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Product differentiation and dynamics of cost pass-through in the German fish market: An error-correction-distance measure approach

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ABSTRACT

Product differentiation is an important tool to target different consumer groups and to generate price premiums for different commodities. Product differentiation affects the level of competition, consumer costs and can alter the dynamics of cost pass-through. In this study, we focus on the natural differences in nutritional levels (omega-3, fats, proteins, vitamins) across fish species to differentiate fish products. We model and test the importance of nutritional differences as an explanatory factor in the dynamics of cost pass-through for different fish species in the German retail frozen fillet market. We combine a large consumer panel of fish purchases at the retail level with trade data on fish import prices covering the period January 2006 to December 2010. A distance measure is used to aggregate over product nutrients. Combining the distance measure within an error-correction equation shows that cost pass-through is (statistically) negatively correlated with the degree of product differentiation. Commodity differentiation matters in the dynamics of convergence to equilibrium.

1. Introduction

The dynamics of cost pass-through are important in characterizing market efficiency and setting the retail price schedule. Delayed or incomplete cost pass-through is related to imperfect competition (Borenstein et al., 2000; Gopinath et al., 2011), menu costs (Levy et al., 1997; Dutta et al., 1999), and consumer search costs (Tappata, 2009; Cabral and Fishman, 2012). In the food sector, retail prices are further influenced by product differentiation on branding, nutritional qualities, taste and product form (Carlton, 1979; Tirole, 1988; Blinder et al., 1998). Product differentiation impacts the level of competition and consumer costs, and thus can impact cost pass through.[1] Product differentiation and cost pass-through are related issues and have received considerable attention in the literature (Bulow and Pfleiderer, 1983; Eaton and Lipsey, 1989; Kate and Niels, 2005). Yet, there are very few papers in the literature that actually address the issue of product differentiation on dynamics of cost pass through, with Loy and Weiss (2019) as one exception.

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[1] By responding to the diversity of consumers' taste preferences, product differentiation is argued to stimulate demand and to generate price premiums (Wirthgen, 2005; Richards et al., 2013; Asche and Bronnmann, 2017).

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Our interest here is to enquire as to the importance of product differentiation over nutrient content impacting the dynamics of cost pass-through for different fish species in the German retail frozen fish market.[2] Specifically, in this paper, we formally model and test the importance of nutritional product differentiation as an explanatory factor of differences in dynamics of cost pass-through across different fish species. Product differentiation across fish species is measured on nutritional attributes; omega-3[3], fats, proteins and vitamins.[4] We assume that differences in nutritional attributes affects health choices, increases taste variety and influences intra-category pricing.[5] Empirical modelling is carried out within an error-correction framework employing a distance measure based on Euclidian space and compares different products by measuring distances across attributes of products. The sum of these pair-wise distances of product attributes is used as a measure of product differentiation in estimation and testing. Empirical application is carried out using a large consumer dataset of household purchases of frozen fish fillets in Germany combined with trade data on fish import prices covering the period January 2006 to December 2010. From this data, a panel of eight fish species is defined over monthly import and retail prices for the period January 2006 to December 2010.

The contribution of the paper is three-fold; first, an empirical contribution to model and test the impact of product differentiation on the dynamics of cost pass through. An important dimension is that product differentiation is defined over product attributes and to our knowledge the first paper to make this contribution.

Second, we investigate nutritional content of fish as a natural form of product differentiation. Marketing people can exploit differences in nutritional content to their advantage. At the retail level, the introduction of new fish species and dropping others alters the placement in attribute space of all fish species and therefore not only influences own-price dynamics but also all other price dynamics. In addition, at the production stage, possibilities exist to alter nutritional levels for specific fish species. With the increasing importance of farmed fish (salmon in the data examined here) it is possible to alter nutritional levels by changing feed inputs; currently, vegetable meal is a substitute for fish meal as feed input for farmed salmon. It is less expensive to feed vegetable meal but it changes the Omega 3 content and, thus, impacts the dynamics of cost pass through.

Third, the paper is similar to Loy and Weiss (2019) but the distance measure used is different yet we get similar results for the dynamics of cost pass through. This provides additional empirical support for the importance of product differentiation on dynamics of cost pass through.

The paper is based on two strands of literature; first, is modelling and measuring price links in domestic and international product supply chains at different nodes with the purpose of measuring incomplete price transmission and feedback effects. Second, is modelling and measuring product differentiation, controlling for the serious challenge of dimensionality increasing with product heterogeneity.

There is a large literature modelling price links in the supply chain for different commodities for both domestic and international markets (Richardson, 1978; Goodwin and Holt, 1999). The modern approach to modelling price links relies on time series techniques of cointegration in order to correctly model the stochastic properties of the price variables of interest and account for endogeneity, which plagued early empirical attempts (see Asche et al., 2007; Bronnmann et al., 2016 [6]). Some recent examples that follow this modelling procedure are Gordon and Maurice (2015) that investigate horizontal and vertical price transmission in the fish supply chain for Uganda; Singh (2016) that tests cross-commodity price transmission for 13 salmon products imported in the U.S. market; and Landazuri-Tveteraas et al. (2018) that study price leadership and pass-through for retail salmon products in France and UK. Of particular interest to this study is Ankamah-Yeboah and Bronnmann (2017) showing strong evidence that price transmission varies by fish species and retailer.

Modelling product differentiation directly in a demand system is possible but restricted because of dimensionality limitations. Nevertheless, Kim and Cotterill (2008) use this direct method within a structural model defined on product characteristics for the U.S. processed cheese market. A more flexible approach is based on early work by Lancaster (1966) where hedonic price analysis is used to model the price of a commodity directly as the sum of product characteristics (Waugh, 1924; Chang et al., 2010; Bronnmann and Asche, 2016). This approach assumes consumers optimize utility over product characteristics. An extension to this procedure, random utility modelling based on revealed choice theory of McFadden (1974) models product differentiation in a discrete choice setting. Consumers are assumed to choose the product that maximizes utility amongst a choice set, with utility defined as a function of product characteristics. In an interesting contribution, Berry et al. (1995) introduced the random parameter approach to investigate consumer preferences based not only on attributes of the own-product but also competitors' products.

An alternative approach is presented in Pinske et al. (2002) and Pinske and Slade (2004) where a multidimensional distance measure approach is employed to model product differentiation. Rojas (2008) is an early application of this method estimating advertising substitution patterns for the U.S. beer market. Rojas and Peterson (2008) made further inroads in the U.S. beer market using a distance measure approach within an AIDS modelling framework. Bonanno (2012) also followed this technique using a multidimensional measure of product differentiation for the Italian yoghurt market.

Our summary of the literature and prior understanding leads us to hypothesize that greater commodity differentiation impedes cost

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[2] In the seafood market, fish is an excellent source of low-fat protein, vitamin b12 and omega-3, and has positive health benefits (Perk et al., 2012; Kornitzer, 2001).

[3] Omega-3 is measured by the level of EPA and DHA fatty acids.

