International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

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Is size-dependent pricing prevalent in fisheries? The case of Norwegian demersal and pelagic fisheries

Fabian Zimmermann
Mikko Heino (heino@iiasa.ac.at)

Approved by

Ulf Dieckmann
Director, Evolution and Ecology Program

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Is size-dependent pricing prevalent in fisheries? The case of Norwegian demersal and pelagic fisheries

Fabian Zimmermann[1] and Mikko Heino[1,2,3]

[1]Department of Biology, Box 7803, 5020 Bergen, Norway

[2]Institute of Marine Research, Bergen, Norway, mikko.heino@imr.no

[3]International Institute for Applied Systems Analysis, Laxenburg, Austria

Contact author: Fabian Zimmermann, Department of Biology, University of Bergen, Box 7803, 5020 Bergen, Norway, fabian.zimmermann@bio.uib.no

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Abstract

It is commonly acknowledged that body weight of fish is a key factor in determining market value of landed catch, thus influencing optimal harvest strategies. However, in management strategy evaluations and bioeconomic modelling body size is often an overlooked economic parameter, and there are no systematic studies on prevalence of size-dependent pricing. Here we assess the presence and magnitude of size-dependent pricing in ex-vessel prices of fish in Norwegian fisheries. The data encompass landings of four pelagic and four demersal stocks in Norway in 2000–2010. Linear mixed models and generalized additive models were used to determine the dependence of unit price on weight class as well as on total yield and time (year). The results show a significant positive relationship between weight class and price for seven out of the eight examined fish stocks. The relative effect of body weight on price was the strongest for cod, Greenland halibut, Norwegian spring-spawning herring and mackerel, lesser for North Sea herring and saithe, and negligible for horse mackerel. These findings demonstrate that size-dependent pricing is common in Norwegian fisheries, and is therefore of high relevance for resource economics and fisheries management.

Introduction

Fish body size affects the economic value of catch in most fisheries, typically showing a positive relationship between the weight of fish and price per weight unit. Size-dependent pricing has been described as a common phenomenon in Northern European markets (Gulland, 1982) and highlighted as a relevant factor in fisheries management (Hilborn and Walters, 1992). Smith and Gopalakrishnan (2010) present a list of examples for size-dependent pricing, covering several fisheries in different countries. Additionally, several studies have analysed the role of size and other attributes like quality, gear and origin in price formation (McConnell and Strand, 2000; Kristofersson and Rickertsen, 2004; Asche and Guillen, 2012). However, in spite of the evidence for the relevance of size-dependent pricing and indications for its widespread prevalence, we are aware of no systematic analysis of the prevalence and magnitude of size-dependent pricing.

Here we evaluate price data from Norwegian fisheries to determine the relationship between average body size and unit price. We analyse landings data for Atlantic herring (*Clupea harengus*), Atlantic mackerel *(Scomber scombrus*), Atlantic horse mackerel (*Trachurus trachurus*), Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus),* Greenland halibut (*Reinhardtius hippoglossoides)* and saithe (*Pollachius virens*). Taken together, these seven species dominate Norwegian fisheries in terms of landings and revenues; they have been responsible for 60% of the annual total landings in 2001–2011 (on average 1.5 million tons per year) and 77% of the total economic value (9.13 billion NOK, or approximately 1.2 billion EUR per year (Norwegian Fisheries Directorate, 2012). All these stocks are assessed by the International Council for the Exploration of the Sea (ICES, 2011a; 2011b; 2011c). In the stock assessments as well as in the landings statistics, Atlantic herring is split up into two stocks, North Sea herring and Norwegian spring-spawning herring (NSSH). Atlantic cod in Norway consists of four management units: Norwegian coastal cod north of 62°N, Northeast Arctic (NEA) cod, North Sea cod, and Skagerrak cod. Because catches from other stocks are low compared to NEA cod and the available price data are indiscriminate, we considered all cod as one unit but utilized biological data from NEA cod only. Data for the resulting eight stocks were provided by the Norwegian Fisheries Directorate, containing total annual catch and landed value for each weight class for the period of 2000–2010. Average unit prices per weight class were directly derived from these data, while catch weight distributions from ICES (2011a, b, c) were used to calculate mean weight of each weight class.

