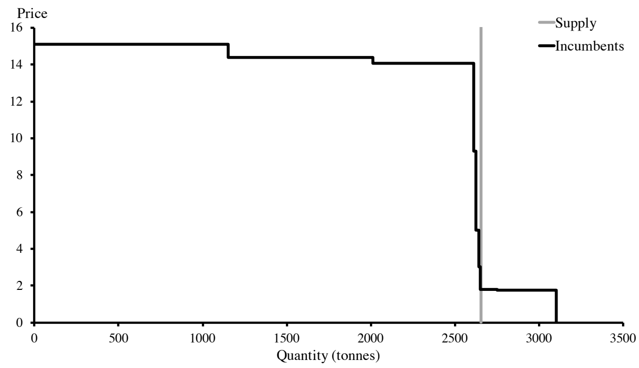
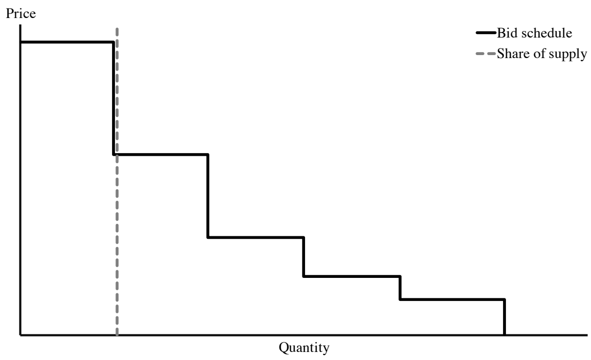
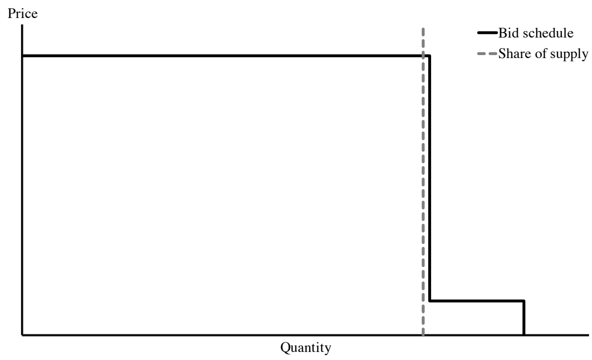


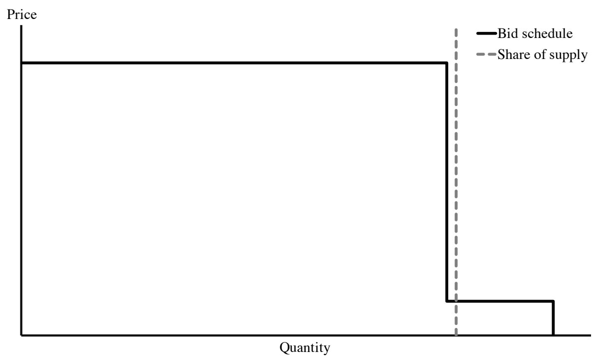

Figure 9: Aggregate bid-schedule in the 2018 auction for one-year quota for demersal fish in Russian waters.




(a) Bidder A




(b) Bidder B




(c) Bidder C

Figure 10: 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).

