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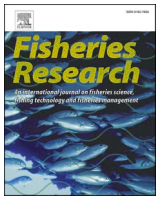

Competition in a fish auction: The case of Atlantic cod in Northern Norway

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ABSTRACT

This study investigates the role of bidder numbers in fish auctions, a neglected area of past research and one that is of key importance for optimal use of limited marine resources. The study of a Norwegian auction for Atlantic cod shows that prices increase when two or more bidders participate in the auction. Holding other variables such as lot size, quality grade, and seasonality constant, price increases of 4.51 %, 6.47 %, 7.18 %, and 9.88 % in auctions with two, three, four, and five plus bidders were found, compared to auctions with only one bidder. The increasing prices following from higher bidder numbers also indicate that fishers should be incentivized to provide high-quality fish at the right time of importance for optimal resource use. Increased competition also means that, over time, winning bids will be placed by the buyers that are the most capable of adding value and earning profits, which also contributes to optimal resource use. Findings also show to what extent factors such as lot size, quality grade, fishing method (bottom trawl, longline, Danish seine), and seasonality influence the probability of two or more participating bidders in auctions, which should be highly relevant information for fishers and policy makers.

1. Introduction

Well-functioning ex-vessel markets for fish and other seafood are important for optimal resource use for at least two reasons. First, in competitive markets, prices should reflect the quality and quantity of catches, and thus fishers providing high-quality fish at the right time will be rewarded with high prices. If the costs associated with such fishing strategies do not exceed revenues, profits will be earned, incentivizing fishers to bring high-quality fish to the market at the right time. Second, in well-functioning markets, the most competitive buyers will be the ones that, over time, are the most capable of adding value to the fish they purchase and of gaining the highest returns from their customers and markets.

Auctions are often used by fishers to organize ex-vessel markets to try to extract the maximum revenue from buyers (Fluvià et al., 2012). This is relevant because auction markets with many sellers and buyers are generally more competitive than direct sales where bargaining power and asymmetric information regarding product quality may distort prices (e.g., Blomquist et al., 2015; McEvoy et al., 2009; Sogn-Grundvåg et al., 2014, 2019). However, somewhat paradoxically, when fishers are free to choose between direct sales and auctions, the share of auction sales often decreases, as is the case for several European seafood auction markets (European Association of Fishing Ports and Auctions, 2005). This is also the case for the auction for frozen Atlantic cod studied here, where the share of auction sales decreased from 53 % in 2012 to below 40 % in 2018, indicating an increasing preference for direct sales.

Buyers' valuations of a lot may depend on key characteristics such as the size of the lot, the species, the size of the fish, its quality grade, and fishing methods used (Asche et al., 2015; Fluvià et al., 2012; Gobillon et al., 2017; Guillioni and Bucciarelli, 2011; Hammarlund, 2015; Kristofersson and Rickertsen, 2004; Kristofersson and Rickertsen, 2007; Sogn-Grundvåg et al., 2019, 2020). Buyers may also differ in their valuation of the same lots, which may depend on differences in buyers' plans for what products to make for different customers and markets (Gobillon et al., 2017). This indicates that the characteristics of the lot and its asking price influence buyers' propensity to participate in specific auctions. However, if fishers are successful in attracting more than one buyer to participate in the auction, it implies competition and improved chances of clearing the market at or above fishers' price expectations. This is indicated by a limited number of studies which find that prices increase, or decrease in the case of contract bidding, with increasing numbers of bidders (e.g., MacDonald et al., 2002; Porter and Zona, 1999).

However, findings regarding the price effect of each additional

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bidder differ substantially between studies. For example, Meyer (1988), who studied Texas rice auctions, detected a price increase of 4.6 % for each additional bidder. Wilson and Diersen (2001), who studied bidding for Egyptian import tenders for different vegetable oils, found that the price declined by only 0.6 % when a second bidder entered the auction and that the effect of additional bidders was less than that of a second bidder, indicating nonlinearity.

To the best of our knowledge, bidder numbers and their importance for competition and hence resource utilization have not been addressed in previous research on fish auctions. This study seeks to fill some of this void in the literature. More specifically, we investigate what determines the number of bidders in the auction for frozen Atlantic cod in Northern Norway and examine to what extent bidder participation is influenced by factors such as quality grade, lot size, starting prices, fishing methods, and seasonality. We also estimate the effect of each additional bidder on final prices while controlling for the same factors as well as heterogeneity among sellers, buyers, and seller–buyer relationships, which may affect prices (Gobillon et al., 2017).

The study analyzes a unique data set based on the bid log from the auction covering the period from 2009 to 2018, which included 9831 auctions and almost 150,000 tons of cod at a value of NOK 3.409 billion. The auction is a web-based ascending or English type of auction with low barriers of entry for potential buyers. The Atlantic cod is mainly sold by oceangoing vessels fishing with bottom trawl, longlines, or Danish seines. Different types of buyers participate in the auction. Some buy the frozen fish to produce saltfish or clipfish, and some produce fillets for a variety of different consumer markets. In addition, some buyers are agents buying the fish for processors located abroad.

2. Material and methods

2.1. The auction

The ex-vessel sale of wild-caught fish in Norway is legally protected through the Raw Fish Act and is organized by sales organizations, owned by fishers, with the exclusive right to coordinate the primary sale of fish. There are several different sales organizations that cover different geographical regions for groundfish, and one sales organization that coordinates the sale of pelagic fish such as mackerel and herring. This study focuses on frozen headed and gutted Atlantic cod auctioned by the Norwegian Fishermen's Sales Organization (NFSO), the largest sales organization for groundfish in Norway, which records all transactions and provided the data for this study.[1] The NFSO has exclusive rights to all ex-vessel sales of groundfish landed along the Norwegian coast from Nordmøre in the southwest to Finnmark in the northeast.

The cod is mainly captured by large oceangoing bottom trawlers, longliners, or Danish seiners. All trawlers and oceangoing longliners have on-board freezing facilities, as do some of the Danish seiners. The fish are mainly headed and gutted and frozen in 20-kilogram boxes at sea. The fishing vessel lands the cod at one of several independent cold storage plants (Bendiksen and Dreyer, 2002). In the NFSO's district there are 14 independent cold storage plants, from which lots are shipped by cargo vessels to customers worldwide. At the cold storage plants, the weights of catches are controlled as part of the Norwegian resource control in order to make sure that fishing quotas are not exceeded. The fisher pays a storage fee, and the fish can be stored for several months if the fisher, for instance, anticipates future price increases. At the same time, longer storage time may lead to quality degradation (Badii and Howel, 2002), which in turn may influence prices negatively.