[4] The market does differentiate fish in terms of fresh or frozen ready to cook, or prepared products, or labelling to target specific consumer groups but, in this study, we focus on the natural and inherent differences that differentiate fish species.

[5] Consumption trends show consumers are concerned with the ingredients and nutritional attributes of food commodities (Verbeke and Viaene, 1999; Verbeke and Vackier, 2005; Turan et al., 2006; Pieniak et al., 2008; Lappo et al., 2015).

[6] And references in, Gordon et al. (1993), Asche et al. (2004), Nielsen (2005), Asche et al. (2007).

pass-through and slows the adjustment process.

There is broad consensus in the retail pricing literature, that consumers prefer stable over volatile prices. Regular customers are important to retailers and frequently fluctuating prices can lead to a loss of consumer goodwill (Blinder et al., 1998 p. 149). Stable prices (despite fluctuations of the underlying market fundamentals) may be interpreted as implicit contracts between retailers and consumers (Okun, 1981).[7] Borenstein and Shepard (2002) argue that delayed cost pass-through for more differentiated products is related to the effect of reduced competition. Product differentiation and consumer search costs are closely related: consumer search costs (switching costs) increase in the degree of product differentiation within a given category. What is more, cost pass-through rates depends on consumer search costs (Loy et al., 2015; Richards et al., 2014). The distance measure in our study may therefore serve as a proxy of search costs.

Following the framework of attribute search (Richards et al., 2017), search intensity "represents the level of effort spent searching for desired attribute combinations". Search intensity decreases with product variety because the marginal cost of attribute search increases and consumers are more likely to find products that match their taste. The underlying process is that product variety changes the distance in attribute space between products. A wider product assortment represents a market structure with less differentiated products. Note that in the model, products are symmetrically placed on a unit circle. Therefore, consumer matching cost is a function of the number of products, which is merely a simplifying assumption. In general, market structure does not depend on the number of products but rather on product variety (or the level of product differentiation). Our measure of product differentiation, i.e. the sum of differences in attribute space maps each product in attribute space. Larger values represent more differentiated products that are located farther apart from all other products in attribute space. Switching from one product to another is more costly because searching for the next best attribute combination is larger. Therefore, the distance measure in our study may be interpreted as a proxy of consumer (attribute) search cost, which is in turn inversely related to consumer search intensity.

It is important to point out that it is not necessary to cover all attributes nor all species to state our case. Modelling imposes an ordering in pass-through rates based on the defined sample. This ordering is according to the sum of differences in product attributes. Empirically, this ordering has explanatory power in explaining heterogeneity in pass-through rates. We theoretically link the sum of differences in product attributes to consumer's ability to substitute with another product and call this measure product differentiation. The inclusion or exclusion of a species changes the ordering of pass-through rates and the distance measure. We assume that product differentiation, i.e. the sum of differences in product attributes, relates to the consumers ability to substitute the product with another product shaping the aggregated demand function under investigation. Thus, our argument is about cross-sectional correlation in pass-through rates. In other words, we should always observe this cross correlation as long as the sample is large enough. With hypothesis testing, we abstract from the sample and state that this correlation should hold for the data generating process under investigation.

The research here builds on this literature with an empirical contribution to model and test the impact of product differentiation on the dynamics of cost pass through across fish species in the German fish market. The paper is organized as follows. The next section describes the German fish market and provides a summary description of the data used in estimation. This is followed by an outline of the methods and tests used in empirical application. Next, empirical and testing results are reported for the multidimensional distance measure and the error-correction model. The empirical results are used to simulate the dynamics of cost pass through based on degree of product differentiation. The final section offers summary comments.

2. The German fish market and data evaluation

Germany is a relatively small fishing nation but is an important participant in trade of seafood products. As a net importer of seafood, Germany is the fourth largest by value in the EU.[8] In 2015, imports of seafood made up approximately 87% of total fish supply to the country. Major fish exporters to Germany include Poland, Netherlands, Norway, Denmark and China. It seems reasonable then, that a natural starting point for an investigation of the German seafood supply chain is the relationship between retail and import prices.

German consumers purchase large quantities of frozen fish, fish preserves and marinades followed by crustaceans, smoked fish and fresh fish. Per capita consumption of seafood is about 14.1 kg per annum, below the world average consumption of 21.8 kg per annum (FAO, 2016). As such, there is potential for market growth.[9] The top four consumed fish species in Germany include salmon the leading species with 21% of total consumption, followed by Alaska pollock (18%), herring (16%), and tuna (14%). More than half of seafood purchases are from supermarkets and discount outlets that lack fresh fish counters (Destatis, 2016); this perhaps explains to some degree the large purchases of frozen fish, preserves and marinades by the German consumer.

The import and retail prices of frozen fish fillets are used in empirical work. The species chosen for investigation are based on product form availability (this excluded herring), a market share greater than 5%, and representation of both high- and low-valued species. The fish species used in analysis cover almost 82% of German fish consumption and includes cod (*Gadus morhua, Gadus ogac and Gadus Macrocephalus*), saithe (*Pollachius virens*), Alaska pollock (*Theragra chalcogramma*), redfish (*Sebastes spp.*), tuna (*Thunnus albacares*), plaice (*Pleuronectes platessa*), hake (*Merluccius spp.*) and salmon (*Salmo salar and Onorhynchus spp.*). The price data represent monthly

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[7] The observation that firms partially and temporally offset input price changes is also known in the exchange rate pass-through literature as pricing to market (Knetter, 1993).

[8] In 2014, Germany imported EUR 1.48 billion of total EU fish imports of EUR 22.3 billion. In 2017, Germany imported EUR 1.74 billion of total EU fish imports of EUR 25.3 billion; the eight largest importer in the EU 28 (EUMOFA, 2016, 2018).

[9] Increased supplies of seafood are likely to be based on farmed fish. The FAO (2016) reports that current farmed production of fish exceeds wild catches as a source of seafood for human consumption.

averages (€ per kg) for the eight fish[10] species over a 60-month time period (January 2006 to December 2010).

Consumer prices are collected for 17 retail brands sold in 9 retail outlets as reported in the Consumer Scan Household panel data set (Gesellschaft für Konsumforschung (GfK)).[11] The panel data describes point and date of purchase and product characteristics.[12] Product nutritional information is available on product labels and available to consumers.[13] For empirical estimation, household retail (ret) data are aggregated[14] to represent average monthly (t) price per fish species (f) or ($P_{f,t}^{ret}$).

The import price series are taken from the German external trade database (Destatis, 2016) and covers trade at an 8-digit level. Prices are CIF (cost, insurance, freight) and are obtained by dividing the imported value by the imported quantity. Import (imp) prices are recorded on a monthly basis by fish species or ($P_{f,t}^{imp}$).

To show variation in prices across fish species at both the retail and import level, Table 1 reports real summary values over the period 2006–2010.[15] The sample covers both high-value fish including plaice, farmed salmon, and tuna with retail price greater than 10€/kg and low-value fish like saithe and Alaska Pollock. A more detailed presentation of the data is graphed in Fig. 1 showing monthly retail and import price realizations for each species over time. All series show a slight positive trend and it appears that for each species import and retail prices follow similar trend. However, the graphs make clear that retail prices show substantially greater monthly variation than import prices.[16] Nevertheless, for all fish species we observe good price variation in both retail and import series, important for empirical work to follow.