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

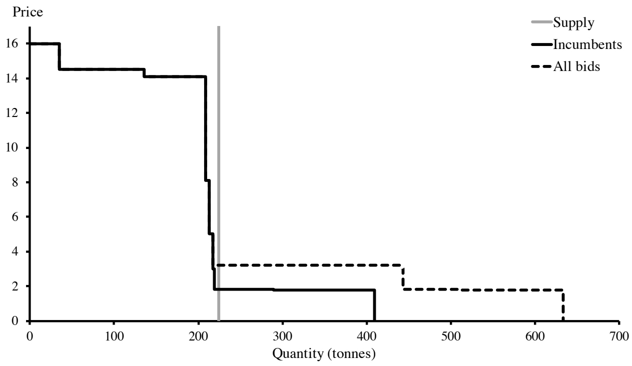
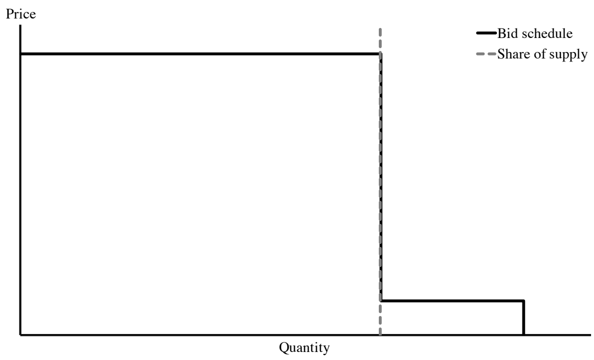
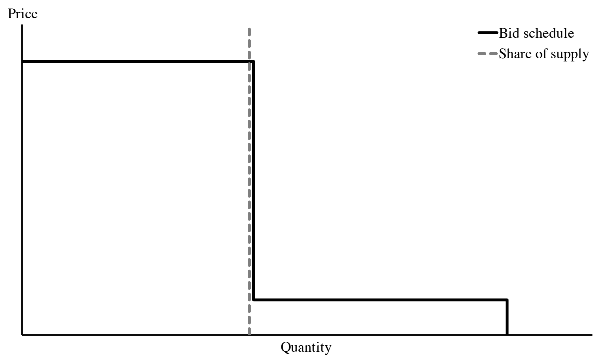


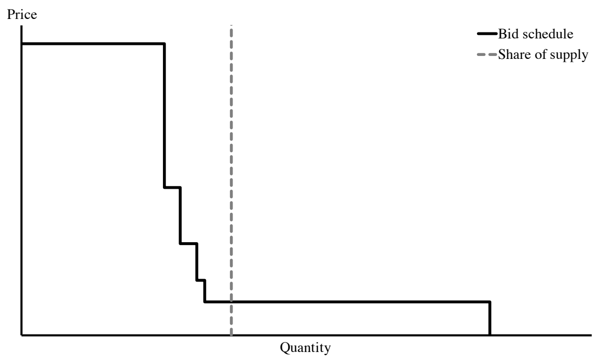

Figure 11: Aggregate bid-schedule in the 2018 auction for eight-year quota for demersal fish in the Norwegian part of the Barents Sea.




(a) Bidder A




(b) Bidder B




(c) Bidder C

Figure 12: 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).

# 11 Other 2018 demersal fish quota auctions

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

In this auction nine bids were submitted by three incumbents (Bidders A, B and C) and one entrant (Bidder D). If looking at the bids of the incumbents only, the sharply declining portion of the aggregate bid-schedule takes place at quantities between 212 to 224 tonnes, with an aggregate supply of 227 tonnes. The final step occurs 1.3 percent from where aggregate demand and supply would have intersected with only the incumbents' bids. The price without the entrant would have been 1.82 kr./kg. However, with the entrant's bid the price was pushed up to 3.20 kr./kg. The entrant bought the remaining 7 tonnes even though it was significantly less than the 227 tonnes demanded. The individual bid-schedules for all incumbents drop of sharply very close to the intersection of the bid-schedule and the share of supply—for Bidder A and C the drop off happens just before, and for bidder B just after.