The auction is conducted online on the NFSO's auction website, implying that physical inspection of the fish is not possible at the time of bidding. However, buyers may complain if the lot does not correspond with the information provided at the auction (e.g., if the size of fish is incorrect, or the quality is below expectations). The fish are auctioned in lots that may consist of one or several fish species of different sizes and quantities. The lot is sold in price (NOK) per kilogram even though it may consist of different species that are valued differently. Thus, buyers must assess how much they might be willing to pay for the whole lot. In order to avoid unnecessary variation, this study includes lots with Atlantic cod only.

The auctioneer puts out lots on the auction website with a fixed closing time, for example 12:10 PM the next day, with one lot auctioned every five minutes. The auction is an ascending or English type of auction where the bidder that has the highest bid at the closing time wins. The auction website is open for registered buyers and sellers. Buyer entry is easy.[2] Bids can only be placed by Norwegian companies, but several foreign buyers have registered Norwegian shell companies so they can participate at the auction.

On the NFSO's auction website, all participants can see details of the lot as well as the starting price and the highest current bid. The identity of bidders is not revealed, preventing the presence of strong buyers negatively influencing the participation and bidding behavior of weaker buyers (Klemperer, 2002). In addition, the number of participating bidders is not revealed, only the highest bid. To entice buyer participation, the auctioneer[3] makes daily phone calls to likely buyers to apprise them of upcoming auctions that might be of interest.

For each specific auction, information is provided regarding the lot, such as the name of the vessel, fishing method used, the time and location of landing, if the fish is downgraded or not, and the product form. The seller may provide a reserve price for the package in NOK[4] per kilogram, but this is not binding, as about one third of the transactions included in this study were sold at a price below the seller's reserve price. In addition, the seller sets a starting price, usually based on discussions with the auctioneer, reflecting auction prices gained for similar products during the last week.

Buyers may place their bids in two ways: manual bids or automatic bidding. Manual bids imply that buyers push virtual buttons on the website with predefined price jumps of NOK 0.05, 0.10, 0.20, 0.50, or 1, until the intended bid price is found, before pressing a confirmation button confirming the bid. With automatic bidding, buyers use the same price buttons as for manual bids until the maximum price they are willing to pay is reached. The maximum price can be seen only by the auctioneer. When the buyer confirms his or her maximum bid price, the system will first place a bid equal to the start price. If a rival places a higher bid, the system will raise bids by NOK 0.05, which is the fixed price jump for all automatic bids, and follow up with new bids of NOK 0.05 should a competitor raise his or her price any further. This will continue until the closing time and the lot is won, or until a buyer's stated maximum price is reached and the lot is won by a rival. The predefined bid jumps of NOK 0.05 have the advantage that price

[1] The Sunnmøre and Romsdal Fishermen's Sales Organization (SUROFI) is the second largest sales organization for groundfish in Norway and has exclusive rights to all ex-vessel sales of groundfish in the Sunnmøre and Romsdal districts. As for the NFSO, fishers selling their catches through SUROFI can choose if they want to sell directly or through an auction. Interestingly, many fishers and buyers participate in both the NFSO and SUROFI auctions.

[2] In order to participate in the auction, buyers must apply to the Directorate of Fisheries to become a registered buyer. The application must contain documentation that the company (buyer) is a publicly registered company and that a service fee has been paid. In addition, the applicant must document that he or she has access (by owning, renting, or cooperation) to a plant that adheres to the regulations for quality control of seafood. Finally, the applicant must act in accordance with the regulations set by the relevant sales organization(s), including a bank guarantee.

[3] The NFSO has five persons acting as auctioneers with responsibility for different groundfish species.

[4] The average exchange rate for 2017 was NOK 1 = USD 0.1209/EUR 0.1071.

Table 1
Descriptive statistics for the variables included in the study.

Variable	Mean	SD	Min	Max
Winning-Price (NOK)	23.48	6.30	5.36	43.04
Starting-Price (NOK)	22.43	6.28	5.31	38.31
Daily-Quantity (kilograms)	147,036	137,192	23	779,351
Transaction-Quant. (kilograms)	15,130	26,369	6	353,157
Fish-Size (kilograms)	3.52	2.29	0.8	17
Storage-Time (days)	12.02	19.22	1	432
log (Winning-Price)	3.12	0.29	1.68	3.76
log (Starting-Price)	3.05	0.33	1.61	3.68
log (Daily-Quantity)	11.37	1.21	3.14	13.57
log (Transaction-Quantity)	8.23	1.96	1.79	12.77
log (Fish-Size)	1.02	0.73	−0.22	2.83
log (Storage-Time)	2.09	0.76	0	6.07
Quality	0.90	0.31	0	1
Bottom-Trawl	0.55	0.50	0	1
Longline	0.29	0.45	0	1
Danish-Seine	0.13	0.33	0	1

signaling between buyers is difficult (Klemperer, 2002). According to the auctioneer, it is common that buyers place their bid at the last opportunity before the fixed closing time, referred to as "sniping" in the literature (Ely and Hossain, 2009; Roth and Ockenfels, 2002). However, if a bid is placed less than 20 s before the closing time, the auction is extended by 20 s.

2.2. Data and descriptive statistics

The data include details of 9831 auctions of frozen headed and gutted Atlantic cod held during the time period June 2, 2010–December 31, 2018, which includes 148,746 tons of Atlantic cod with an ex-vessel value of NOK 3.409 billion (USD 412 million). For each auction, the data include the weight of the package in kilograms, the fishing gear (bottom trawl, longline, Danish seine, or other gear), the average size of the fish in kilograms, its quality (regular or downgraded), the name of the vessel and buyer, the start price and winning price, the date of landing, the date of the auction, and the number of participating bidders. Table 1 shows descriptive statistics for the variables included in the econometric models.

Table 1 shows that winning prices average slightly higher (NOK 23.48) than starting prices (NOK 22.43) but with similar standard deviations. The average daily quantity was about 147 tons. The average quantity for each auction was about 15 tons, with substantial variation, as indicated by the high standard deviation. The average fish size was 3.52 kilograms, varying between 0.8 and 17 kilograms.. The average storage time was 12 days, and the maximum storage time was 432 days. Table 1 also shows a dummy variable for regular quality with downgraded fish as the base and dummies for the three main fishing methods, with other fishing methods[5] as a base. The reported mean for each dummy variable is the number of observations within each category as a proportion of the total number of observations. For example, bottom trawl accounted for 55 % of auctions during the sample period, and the three primary fishing methods accounted for 97 % of all fishing methods in the auction.

