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hedonic prices and inverse demand for Baltic cod

AgriFood economics centre

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Abstract

The price of fish depends on quality attributes such as size and freshness. In turn, quality attributes are related to fishery management. This article presents a hedonic analysis where attribute prices of size and quality ratings are estimated for the Swedish Baltic Cod Fishery. Using information from 5307 landing days, hedonic inverse demand functions are estimated with a random coefficient model. Results show that there are price premiums for larger sizes of cod and for cod with the highest quality rating. Results also show that own- quantity effects and cross-quantity effects are negative for most attributes. Thus, there is indication that the quality composition of landed fish affect the prices of quality attributes and that the management of a fish stock that changes the quantity of attributes will also change the prices of fish.

Keywords: Attribute prices - Hedonic inverse demand - Baltic Cod fishery

JEL classification: D21, Q22

1. Introduction

Much focus in fishery economics has been on the total biomass of the fish stock that is harvested without any consideration of the size or the quality of the fish. In order to maximize the economic value of a fishery, it is not just the weight in tons that matters, since attributes such as size and freshness can change the value of the catch substantially. In this paper the prices of different sizes and qualities[2] are closely related to the management of fishery resources. Fisheries, such as the Baltic Cod fishery, are often regulated by quota restrictions set in tons of fish, with the size of the fish regulated by restrictions on mesh sizes and minimum legal landing sizes. As discussed below, a fish stock that is managed economically efficiently often has a larger amount of large sized fish as well as a larger amount of undamaged and fresh fish.

The pricing of size attributes is especially interesting since price has been the focus of a large number of studies relating fishery management to the size (or age) structure of the biomass (Döring and Egelkraut 2008, Froese; Stern-Pirlot; Winker et al. 2008, Quaas; Requate; Ruckes et al. 2010, Diekert 2011, Ravn-Jonsen 2011, Cardinale and Hjelm 2012). Numerous benefits of delaying harvesting until

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[2] Although it is possible to refer to size as a quality, this paper regards size as separated from quality, and considered to be quality aspects related to freshness and appearance of the product as set down in the EU regulation *No 2406/96 of 26 November 1996.*

fish have reached a certain size have been pointed out. Firstly, the most obvious point is that larger sized fish increase the value of the total catch. Secondly, larger fish can also decrease uncertainties about the future stock since the spawning success will be less likely to be dependent on a single age group (Döring and Egelkraut 2008). Finally, societal values, like a good ecosystem status of the sea and higher values of recreational fisheries can be achieved in a fishery with larger fish (Cardinale and Hjelm 2012).

Quality attributes that are not related to size may be related to the status of the biomass stock, but will also depend on how the fish are handled after they have been caught. The incentive for fishermen to produce high quality fish is expected to increase in an economically efficient fishery, and fishermen will therefore deliver a larger amount of fresh and undamaged fish (Squires; Kirkley and Tisdell 1995, Larkin and Sylvia 1999, Grafton; Squires and Fox 2000, Carroll; Anderson and Martinez-Garmendía 2001). The price paid by fish processors to fishers is likely to depend on these quality aspects. Fish that have been handled more carefully and not stored for too long are expected to receive a higher price on the market. Hence, the pricing of quality attributes, other than size, is interesting from a fishery management perspective.

Using a unique and detailed dataset on the Swedish Baltic Cod fishery, this paper takes a closer look at prices related to the size and quality ratings of cod. In addition, the study contributes to the literature on hedonic prices and inverse demand by using two methods (the random coefficient model and the Brown and Rosen method) suggested in the literature (Kristofersson and Rickertsen 2004). Lately, the size and quality composition of Swedish Baltic cod have become an important issue as the problems of a diminishing fish stock, especially for Eastern Baltic Cod, have become less severe (BSRAC 2011, Cardinale och Hjelm 2012, Eero et. al 2012). Despite the recovery in the stock biomass, the size of the cod caught is still small (Cardinale and Hjelm 2012). Fishermen as well as society could benefit from larger cod and cod of better quality. The price premiums of different attributes, five size classes and two quality ratings, are investigated using the hedonic method. In addition, the effects of increasing the amounts of cod with different attributes are analyzed in an inverse demand system. Increasing the quantities of attributes is expected to result in decreasing attribute prices. By not considering these price increases, the benefits of sustainable management might be overestimated. Hence, the aim of this study is to offer guidance on the economic value of different size and quality compositions of cod landings.

The paper proceeds with a short description of the Swedish Baltic cod Fishery and the regulations surrounding it. This is followed by a description of the estimation of the hedonic model and the inverse demand model in the literature and in this paper. Next, the database of the Swedish cod fishery and some statistics based on the database are presented, as are the results from the hedonic inverse demand model. A discussion on how the results are related to fishery management issues brings the paper to a close.

2. The Swedish Baltic Cod Fishery

The Baltic Cod Fishery is one of the most important fisheries in Sweden; in 2011 around 17 percent of the value of all landings of fish and seafood in Sweden consisted of cod, mostly landed along the south coast of Sweden (Swedish Agency of Marine and Water Management 2012). The fishing areas include the Western Baltic (the Belt Sea, the Sound and the Arcona basin) and the Eastern Baltic (including the Bornholm basin, the Gdansk basin, the Gotland basin, the Bothnian Sea, the Bothnian

Bay and the Gulf of Finland). In 2011 nine countries were fishing for cod in these two stocks in the Baltic. Poland, Denmark and Sweden were the major fishing nations in the Eastern Baltic while Denmark, Germany and Sweden fished in the Western Baltic Cod Stock. In total, 50 368 tons of cod was landed from the Eastern Baltic in 2011, of which 20 percent was landed by Swedish vessels; 16 332 tons of cod from the Western Baltic stock was landed, of which Swedish vessels landed 16 percent (ICES 2012).

The Swedish Cod fishery is regulated by EU legislation and national legislation that in some cases goes further than the EU regulations. The regulations consist of the setting of quotas, limiting the number of days out of port, fishing bans and closed areas. A multiannual plan (European Commission 2007) for the cod stocks in the Baltic Sea was established in 2007, the motivation being a decline in the stock to levels where it was suffering from reduced reproductive capacity and unsustainable harvesting. The purpose was to gradually reduce and maintain fishing mortality rates at levels no lower than 0.6 for cod aged 3 to 6 years for the Western Baltic stock and 0.3 for cod aged 4 to 7 for the Eastern Baltic stock. This regulation also stipulated prohibited periods and closed areas for the two Baltic cod stocks. Fishing with most types of fishing gear is prohibited from the 1st of April until the 30th of April in the Western Baltic Sea (the April closure) and from the 1st of July until the 31st of August in the Eastern Baltic Sea (the summer closure). Most types of fishing activities in the Gdansk deep, the Bornholm deep and the Gotland deep (European Commission 2007) are prohibited from the 1st of May to 31st October. The number of days at sea is regulated from year to year in different EU regulations. For example, in 2011, vessels were limited to 163 days absence from port in the Western Baltic Sea, and 160 days absence from port in the Eastern Baltic Sea (European Commission 2010). In addition, regulations require fishers to have licenses and vessel permits, and stipulate the allocation rules for fishing quotas. Special rules also apply to cod fishing, which requires a special permit in the Baltic Sea, and the number of ports with the right to receive more than 750 kilos of cod has been limited to 29 since 2005 (Swedish Board of Fisheries 2004, European Commission 2007).