Our empirical equation is an error-correction model and as such we are interested in measuring the stochastic panel properties of each price series. The purpose of this is to ensure the price series are compatible to initiate statistical testing in an error-correction framework. Here we evaluate the stationary prospects of our panel using two statistics for testing a unit root hypothesis in balanced panels. First, Hardi (2000) is a flexible approach in allowing autocorrelation to vary by panel for testing the null hypothesis that all panels are stationary against an alternative that at least one panel contains a unit root. A Lagrange Multiplier statistic is used in testing. The test is valid for a large time series component relative to the cross-section component.[17]

The second test is a Fisher-type test where the individual Dickey-Fuller statistics obtained for each panel are combined using meta-analysis to generate a powerful test for stationary in the panels. Choi (2001) shows that if the time dimension is large and the number of panels finite[18] the test statistic follows an inverse normal. Choi (2001) defines the test statistic as a 'Z-statistic' and suggests its use based on power and size. The null hypothesis is that all panels have unit root against an alternative that at least some panels are stationary.

The results of the panel stationary tests are reported in Table 2. The results of testing using both procedures cannot reject the conclusion that both retail and import prices are stationary in first differences and this supports statistically our empirical strategy to proceed with estimation and testing in an error-correction framework.

The nutrient content for each fish species is fundamental to the development of the Distance measure index of product differentiation. Nutrient levels for each fish species are reported in Table 3. The nutrient levels included in this study are omega-3 (EPA, DHA), fat, protein, kcal, sodium, potassium, calcium, magnesium, iodine, zinc and vitamin B12. From the table, notice that there is considerable variation in most nutrient levels across fish species. For example, salmon shows substantially higher levels of omega-3 relative to all other species. Whereas, protein levels are similar across species. PL Products' nutritional information is available on the products' label and from in-store visits or website invesigation (Deutsche, 2017).

3. Methods

The empirical investigation will be carried out in two stages; first, define the distance index that measures and aggregates the 'differences' in nutrient levels for each fish species relative to all other fish species and, second, specify the equations that define the error-correction model and test for equilibrium. The purpose of this section is to outline the methods used in each step of the empirical model.

In a general sense, the distance matrix is an aggregator function to combine the different nutrient levels to a single index for comparing across fish species. In setting up the basic structure of the distance index, let n_i^k be the nutrient level k for fish species i. And for this discussion, let $i = 1, 2, 3$ and $k = a, b, c$. With this information define the squared pairwise difference in nutrient values k between species i, j or,

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[10] Salmon is identified in the data set as farmed.

[11] The brands include Tengelmann, Metro, Edeka, Netto, Rewe, Lidl, Aldi, Bofrost, Costa, Eismann, Deutsche See, Femeg, Iglo, Pickenpack, Royal, Greenland, and Paulus. The retail outlets include Tengelmann, Metro, Edeka, Netto, Rewe, Lidl, Aldi, Bofrost, and Eismann. These are the major retail outlets in Germany and account for 80% of the sectors turnover (Bundeskartellamt, 2014).

[12] Based on the European Article Number (EAN) code of each purchase.

[13] One concern is that product attributes may be unobserved or perceived differently by consumers (Ackerberg and Rysman, 2005). In our case, product labelling ensure consumers are aware of nutrient content of fish product and product taste is a sum of different nutrition attributes and is observed by the consumer on consumption.

[14] Incomplete data forces the aggregation to monthly observations.

[15] German CPI retrieved from https://stats.oecd.org/#. Summary statistics by year are reported in Appendix A.

[16] For store level retail data, prices show less variation than wholesale prices; with retail prices showing long periods of stability. However, with aggregation across space and time for 17 retail brands sold in 9 retail outlets we observe increased price variation.

[17] Asymptotically the test is valid under the assumption T→ ∞ followed by N→ ∞.

[18] Choi (2001) suggests that the number of panels should be less than 100.

Table 1
Summary statistics retail and import price €/kg by fish species; 2006–2010.

Mean and (Standard Deviation) Values by Fish Species

Species	Farmed Salmon	Hake	Redfish	Plaice
Retail[a]	12.8	6.69	8.73	11.02
	(1.34)	(1.46)	(0.76)	(0.99)
Import[b]	6.25	2.64	4.36	5.45
	(0.53)	(0.23)	(0.64)	(0.38)

Species	Cod	Alaska Pollock	Tuna	Saithe
Retail	10.67	5.31	11.71	5.69
	(1.56)	(0.57)	(2.46)	(0.44)
Import	4.36	2.47	5.62	2.98
	(0.52)	(0.29)	(1.39)	(0.22)

Minimum and Maximum Values by Fish Species

Species	Farmed Salmon	Hake	Redfish	Plaice
Retail	9.46–15.68	3.10–11.01	7.06–10.79	9.50–13.56
Import	5.12–7.34	2.25–3.29	3.19–5.86	4.58–6.34

Species	Cod	Alaska Pollock	Tuna	Saithe
Retail	7.64–15.54	3.98–6.43	7.84–20.18	4.80–6.50
Import	3.39–5.46	2.03–3.09	3.67–9.53	2.54–3.51

[a] Source: Gesellschaft für Konsumforschung.

[b] Source: German External Trade Database.

$$\left(n_i^k - n_j^k\right)^2 = n_{ij}^k,$$

where, n_{ij}^k is a positive measure of the difference in nutrient value for any two fish species. Calculating this value over all species, for nutrient level k, arrange the squared difference values in matrix notation as,

$$\begin{bmatrix} 0 & n_{12}^k & n_{13}^k \\ n_{12}^k & 0 & n_{23}^k \\ n_{13}^k & n_{23}^k & 0 \end{bmatrix},$$

and summing across columns $= \begin{bmatrix} \sum_j n_{1j}^k \\ \sum_j n_{2j}^k \\ \sum_j n_{3j}^k \end{bmatrix}$.

The summed values are the squared differences in nutrient value k for each fish species relative to all other species. For empirical work, we standardize (*) each value by its mean and standard deviation and define this transformation as $= \begin{bmatrix} x_1^{k*} \\ x_2^{k*} \\ x_3^{k*} \end{bmatrix}$.