Methods

We use price data for Atlantic horse mackerel, Greenland halibut, Northeast Arctic cod, Northeast Atlantic haddock, Northeast Atlantic mackerel, Northeast Atlantic saithe, North Sea herring, and Norwegian spring-spawning herring (NSSH) provided by the Norwegian Fisheries Directorate (P. Sandberg, pers. comm.). The data contain total annual yield and value per weight class for the period 2000–2010 as registered by the sales organizations. Weight classes from sales organizations comprise a range of catch weights, defined through lower and upper boundaries (the latter is not always specified). Different systems of weight classes are sometimes used for a single stock, and these may also have changed over time. Because weight classes are linked to the landing state of fish, the weight classes were converted from product weight to live weight based on the corresponding conversion factor for the specific weight class; results are similar for unconverted weights. We characterize each weight class by its year-specific mean weight. To estimate the mean weight, we assumed a normally distributed weight-at-age with mean as reported in ICES stock assessments (2011a-c) and a coefficient of variation (CV) of 30%. We then multiplied the weight-at-age distribution with age-specific catch numbers (ICES 2011a-c) to obtain total annual weight distributions, from which mean weight for each weight class (defined by their lower and upper boundaries) could be estimated. Our results are insensitive to the exact CV used in the procedure; the value 30% was chosen because it gave weight distributions that looked realistic.

The resulting data of mean weights, average prices and total yield per weight classes and year were used for further analysis. We fitted linear mixed models (Bates and Maechler, 2010) and general additive models (Wood, 2010) in R (R: Development Core Team, 2012), using mean price and mean body weight as the response variable and covariate, respectively. Thus, the statistical models took the form

(1) $$p_i \sim c_0 + c_1 w_i + f(y_i)$$

where p is price of observation i, w_i is the mean weight of the corresponding weight class, and the term $f(y_i)$ corresponds to the effect of year, treated either as a random effect or as a smooth term. Because landings corresponding to each weight class varied dramatically, sometimes by several orders of magnitude, we used log-transformed total annual yield per weight class as the statistical weighting factor in the above models. Alternatively, to test the sensitivity of the results, we did not apply any weighting but excluded data corresponding to the lowest 10% quantile of annual yield, so that observations corresponding to very low yields would not influence the results. All models were fitted independently to each stock.

To make results for different stocks easier to compare, we considered a number of ways of standardizing the price-weight relationships. Change in price was expressed in either absolute units or relative to the mean price for a species. Change in weight was expressed in either absolute units or relative to mean or standard deviation of weight class.

Results

Mean price is significantly ($p < 0.05$) influenced by mean weight per weight class for all analysed stocks except horse mackerel ($p = 0.37$) (Fig. 1). The overall model fits are good, and they explain a non-negligible proportion of deviance. In absolute terms, the increase of price per weight unit is highest for mackerel, being almost 20 NOK•kg^{-1} (about 2.6 EUR•kg^{-1}), while the weight-dependent pricing appears to be of modest magnitude for cod and saithe (Table 1).

Comparing size-dependent pricing across species with very different body sizes can be misleading. To make the size effects more comparable, we standardize them with respect to either stock-specific mean weight or standard deviation of weight (Fig. 2). Indeed, standardisation of weight-dependent price-effects yields a different picture about their relative strengths across the stocks (Table 1). When the size effect is measured relative to the standard deviation of weight, Greenland halibut displays the strongest effect. Standardized with mean weight, Greenland halibut is second only to mackerel. The strong absolute size effect seen in mackerel is carried over to standardized size effects; whether Greenland halibut or mackerel shows the strongest size dependence depends on which standardisation is applied (Table 1). Standardized values reveal considerable price increases also for cod and haddock, while the two herring stocks show weaker, though for Norwegian spring-spawning herring still non-negligible, size dependence. Saithe continues to suggest a weak price premium of weight, and the negligible size dependence for horse mackerel also applies for relative price effects.