Regulations related to the size of the cod are mainly requirements on mesh sizes and minimum legal landing sizes found in Council regulation no 2187/2005, which also lays down the technical measures for the conservation of fishery resources in the Baltic Sea. The regulations on mesh sizes for vessels using active gear are part of the detailed requirements for Bacoma and T90 trawls; the mesh size is set at 105 mm on the Bacoma trawl, except for the exit window which should have a minimum mesh opening of 110 cm. For the T90 trawl the mesh size should be at least 110 mm. For vessels using passive gear, mesh sizes should be larger than 157 cm when vessels only target cod, and between 110 and 157 cm when more than 90 percent of the target species consists of cod (European Commission 2005). Regarding minimum landing sizes, the EU regulation on technical measures, issued in 2005, establishes that the minimum length of cod from the Baltic Sea is to be 38 cm.

The attributes of cod fished in the Baltic are the result of biological conditions as well as management decisions. The regulations discussed above influence the size and quality composition of landings that are discussed in the following sections. A suitable model for estimating attribute prices is discussed in the next section.

3. The hedonic model and inverse demand

The most common model for the estimation of attribute prices is the hedonic model. The simplest form of the hedonic model is an equation where the price of a product is described as a function of the attributes of that product:

$$p_n = \boldsymbol{z}'_n \boldsymbol{\beta} + \varepsilon_n \tag{1}$$

where p_n are observations n of prices of a product, $\boldsymbol{z}'_n$ is a vector of observations of different attributes, $\boldsymbol{\beta}$ is a vector of average attribute prices which is to be estimated and ε_n is a random factor influencing the price of the product.

Hedonic price analysis is often used to explore revealed preferences of quality attributes where no market prices exist. The attribute prices of colour, size and uniformity of spears of asparagus were estimated by Waugh (1928) in the very first paper on hedonic prices. Since then, the method has been widely used to estimate not only prices of the attributes of different products, but also the revealed preferences of environmental amenities. In relation to fish markets, McConnell and Strand (2000) use a hedonic function including landed quantities of different fish species to investigate the qualities of Hawaiian Tuna sold at fish auctions. Hedonic prices have also been estimated by Roheim; Gardiner and Asche (2007) with a hedonic pricing model to determine the relative value of the attributes of frozen processed seafood in the UK. A recent study by Asche and Guillen (2012) investigates the prices of hake caught by longline, trawl and gillnets in the Spanish whole-sale market. The results show that fish caught by longline are more expensive than fish caught by trawl or gillnets. However, hake caught by gillnets have smaller price premiums than hake caught by trawlers, which suggests that trawling does not reduce quality as much as gillnetting. The value of line-caught haddock and cod in British supermarkets is also investigated by Sogn-Grundvåg; Larsen and Young (2013) . The results suggest that there is a price premium for line-caught cod and haddock and thus that consumers pay more for line-caught fish compared to fish caught by other methods. This study also finds a price premium for fish labeled by the Marine Stewardship Council (MSC).[3]

All of the above studies focus on the hedonic price function as such, without considering how changing quantities of attributes affect hedonic prices. Rosen (1974) pointed out that this type of hedonic price function can only reveal something about attribute prices at prevailing quantities, since prices normally are determined by the demand as well as supply of attributes. Hence, in order to identify the demand and supply of attributes, a system of demand and supply equations should be estimated (Rosen 1974). However, it is possible that in markets like housing markets (Palmquist 1984) and markets for natural resources (Wang 2003), or fresh produce like fish (Barten and Bettendorf 1989, Kristofersson and Rickertsen 2004), the supply of attributes can be assumed to be exogenous. In this case the estimation of an inverse attribute demand equation for an attribute is possible:

$$\beta_t = \delta' \boldsymbol{q} + u_t \tag{2}$$

[3] The Marine Stewardship Council is a non-profit organization with a certification program that recognizes and rewards sustainable fishing.

where β_t are observations of prices of the attribute, q are quantities supplied of different attributes and u_t are unobserved factors influencing the price of the attribute.

In order to estimate an inverse demand equation it is necessary for attribute prices to vary. One way to find variation is to use a non-linear hedonic model where hedonic prices differ among buyers who prefer different amounts of these attributes. A functional form of the hedonic model must be assumed, and then the attribute prices for different buyers are used in a second step demand model (Bajari and Kahn 2003, Ekeland; Heckman and Nesheim 2004). Another way to find variation in prices is to use information from multiple markets assuming that consumers in each market share a common preference structure. This method was first suggested by Brown and Rosen (1982) and has been used by Palmquist (1984), Bartik (1987), Zabel and Kiel (2000), and Kristofersson and Rickertsen (2004).

In relation to fish markets, Kristofersson and Rickertsen (2004)) use the Brown and Rosen model to estimate hedonic inverse input demand for Icelandic cod. In the first stage, 881 trading days in the Icelandic fish auctions are used to estimate hedonic prices for different sizes of cod, non-gutted cod and storage time. In the second stage, input demands for these attributes are estimated. The results show that price changes are small as a response to increased quantities of the size attributes. The price changes are larger when the quantities of the attributes non-gutted and storage increase. The study also shows that the attribute prices of larger sizes have increased more over time than smaller sizes.

Another problem that has caused much debate concerning the hedonic demand function is that unobserved demander characteristics can affect the choice of product attributes (Bartik 1987, Epple 1987). In a fish market context this translates into processor characteristics affecting the choices of quantities of fish with different attributes. For example, it might be the case that processors with fillet machines have a demand for fish of a certain size that fit in the machine, or there could be buyers of fish that sell to luxury restaurants with a demand for fish of higher quality.

One way to find variation of prices and solve the problem of unobserved demander characteristics is to use daily observations of the hedonic price function under the assumption that this function varies from day-to-day, but that unobserved characteristics of the processors do not. This allows the estimation of hedonic price functions that are unaffected by processor characteristics.

4. Estimation

In this study fishers are assumed to be price takers in the short run. The assumption seems especially motivated for daily supplies. When fishers have landed the catch, the attributes of the fish cannot be changed. It is also assumed that unobserved processor characteristics do not vary from day-to-day. Thus, on a daily basis, the prices of fish attributes are determined by the demands of fish processors. The details of the theoretical framework underlying the model used in this study is described in Kristofersson and Rickertsen (2004) and Kolstad and Turnovsky (1998).