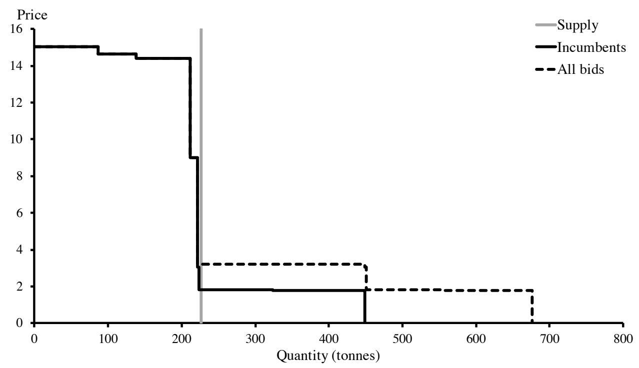
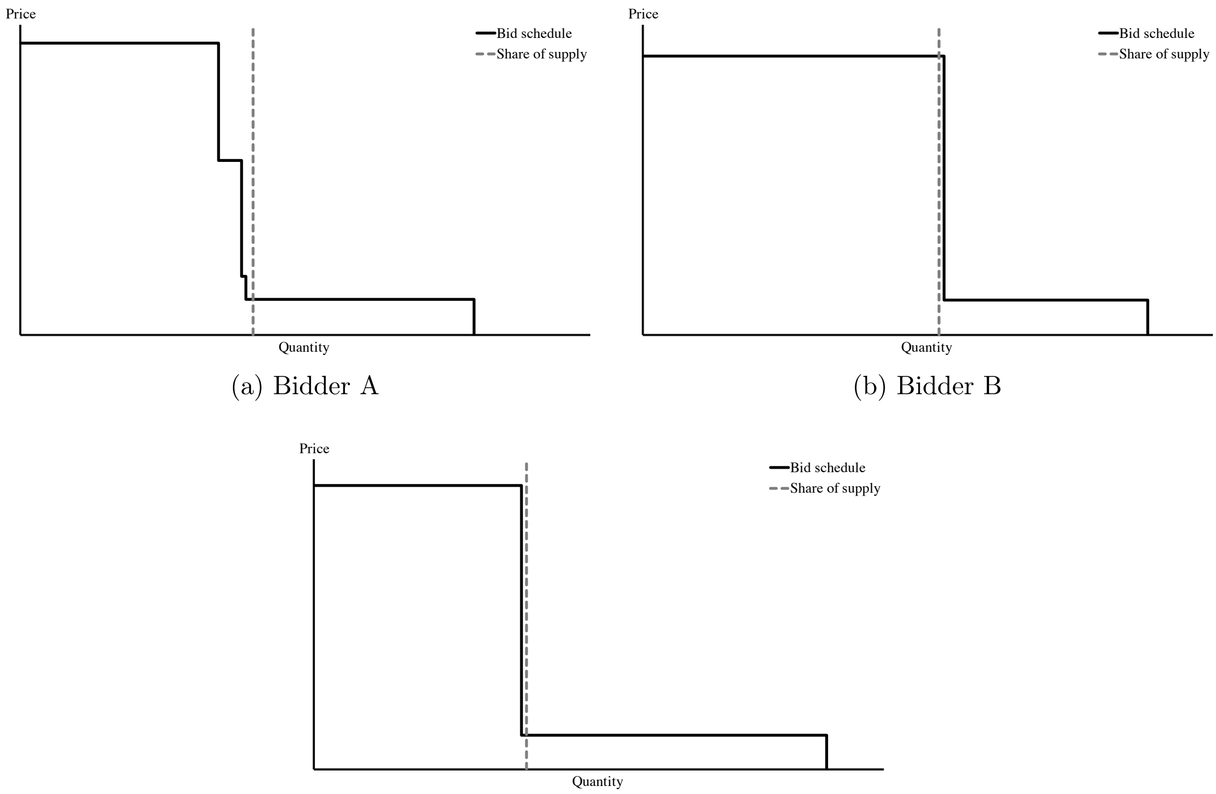



Figure 13: Aggregate bid-schedule in the 2018 auction for three-year quota for demersal fish in Russian waters.




(a) Bidder A

(b) Bidder B

(c) Bidder C

Figure 14: 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).

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

In this auction there was a total of ten bids submitted by the three incumbents (Bidders A, B and C) and one entrant (Bidder D). If looking at the bids of the incumbents only, the sharply declining portion of the aggregate bid-schedule takes place at quantities between 433 to 448 tonnes, with an aggregate supply of 453 tonnes. The final step occurs at 1.1 percent 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 settled at 3.20 kr./kg. Once more, the Bidder D bought the remaining 10 tonnes, although significantly less than the 453 tonnes demanded. Like in the previous example, the individual bid-schedules for all three incumbents drop off sharply very close to the intersection of their individual demands and their share of the supply—the drop off for bidders B and C is just before the intersection of the bid-schedule and share of supply whilst for bidder A the drop off happens 150 kg after this intersection.