Comparisons are also influenced by differences in overall price level. Relative price increase in respect to overall mean price (weighted by log-transformed total yield per weight class) underlines the previous finding that mackerel shows a strong size-dependence (Fig. 2). However, the strong absolute price increase in Greenland halibut does not appear strong when seen relative to the generally high price per weight unit for this species, while Norwegian spring-spawning herring emerges as a stock with strong relative size-dependence.

Prices show fluctuations between years, and these are significant for all stocks, irrespective whether explanatory term ‘year’ was treated as random effect or smooth term. As random effect, year displays fluctuations without clear trends (Fig. 3). Yearly anomalies show common patterns that suggest commonalities in price development between several stocks in specific periods, in particular for pelagic stock between 2004 and 2010. However, owing to short time series, correlations are mostly not significant (Table 2), even when not correcting for multiple comparisons. The exceptions are haddock and saithe as well as the North Sea herring with horse mackerel; both pairs show positive associations.

Discussion

Size or weight structures in prices of fish are common in most commercial fisheries. The reasons for such size-dependent pricing are related to quality attributes, market preferences, or processing issues. For instance, fillet yield can increase with increasing body size (Bosworth et al., 1998; Einen et al., 1999), and consumers may prefer large fillet sizes or high or low fat content (Carroll et al., 2001). Similarly, size is often connected to the end use, particularly when catch is divided between human consumption and fish meal/oil. Additionally, prices may be influenced by supply effects: within each species, big fish tend to be scarce, potentially making them more desirable, and thus, more valuable. Previous analyses of prices of tuna in Hawaii (McConnell and Strand, 2000), Icelandic cod trade (Kristofersson and Rickertsen, 2004) and Spanish hake market (Asche and Guillen, 2012) found higher prices for larger fish, identifying size as one major determinant of fish prices along with other factors like origin, quality and state. The goal of this study was therefore to complement the existing literature on size-dependent pricing with a systematic assessment of its prevalence and significance in commercial fisheries in Norway.

Although the causes of size-dependent pricing are multifaceted, there is widespread theoretic recognition that size-dependent pricing is relevant for harvest optimization (Hilborn and Walters, 1992). Several studies have analysed the impact of size-dependent pricing in generic models (Tahvonen, 2009; Smith and Gopalakrishnan, 2010; Zimmermann et al., 2011b; Skonhoft et al., 2012) or simulations of specific fisheries (Gallagher et al., 2004; Holland et al., 2005; Zimmermann et al., 2011a; Cardinale and Hjelm, 2012). For example, Tahvonen (2009) demonstrated how positively (negatively) size-dependent pricing shifts the biomass maximizing revenues to lower (higher) levels. Zimmermann et al. (2011b) expanded this result to influences of size-dependent pricing on optimal paths. Smith and Gopalakrishnan

(2010) presented evidence that size-dependent pricing is common and acts as an incentive for high-grading in ITQ-regulated fisheries. Gallagher et al. (2004) and Holland et al. (2005) evaluated the influence of a few alternative price regimes on optimal management of Oregon ocean shrimp (*Pandalus jordani*) and Southern rock lobster (*Jasus edwardsii*), respectively. Similarly, Cardinale and Hjelm (2012) showed for Eastern Baltic cod that the consideration of size-dependent prices (based on Swedish price data) could attenuate short-term economic losses in transition to optimal size-selectivity and increase expected long-term gains. Zimmermann et al. (2011a) approximated linear price-weight relationships for Northeast Atlantic mackerel *(Scomber scombrus*) and Norwegian spring spawning herring (*Clupea harengus*), based on the same data as analysed in this study, to demonstrate how increasing size dependence of prices decrease optimal fishing mortality and influence the resulting net present value. Additionally, the occurrence of size-dependent pricing and its influence on optimal management has also been examined in aquaculture (Bjørndal, 1988; Asche and Guttormsen, 2001).