The estimation follows the approach of Kristofersson and Rickertsen (2004) where the hedonic inverse demand equation is estimated using a random coefficient model. The motivation for using this model is that there is a need to take the importance of each landing day into account. For comparison, as in Kristofersson and Rickertsen (2004), the Brown and Rosen (1982) model, which relies on an underlying assumption that estimates from each landing day have the same level of accuracy, is used. The Brown and Rosen model is estimated in two steps whereas the random coefficient model is estimated in one step.

Starting with the Brown and Rosen model, the hedonic equation is estimated for each trading day in a first step. Then the inverse demand equations of the attributes are estimated in the second step using the estimated hedonic prices from the first step. That is, for each landing day t we have:

$$p_{nt} = \boldsymbol{z'}_{nt}\boldsymbol{\beta_t} + \varepsilon_{nt} \tag{3}$$

where real prices[4] on each trading day (t) are regressed on the attributes z. The first stage equation gives the attribute prices on each trading day. The second stage inverse demand functions for each attribute are then estimated as:

$$\boldsymbol{\beta_t} = \boldsymbol{\gamma} + \boldsymbol{\delta' q_t} + \boldsymbol{\theta' t} + \boldsymbol{u_t} \tag{4}$$

where the coefficients from the first-stage models are used as dependent variables, $\boldsymbol{\delta}$ are price effects in SEKs of increasing the quantity of fish with different attributes and q_t are quantities of fish with a certain attribute on trading day t divided by monthly imports. Monthly imports are used as a numraire in order to impose homogeneity[5] and t is a time trend. The second stage coefficients are interpreted as own-quantity effects and cross-quantity effects. The own-quantity effects show how much a certain attribute price is affected by a change in the quantity supplied of that attribute, whereas the cross-quantity effects show the effects of changing quantities of other attributes on the price of a certain attribute. Symmetry is imposed a priori on the system, which reduces the number of cross-quantity effects to be estimated. Furthermore, quantity effects are normalized to facilitate interpretation; the coefficients can then be interpreted as the fall in price in SEK if the quantity of an attribute increases by 100 percent. Finally, the trend variables are adjusted so that the coefficients accompanying them can be interpreted as yearly effects.[6]

Using the Brown and Rosen two-stage method, the two steps are estimated separately. As mentioned above, the problem with this model is that it gives equal weight to the estimates from each trading day. Hence, the main focus in this study is on the random coefficient model, i.e. the two steps are estimated simultaneously by inserting the second equation into the first equation (as in Kristofersson and Rickertsen (2004)):

$$p_{nt} = \boldsymbol{z'_{nt}\gamma} + \boldsymbol{z'_{nt}\delta' q_t} + \boldsymbol{z'_{nt}\theta' t} + \boldsymbol{z'_{nt}u_t} + \varepsilon_{nt} \tag{5}$$

The first part of the equation, $\boldsymbol{z'_{nt}\gamma} + \boldsymbol{z'_{nt}\delta' q_t} + \boldsymbol{z'_{nt}\theta' t}$, is the fixed part and the second part, that is $\boldsymbol{z'_{nt}u_t} + \varepsilon_{nt}$,, is the random part. The estimation will contain main effects, $\boldsymbol{z'_{nt}\gamma}$, as well as cross-level interaction effects, i.e. $\boldsymbol{z'_{nt}q_t}$. The coefficient of the interaction terms involving $\boldsymbol{q_t}$ will be the

[4] Prices are deflated by 1997 consumer prices in order to account for macro-economic fluctuations.

[5] Imports are important to Swedish processors since the supply from Swedish fishers is uneven and of varying quality. Morf, Andrea, Lena Giffperth, Anders Grimvall and Eva-Lotta Sundblad (2012). Fallstudie: Selektivt uttag av torsk - för samhällsanalys i inledande bedömningen i havsmiljöförordingen. Havsmiljöinstitutets rapportserie.

[6] In practice, the trend variable has been divided by 365.

quantity effects of the model. Assuming that the time effects are attribute-specific results in them being specified as interactions in the model. The same restrictions regarding homogeneity and symmetry as in the Brown and Rosen model are used, as is the same normalization of the q-variables. Additionally, the covariance's of the $\boldsymbol{u_t}$:s are included in the model, which results in the model being estimated with 22 random effects terms.[7]

More specifically, the random coefficient model assumes that each landing day has different slope coefficients, and that the variation of these coefficients can be explained by the q-variables (and a time trend). This means that the relationship between the kilo price of cod and the attributes of cod depend on the quantities of different attributes that are traded. The quantities purchased thus act as moderator variables for the relationship between price and attributes where the relationship varies according to the value of the moderator variables (i.e. the quantities purchased on a certain day). The coefficients, $\boldsymbol{\gamma}$, $\boldsymbol{\delta}$ and $\boldsymbol{\theta}$ are fixed coefficients since they apply to all landing days. All between-days variation that is left in the $\boldsymbol{\beta}$ coefficients, after predicting using these coefficients, is residual error variation indicated by $\boldsymbol{u_t}$.

5. Data

Data on values and quantities of landings of cod by Swedish vessels in Swedish Baltic ports for the period 1997-2011 is available from the Swedish Agency for Marine and Water Management. Price per unit of cod can thus be calculated for each observation. In addition, quality ratings (Class E, A or B) and size classes (1-5) of the observations are included. There is a total of 731 540 observations in the database used in this study. The data is collected from sales notes that are sent from fish receivers to the Swedish Agency for Marine and Water Management. All primary receivers of fish are required to register and report to the Agency (European Commission 2009), and the database thus includes all cod that is reported as sold in Swedish Baltic ports. For each observation the following is reported: the amount landed, the price paid for the fish, the id-number of the vessel, the size class of the landing, the quality class of the landing, the port where the landing was registered, the id-number of the buyer and the date when the landing arrived. As mentioned above, imports are used as a numraire when estimating the inverse demand function. The data on imports of fresh and chilled cod[8] to Sweden is available on the Statistics Sweden homepage, which shows that imports have increased over the time period. Some summary statistics, together with data on Swedish quotas, are presented in Table 1.

[7] A log-ratio test of the model with covariance terms (unconstrained model) versus the model with only variance terms (constrained model) indicates that the model with covariance terms is the preferred model.

[8] Fresh and chilled cod has the CN-number 030250 according to the Combined Nomenclature of tariff lines used in the European Union.

Table 1: Summary statistics: Baltic cod catches from Swedish vessels 1997-2011.