Table 2 presents the number of auctions categorized by the number of bidders for each of the nine years represented in the data set. The table reveals several interesting aspects of the auction. For example, for the whole period, the average number of bidders in each auction was only 2.46. The low average number of bidders indicates that competition is not very strong. It is also interesting that there were 2341 auctions, representing 23.8 % of all auctions, with one bidder only, implying no competition. It can also be seen that few auctions had five or more bidders (less than 6% of all auctions).

Table 2 also shows that the average number of bidders per auction was higher in 2010 and 2011 than in the succeeding years. This may be explained by more interest from buyers due to lower fishing quotas for cod in 2010 (about 283,000 tons) and 2011 (about 337,000 tons) compared to the 2012–2018 period, which averaged about 414,000 tons per year.

It has been argued convincingly in the auction literature and shown empirically that a low starting price will attract more bidders and increase prices (Ku et al., 2006). Table 3 presents the average starting and winning prices in auctions categorized by the number of bidders. Table 3 indicates a negative relationship between the number of participating bidders and starting prices; that is, the lower the starting prices are, the more bidders participate. There also seems to be a positive relationship between the number of bidders and winning prices. Even though auctions with only one bidder have the highest average starting price (NOK 22.73), these auctions have the lowest average winning prices (NOK 22.75). Inspection of Table 3 also shows that the gap between starting and winning prices increases with the number of bidders, except for auctions with seven bidders. The econometric models outlined below will explore whether starting prices influence bidder numbers, while controlling for the influence of other variables.

2.3. Econometric modeling

To examine the influence of various factors on the number of bidders, we use a binary logit model, and to estimate the anticipated effect of each additional bidder on price, a hedonic price modeling is used.

2.3.1. Binary logit model

For the binary logit model, we first estimate the effect of different variables on the probability of more than one bidder. The dummy variable *Bidders* equals 1 for auctions with more than one bidder, and zero for auctions with only one bidder. The logit model is represented by the following equation:

$$Bidder_i = \begin{cases} 1 & \text{if } Bidder_i^* > 0 \\ 0 & \text{if } Bidder_i^* \le 0 \end{cases} \quad (1)$$

$$\Pr(Bidder_i = 1|\boldsymbol{X}) = \varphi(Z_i) \quad (2)$$

where $Bidder^*$ is a latent, unobserved variable. For example, the difference between the starting price and bidders' valuation of a lot may determine whether they choose to participate in an auction or not. $Bidder_i$ equals 1 when $Bidder_i^* > 0$. For Eq. (2), $\Pr(Bidder_i = 1)$ conditional on the explanatory variable X is a logistical distribution function, with a range between 0 and 1. The specification of Z_i, which is the logarithm odds ratio between the probabilities of two or more bidders and one bidder, is in the form:

$$z_1 = a_0 + a_1 \log(Starting\_Price_i) + \sum_{o=2}^{9} y_o Year_o + \sum_{o=2}^{12} m_o Month_o + Residual_i \quad (3)$$

where i represents the number of transactions, and *Starting-Price* is the price fishers set as a minimum asking price. *Year* and *Month* are dummy variables with the first year (2010) and December as the base, respectively. The error term, *Residual,* captures other unobserved factors that might affect bidder participation.

We modify the basic logit model (Model 1) by adding the characteristics of the fish, transaction quantity, and daily sales quantity for Model 2 and by further adding the seller dummies for Model 3.

$$\begin{aligned} z_1 = {} & a_0 + a_1 \log(Starting\_Price_i) + c_1 \log\left(Daily\_Quantity_i\right) \\ & + c_2 \log(Transaction\_Quantity_i) + d_1 \log(Fish\_Size_i) \\ & + e_1 Quality_i + e_2 \log(Storage\_Timei) + f_1 Bottom\_Trawl_i + f_2 Autoline_i \\ & + f_3 Danish\_Seine_i + \sum\nolimits_{o=2}^{9} y_o Year_o + \sum\nolimits_{o=2}^{12} m_o Month_o + Residual_i \end{aligned} \quad (4)$$

[5] Several other fishing methods were used, such as traps and pots. These are treated as one group and used as a base category for comparisons with bottom trawl, longline, and Danish seine.

Table 2
The number of auctions categorized by the number of bidders.

Bidder number	2010	2011	2012	2013	2014	2015	2016	2017	2018	Sum
1	11	20	234	230	310	356	485	358	337	2341
2	49	184	263	515	404	462	448	413	445	3183
3	156	313	211	333	362	271	290	299	260	2495
4	119	226	93	158	181	140	116	106	99	1238
5	72	56	30	37	102	30	35	31	20	413
6	23	26	6	20	22	7	3	10	4	121
7	7	3	4	4	12	1	1	0	6	38
8	0	0	0	0	2	0	0	0	0	2
Sum (Deals)	437	828	841	1,297	1,395	1,267	1,378	1,217	1,171	9,831
Total Active bidders	1,600	2,688	1,979	3,224	3,670	2,852	2,915	2,720	2,569	24,217
Total transaction quantity (tons)	6363	12794	12545	24825	22945	17651	20394	15968	15260	148746
Total active bidders / Deals	3.66	3.25	2.35	2.49	2.63	2.25	2.12	2.24	2.19	2.46

Table 3
Starting and winning prices in auctions by the number of bidders.

Bidder number	Starting-Price	Winning-Price	Gap
1	22.73	22.75	0.02
2	22.50	23.36	0.86
3	22.53	24.03	1.51
4	21.89	23.85	1.96
5	21.68	24.15	2.47
6	21.24	23.76	2.52
7	21.15	23.29	2.14
8	21.96	25.03	3.06

$$z_1 = a_0 + a_1\log(Starting\_Price_i) + c_1\log\left(Daily\_Quantity_i\right) + c_2\log(Transaction\_Quantity_i) + d_1\log(Fish\_Size_i) + e_1 Quality_i + e_2 log(\text{Storage\_Timei}) + f_1 Bottom\_Trawl_i + f_2 Autoline_i + f_3 Danish\_Seine_i + \sum_{o=2}^{9} y_o Year_o + \sum_{o=2}^{12} m_o Month_o + \sum_{o=1}^{50} n_o Seller_o + \sum_{o=1}^{50} r_o Buyer_o + \sum_{o=1}^{99} s_o SellerBuyer_o + Residual_i \quad (5)$$

The estimation from the logit model is the logarithmic odds ratio between the probabilities of more than one bidder and one bidder. We follow the common practices in the literature and compute the marginal effect of the determinants. The marginal effect directly demonstrates the change in the probability of more than one bidder when the covariate increases by one unit (from 0 to 1 for dummy variables), ceteris paribus.