Our study empirically substantiates the postulate that size-dependent pricing is widespread and of significant magnitude. The results show that in seven out of eight examined fish stocks there is a statistically and economically significant positive relationship between weight and unit price. The lack of size-dependent pricing for horse mackerel can be explained by its main use as fish meal and oil. Likewise, differences in size dependence between similar species can be interpreted as differences in their main use (e.g. there is a premium market for cod filets while saithe is mainly sold as processed low-price product). These patterns support the assumption that the usage of the fish and its end market are driving differences in size-dependent pricing.

Due to the short time series, we found few significant temporal correlations in price between the stocks. However, the temporal patterns suggest that simultaneous price changes might be more common. This could be expected considering that fish markets are increasingly integrated on a regional or even global scale (Asche et al., 2002; Asche et al., 2004; Tveterås et al., 2012).

Our results underline the importance of size-dependent pricing for optimal harvest strategies and therefore management decisions, as described in previous studies. The price premium of size complements the biological importance of big fish for stock productivity (Berkeley et al., 2004; Birkeland and Dayton, 2005; Francis et al., 2007) and economically optimal fishing (Tahvonen, 2008; Diekert et al., 2010). Therefore, with size-dependent pricing the market indirectly mirrors the general valuation of fish size in fisheries, suggesting that to avoid mismanagement and rent dissipation, policy decisions should more explicitly consider this aspect.

The results of our study might be influenced by choice of stocks, data quality and incomplete information with regard to price formation. Data collection is conducted directly through the sales organizations; therefore we cannot evaluate their accurateness and overall quality. Additional information regarding the state of the fish, purpose, landing port or other factors that could influence the price would be desirable but are currently not available. These factors will add noise to our results, but they are unlikely to introduce significant bias. Furthermore, ex-vessel prices in Norwegian fisheries are not entirely formed in a free market but are restricted by weight categories in use and minimum prices set by the sales organizations. We have no information how often minimum prices were constraining actual prices, but the high variability of ex-vessel prices suggests that this was not very frequent.

The specific stocks we studied were determined by the data made available by the Norwegian Fisheries Directorate. Of the high-volume fisheries in Norway, we did not have data from blue whiting and capelin. Presumably, these species show weakly size-dependent pricing because they are mostly destined as fish meal and oil. On the other hand, there is a large number of demersal fish species for which we do not have data but which probably show positively size-dependent pricing as their destined for human consumption. Thus, we consider that inclusion of more species would not change the conclusion that size-dependent pricing is common.

In summary, this study demonstrates a high prevalence of size-dependent pricing in major Norwegian fisheries. In seven out of eight cases we show that this relationship is statistically significant, positive, and is thus an important factor in price formation. Our results quantitatively confirm the common assumption of a positive relationship between catch weight and price. These findings are of great practical relevance because size-dependent pricing influences optimal harvesting and therefore management strategies. Because the analysed fisheries encompass demersal and pelagic species and diverse market positioning of their products, we believe that our qualitative results are representative for industrial-scale fisheries in developed countries. We nevertheless recommend an extension of the analysis to further fisheries and other countries to better understand the prevalence and strength of size-dependent pricing more widely.

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Table 1: Mean price, and price increase per weight unit in actual values, standardized by mean weight and standardized by standard deviation of weight, as estimated with general additive models weighted by logarithm of yield (a), or unweighted but with the lowest 10% quantile of yield excluded (b). NSS herring = Norwegian spring-spawning herring.