	Number of observations	Number of vessels	Quantity Landed (tons)	Swedish quota* (tons)	Price per kilo (SEK)**
1997	65 848	612	22 093	38 860	9.6
1998	58 599	563	14 024	29 246	13.2
1999	64 356	536	14 134	25 870	13.8
2000	68 005	546	16 154	21 303	13.9
2001	69 218	517	16 286	22 083	14.9
2002	55 043	476	12 378	15 203	14.9
2003	58 297	440	12 332	15 438	12.5
2004	53 852	408	12 697	12 323	12.2
2005	46 567	391	8 892	12 918	13.8
2006	42 168	350	10 243	14 969	14.2
2007	33 090	323	10 427	13 649	14.5
2008	35 933	320	9 311	12 011	13.9
2009	32 399	276	9 892	12 916	10.6
2010	24 760	237	9 564	14 685	11.1
2011	23 467	228	10 258	16 645	11.1

**Quotas as set by the original EU regulations setting quotas each year, i.e. amendments are disregarded.*
*** Deflated by 1997 consumer prices.*

The total number of observations in 2011 was only 36 percent of the total number of observations in 1997. The decrease in observations is accompanied by a decrease in the number of vessels and a decrease in the quantity of cod landed, which in turn is related to the decrease in quotas for the Swedish Cod Fishery. For example, the national quota for Sweden, which was 38 860 tons in 1997, had decreased to 12 011 tons by 2011 (European Commission 1996a, European Commission 2010). In 2011 the number of vessels landing cod was less than half (38 percent) of the number of vessels in 1997. A further look at the data reveals that the decrease in the number of vessels is due to a decrease in the number of vessels using passive gear. The share of the total quantity landed by vessels using active gear was around 60 percent in 1997, which had increased to more than 80 percent by the end of the time period (own calculations). Table 1 also displays the average price of cod over the time period and shows that the price of cod is negatively correlated with landed quantities. The highest average prices were recorded in 2006-2008 when Swedish fishers received around 16 SEK (around 14 SEK in 1997 prices) for a kilo of cod. The average price has since declined.

Prices are related to size and quality and therefore a change in the composition of landings could hide the effect that different characteristics have on average prices. Size classes and quality ratings are regulated by the European Commission in a regulation that lays down common marketing standards for certain fishery products (European Commission 1996b). The five size classes for cod are: 0.3 to 1 kilo, 1 to 2 kilos, 2 to 4 kilos, 4 to 7 kilos and more than 7 kilos. The quality classes are determined on the basis of the freshness of the fish and are the same for all whitefish. To be classified in category E, the fish must be free of pressure marks, injuries, blemishes and bad discoloration. For category A, the fish must be free of blemishes and bad discoloration. A very small proportion with slight pressure marks and superficial injures can be tolerated. Finally, for category B, blemishes and bad discolorations are not tolerated, but a small proportion with more serious pressure marks and superficial injuries is accepted. Further definitions of the categories are specified in the regulation where special ratings are based on the skin, skin mucus, eyes, gills, peritoneum (in gutted fish), smell of gills and abdominal cavity and flesh. For ease of presentation the quality classes are referred to as Class A, Class B and Class E in the following.

Figure 1 presents shares of cod with different attributes in total landings. The two largest size classes (>4 kilos) have been added together since they represent small shares of the total quantity landed. Only around 1-3 percent of the cod weigh more than 4 kilos. Between 5 and 10 percent of the landings of cod weigh between 2 and 4 kilos, whereas most of the cod landed are smaller than 2 kilos since more than 90 percent are classified into one of the smaller size classes. The most notable change during the time period is the increase of landings of very small fish. Cod weighing between 1-2 kilos become more unusual and cod weighing 0.3-1 kilos constitute almost 60 percent of landings by the end of the time period.

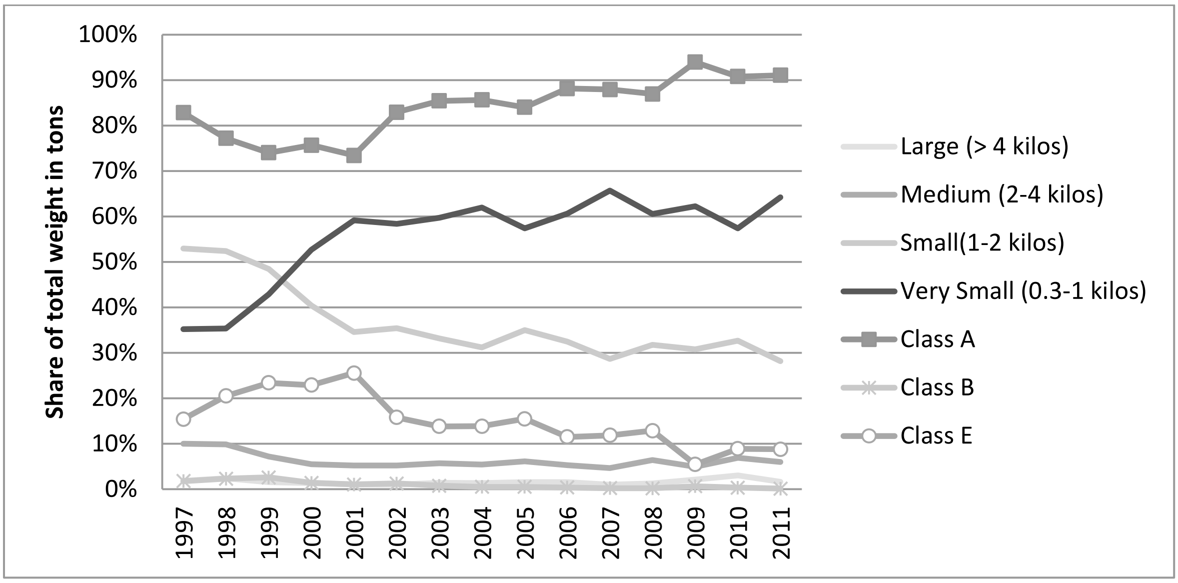

Figure 1: Shares of quantities (tons) of cod with different characteristics (1997-2011)

The quality ratings outlined in the EU regulation result in most fish being classified as of average quality, i.e. Class A. A varying amount of fish is classified as Class E, that is, the finest quality available in the EU classification; over the years this share ranges between 5 and 25 percent. A very small share of the fish is classified as Class B, i.e. below average quality. The trend is towards more fish being classified as Class A. In summary, the data show that cod landed in Baltic Swedish ports have decreased in quality as well as in size.

Figure 2 presents the real prices of cod with different characteristics. Real prices increase for almost all types of cod except for cod in Class B until 2007. Since then, real, as well as nominal, prices have decreased. Comparing cod of different characteristics, it appears that Class B has considerably lower prices than the other classes, and that the price of cod in this class decreases over time. Most of the cod landings in Swedish Baltic harbours are classified as Class A and the price of this class is therefore close to the average price during the time period. The price of Class E cod follows the price of Class A cod closely until 2008 when a price premium of Class E cod appears.