In order to test the monotonic pattern between the starting price and number of bidders, we further apply the binary logit model to the dependent variable, number of *Bidders* = 2 against 1, 3 against 2, 4 against 3, and 5 plus against 4. Finally, an ordered logit regression is applied to the ordinal dependent variable (*Bidders* = 1, 2, 3, 4, and 5 plus).

2.3.2. The price model

The basic model includes the dummies for the number of bidders, and the dummies for years and months, which captures any effects seasonality might have on prices. This leads to the following specification of Model 4:

$$\log(Price_i) = a_0 + b_1 Bidders\_2_i + b_2 Bidders\_3_i + b_3 Bidders\_4_i + b_4 Bidders\_5plus_i + \sum_{o=2}^{9} f_o Year_o + \sum_{o=2}^{12} w_o Month_o + Residual_i \quad (6)$$

where *i* represents the number of transactions and log is the logarithm function, and $Price_i$ is the winning price. All the price variables are deflated by the Norwegian consumer price index for food. With the auctions with only one bidder as the base, *Bidders-2* is a dummy for auctions with two bidders, *Bidders-3* for three bidders, *Bidders-4* for four bidders, and *Bidder-5plus* for five or more bidders. The error term, *Residual,* captures other unobserved factors that might affect prices.

Besides the number of bidders, the price of an individual lot of Atlantic cod may also depend on its quality characteristics, such as the average size of the fish, whether the fish were downgraded or not, the storage time, and the fishing method used. The size of each individual lot (transaction quantity) and the daily sales quantity at the auction may also influence prices.[6] Thus, Eq. (6) (for Model 4) is modified in Model 5:

$$\log(Price_i) = a_0 + b_1 Bidders\_2_i + b_2 Bidders\_3_i + b_3 Bidders\_4_i + b_4 Bidders\_5plus_i + c_1\log\left(Daily\_Quantity_i\right) + c_2\log(Transaction\_Quantity_i) + d_1\log(Fish\_Size_i) + e_1 Quality_i + e_2\log(Storage\_Timei) + f_1 Bottom\_Trawl_i + f_2 Autoline_i + f_3 Danish\_Seine_i + \sum_{o=2}^{9} y_o Year_o + \sum_{o=2}^{12} m_o Month_o + Residual_i \quad (7)$$

where *Daily-Quantity* is the daily traded quantity; *Transaction-Quantity* is the quantity of each lot; *Fish-Size* is the average size of the fish; *Quality* is a dummy for cod with regular quality, with downgraded fish as the base; and Storage-Time is the average storage time of a lot. The three main fishing methods (*Bottom-Trawl*, *Longline*, and *Danish-Seine*) are dummies, with the other fishing methods as the base.

Since fish prices are probably affected by auction market imperfections due to heterogenous sellers, heterogenous buyers, and seller–buyer relationships (Gobillon et al., 2017), we modify Eq. (7) by including dummies for the 50 largest sellers (by total quantity sold), the 50 largest buyers (by total quantity purchased), and the largest 99 seller–buyer pairs in terms of traded quantity. This yields Model 6:

$$\log(Price_i) = a_0 + b_1 Bidders\_2_i + b_2 Bidders\_3_i + b_3 Bidders\_4_i + b_4 Bidders\_5plus_i + c_1\log\left(Daily\_Quantity_i\right) + c_2\log(Transaction\_Quantity_i) + d_1\log(Fish\_Size_i) + e_1 Quality_i + e_2\log(Storage\_Timei) + f_1 Bottom\_Trawl_i + f_2 Autoline_i + f_3 Danish\_Seine_i + \sum_{o=2}^{9} y_o Year_o + \sum_{o=2}^{12} m_o Month_o + \sum_{o=1}^{50} n_o Seller_o + \sum_{o=1}^{50} r_o Buyer_o + \sum_{o=1}^{99} s_o SellerBuyer_o + Residual_i \quad (8)$$

Models 4, 5, and 6 assume constant impacts of the number of bidders on the winning price. The impacts of the number of bidders may vary over time. Accordingly, following Kristofersson and Rickertsen (2004)

[6] In the literature, the hedonic price model is applied to explore the impact of fish characteristics and other determinants on fish price (Asche et al., 2015; Roheim et al., 2011 et al., 2011; Sogn-Grundvåg et al., 2013, 2014, 2019, 2020). The preliminary estimation results indicate a positive impact of starting price on the final price. This is probably due to multicollinearity between starting price and bidder numbers. Thus, the price model excludes the starting price to avoid multicollinearity and over-specification.

Table 4
Estimation of marginal effects of the logit models.