Following this procedure for each nutrient level k, we define the distance value for each fish species and each nutrient level as,

$$\begin{bmatrix} n_1^{a*} & n_1^{b*} & n_1^{c*} \\ n_2^{a*} & n_2^{b*} & n_2^{c*} \\ n_3^{a*} & n_3^{b*} & n_3^{c*} \end{bmatrix} \tag{1}$$

Finally, calculating the average of each row in matrix (1), we define the average cumulative distance measure index, Φ_i for each fish species.

$$\begin{bmatrix} \sum_k n_1^{k*}/k \\ \sum_k n_2^{k*}/k \\ \sum_k n_3^{k*}/k \end{bmatrix} = \begin{bmatrix} \Phi_1 \\ \Phi_2 \\ \Phi_3 \end{bmatrix} \tag{2}$$

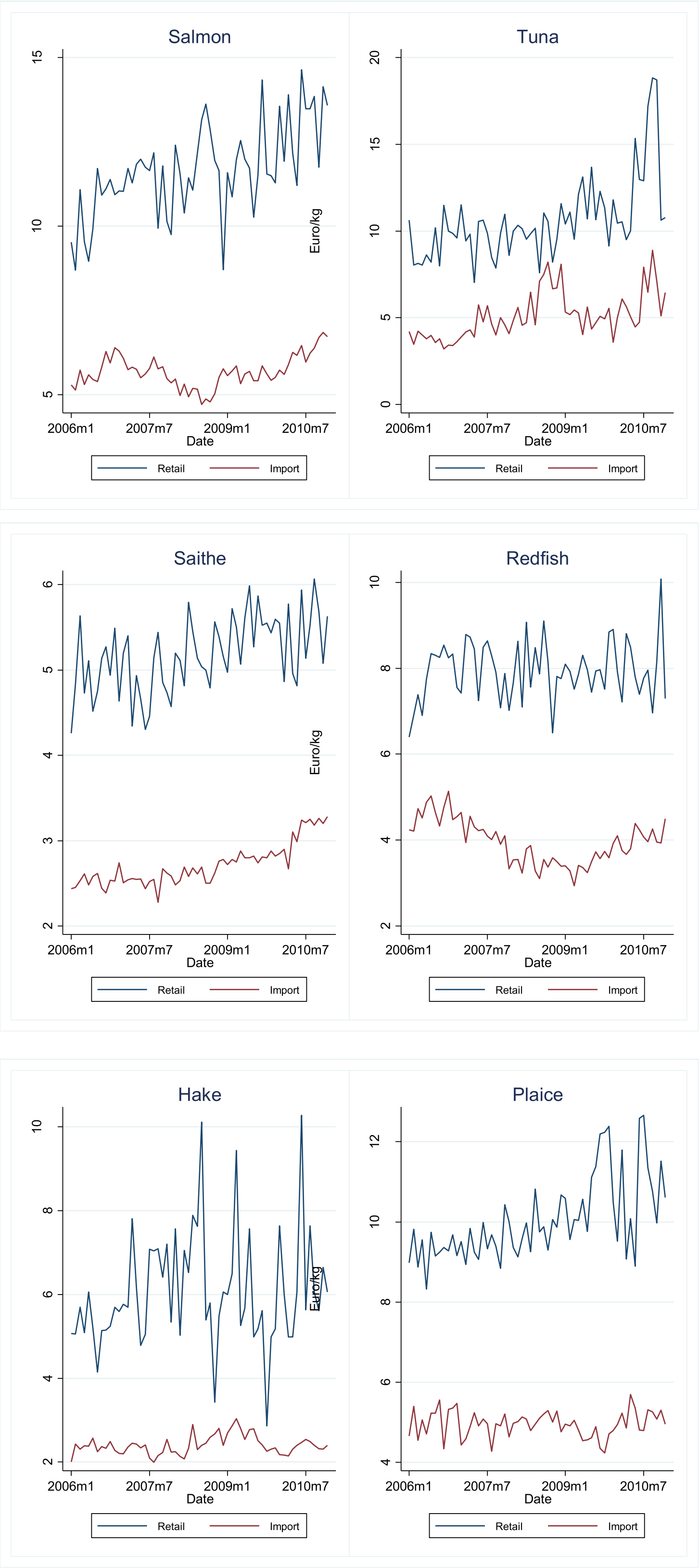

Fig. 1. Monthly retail and import fish prices by species- 2006–2010.

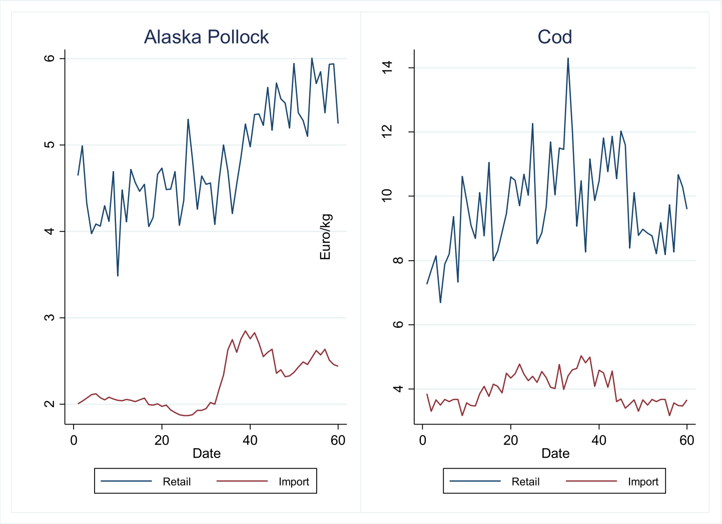

Fig. 1. . (*continued*).

Table 2
Panel unit root tests.

	Hardi[a]	Choi[b]
$P^{ret}_{f,t}$	29.04	−0.56
	(0.000)[c]	(0.71)
$P^{imp}_{f,t}$	33.69	0.26
	(0.002)	(0.40)
$\Delta P^{ret}_{f,t}$	−2.83	10.73
	(0.99)	(0.00)
$\Delta P^{imp}_{f,t}$	−2.71	3.68
	(0.99)	(0.00)

[a] Null of stationary in levels.
[b] Null of stationary in first-differences.
[c] p-values in parentheses.

In empirical application, Φ_i is defined for each of the twelve nutrient levels, for each of the eight fish species examined and used to define the product differentiation variable for specification in the error-correction model.

The price equilibrium relationship motivating the research is a simple bivariate model of the supply chain linking import prices to retail prices in the German fish market. With retail price as the dependent variable[19] this is written as,

$$P^{ret}_{f,t} = \alpha_{0f} + \alpha_{1f} \cdot P^{imp}_{f,t} + \varepsilon_{f,t} \tag{3}$$

where $P^{ret}_{f,t}$ is retail price of fish species f in the t^{th} period and $P^{imp}_{f,t}$ is import price of fish species f, α_{0f} is time invariant unobserved heterogeneity associated with fish species f, and $\varepsilon_{f,t}$ is a stochastic residual term that gathers up all other factors that determine retail price.

In order for equation (3) to represent an equilibrium relationship between prices in the supply chain, $\varepsilon_{f,t}$ must be stationary in distribution. Previously, we observed import and retail prices stationary in first differences (Table 2) and, therefore, it is possible that equation (3) represents a cointegrated system (Engle and Granger, 1987). Westerlund (2007) suggests four panel cointegration tests for a null (H_o) hypothesis of no panel cointegration against either the alternative (H_{a1}) of at least one cointegrating panel or the alternative (H_{a2}) that all panels are cointegrated.[20] Westerlund (2007) shows that each statistic converges to a standard normal distribution and argues that the tests perform well even in small samples. Equation (3) will be tested for cointegration prior to error-correction estimation.