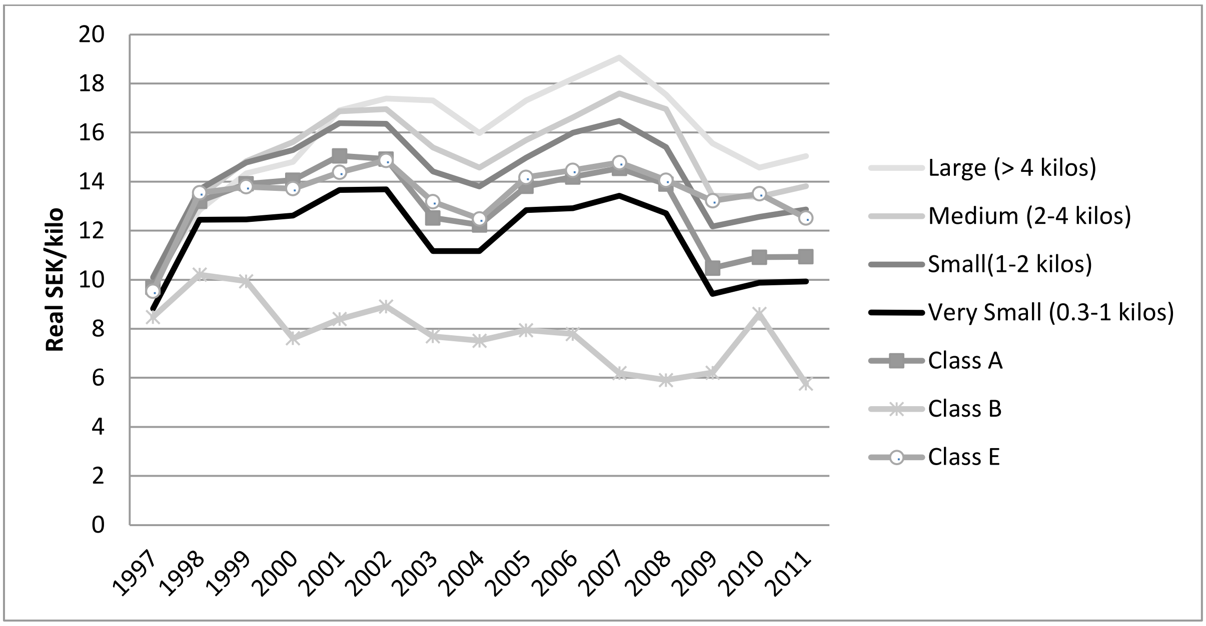

Figure 2: Prices of cod with different characteristics (1997-2011), SEK/kilo*

**Deflated by 1997 consumer prices from Statistics Sweden.*

Looking at the prices of cod of different sizes, it is apparent that larger sizes have higher prices. However, it appears that the smallest size category (Very Small) has substantially lower prices than the other size categories. Another interesting observation is that the prices of different categories of cod appear to be more similar in the beginning of the time period, and diverge more towards the end of the time period. This is an indication that different attributes of cod have become more important over time.

The inverse demand model uses information on daily attribute prices and landed quantities to estimate the effect of quantity changes on attribute prices. Hence, it is important that prices vary from day to day. An example of the variation of prices is shown in Figure 3 where prices (in SEK per kilo) vary considerably between days in 2011. The diagram shows that prices, as before, are lower for the very small cod (0.3 to 1 kilo). The price difference between the other sizes is more difficult to observe in the diagram, although it is clear that the smaller cod (1-2 kilos) vary less in price than cod in the two largest size categories.

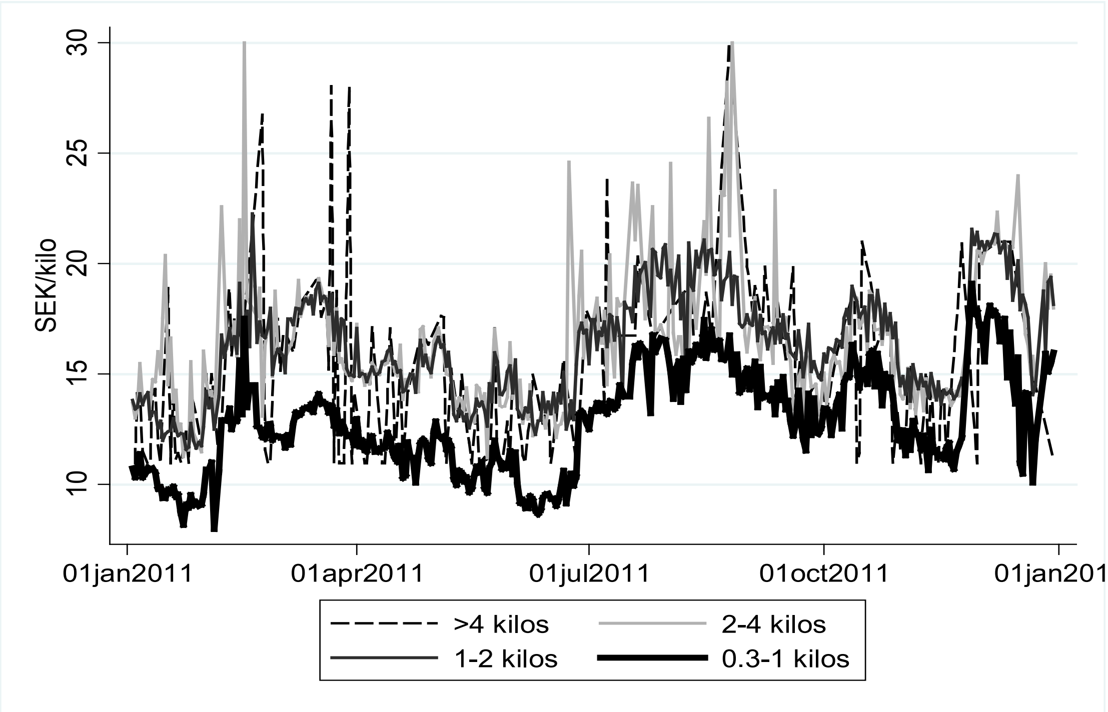

Figure 3: Day-to-day variation of prices of Class A cod landed in the Baltic in 2011.

Note: Price observations that are larger than 30 SEK or smaller than 1 SEK have been omitted from the diagram in order to get a clearer picture. A total of 1394 observations are lost, which is only 0.002 percent of the total number of observations in the dataset.

The diagram also reveals seasonal patterns; the price is higher in late summer and lower in the beginning of the year. Running a regression of monthly dummies in a simple hedonic model shows that a similar pattern occurs during the entire time period. This regression also shows that the price is highest in October and lowest in May.[9]

Table 2 summarizes the variables used in the regressions. In the first stage of the Rosen-Brown model $\boldsymbol{p_{nt}}$ is regressed on six dummy variables (z-variables). In the second stage the estimated marginal prices of the first stage are used to estimate the inverse demand functions using the quantity variables and the time variables defined in Table 3. In the random coefficient model all variables are estimated in one step.

[9] The results are available upon request.

Table 2. Definition of variables.