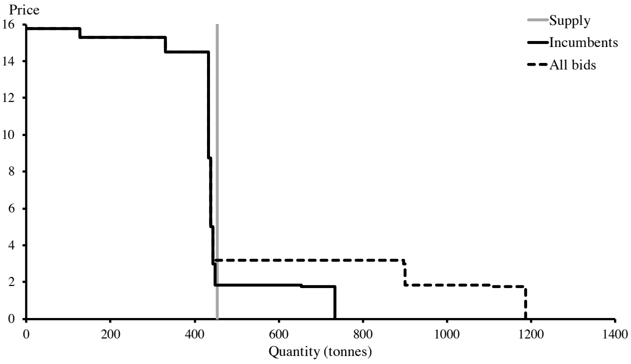



Figure 15: Aggregate bid-schedule in the 2018 auction for eight-year quota for demersal fish in Russian waters.

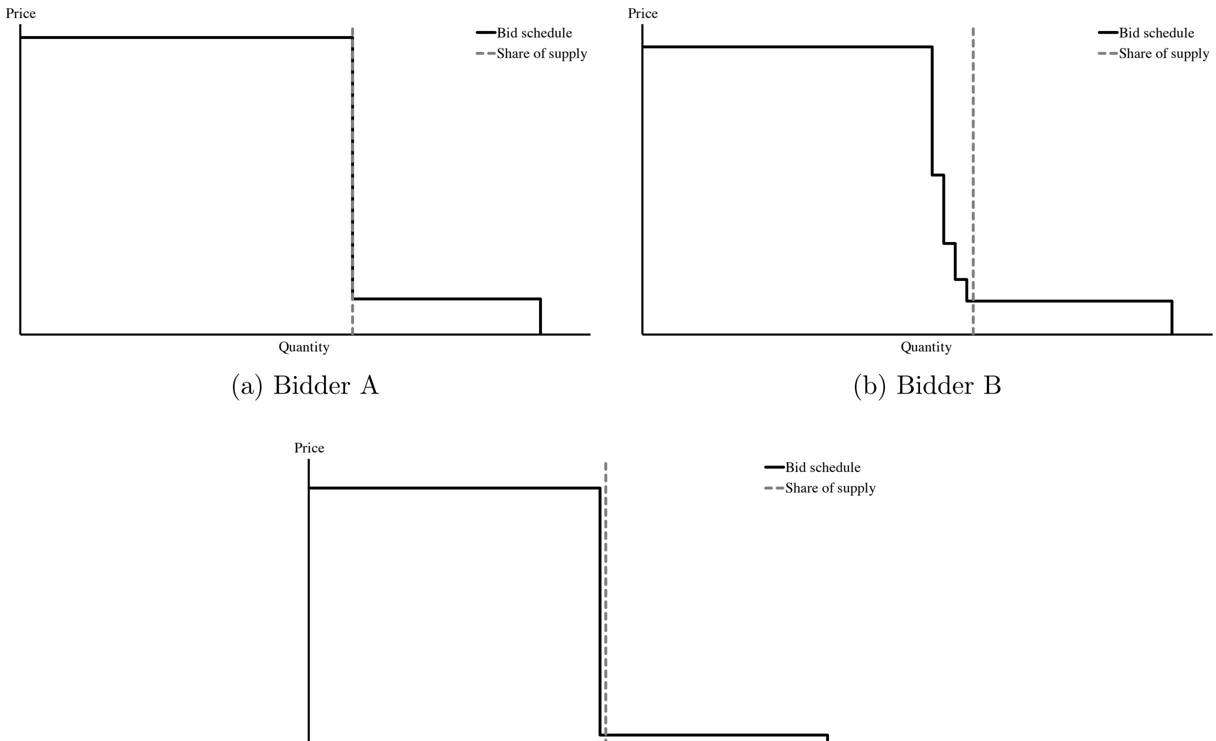



Figure 16: Individual bid-schedules in the 2018 auction for eight-year quota for demersal fish in Russian waters and grandfathered quota share of supply (prior to the auction).