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[19] Retail price as the dependent variable is consistent with the literature, see Asche et al. (2007), Richards et al. (2013), Loy et al. (2015). And, to support this modelling approach, Granger testing suggests import prices are exogenous in a retail/import price bivariate equation (see, Appendix B).
[20] See, Westerlund (2005) for early work on testing panel cointegration.

Table 3
Nutrient Content by Fish Species (per 100 g consumable portion fish).

Nutrient	Farmed Salmon	Hake	Redfish	Plaice
Omega-3				
EPA[b]	593	236	258	249
DHA[b]	1155	443	165	199
Fat[a]	13.6	0.85	3.61	1.9
Protein[a]	19.9	18.4	18.2	17.1
Kcal	202	81	105	86
Sodium[b]	60	75	80	104
Potassium[b]	331	318	308	311
Calcium[b]	16	32	22	61
Magnesium[b]	25	29	29	22
Iodine[c]	34	0	35	53
Zinc[c]	489	785	0	529
Vitamin B12[c]	2.9	0	3.8	1.5

Nutrient	Cod	Alaska Pollock	Tuna	Saithe
Omega-3				
EPA[b]	71	130	10	101
DHA[b]	194	195	65	338
Fat[a]	0.69	0.8	15.5	0.91
Protein[a]	17.7	16.7	24.3	18.3
Kcal	77	74	106	81
Sodium[b]	72	100	43	81
Potassium[b]	340	338	450	374
Calcium[b]	28	8	5	14
Magnesium[b]	24	57	37	0
Iodine[c]	229	103	14	119
Zinc[c]	396	433	500	0
Vitamin B12[c]	1.2	1.2	5.8	3.5

[a] %.
[b] mg.
[c] µg.

The error correction model is particularly well suited for empirical work as it combines long-run equilibrium with short-run price behavior. In other words, in the short run, prices can vary from long-run equilibrium levels but the error correction process forces convergence in the long run. The speed of adjustment in convergence to equilibrium is recovered in estimation. Our strategy is to modify the adjustment parameter to model product differentiation (*pd*) restricting the speed of adjustment. This is a testable hypothesis. For the case at hand, we specify the following panel error correction model,

$$\begin{aligned} \Delta P^{ret}_{f,t} = {} & \beta_{fo} + \sum_{j=1}^{J} \beta_{r_j} \Delta P^{ret}_{f,t-j} + \sum_{k=0}^{K} \beta_{I_k} \Delta P^{imp}_{t-k} + \psi(\gamma) \left(\varepsilon_{f,t-1}\right) + \vartheta_{f,t} \\ \text{and } & \psi_f(\gamma) = \gamma_O + \gamma_{pd}\Phi_f \end{aligned} \tag{4}$$

where Δ represents a first-difference transformation, prices are as previously defined, β_{fo} is the fixed effect for each fish species, $\varepsilon_{f,t-1}$ is the error correction factor[21] defined from equation (3), and $\psi_f(\gamma)$ functionally describes the speed of convergence to long-run equilibrium. The second equation in (4) describes the convergence relationship as a linear function of the product differentiation index. Deviations from the steady state are weighted in terms of perceived distances between competing fish products. If Φ_f is zero, γ_O defines the base reference level defining speed of adjustment to equilibrium. If $\Phi_f > 0$, the speed of adjustment depends on the level of product differentiation by species and defined as $\psi_f(\gamma)$. A null hypothesis of $\gamma_{pd} = 0$ is a test that product differentiation has no effect on speed of adjustment to regain the equilibrium.[22] Or, in other words, the dynamics of cost pass through are not affected by the level of product nutrient differentiation.

4. Empirical results

We first calculate the distance index as outlined in the Methods section. For each nutrient level reported in Table 3, we calculate the squared difference for each pairwise comparison across fish species. Without a clear indication regarding the appropriate functional form for the distance variable we chose to normalize all attribute variables to account for differences in the variance of the original

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[21] In equilibrium, $\varepsilon_{f,t-1}$ takes the value zero, but if the retail price is below the equilibrium the expression is negative and if the price is above the equilibrium the expression is positive; this is what is meant by the short run constrained by long-run equilibrium.

[22] That is, differences in nutrient attributes provide no explanatory power to explain differences in retail price dynamics.

Table 4
Standardized distance values and index of product differentiation.

	EPA[a]	DHA[a]	Fat	Pro[b]	kcal	Sod[c]	Pot[d]	Cal[e]	Mag[f]	Iod[g]	Zinc	B12	Φ_f[h]
Salmon[i]	2.40	2.46	1.11	−0.39	2.47	−0.14	−0.47	−0.47	−0.58	−0.43	−0.71	−0.78	0.89
Redfish	−0.51	−0.33	−0.78	−0.46	−0.45	−0.78	−0.13	−0.58	−0.60	−0.44	1.20	−0.36	0.00
Plaice	−0.53	−0.38	−0.61	−0.21	−0.39	0.92	−0.19	2.40	−0.51	−0.57	−0.58	−0.56	0.24
Cod	−0.21	−0.37	−0.41	−0.38	−0.28	−0.75	−0.52	−0.54	−0.56	2.42	−0.83	−0.38	0.12
Hake	−0.55	−0.43	−0.44	−0.48	−0.33	−0.80	−0.31	−0.42	−0.60	0.06	1.22	0.85	0.16
Tuna	−0.19	−0.12	2.01	2.45	−0.45	1.88	2.45	0.11	−0.38	−0.18	−0.68	2.15	1.05
Saithe	−0.35	−0.43	−0.45	−0.47	−0.33	−0.77	−0.32	−0.41	1.52	−0.36	1.20	−0.55	0.20
Pollack[j]	−0.45	−0.37	−0.43	−0.06	−0.24	0.45	−0.51	−0.10	1.71	−0.51	−0.81	−0.38	0.21

[a] Omega-3.
[b] Protein.
[c] Sodium.
[d] Potassium.
[e] Calcium.
[f] Magnesium.
[g] Iodine.
[h] Index Product Differentiation.
[i] Farmed salmon.
[j] Alaska pollack.

attribute data. This is a simple measure that does not account for consumer perception but is useful for empirical work. We follow this procedure applied to all attributes and obtain a distance vector for each nutrient level. These values are reported in Table 4. Finally, the distance matrix product differentiation index for each fish species is defined as the arithmetic mean across the standardized distance values for each nutrient level. This value is reported in column 13 of Table 4. The base index is defined as the least differentiated species (Redfish) and for empirical interpretation this index value is normalized to zero (i.e., the index is bounded by zero). Notice that tuna and salmon show substantial product differentiation relative to other fish species included in the index.

The empirical identification strategy for econometric estimation is based on three factors; first, we assume the existence of an equilibrium equation combining retail and import prices over the different fish species in a long-run relationship. Empirical testing is used to support this assumption. Second, we assume causality runs from import to retail prices in equilibrium[23] and as such import prices are assumed conditionally independent of residual factors, or $E(\varepsilon|P^{imp}_{f,t}) = 0$, where E(|) is the conditional expectation operator. Again, empirical testing is used to support this assumption.[24] Finally, the product differentiation index is assumed predetermined and independent of residual factors, or $E(\Phi\varepsilon) = 0$.