Variable	Model 1		Model 2		Model 3	
log (Starting-Price)	0.2377	***	0.1308	***	0.1835	***
	[0.0215]		[0.0354]		[0.0355]	
log (Daily-Quantity)			0.0162	***	0.0144	***
			[0.0035]		[0.0035]	
log (Transaction-Quantity)			0.0186	***	0.0168	***
			[0.0022]		[0.0022]	
log (Fish-Size)			0.0153	**	0.0157	***
			[0.0061]		[0.0059]	
Quality			−0.0458	***	−0.0532	***
			[0.0150]		[0.0142]	
log (Storage-Time)			−0.0358	***	−0.0422	***
			[0.0054]		[0.0055]	
Bottom-Trawl			−0.0072		0.1135	***
			[0.0217]		[0.0317]	
Longline			0.0484	**	0.0878	***
			[0.0208]		[0.0241]	
Danish-Seine			−0.0054		0.0266	
			[0.0238]		[0.0272]	
Year-2011	−0.0264		−0.0153		−0.0164	
	[0.0660]		[0.0630]		[0.0607]	
Year-2012	−0.6008	***	−0.5778	***	−0.5995	***
	[0.0554]		[0.0592]		[0.0584]	
Year-2013	−0.3804	***	−0.4322	***	−0.4251	***
	[0.0729]		[0.0720]		[0.0732]	
Year-2014	−0.5088	***	−0.5237	***	−0.5299	***
	[0.0652]		[0.0645]		[0.0653]	
Year-2015	−0.6583	***	−0.6349	***	−0.6527	***
	[0.0485]		[0.0534]		[0.0529]	
Year-2016	−0.7233	***	−0.7075	***	−0.7056	***
	[0.0389]		[0.0431]		[0.0456]	
Year-2017	−0.7095	***	−0.6858	***	−0.6977	***
	[0.0407]		[0.0469]		[0.0474]	
Year-2018	−0.735	***	−0.6979	***	−0.7372	***
	[0.0366]		[0.0467]		[0.0422]	
January	0.0987	***	0.0949	***	0.1101	***
	[0.0120]		[0.0122]		[0.0105]	
February	0.0554	***	0.0501	***	0.0759	***
	[0.0160]		[0.0164]		[0.0139]	
March	0.083	***	0.089	***	0.1009	***
	[0.0147]		[0.0142]		[0.0123]	
April	0.0911	***	0.1003	***	0.1086	***
	[0.0141]		[0.0131]		[0.0114]	
May	0.0893	***	0.1048	***	0.1154	***
	[0.0136]		[0.0122]		[0.0105]	
June	0.0426	***	0.0671	***	0.0826	***
	[0.0155]		[0.0140]		[0.0123]	
July	0.0397	**	0.074	***	0.0855	***
	[0.0164]		[0.0141]		[0.0125]	
August	0.0528	***	0.0794	***	0.0923	***
	[0.0159]		[0.0140]		[0.0123]	
September	0.0305	**	0.0674	***	0.0768	***
	[0.0162]		[0.0140]		[0.0128]	
October	0.0745	***	0.0845	***	0.0903	***
	[0.0129]		[0.0123]		[0.0114]	
November	0.027	*	0.0349	**	0.0458	***
	[0.0151]		[0.0147]		[0.0137]	
With seller, buyer, and seller-buyer dummies	No		No		Yes	
McFadden's pseudo-R squared	0.0352		0.0584		0.096	

Notes: ***, **, and * indicate significant at the 0.01, 0.05 and 0.10 level, respectively. Standard errors are in parentheses.

and Hammarlund (2015), we estimate a multilevel hedonic price model with a particular focus on the dynamic coefficients of bidder numbers in Models 4, 5, and 6.

3. Results

3.1. Binary logit model

Table 4 presents the estimation results of the logit models. The McFadden (1973) pseudo-R^2 value is 0.0352 for Model 1, 0.0584 for Model 2, and 0.096 for Model 3, indicating that Model 3 has better goodness of fit than the other two models.[7] We further use the log likelihood ratio to test Model 1 against Model 2, and Model 2 against Model 3. For each test, the model with fewer variables is nested under the other model. The results show that Model 3 fits the data better than the other two models. Accordingly, we focus on the estimation results of Model 3.

For the starting price, the estimate is 0.1835, which implies that a 0.1 unit increase in log (*Starting-Price*), corresponding to 11 % of the mean starting price, increases the probability of two or more bidders by 1.84 %. This rather marginal effect of starting price on the probability of two or more bidders is reasonable given the small differences between starting prices in auctions with different numbers of bidders. Table 2 shows that the difference in average starting prices between auctions with two and three bidders—which account for 57.8 % of all auctions—is only NOK 0.032.

For the other numeric variables, the coefficients are significant. A one-unit rise in log (*Daily-Quantity*) results in a 1.44 % higher probability of two or more bidders. For log (*Transaction Quantity*) and log (*Fish-Size*), a one-unit rise leads to 1.68 % and 1.57 % higher probabilities of two or more bidders, respectively. However, these estimates are all rather small. The log (*Storage-Time*) is negative and significant. A one-unit increase in log (*Storage-Time*) results in a 4.22 % lower probability of two or more bidders.

The estimate for the dummy for *Quality* is -0.0532, indicating that cod of downgraded quality has a 5.32 % higher probability of two or more bidders than cod of regular quality does. That fish of lower quality attracts more bidders than fish of regular quality may seem counterintuitive. However, it is in accordance with the perception of the auctioneers, who believe that some of the downgraded fish may have faults that are less important to some buyers, which may hope to make a bargain.

The dummies for *Bottom-Trawl* and *Longline* are significant and positive, indicating that the probability of two or more bidders is 11.35 % higher for cod caught by bottom trawl and 8.78 % higher for cod caught with longline, compared with other fishing methods (the base) and Danish seine, which is not significant, indicating no difference from the base.

All the yearly dummies, except for the dummy for 2011, are significant and negative compared to the base (2010). This indicates that 2010 and 2011 have the same probability of two or more bidders, which is higher than the probability for the other seven years from 2012 to 2018. This is probably explained by lower fishing quotas and thus a more competitive market in 2010 and 2011 than in the subsequent years.[8] All the monthly dummies are significant and positive, indicating that compared to the base (December), buyers are more active in the other months, with probabilities for two or more bidders higher than December and ranging between 4.58 % (November) and 11.54 % (May).

We further estimated Model 3 with pairwise bidder numbers. The estimated coefficients for the starting price are reported in Table 5 (the complete results are available upon request). Compared to *Bidders* = 1, an increase in the starting price would increase the probability of *Bidders* = 2. Although the starting price does not affect *Bidders* = 3 versus *Bidders* = 2 and *Bidders* = 5+ versus *Bidders* = 4, an increase in

[7] The McFadden (1973) Pseudo R^2 is generally much lower than R^2 in the OLS models, since the continuous dependent variable in profit/logit models is unobserved (Veall and Zimmerman, 1996; Dedman et al., 2014).

[8] The Norwegian cod quota was 217,000 and 319,000 tons in 2010 and 2011, respectively. The average quota for the 2012–2018 period was 405,550 tons.

Table 5
Estimated Marginal Effects log (Starting-Price) from the Logit Model for Pairwise Bidder Numbers.