Variable	Definition	Mean
p	Real price per kilo of each landing in SEK	14.26
z_L	Dummy variable, 1 for Large(>4 kilos)	0.05
z_M	Dummy variable, 1 for Medium (2-4 kilos)	0.18
z_S	Dummy variable, 1 for Small(1-2 kilos)	0.41
z_VS	Dummy variable, 1 for Very Small(0.3-1 kilos)	0.36
z_B	Dummy variable, 1 for Class B	0.04
z_E	Dummy variable, 1 for Class E	0.2
qL	Total quantity of Large cod, tons per day	0.56
qM	Total quantity of Medium cod , tons per day	2.25
qS	Total quantity of Small cod, tons per day	13.48
qVS	Total quantity of Very small cod, tons per day	19.36
qB	Total quantity of Class B cod, tons per day	0.40
qE	Total quantity of Class E cod, tons per day	5.10
qIM	Total quantity of imports fresh and chilled cod, tons per month	521
tr	Trend	
Constant	Constant	

6. Results

Hedonic real prices are presented in Table 4 which shows the results of an OLS regression using all observations, the average of the coefficients from the first stage of the Brown and Rosen model and the sum of the coefficients of the dummy variables of attributes ($\boldsymbol{z'_{nt}}$) and the interaction coefficients ($\boldsymbol{z'_{nt}\delta' q_t}$) at average quantites in the random coefficient (RC) model[10]. Since the model is run without a constant and all the size variables are included, the coefficients of the size variables show the average prices of cod for each size in quality class A. The coefficients of the quality attributes (Class E and Class B) show the price premia of supplying a product of better or worse quality.

[10] Here the RC model is estimated without a time trend in order to get average values comparable with the OLS and Brown and Rosen models. The full results of the RC model are available upon request.

Table 3. Attribute prices

	OLS	Average of β-coefficients of BR model	Hedonic prices from the RC-model at average quantities
z_L	14.97***	15.69	15.61
z_M	14.22***	14.89	14.76
z_S	14.22***	14.64	14.52
z_VS	11.60***	11.95	11.83
z_B	-5.89***	-6.41	-6.37
z_E	1.26***	1.27	1.04

*Note: No of observations in OLS and RC-model is 731 540. No of regressions in first stage of RB-model is 5307. Significant levels are * for p<0.05, ** for p<0.01, and *** for p<0.001 for the OLS model.*

All models show the same pattern and have similar coefficients. Since the number of observations is much larger in the beginning of the time period the price differences in the OLS model reflect the situation in the beginning of the time period to a larger extent than the other models (compare Figure 2). The Brown and Rosen model shows the average of the coefficients from 5307 landing-day regressions and hence accords each landing day equal importance. Since price differences increase over the time period (see Figure 2) the higher prices of Medium and Large cod as compared to OLS is not surprising. Finally, the RC model, which includes all the interaction terms (except the trend interactions) and random error terms in equation 5, give attribute prices that are very similar to the BR-model.

Using the results from the RC model, the real price difference between Very Small cod and Small cod is 2.69 SEK. The difference between the real prices of other size classes is smaller; the difference between Small and Medium cod is only 0.25 SEK on average over the time period using the RC model results. Large cod has a somewhat higher price premium; the price of Large cod is 0.85 SEK higher than the price of Medium cod according to the RC model. The effect on price of increased quality, i.e. the change from Class A to Class E, increases the price of cod by 1.04 SEK using the RC model. Class B cod, on the other hand, generates significantly lower prices than Class A or Class E cod in all models. This suggests that Class B cod is of significantly lower quality than Class A cod.[11]

The results of inverse demand from the RC model, i.e. the coefficients of the interaction variables in equation 5 above, are presented below.[12] The coefficients are interpreted as the effect on price of a hundred percent increase in the quantities of different attributes, as compared to the mean quantities (see Table 2). On average 37 tons of fish is traded on a typical day during the time period, although the variation is large.

[11] Testing the coefficients on the $\boldsymbol{z'_{nt}}$- variables of the size attributes show that these coefficients are significantly different from each other in the RC model.

[12] Estimated using the xtmixed command in STATA.

Table 4. Results of inverse demand from the RC model: marginal effects of quantity changes.

	z_L	z_M	z_S	z_VS	z_E	z_B
qL	**-0.1872*****	-0.1189***	-0.1055***	-0.0987***	0.0133	0.0675***
qM	-0.1189***	**-0.1708*****	-0.1477***	-0.01	-0.0006	0.0709***
qS	-0.1055***	-0.1477***	**-0.1758*****	-0.0805***	0.0211	0.0708***
qVS	-0.0987***	-0.01	-0.0805***	**-0.2923*****	0.0027	0.0508***
qE	0.0133	-0.0006	0.0211	0.0027	**-0.1055*****	-0.0144
qB	0.0675***	0.0709***	0.0708***	0.0508***	-0.0144	**-0.0184**
tr	0.1943***	0.0703***	0.0003	-0.0670***	0.1385***	-0.1452***

*Note: The number of observations are 731 540. Significant levels are * for p<0.05, ** for p<0.01, and *** for p<0.001.*

Most coefficients are significant and have the expected sign. The own-quantity effects are as expected; increasing the amount of Large, Medium, Small, Very Small and Class E cod gives lower prices of these attributes. The effect of increasing the amount of cod in Class B on the price premia of Class B cod is not significant. B-cod has a substantially lower price than other types of cod, and the number of observations is small (see Table 1 and 2). The own-quantity effect is largest for the Very Small cod (0.3-1 kilo); when the quantity of very small cod doubles, the price decreases by 0.29 SEK. The own-quantity effects of the other size attributes are very similar, and the results indicate that the price decreases by 0.17-0.18 SEK on average when quantities increase by 100 percent. This suggests that increasing the weight of cod to more than 2 kilos would not affect prices substantially. However, the relatively small price premia on larger sizes of cod might discourage fishers from aiming for cod larger than 2 kilos. One possibility is that this is a short-term effect due to processors being restrained by current technology. If the supply of larger sized cod was to increase substantially, technology could also change and prices would increase for larger sizes of cod. An increase of the amount of Class E cod in the market does not affect price as much as increases in the size attributes, indicating that demand for Class E cod is relatively insensitive to quantity changes.

Cross-quantity effects are negative between the size attributes, indicating that different sizes are substitutes. Cross-quantity effects are significant in all cases except between Very Small and Medium cod. There is also some indication that when cod are closer in size, the effect of quantity changes on price is larger; for example, if the quantity of Medium and Small cod increases by the same amount, the price of Large cod will be more affected by the increase of Medium cod. The price of Medium cod also seems to be more affected by quantity changes in Large and Small cod than by quantity changes of Very Small cod. In fact, Very Small cod does not seem to be affected much by quantity changes in substitute attributes at all.