Stock	**Mean price (NOK/kg)**		**Actual price increase (NOK/kg)**	
	a	b	a	b
Cod	17.15 ±7.49	17.78 ±8.11	0.46 ±0.09	0.53 ±0.10
Haddock	10.54 ±4.49	10.49 ±4.66	2.40 ±0.3	3.02 ±0.43
Saithe	4.85 ±2.21	4.85 ±2.14	0.23 ±0.04	0.26 ±0.04
Greenland halibut	22.58 ±7.92	22.67 ±8.26	2.48 ±0.20	2.48 ±0.21
Mackerel	8.46 ±3.49	4.26 ±1.68	18.41 ±1.74	19.87 ±1.53
Horse mackerel	4.32 ±1.69	4.42 ±1.65	1.68 ±1.85	1.21 ±2.16
NSS herring	2.57 ±1.23	2.72 ±1.20	9.13 ±0.53	8.77 ±0.55
North Sea herring	2.80 ±0.88	2.79 ±0.71	4.35 ±0.87	3.75 ±0.77
	Standardized by mean(w) (NOK)		**Standardized by stdev(w) (NOK)**	
	a	b	a	b
Cod	2.18 ±0.44	2.48 ±0.49	1.92 ±0.30	1.97 ±0.39
Haddock	3.55 ±0.54	4.26 ±0.60	2.17 ±0.33	2.34 ±0.33
Saithe	0.72 ±0.14	0.81 ±0.13	0.56 ±0.11	0.63 ±0.10
Greenland halibut	6.82 ±0.56	6.85 ±0.59	5.29 ±0.43	5.12 ±0.44
Mackerel	8.70 ±0.84	8.87 ±0.68	2.23 ±0.39	2.28 ±0.18
Horse mackerel	0.50 ±0.54	0.40 ±0.71	0.24 ±0.26	0.16 ±0.28
NSS herring	2.40 ±0.14	2.31 ±0.14	1.2 ±0.06	0.98 ± 0.06
North Sea herring	0.96 ±0.19	0.83 ±0.17	0.40 ±0.08	0.35 ±0.07

Table 2: The correlations (white) and correlations of detrended (i.e., after removing linear time trend; grey) time series of yearly anomalies in price for all stocks. Significant correlations ($p < 0.05$) are shown in bold, and marginally significant correlations ($0.05 \leq p < 0.10$) in italics.

	Atlantic cod	Haddock	Saithe	Greenland halibut	Atlantic mackerel	NSS herring	North Sea herring	Horse mackerel
Atlantic cod		0.213	0.308	-0.120	*0.581*	-0.093	0.119	0.299
Haddock	-0.037		**0.844**	0.272	0.013	-0.065	-0.204	0.464
Saithe	-0.149	**0.854**		0.423	0.294	-0.103	-0.152	*0.585*
Greenland halibut	-0.295	0.172	0.367		0.138	-0.116	-0.195	0.435
Atlantic mackerel	0.382	-0.520	*-0.569*	-0.060		0.256	0.094	0.293
NSS herring	-0.024	0.007	0.019	-0.082	0.502		*0.539*	0.133
North Sea herring	0.215	-0.160	-0.075	-0.167	0.264	*0.530*		*0.563*
Horse mackerel	0.122	0.331	0.466	0.373	0.013	0.214	**0.684**	