Model	Estimate	
Bidders = 2 versus Bidders = 1	0.2763	***
Bidders = 3 versus Bidders = 2	−0.0178	
Bidders = 4 versus Bidders = 3	−0.2171	***
Bidders = 5+ versus Bidders = 4	0.0775	

Notes: *** indicates significant at the 0.01 level.

the starting price would raise the number of bidders from three to four.[9]

3.2. The price model

Tables 6 presents the econometric results for Models 4, 5, and 6. The Newey–West covariance matrix is applied to correct for heteroskedasticity and serial correlation in the error terms. As shown in Table 6, the adjusted R^2 is 0.662 for Model 4, 0.847 for Model 5, and 0.867 for Model 6. The models with more variables have a larger adjusted R^2 than the models with fewer variables, indicating that the additional variables improve the goodness of fit. The results of an F-test indicate that Model 4 is rejected against Model 5, and Model 5 is rejected against Model 6. Thus, Model 6 fits the data better than the other two models. Consequently, we focus on the estimation results of Model 6.

As shown in Table 6, the four dummies representing different numbers of bidders are all significant at the 1% level. As the dependent variable is in the logarithmic scale, the estimates of dummy variables are percentages, compared to the base. Thus, compared to auctions with only one bidder, auctions with two bidders gain a 4.51 % higher price. Auctions with three, four, and five plus bidders gain premiums of 6.47 %, 7.18 %, and 9.88 %, respectively, compared with auctions with only one bidder, holding other variables constant. The relationship between bidder numbers and price is illustrated in Fig. 1.

The estimates of the numeric variables are explained as elasticity, since they (and the dependent variable) are in the logarithmic scale. For a one-percentage-point increase, daily quantity raises the final price by 0.36 % and a one-percentage-point increase in fish size raises the final price by 7.37 %. Transaction quantity does not affect the final price. The log (*Storage-Time*) is significant and negative, indicating that a one-unit increase in log (*Storage-Time*), implying reduced quality, leads to a 2.11 % reduction in price, holding other factors constant.

For the dummies for fishing methods, *Bottom-Trawl* is insignificant, *Longline* is significant and positive, and *Danish-Seine* is significant and negative. Holding other factors constant, cod caught by bottom trawl has the same price as cod caught by other fishing methods (the base), cod caught by longline gains a 7.66 % price premium, and cod caught by Danish seine has a 3.56 % discount.

All yearly dummies are significant. Compared to 2010 as the base, cod in 2012, 2013, and 2014 were 10.53 %, 36.8 %, and 18.9 % cheaper, respectively. For the subsequent years, the price was higher than the base. These yearly price variations probably reflect large variations in the yearly Norwegian cod catches. The monthly dummies with the exception of November are significant, with values ranging between 2.09 % (October) and -10.02 % (February).

Table 7 presents the results of the multilevel regressions for Models 4, 5, and 6. We mainly focus on the dynamic pattern of the coefficients of bidder numbers, since the regressions with all dynamic coefficients are not convergent. For each of the new regressions, although the

[9] We further estimated a partial parallel ordered model for bidder numbers = 1, 2, 3, 4, and 5 plus. The estimation results (see Appendix 2) indicate that the odds ratios between the probabilities of more bidders and fewer bidders are less than 1.

Table 6
Estimation of the price model using OLS approach.

Variable	Model 4		Model 5		Model 6	
Intercept	3.1027	***	2.7457	***	2.7148	***
	[0.0109]		[0.0177]		[0.0182]	
Bidders-2	0.0685	***	0.0501	***	0.0451	***
	[0.0051]		[0.0032]		[0.0032]	
Bidders-3	0.114	***	0.0673	***	0.0647	***
	[0.0052]		[0.0034]		[0.0034]	
Bidders-4	0.1208	***	0.0691	***	0.0718	***
	[0.0059]		[0.004]		[0.004]	
Bidders-5+	0.1565	***	0.0981	***	0.0988	***
	[0.0075]		[0.0057]		[0.0056]	
log (Daily-Quantity)			0.0038	***	0.00360	***
			[0.0013]		[0.0012]	
log (Transaction-Quantity)			−0.0013	*	−0.0006	
			[0.0007]		[0.0006]	
log (Fish-Size)			0.0882	***	0.0737	***
			[0.0017]		[0.0021]	
Quality			0.2862	***	0.3063	***
			[0.0056]		[0.0059]	
log (Storage-Time)			−0.0195	***	−0.0211	***
			[0.0019]		[0.0018]	
Bottom-Trawl			0.0241	***	0.0139	*
			[0.0049]		[0.0081]	
Longline			0.0874	***	0.0766	***
			[0.0051]		[0.0075]	
Danish-Seine			−0.0241	***	−0.0355	***
			[0.0057]		[0.0085]	
Year-2011	0.0379	***	0.021	***	0.0206	***
	[0.0103]		[0.0078]		[0.0072]	
Year-2012	−0.1071	***	−0.1192	***	−0.1053	***
	[0.0119]		[0.0094]		[0.0088]	
Year-2013	−0.3829	***	−0.3847	***	−0.3684	***
	[0.0095]		[0.0073]		[0.007]	
Year-2014	−0.2092	***	−0.2013	***	−0.1886	***
	[0.0101]		[0.0078]		[0.0076]	
Year-2015	0.0761	***	0.0667	***	0.0711	***
	[0.0095]		[0.0072]		[0.0071]	
Year-2016	0.1384	***	0.1114	***	0.1071	***
	[0.0094]		[0.0073]		[0.0072]	
Year-2017	0.2239	***	0.1979	***	0.1968	***
	[0.0096]		[0.0071]		[0.0072]	
Year-2018	0.3803	***	0.351	***	0.338	***
	[0.0093]		[0.0074]		[0.0074]	
January	−0.0889	***	−0.0914	***	−0.0811	***
	[0.0081]		[0.0056]		[0.0054]	
February	−0.115	***	−0.109	***	−0.1002	***
	[0.01]		[0.0067]		[0.0063]	
March	−0.1317	***	−0.111	***	−0.1004	***
	[0.0097]		[0.0069]		[0.0067]	
April	−0.1442	***	−0.0947	***	−0.0908	***
	[0.0092]		[0.0063]		[0.0064]	
May	−0.1281	***	−0.079	***	−0.0718	***
	[0.0089]		[0.0061]		[0.0061]	
June	−0.1214	***	−0.0686	***	−0.0634	***
	[0.0084]		[0.0061]		[0.0057]	
July	−0.1636	***	−0.0979	***	−0.091	***
	[0.0088]		[0.006]		[0.0059]	
August	−0.1479	***	−0.0607	***	−0.0594	***
	[0.0085]		[0.006]		[0.0058]	
September	−0.0675	***	−0.0363	***	−0.0307	***
	[0.0078]		[0.0054]		[0.0053]	
October	−0.0369	***	−0.0218	***	−0.0209	***
	[0.0076]		[0.0052]		[0.0049]	
November	0.0175	**	0.0055		0.0074	
	[0.0076]		[0.0052]		[0.005]	
With seller, buyer, and seller–buyer dummies	No		No		Yes	
Adj.R^2	0.6623		0.847		0.8669	

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 level, respectively. Standard errors are in parentheses.