The cross-quantity effects of Class E and Class B cod are positive in most cases, although insignificant for Class E cod. Increasing the amount of Class E cod does not seem to affect the prices of other attributes than the price of Class E cod itself. However, increasing amounts of Class B cod increase the price of all the size attributes, indicating that larger amounts of low quality cod increase the value of average quality cod.

The coefficients for the trend variables show that, over time, Class B cod and Very Small cod are less preferred, while Class E cod and Large cod are more preferred. On average, the price of Class E cod increases by 0.14 SEK per year, and the price of Large cod increases by 0.19 SEK per year. Also, the price of Medium sized cod is increasing, although a bit less, over time. The pattern is similar to

Kristofersson and Rickertsen (2004), who find a trend in demand away from bad and towards better quality cod over time.

The variance components of the RC model are shown in the appendix (Table A2). All components are significant. The estimates show that the variability of attribute prices is larger the larger the cod, and larger for cod in quality Class B. The variability of the size attributes confirms the picture in Figure 3. The results from the Brown and Rosen model are also shown in the appendix (Table A1). These results are similar to the results presented above: own-quantity effects are negative, cross-quantity effects are smaller and give an indication of whether attributes are substitutes or complements. As in the RC model, time trends indicate that larger and better quality cod is valued more over time. However, the coefficients are smaller in magnitude and the number of coefficients significant on the 0.1 percent level is smaller. The results from the RC model thus seem to be more robust. Finally, since landings of cod from different ports are used in the estimation of the inverse demand equation, it is possible that specific port effects could influence the quantity effects. However, running a regression where random effects of ports are included does not change the estimated coefficients significantly (see appendix and Table A3 for a further discussion).

7. Discussion and policy implications

An interesting aspect of the Swedish Baltic Cod Fishery is that both fishermen and researchers are looking for methods to increase the size of Baltic cod. For example, the Swedish Association of Cod Producers is aiming at increasing the minimum size of landed cod to 40 cm (STPO Action Plan 2012). In addition, as mentioned above, increasing the size of the Baltic cod has also been suggested as desirable by a number of biological studies. One of the most important expectations of increasing the cod size is that it will generate higher revenues to fishermen[13]. Thus, the effects of quantity changes on attribute prices could be used to indicate how revenues change as the composition of landings change.

Cardinale and Hjelm (2012) estimate revenues from changing the size range of Eastern Baltic cod by introducing methods for size selectivity (i.e. regulating gear mesh size). The optimal scenario is when the cod that is harvested has reached a length of 70-77 cm and is 5-6 years of age. This cod would be of medium size, weighing between 2 and 4 kilos, according to the definition used above.[14] Two different price scenarios are used in Cardinale and Hjelm (2012), where prices are assumed to be either the same for all sizes or vary between sizes such that the largest cod is 65 percent more expensive than the smallest cod. These prices are based on Swedish cod prices in 2010. Initially size selective harvesting would result in a loss, since there are currently few large cod in the population. However, the authors conclude that revenues would increase in the long run and would be higher than under the current management plan within five years. Prices in the study are unrelated to other quality attributes or changes in quantities.

[13] Although it could theoretically be possible that costs per unit increase when catching larger fish, it is not a realistic assumption since the inputs of fishermen (boats, nets, fuel consumption) are likely to be the same for different sizes of fish.

[14] The length-weight relationship is approximate and based on personal information given by the Swedish Institute of Marine Research 2013-04-22, Hans Nilsson.

Froese; Stern-Pirlot; Winker et al. (2008) investigate how size selective fishing in the Western Baltic can increase the biomass more than under the management regime proposed by the European Commission, which aims at the maximum sustainable yield of the fisheries. An age structure that is similar to an unfished stock could give the same yield as in the EU management regime. The optimal size of cod is then 80 cm, which would be equivalent to cod in the largest size category, Large, in the dataset used above.

Considering that only 10 percent of the cod catch consisted of cod larger than 2 kilos on average during 1997-2011, the optimal scenarios in the biological studies above are far from today's situation. One challenge when using the coefficients from the RC model is that it is difficult to extrapolate to compositions of landings that differ from those observed during the time period studied. However, by experimenting with the quantities caught of different size attributes, we can move in the direction of the optimal scenario. An attempt to do so is presented below. The results have to be interpreted with caution.

To simplify, we assume that the total quantity does not change and that all cod is Class A. Then, assuming that cod weighing less than 1 kilo is no longer fished, perhaps because of a mesh size regulation, the revenues from Very Small cod will disappear. Initially, as discussed by Cardinale and Hjelm (2012), total revenues will decrease. But eventually the Very Small cod that are left will grow and become larger in size. Assuming that all cod that are caught have grown into the next size category, the quantities of Large, Medium and Small cod will increase and attribute prices will decrease. The effects of this experiment on revenue are shown in Table 5 where the new revenue is also compared to the old revenue and the expected revenue without taking into consideration quantity effects.

Table 5. Experimenting with the coefficients from the RC model (see text for details).

	p_L	**p_M**	**p_S**	**p_VS**	
Price in 2011 at average quanitities	***18.511***	***15.733***	***14.341***	***10.653***	
Price change because of change in qVS	-0.099	0.000	0.081	**0.292**	
Price change because of change in qS	-0.046	-0.065	**-0.077**	-0.035	
Price change because of change in qM	-0.592	**-0.850**	-0.735	0.000	
Price change because of change in qL	**-0.757**	-0.481	-0.427	-0.399	
Total price change	**-1.395**	**-1.395**	**-1.238**	**-0.434**	
Price at new quantities	***17.215***	***14.337***	***13.183***	***10.511***	**Total revenue**
Revenue in SEK	48 136	193 211	253 685	0	495 032
Initial revenue in SEK	10 323	35 471	193 261	206 265	445 320
Unadjusted revenue in SEK	52 058	212 014	277 662	0	541 734

Using the calculated attribute prices from the RC model for 2011 as the initial prices, the price changes from quantity changes of different attributes are calculated. The new attribute prices are lower for Large, Medium and Small cod. In this case, the price of Large and Medium cod is affected more than the price of Small cod. This is because the percentage quantity changes are much larger for Medium and Large cod. However, despite the lower prices, the last column to the right shows that the average revenues per day increase in the new situation. This is due to the shift away from Very Small cod that have lower prices. The last column also shows that total revenue is lower when using the coefficients from the inverse demand model than if unadjusted prices are used as in Cardinale and Hjelm (2012). Using unadjusted prices results in an overestimation of approximately 47 000 SEK or a 10 percent increase of the initial revenue.

Several studies (Quaas; Requate; Ruckes et al. 2010, Diekert 2011, Ravn-Jonsen 2011) conclude that TACs and tradable quotas, measured in terms of biomass, will fail to solve the problem of growth overfishing, i.e. the situation when fish are caught at an inefficiently low age and weight class. The solution would be to measure the TACs and tradable quotas in terms of number of fish[15]. An underlying assumption in studies on growth overfishing is that the revenues of fishermen increase when larger sized fish are landed. Here, we have shown that prices are higher for larger sized cod than for the smaller cod, and that prices will not decrease substantially when the amount of larger cod increases on the market. Hence, there will be incentives for fishermen to aim for larger sizes of cod if quotas are set in numbers of fish rather than in quantities. Furthermore, the time trends in this study show that larger sizes and better quality fish have become more valuable over time.