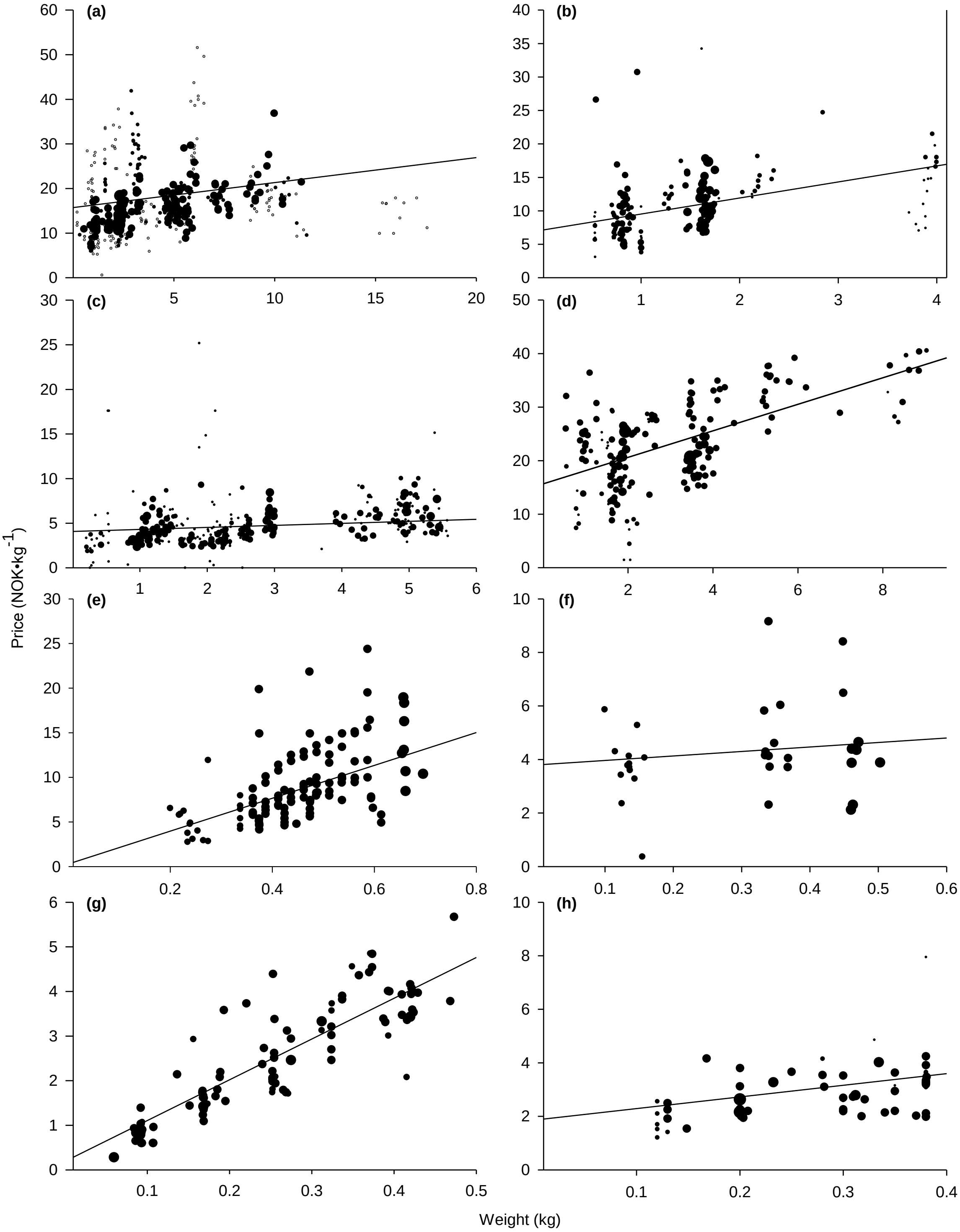

Figure 1: Annual average prices per mean weight class in 2000–2010 for Atlantic cod (a), haddock (b), saithe (c), Greenland halibut (d), Atlantic mackerel (e), horse mackerel (f), Norwegian spring-spawning herring (g), and North Sea herring (h). Regression lines show fits of general additive models, which indicate a significant relationship (p < 0.05) between weight and price for all stocks except horse mackerel (p = 0.37) (f). Year is used as a smooth term and data are weighted by log-transformed total yield per weight class. Relative dot size

in the plot represent weighting by total yield per weight class, distributed into five groups (group 1< 0.1% <group 2 < 1% <group 3 < 50% < group 4 < 90% < group 5 of maximum total yield per weight class). The data are provided by the Norwegian Fisheries Directorate (Per Sandberg, personal communication).