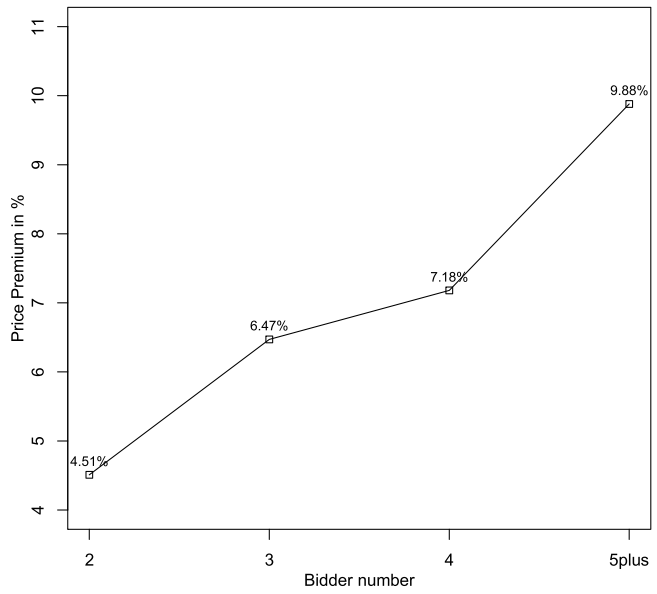

Fig. 1. Relationship between bidder numbers and prices.

coefficients are slightly different from their counterparts in the OLS regressions, all the coefficients of the bidder numbers are significant, and with a monotonic increasing pattern, in line with the findings from the OLS regressions.

4. Discussion

This study contributes to the literature on fish auctions by examining empirically the antecedents and consequences of the number of participating bidders in an ex-vessel auction for frozen Atlantic cod. The results clearly demonstrate that bidder participation has a substantial effect on prices. For example, compared to auctions with only one bidder, auctions with two bidders gain 4.51 % higher prices, holding other variables constant. With five or more bidders, prices increase by 9.88 % compared to auctions with one bidder only. With an increasing number of bidders, competition increases, and prices should reflect the quality and quantity of catches and incentivize fishers to provide high-quality fish of importance for optimal use of the valuable Atlantic cod stock. Competition also means that winning bids will be provided by the buyers that, over time, are the most capable of adding value and earning profits, which also contributes to optimal resource use.

At the same time, however, it is somewhat puzzling that almost 24 % of the studied auctions were completed with only one bidder, implying no competition whatsoever, and also that the average number of bidders was only 2.46. This should be a concern for both fishers and policy makers aiming to optimize the use of the Atlantic cod stock. In order to address this concern, the NFSO should consider mandatory auctions. Integrating the NFSO and SUROFI auctions, in which many of the same fishers and buyers participate, may also lead to enhanced competition, as indicated by Guillotreau and Jiménez-Toribio (2011), showing that integrating French fish auctions led to increased ex-vessel prices.

Our findings regarding factors influencing bidder participation are also of relevance and should be considered carefully by fishers who want to attract more bidders and obtain better prices. For example, the results indicate that larger lots and cod of larger size increase the probability of two or more buyers and lead to higher prices. Also, longer storage time reduces the probability of two or more bidders and leads to lower prices, indicating that longer storage time makes the fish less attractive to buyers. In addition, the probability of two or more bidders varies over the year, with May being the month with the highest probability of two or more bidders. At the same time, however, fish auctioned in the fall (September, October, and December) gain better prices than in other months of the year, and in particular the winter months of February, March, and April. This probably reflects the large landings of fresh cod from the coastal fleet during the winter months, given that the ex-vessel markets for fresh and frozen cod in Norway have been found to be integrated (Helstad et al., 2015; Pettersen et al., 2018).

An interesting finding is that cod caught with bottom trawl has a higher probability of two or more bidders than fish caught with longline. This may seem surprising given that cod caught with longline has been found to be of better quality than trawl-caught cod (Rotabakk et al., 2011). However, line-caught cod is also more expensive than trawl-caught cod. Thus, the less expensive fish may be preferred by buyers making end products of medium quality such as breaded fish fingers. That fishing methods influence prices differently, indicating quality differences, is in line with previous studies of ex-vessel fish markets (e.g., Asche et al., 2015; Hammarlund, 2015; Lee, 2014; McConnell and Strand, 2000; Sogn-Grundvåg et al., 2020). A price premium for line-caught cod compared to cod caught with other fishing methods has also been found at the retail level of the supply chain (Sogn-Grundvåg et al., 2013, 2014).

Although this study is conducted in a specific context, the results and implications should be of relevance for other fish auctions, as they contribute to improved understanding of antecedents and consequences of bidder numbers and competition in fish auctions, which is important to optimize the utilization of limited marine resources.

Table 7
Estimation of the price model with dynamic coefficient of dummies for bidder numbers.

Variable	Model 4		Model 5		Model 6	
Intercept	3.0405	***	2.6725	***	2.6631	***
	[0.0268]		[0.0272]		[0.0268]	
Bidders-2	0.0582	***	0.0389	***	0.0338	***
	[0.011]		[0.0061]		[0.0054]	
Bidders-3	0.0984	***	0.0528	***	0.05	***
	[0.011]		[0.0071]		[0.0063]	
Bidders-4	0.1013	***	0.05	***	0.0502	***
	[0.0121]		[0.0079]		[0.0065]	
Bidders-5+	0.1127	***	0.0529	***	0.0547	***
	[0.013]		[0.0089]		[0.0081]	
log (Daily-Quantity)			0.0027	***	0.0024	***
			[0.0009]		[0.0009]	
log (Transaction-Quantity)			0.0000		0.0002	
			[0.0005]		[0.0005]	
log (Fish-Size)			0.0895	***	0.0778	***
			[0.0013]		[0.0016]	
Quality			0.2844	***	0.2927	***
			[0.0035]		[0.0038]	
log (Storage-Time)			−0.0066	***	−0.0078	
			[0.0014]		[0.0013]	
Bottom-Trawl			0.0211	***	0.0114	
			[0.0054]		[0.007]	
Longline			0.095	***	0.0861	***
			[0.0055]		[0.0068]	
Danish-Seine			−0.0209	***	−0.03	***
			[0.0058]		[0.0073]	
With seller, buyer, and seller-buyer dummies	No		No			Yes
Chi-Square	12172	***	18646	***	15854	***

Notes: ***, **, and * indicate significance at the 0.01, 0.05, and 0.10 level, respectively. Standard errors are in parentheses.