8. Conclusions

This study uses a random coefficient model to estimate the attribute prices and inverse demand of Baltic cod landed in Swedish ports in the period 1997-2011. A detailed dataset makes it possible to use daily observations of cod landings in different size and quality rating classes. The results show that there is a price difference of 2.69 SEK between cod weighing 0.3-1 kilo and cod weighing 1-2 kilos. Looking at larger sizes of cod, price premiums are increasing less per kilo added. The price difference between cod weighing 1-2 kilo and cod weighing 2-4 kilo is only 0.25 SEK. The largest cod in this study, defined as weighing more than 4 kilos, are on average 0.85 SEK more expensive than the 2-4 kilo cod.

Looking at the quality ratings, there is a clear indication that cod classified as Class B is of inferior quality. Prices are much lower than for the most common quality rating, Class A. However, the highest quality class, Class E, generates only somewhat higher prices (a price premium of 1.04 in the random coefficient model) than Class A cod.

The results of inverse demand show that own-quantity effects are negative for all attributes and cross-quantity effects are negative between size attributes, indicating that size attributes are substitutes. This means that when the quantity of cod with a certain attribute increases, attribute prices of that particular attribute decrease, as do prices of other size attributes. The largest own-quantity effect is for the smallest cod in the sample; when the quantity of small cod increases by 100 percent, the price decreases by 0.29 SEK. The own-quantity effects of the other size attributes range between 0.17 and 0.18 SEK. Over time, the results suggest that the prices of larger cod and cod with the highest quality rating are increasing.

The management system chosen for a particular fishery will affect the size and quality composition of fish landed. A management system that increases the size and the quality of landed fish will face the law of demand; as the quantity of attributes increase, prices will decrease. This paper has shown that the price effects of increasing quantities of attributes are moderate, but nevertheless too important

[15] The same effect could of course arise if mesh size was increased by regulation, but the cost of monitoring would perhaps be higher for society.

to ignore. Thus, when the revenues of future management systems are modeled, the price effects of attributes should be taken into account.

9. Appendix

The Brown and Rosen model

The results from the second stage inverse demand functions of the Brown and Rosen model are presented in Table A1. The price premiums of each attribute from the first stage models are used as dependent variables in the regressions, together with a time trend. The equations are estimated as a system[16], which is reasonable since error terms might be correlated across the equations. For example, what influences prices of large fish on a certain day will also influence prices of small fish on that day. The system is also estimated with the same homogeneity and symmetry restrictions used in the RC model.

Table A1. Results from the second stage inverse demand Brown and Rosen model (system estimation)

	z_L	**z_M**	**z_S**	**z_VS**	**z_E**	**z_B**
qL	**-0.0659*****	-0.0343**	-0.0345***	-0.0303**	0.0072	0.0105
qM	-0.0343**	**-0.0694*****	-0.0566***	0.003	-0.0021	0.0159*
qS	-0.0345***	-0.0566***	**-0.0830*****	-0.0199*	0.0186**	0.0180**
qVS	-0.0303**	0.003	-0.0199*	**-0.1229*****	-0.0016	0.0101
qE	0.0072	-0.0021	0.0186**	-0.0016	**-0.0342****	-0.0032
qB	0.0105	0.0159*	0.0180**	0.0101	-0.0032	**0.0038**
tr	0.3541***	0.1553***	0.0531***	-0.0349**	0.1432***	-0.1922***
Constant	13.7495***	14.0660***	14.4054***	12.2432***	0.0736	-5.2652***

*No of regressions in first stage of BR model is 5307. Significant levels are * for p<0.05, ** for p<0.01, and *** for p<0.001.*

The results, when significant, are of the expected sign. Similar to the RC model, the own-quantity effects (in bold) are negative for the prices of Large, Medium, Small, Very Small and Class E and, looking at the size prices, the largest effect of increasing the quantity is on the very smallest fish. Additionally, similar to the RC model, the own-quantity effect of Class E cod is smaller than the own-quantity effects of the size attributes.

Variance component estimates of the RC-model

The variance components of the RC model are shown in Table 7. All components are significant. The estimates show that the variability of attribute prices is larger the larger the cod, and larger for cod in quality Class B. The variability of the size attributes confirms the picture in Figure 3.

Table A2. Variance component estimates of the RC model

Variable	Estimate
z_L	3.5865
z_M	2.8765
z_S	2.7253
z_VS	2.4502
z_E	1.2781
z_B	2.5960

[16] Using the surreg command in STATA.

The random coefficient model with port effects

Since landings are in 157 different ports along the coast, there is a possibility that prices differ in different landing places. In order to control for port effects, a regression, as specified below, with random port effects has been run:

$$p_{nt} = \boldsymbol{z'}_{\boldsymbol{nt}}\boldsymbol{\gamma} + \boldsymbol{z'}_{\boldsymbol{nt}}\boldsymbol{\delta'}\boldsymbol{q_t} + \boldsymbol{z'}_{\boldsymbol{nt}}\boldsymbol{\theta'}\boldsymbol{t} + \boldsymbol{z'}_{\boldsymbol{nt}}\boldsymbol{u_t} + \delta_{nt} + \varepsilon_{nt} \qquad (6)$$

where the term $\boldsymbol{\delta_{nt}}$ has been added to equation 5 to include an intercept for port effects. The results are shown in Table A3 below.

Table A3. Results from a random coefficient model with port effects

Variable	Coefficient
z_E	-0.1084*
z_B	-5.7644***
z_M	14.6758***
z_S	14.8963***
z_VS	12.6440***
z_L	14.7068***
int_zE_tr	0.1660***
int_zB_tr	-0.1364***
int_zVS_tr	-0.0823***
int_zM_tr	0.0520***
int_zS_tr	-0.0164
int_zL_tr	0.1700***
intz_EqE	-0.1090***
intz_BqB	-0.0265
intz_MqM	-0.1802***
intz_SqS	-0.1779***
intz_VSqVS	-0.2902***
intz_LqL	-0.1970***
intEM	0.0042
intES	0.0249*
intEL	0.011
intBE	-0.0138
intBM	0.0735***
intBS	0.0725***
intBL	0.0690***
intMS	-0.1486***
intML	-0.1226***

*Note: The number of observations is 731 540. Significant levels are * for p<0.05, ** for p<0.01, and *** for p<0.001.*

In general, the results are very similar to the results of the RC model without port effects. The major difference is that the direct effect, i.e. the attribute price, of Class E cod is now negative and only significant at the 5 percent level.

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