We first carry out the panel cointegration tests suggested by Westerlund (2007) and outlined in the Methods section. The results of testing are reported in Table 5. For all tests the data reject the null hypothesis of no panel-co-integration at better than 1% significance level for either alternative hypotheses. This provides statistical support for the existence of a long-term equilibrium relationship between retail and import prices as described by equation (3). Based on these results we move on to estimation of the error correction equation under product differentiation.

We assume that all panel units follow the same cost pass-through process and set lag lengths, $J = K = 4$. This choice is motivated by bivariate AIC lag selection criteria, which range between one and four. To be complete, two alternative specifications for robustness in estimation are also considered (reported in Appendix C). However, our main results are robust to lag specification. We estimate in two stages. First, we estimate equation (3) for each fish species individually. By doing so, we allow for individual intercepts (fixed effect, α_{0f}) and long-run cost pass-through parameters (α_{1f}). The purpose of this is to predict the error terms for use in the second-stage error-correction model. We stack the error terms and combined with the full panel data set allows us to estimate a fixed-effect panel error correction model with robust standard errors. Table 6 reports the results of the specifications. As we are particularly interested in the speed of the adjustment parameters we do not report short-run parameters.[25] Recall the adjustment process $\psi_f(\gamma) = \gamma_O + \gamma_{pd}\Phi_f$, where γ_O is the speed of adjustment for the base case[26] (Redfish) and $\gamma_{pd}\Phi_f$ alters the speed of adjustment for the various levels of product differentiation, where γ_O and γ_{pd}, are parameters recovered in estimation.

In testing, the null hypothesis that product differentiation has no effect on speed of adjustment to regain the equilibrium is easily rejected. These test results hold both for the base adjustment parameter and the product differentiation parameter. The results show that the base adjustment parameter γ_O adjusts rapidly accounting for about 62% of the shock in one period. This implies that the market responds quickly to short-run shocks; we suspect that a part of the response is due to the perishable nature of the product, notwithstanding the frozen nature of the product. However, the differences in nutrient level measured by the product differentiation index (Φ_f)

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[23] This assumption is not fundamental to empirical testing but is consistent with the literature and allows for ease of presentation.

[24] Granger causality tests to support the assumption of exogenous import prices are reported in Appendix B.

[25] The complete model under alternative lag specifications is reported in Appendix A. In addition, we evaluate the model under a number of alternative specifications and report these robust results in Appendix D.

[26] The base group is the minimum differentiated species normalized to a lower bound or zero-index value.

Table 5
Westerlund panel cointegration tests.

H_o: no cointegration[a]	Statistic	p-value
H_{a1} : Group mean statistics		
G_τ	−2.02	0.001
G_α	−21.21	0.000
H_{a2} : Panel statistics		
P_τ	−5.79	0.000
P_α	−16.20	0.000

[a] Westerlund argues that for both group and panel statistics the τ statistic has higher power relative to the α statistic.

Table 6
Error correction measuring product differentiation.

Coefficients	Model A	Model B	Model C
γ_O	−0.62***	−0.59***	−0.52***
	(0.07)[a]	(0.10)	(0.12)
γ_{pd}	0.23***	0.30***	0.35***
	(0.06)	(0.08)	(0.10)
constant	0.01***	0.01***	0.02***
	(0.00)	(0.00)	(0.00)
Lags on Retail Price	4	8	12
Lags on Import Price	4	8	12
Obs.	432	408	376
R^2	0.39	0.44	0.47

[a] Robust standard error in parentheses, ***$p < 0.01$.

slows the speed of adjustment substantially with a measured value of $0.23^*\Phi_f$. For the fish species examined here, we measure a speed of adjustment ranging from −0.37 to −0.62 depending on the level of product nutrient differentiation. The results for the adjustment parameters are robust across lag specifications reported in Table 6.

To visualize the importance of product differentiation on dynamics of cost pass through we simulate the error-correction process under alternative degrees of product differentiation. Fig. 2 reports the convergence process for the extreme bounds of the least and most differentiated fish categories, i.e., the base group with a zero-product differentiation index compared to the upper bound or most differentiated product. The way to interpret the figure is that in period 1 the system is shocked by a one unit change in import price (i.e., for each of the base and most differentiated species), next we use the error-correction model to simulate the time path for the system to regain the equilibrium. For the base group, we observe a one period recovery of 63% of the shock and that it takes between 5 and 6 periods for the import price shock to be fully accounted for by the system. On the other hand, the most differentiated product recovers only 37% of the initial import price shock in the first period and requires between 8 and 10 periods to return to equilibrium.

The margin between the groupings is statistically important and shows the dynamic adjustment in cost pass-through for the upper and lower bounds. Visually we observe that convergence under zero product differentiation is complete within 5–6 periods whereas extreme product differentiation requires between 8 and 10 periods for convergence. Finally, and for completeness we graph out in Fig. 3 the full extent of product differentiation showing 8 alternative levels of product differentiation. The purpose of the graph is to clearly show the negative relationship between degree of product differentiation and dynamics of cost pass through.

In summing up, the error-correction results statistically support the conclusion that less differentiated products adjust quicker than highly differentiated products from short-run shocks. Differences in product nutrient attributes explain to some degree intra-category differences in cost-pass through rates.

5. Final comments

Product differentiation is argued to stimulate demand and to generate price premiums. This research investigates the importance of differences in nutrient levels for different fish species as an explanatory factor of differences in the dynamics of cost pass-through. Empirical work is carried for the import/retail fish market in Germany. Studies of cost pass-through and price transmission have focused on economic factors behind differences in estimated price processes. Market power and consumer search costs are the main factors for which theoretical hypotheses have been tested against empirical data (Loy et al., 2015; Richards et al., 2014). There are many definitions of 'pass-through' in price transmission literature. For this study we refer to the rate of pass-through in terms of speed of adjustment toward the long-run equilibrium. We impose an ordering in pass-through rates. This ordering is the sum of differences in product attributes. We find that this ordering has explanatory power in explaining heterogeneity in pass-through rates. We link the sum of differences in product attributes theoretically to the consumer's ability to substitute the product with another product in the categories defined, and we call this measure product differentiation. Consistent with other research (Loy and Weiss, 2019), we find a more sluggish price adjustment for more differentiated products indicating that product differentiation is also significantly related to differences in pass-through rates in the categories defined. Delayed cost pass-through for more differentiated products may be related to the