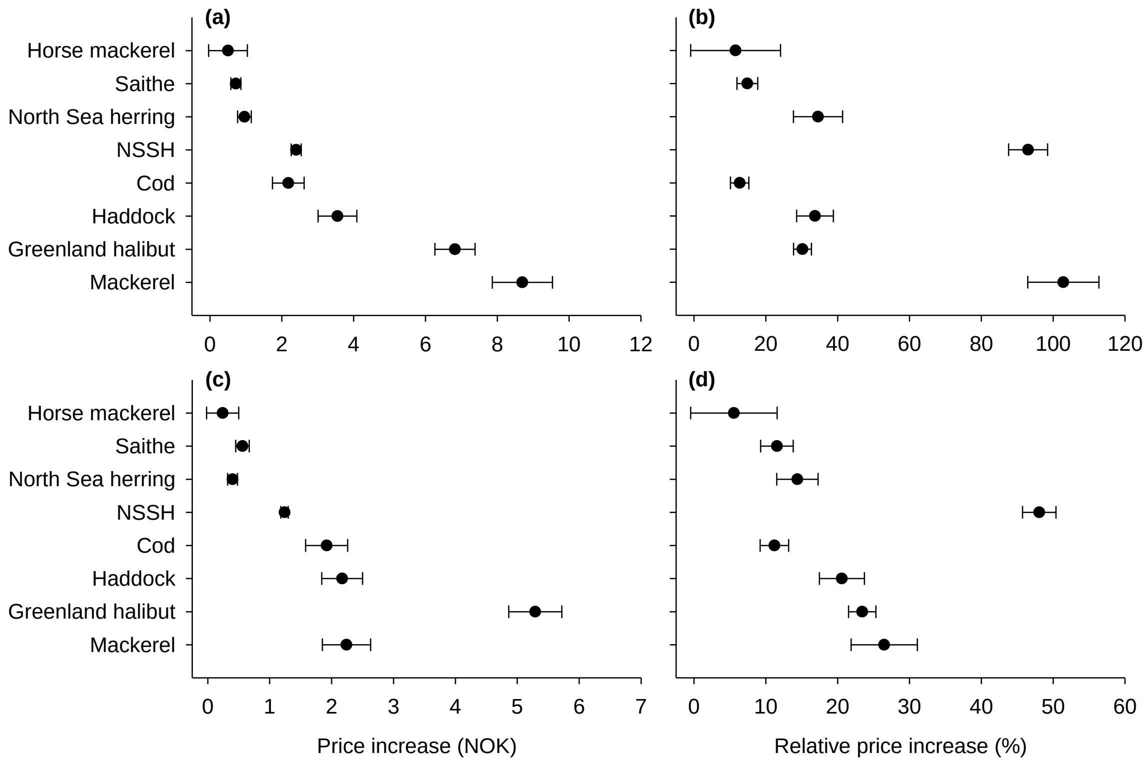

Figure 2: Average price increase and standard error in Norwegian kroner (NOK) for all stocks standardized by mean weight (a) or by standard deviation of weight (c), and the corresponding relative price increase (%) and standard error in percentage of mean price (b, d). Price increase was estimated with general additive models, with price data weighted by log-transformed total yield per weight class and year used as a smooth term. Relative price increase is expressed relative to overall mean price, weighted by log-transformed total yield.

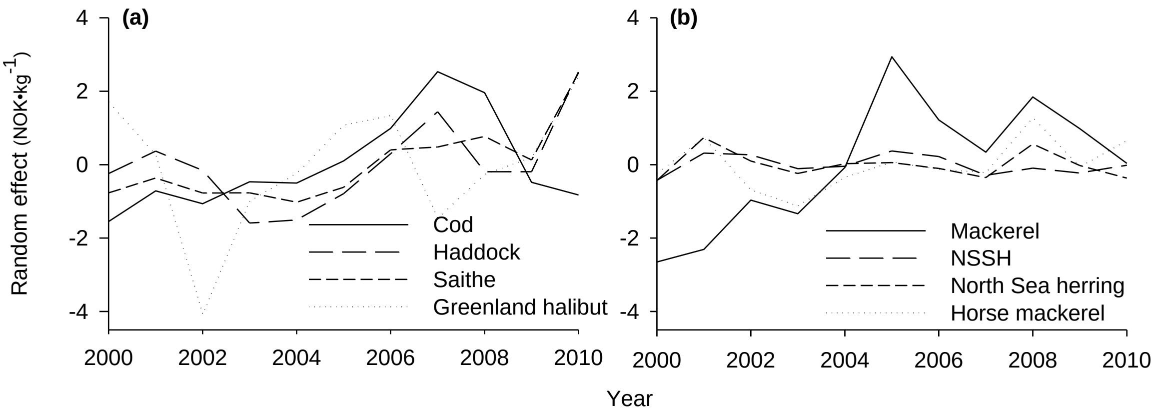

Figure 3: Temporal patterns in price as illustrated by linear mixed models regressing price against weight, with 'year' as a random intercept and weighted by log-transformed total yield. For clarity, demersal (a) and pelagic stocks (b) are illustrated separately. In all cases the random effects are significant ($p < 0.05$).