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

In this auction there was a total of nine bids submitted by the same three incumbents (A, B and C) and one entrant (Bidder E). If looking at the bids of the incumbents only, the sharply declining portion of the aggregate bid-schedule takes place at quantities between 844 to 869 tonnes, with an aggregate supply of 874 tonnes. The final step occurs less than

0.6 percent 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 ended up being 3.10 kr./kg. The entrant did not buy the remaining 20 tonnes as this was short of the 437 tonnes demanded. The striking feature about this auction is that the individual bid-schedules for all three incumbents drop of sharply right before the intersection with the grandfathered quota share of the supply.

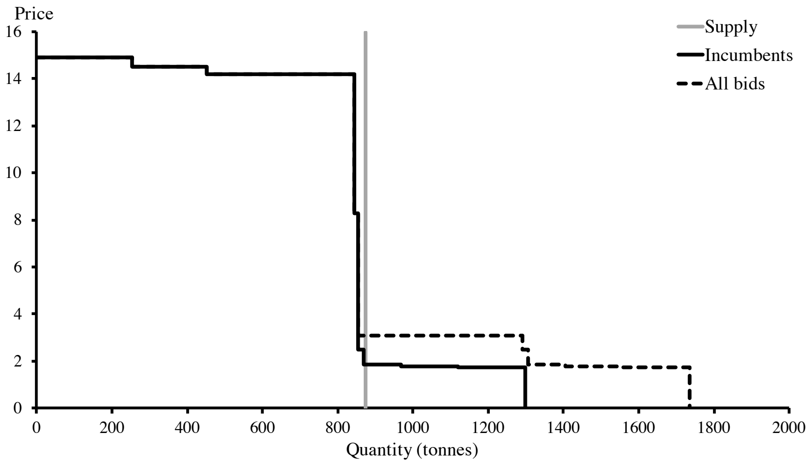
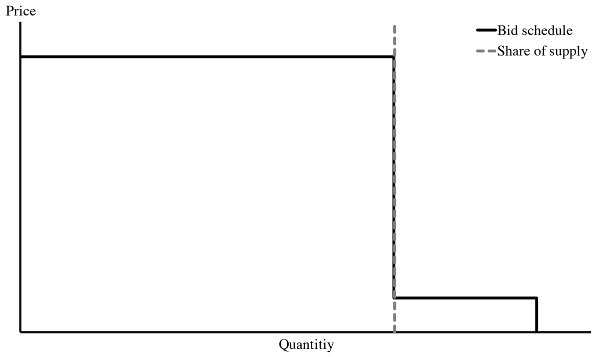
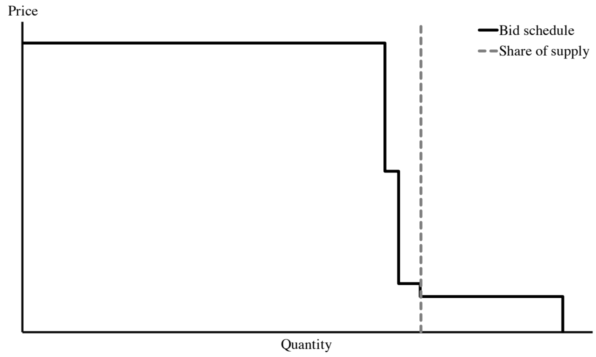