CRediT authorship contribution statement

Geir Sogn-Grundvåg: Conceptualization, Funding acquisition, Investigation, Project administration, Writing - original draft, Writing - review & editing. **Dengjun Zhang:** Conceptualization, Formal analysis, Investigation, Methodology, Writing - review & editing. **Bent Dreyer:** Conceptualization, Funding acquisition, Project administration, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix 1 Transaction shares for top sellers, buyers, and seller–buyer pairs

Top	Seller	Buyer	Seller-Buyer
1	4.71 %	10.79 %	0.65 %
2	3.71 %	10.74 %	0.61 %
3	3.50 %	5.69 %	0.56 %
4	3.18 %	5.08 %	0.48 %
5	2.90 %	4.25 %	0.48 %
6	2.85 %	4.08 %	0.47 %
7	2.63 %	4.07 %	0.40 %
8	2.49 %	3.59 %	0.44 %
9	2.28 %	3.42 %	0.42 %
10	2.12 %	3.18 %	0.41 %
11	2.12 %	3.09 %	0.41 %
12	1.98 %	2.47 %	0.39 %
13	1.93 %	2.40 %	0.39 %
14	1.73 %	2.11 %	0.39 %
15	1.71 %	2.08 %	0.38 %
16	1.61 %	1.94 %	0.38 %
17	1.63 %	1.48 %	0.38 %
18	1.58 %	1.42 %	0.37 %
19	1.53 %	1.38 %	0.35 %
20	1.52 %	1.29 %	0.34 %
21	1.44 %	1.26 %	0.34 %
22	1.42 %	1.21 %	0.29 %
23	1.39 %	1.14 %	0.33 %
24	1.35 %	1.04 %	0.33 %
25	1.22 %	0.97 %	0.32 %
26	1.21 %	0.80 %	0.32 %
27	1.13 %	0.87 %	0.32 %
28	1.10 %	0.81 %	0.32 %
29	1.06 %	0.80 %	0.31 %
30	1.02 %	0.78 %	0.29 %
31	1.02 %	0.75 %	0.29 %
32	0.96 %	0.74 %	0.29 %
33	0.94 %	0.71 %	0.28 %
34	0.85 %	0.66 %	0.28 %
35	0.84 %	0.68 %	0.28 %
36	0.75 %	0.63 %	0.28 %
37	0.70 %	0.55 %	0.27 %
38	0.75 %	0.53 %	0.26 %
39	0.72 %	0.53 %	0.27 %
40	0.70 %	0.50 %	0.27 %
41	0.68 %	0.49 %	0.27 %
42	0.68 %	0.48 %	0.26 %
43	0.67 %	0.43 %	0.25 %
44	0.66 %	0.37 %	0.25 %
45	0.66 %	0.37 %	0.25 %
46	0.65 %	0.35 %	0.25 %
47	0.64 %	0.30 %	0.24 %
48	0.64 %	0.29 %	0.24 %
49	0.61 %	0.29 %	0.24 %
50	0.62 %	0.29 %	0.24 %
51			0.24 %
52			0.23 %
53			0.23 %
54			0.23 %
55			0.23 %
56			0.23 %
57			0.23 %
58			0.22 %
59			0.22 %
60			0.22 %
61			0.22 %
62			0.22 %
63			0.22 %

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(*continued*)

Top	Seller	Buyer	Seller-Buyer
64			0.22 %
65			0.22 %
66			0.21 %
67			0.21 %
68			0.21 %
69			0.21 %
70			0.21 %
71			0.20 %
72			0.20 %
73			0.20 %
74			0.20 %
75			0.20 %
76			0.20 %
77			0.20 %
78			0.20 %
79			0.20 %
80			0.20 %
81			0.20 %
82			0.20 %
83			0.20 %
84			0.20 %
85			0.19 %
86			0.19 %
87			0.19 %
88			0.19 %
89			0.19 %
90			0.19 %
91			0.19 %
92			0.19 %
93			0.19 %
94			0.18 %
95			0.17 %
96			0.18 %
97			0.18 %
98			0.18 %
99			0.18 %
Other	25.23 %	5.82 %	72.87 %

Appendix 2 Estimation Results of Partial Parallel Ordered Logit Model

Variable	Estimate	Std. Error	
Intercept:2	1.112	0.520	*
Intercept:3	3.013	0.512	***
Intercept:4	3.986	0.538	***
Intercept:5	5.238	0.651	***
log (Starting-Price):2	−0.601	0.176	***
log (Starting-Price):3	−0.686	0.173	***
log (Starting-Price):4	−0.532	0.181	***
log (Starting-Price):5	−0.476	0.218	**
log (Daily-Quantity)	−0.123	0.018	***
log (Transaction-Quantity)	−0.117	0.011	***
log (Fish-Size)	−0.187	0.031	***
Quality	0.059	0.091	
Bottom-Trawl	−0.406	0.146	***
Longline	−0.298	0.140	**
Danish-Seine	0.009	0.152	
log (Storage-Time)	0.208	0.028	***
Year-2011	0.738	0.112	***
Year-2012	2.138	0.115	***
Year-2013	1.841	0.113	***
Year-2014	1.704	0.107	***
Year-2015	2.389	0.120	***
Year-2016	2.663	0.127	***
Year-2017	2.531	0.136	***
Year-2018	2.752	0.157	***
January	−0.606	0.087	***
February	−0.540	0.100	***
March	−0.762	0.106	***
April	−0.608	0.104	***
May	−0.723	0.100	***
June	−0.342	0.092	***
July	−0.455	0.098	***
August	−0.514	0.095	***
September	−0.329	0.091	***

(*continued on next page*)

(*continued*)

Variable	Estimate	Std. Error	
October	−0.623	0.078	***
November	−0.233	0.077	***
With seller dummies	Yes		

Notes: ***, **, and * indicate significant at the 0.01, 0.05 and 0.10 level, respectively. For bidder number, the base is Bidders = 1.

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