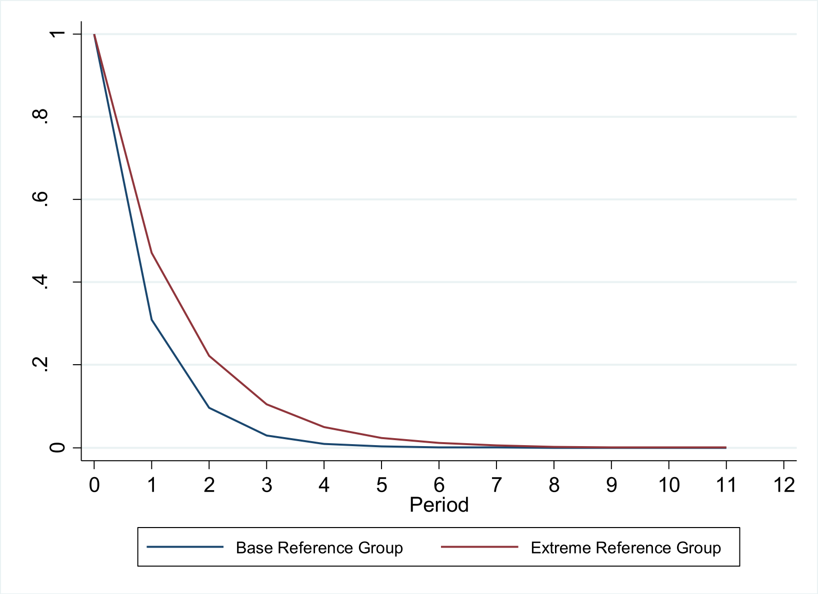

Fig. 2. Convergence process for least and most differentiated categories.

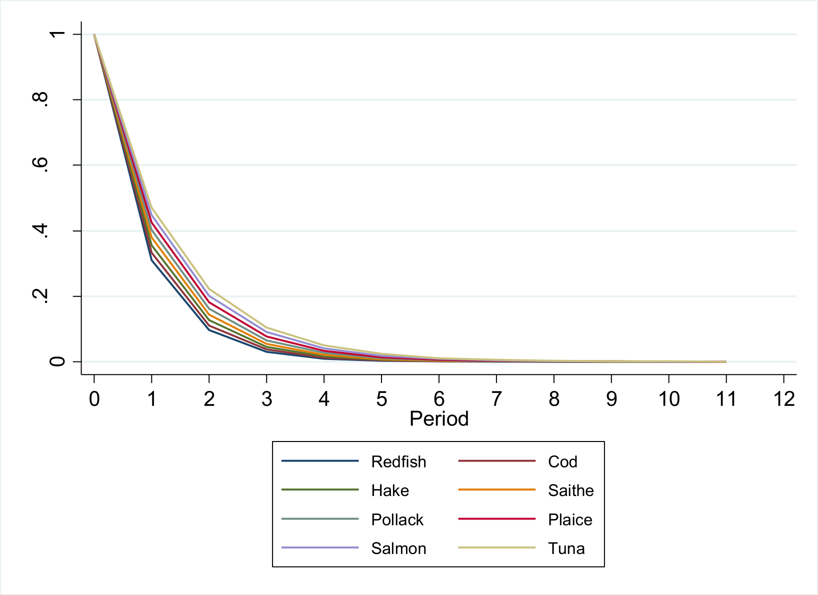

Fig. 3. Convergence process alternative degrees product differentiated categories.

effect of a reduced competition (Borenstein and Shepard, 2002). Richards et al. (2017) develop a model of attribute search that links consumer search intensity to the number of products a retailer stocks in a category predicting a systematic relationship between product variety and attribute search in which consumer search intensity falls with product variety. The distance measure in our study may also interpreted as a proxy negatively related to search intensity.

The dynamics of cost pass-through and implications for retail pricing is not only important to consumers and retailers, but also to manufactures and policy makers. Sluggish price adjustment at the aggregate level plays a key role in determining how monetary shocks or fluctuations in aggregate demand affect economic activity. Rapidly rising food prices in 2001 and in 2007/2008 highlights the importance to consider price transmission dynamics along the value chain.

Further research could investigate systematically the intra-category substitution patterns identified in this research and investigate retailer specific supply chain characteristics and distribution structures for a wider range of goods and markets. A caveat on the research presented here is that possible asymmetries in cost pass-through have not been investigated.

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Appendix A

Annual real summary statistics showing mean and (standard deviation) by species reported in Table A1.

Table A1

Summary Statistics by Year and Species.

	2006	2007	2008	2009	2010
Farmed Salmon					
Retail[a]	11.87	12.55	12.77	12.74	14.07
	(1.16)	(0.94)	(1.43)	(1.07)	(1.15)
Import[b]	6.52	6.39	5.58	6.04	6.69
	(0.49)	(0.25)	(0.35)	(0.18)	(0.42)
Hake					
Retail	6.01	7.01	7.10	6.25	7.07
	(0.54)	(1.08)	(1.85)	(1.72)	(1.55)
Import	2.66	2.54	2.66	2.82	2.49
	(0.16)	(0.18)	(0.27)	(0.27)	(0.13)
Redfish					
Retail	8.83	8.92	8.66	8.69	8.55
	(0.81)	(0.73)	(0.83)	(0.51)	(0.91)
Import	5.27	4.61	3.78	3.76	4.34
	(0.33)	(0.37)	(0.24)	(0.28)	(0.27)
Plaice					
Retail	10.57	1.63	10.65	11.77	11.51
	(0.48)	(0.53)	(0.57)	(1.36)	(1.36)
Import	5.78	5.40	5.48	5.09	5.49
	(0.46)	(0.33)	(0.18)	(0.27)	(0.29)
Cod					
Retail	9.59	10.79	11.76	11.45	9.78
	(1.32)	(1.11)	(1.83)	(1.36)	(0.86)
Import	4.05	4.71	4.80	4.46	3.78
	(0.20)	(0.34)	(0.34)	(0.59)	(0.17)
Alaska Pollock					
Retail	4.87	4.98	4.98	5.70	5.97
	(0.44)	(0.27)	(0.37)	(0.36)	(0.36)
Import	2.35	2.22	2.29	2.83	2.66
	(0.03)	(0.06)	(0.33)	(0.19)	(0.10)
Tuna					
Retail	10.54	10.66	10.73	12.25	14.34
	(1.37)	(1.49)	(1.19)	(1.47)	(3.36)
Import	4.25	5.09	6.80	5.34	6.61
	(0.37)	(0.71)	(1.47)	(0.68)	(1.41)
Saithe					
Retail	5.64	5.39	5.65	5.96	5.81
	(0.46)	(0.43)	(0.32)	(0.32)	(0.46)
Import	2.88	2.82	2.84	3.03	3.31
	(0.11)	(0.11)	(0.11)	(0.05)	(0.21)

[a] Source: Gesellschaft für Konsumforschung

[b] Source: German External Trade Database.

Appendix B

The assumption of exogenous import prices is common (Ankamah-Yeboah and Bronnmann, 2017; Bronnmann et al., 2016), nevertheless, to support our model we report panel Granger causality test results based on the procedure described in Dumitrescu and Hurlin, 2012[1]. Results are reported in Table B1.

Table B1
Bootstrap Granger Panel Causality Test Results.