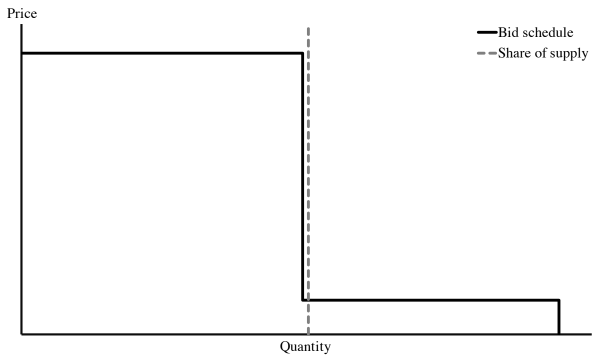

Figure 17: Aggregate bid-schedule in the 2018 auction for one-year quota for demersal fish in the Norwegian part of the Barents sea.




(a) Bidder A




(b) Bidder B




(c) Bidder C

Figure 18: 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).

# 12 Demersal fish quota auctions in 2016 and 2017

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

The first evidence of crank-handle bidding was in the auction for one-year quota for demersal fish in the Russian part of the Barents Sea. The uniform-price 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—three incumbents and one entrant. If looking at the bids of the incumbents only, the sharply declining portion of the aggregate bid-schedule takes place at quantities between 550 to 575 tonnes, with an aggregate supply of 600 tonnes. The final step occurs less than 4.2 percent 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 19: 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 20: Incumbents' bids in the 2016 auction for one-year quota for demersal fish in Russian waters.

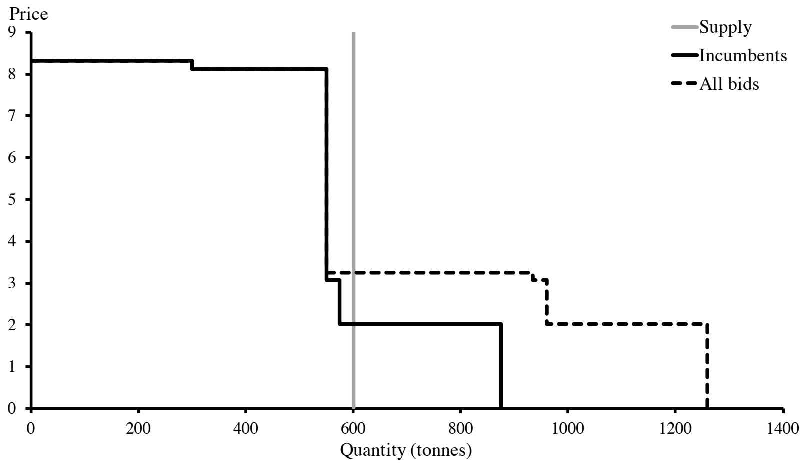



Figure 21: Aggregate bid-schedule in the 2016 auction for one-year quota for demersal fish in Russian waters.

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

Crank-handle bidding was also observed in the auction of one-year quota for demersal fish in the Russian part of the Barents Sea on 24 August 2017. Companies were allowed to submit three bids per vessel in 2017 following a change in the executive order concerning the auctions of fishing quota. A total of eight bids were submitted by four companies – the same three incumbents and one entrant. The sharply declining portion of the incumbents' aggregate bid-schedule 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 percent 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.

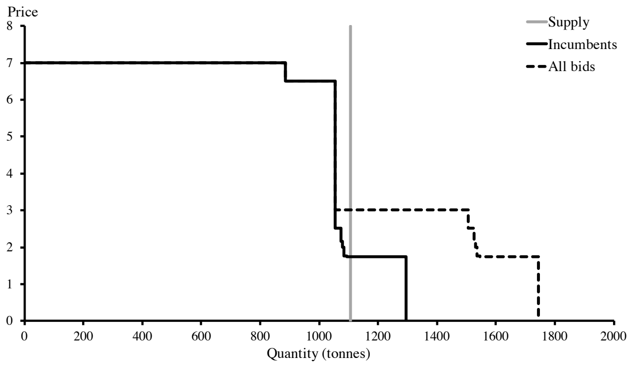



Figure 22: Aggregate bid-schedule in the 2017 auction for one-year quota for demersal fish in Russian waters.