Ho: Retail prices do not Granger-cause Import prices. Ha: Retail prices do Granger-cause Import prices for at least one panel.			
Statistic	Calculated value*	Critical Value	p-value
W-bar	1.99		
Z-bar	1.98	2.55	0.11
Z-bar tilde	1.78	2.32	0.11
Ho: Import prices do not Granger-cause retail prices. Ha: Import prices do Granger-cause retail prices for at least one panel.			
W-bar	3.65		
Z-bar	5.31	2.49	0.002
Z-bar tilde	4.91	2.26	0.002

Computed based on 1000 bootstrap replications.
Lag order based on Schwarz criterion.

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[1] http://blog.eviews.com/2017/08/dumitrescu-hurlin-panel-granger.html.

Appendix C

Table C1
Error-Correction Models, Alternative Lag Structure.

	Model A	Model B	Model C
$\varepsilon_{f,t-1}$	−0.62***	−0.59***	−0.52***
	(0.07)[a]	(0.10)	(0.12)
$\varepsilon_{f,t-1}\Phi_f$	0.23***	0.30***	0.35***
	(0.06)	(0.08)	(0.10)
$\Delta P^{ret}_{f,t-1}$	−0.25***	−0.30***	−0.40**
	(0.04)	(0.08)	(0.12)
$\Delta P^{ret}_{f,t-2}$	−0.12	−0.16	−0.31*
	(0.07)	(0.09)	(0.15)
$\Delta P^{ret}_{f,t-3}$	−0.13**	−0.17**	−0.31**
	(0.04)	(0.07)	(0.11)
$\Delta P^{ret}_{f,t-4}$	−0.05	−0.12	−0.29***
	(0.03)	(0.10)	(0.06)
$\Delta P^{ret}_{f,t-5}$	–	−0.02	−0.18**
		(0.11)	(0.06)
$\Delta P^{ret}_{f,t-6}$	–	−0.14	−0.33**
		(0.08)	(0.14)
$\Delta P^{ret}_{f,t-7}$	–	−0.21**	−0.41**
		(0.07)	(0.14)
$\Delta P^{ret}_{f,t-8}$	–	0.00	−0.23**
		(0.07)	(0.07)
$\Delta P^{ret}_{f,t-9}$	–	–	−0.26**
			(0.10)
$\Delta P^{ret}_{f,t-10}$	–	–	−0.11
			(0.08)
$\Delta P^{ret}_{f,t-11}$	–	–	−0.15
			(0.10)
$\Delta P^{ret}_{f,t-12}$	–	–	0.05
			(0.08)
ΔP^{imp}_{t}	0.22*	0.23*	0.19*
	(0.12)	(0.10)	(0.0.08)
ΔP^{imp}_{t-1}	0.27	0.21	0.29
	(0.29)	(0.24)	(0.28)
ΔP^{imp}_{t-2}	−0.10	−0.17*	−0.03
	(0.09)	(0.07)	(0.05)
ΔP^{imp}_{t-3}	0.04	−0.01	0.14*
	(0.03)	(0.04)	(0.07)
ΔP^{imp}_{t-4}	−0.10	−0.35***	−0.21**
	(0.06)	(0.07)	(0.08)
ΔP^{imp}_{t-5}	–		

(continued on next page)

Table C1 (*continued*)

	Model A	Model B	Model C
		−0.39**	−0.27**
		(0.13)	(0.10)
ΔP^{imp}_{t-6}	–	−0.10	−0.11
		(0.06)	(0.08)
ΔP^{imp}_{t-7}	–	0.40*	0.41*
		(0.19)	(0.21)
ΔP^{imp}_{t-8}	–	0.12	0.01
		(0.08)	(0.12)
ΔP^{imp}_{t-9}	–	–	0.05
			(0.08)
ΔP^{imp}_{t-10}	–	–	0.24*
			(0.11)
ΔP^{imp}_{t-11}	–	–	0.39*
			(0.18)
ΔP^{imp}_{t-12}	–	–	0.23
			(0.21)
Constant	0.01***	0.01***	0.02***
	(0.00)	(0.00)	(0.00)
Observations	440	408	376
R-squared	0.39	0.44	0.47
Number of id	8	8	8

[a] Robust standard error in parentheses, ***p < 0.01, **p < 0.05, *p < 0.1.

Appendix D

Table D1 reports robust regression results. Ramsey Reset test results (column 2) show we cannot reject the null of a false functional form. The inclusion of a quadratic term of the distance measure (column 3) is not significant, which statistically suggests that additional non-linarites will not improve the model. (The F-Tests on both coefficients are significant). We also considered a functional from that only includes the quadratic distance measure (column 4), which leads to similar results. These specifications support the model reported and indicate a robust specification.

Table D1

Error-Correction Models, Robust Testing.

Variables	Model A	Ramsey	Squared	Squared only
$\varepsilon_{f,t-1}$	−0.62***	−0.60***	−0.66***	−0.58***
	(0.07)[a]	(0.06)	(0.14)	(0.07)
$\varepsilon_{f,t-1}\Phi_f$	0.24**	0.25**	0.55	–
	(0.07)	(0.08)	(0.86)	
$\widehat{y}^{2}$[b]	–	−0.39	–	–
		(0.46)		
$\varepsilon_{f,t-1}\Phi_f{}^{2}$	–	–	*−0.27*	*0.20***
			(0.73)	(0.06)
$\Delta P^{ret}_{f,t-1}$	−0.25***	−0.26***	−0.25***	−0.25***
	(0.04)	(0.03)	(0.04)	(0.04)
$\Delta P^{ret}_{f,t-2}$	−0.12	−0.13	−0.12	−0.12
	(0.07)	(0.07)	(0.07)	(0.07)
$\Delta P^{ret}_{f,t-3}$	−0.13**	−0.13***	−0.13**	−0.13**
	(0.04)	(0.04)	(0.04)	(0.04)
$\Delta P^{ret}_{f,t-4}$	−0.05	−0.06	−0.06	−0.06
	(0.03)	(0.03)	(0.03)	(0.03)
ΔP^{imp}_{t}	0.22*	0.22*	0.22*	0.22*
	(0.12)	(0.11)	(0.11)	(0.12)
ΔP^{imp}_{t-1}	0.27	0.27	0.26	0.27
	(0.29)	(0.29)	(0.30)	(0.30)
ΔP^{imp}_{t-2}	−0.10	−0.07	−0.09	−0.10
	(0.09)	(0.11)	(0.09)	(0.08)
ΔP^{imp}_{t-3}	0.04	0.08	0.04	0.04
	(0.03)	(0.05)	(0.03)	(0.03)
ΔP^{imp}_{t-4}	−0.10	−0.05	−0.09	−0.10
	(0.06)	(0.08)	(0.06)	(0.06)
Constant	0.01***	0.01***	0.01***	0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
Observations	440	440	440	440
R-squared	0.39	0.39	0.39	0.39

***p < 0.01, **p < 0.05, *p < 0.1.

[a] Robust standard errors in parentheses.

[b] $\widehat{y}^{2}$ denotes the squared predicted retail price Model A.

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