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Testing Structural Changes in the U.S. Whitefish Import Market: An Inverse Demand System Approach

Frank Asche and Dengjun Zhang

The seafood market has changed substantially in recent decades, becoming increasingly globalized. This has led to introduction of new species and new sources of fish in most markets. We estimate a seafood demand system that, unlike models in previous studies, accounts for potential structural shifts caused by these market changes. We investigate the impact of tilapia as a new species and China as a new source on demand for imported whitefish in the United States. The results indicate that price flexibilities change substantially over time and that the structural shift takes place over a prolonged period.

Key Words: aquaculture, inverse demand, structural change, whitefish

In recent decades, the world's seafood markets have been exposed to a number of shocks due to increased production and globalization that led to growth in trade and new types of supply chains. While these changes have influenced the species and sources studied by researchers who are investigating seafood demand, little attention has been given to how new species and producer countries induce structural changes in demand. Most prior studies have employed models in which the demand equations were assumed to be stable (Wessells and Wilen 1994, Asche 1996, Eales, Durham, and Wessells 1997, Kinnucan and Miao 1999, Lee and Kennedy 2008, Xie, Kinnucan, and Myrland 2009, Dey, Alam, and Paraguas 2011, Chidmi, Hansson, and Nguyen 2012, Singh, Dey, and Surathkal 2012).

This study investigates potential structural shifts in demand due to new species and sources of fish by examining demand for four whitefish species imported to the United States (wild cod, haddock, and pollock and aquaculture-produced tilapia) and for wild whitefish from three nations (Canada, China, and Iceland). Tilapia has, since the early 1990s, gone from a negligible species in the market to the most consumed whitefish in the United States. Canada used to be the leading supplier of whitefish to the U.S. market. However, that changed substantially, in part because of the collapse of Northwest Atlantic cod but more because China became an international hub for fish processing. Hence, tilapia as a species and China as a source of whitefish provide good examples of systems within which the demand structure may be changing in response to the growth of aquaculture and changes in the supply chain.¹

¹ From a consumer perspective, demand for more convenient and safer food led to growing demand for new species and differentiated seafood products (Xie and Myrland 2011). Parsons

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Between 1976 and 2008, trade in seafood grew dramatically with an annual rate of growth of 8.3 percent in value (Food and Agriculture Organization (FAO) 2012), and the expanding trade had a significant impact on the kinds of seafood consumed in most markets (Smith et al. 2010). A number of factors underlie this development. Aquaculture has been the world's fastest growing food production technology in the past three decades and is an obvious candidate (FAO 2012, Smith et al. 2010), and tilapia, a farmed species, has become one of the most important new species (Norman-López and Asche 2008, Asche, Roll, and Trollvik 2009). The growth in aquaculture also led to significant changes in the flow of trade and in price-determination processes (Gordon, Salvanes, and Atkins 1993, Holland and Wessells 1998, Asche et al. 2005, Nielsen, Smit, and Guillen 2009, Larsen and Kinnucan 2009, Valderrama and Anderson 2010, Muhammad et al. 2010, Muhammad and Jones 2011, Asche et al. 2012), although changes in fishery management regimes also have been important in this process (Homans and Wilen 2005).

Improved logistics and sales technologies also have contributed to dramatic changes in supply chains and trade flow (Kvaløy and Tveterås 2008, Olson and Criddle 2008, Guillotreau and Jiménez-Toribio 2011, Larsen and Asche 2011, Asche et al. 2012, Roheim, Asche, and Insignares 2011, Roheim, Sudhakaran, and Durham 2012, Simioni et al. 2013). Those technologies not only facilitated the growth of aquaculture, which allowed new countries to export fish, but also led to development of processing industries in third countries with China as the most important one (Tveterås et al. 2012).

While potential structural changes in demand due to new species and/or new sources have received little attention in the literature on seafood demand, there has been ongoing interest in the notion of structural changes in the literature on demand for meat (Dahlgran 1987, Moschini and Meilke 1989, Peterson and Chen 2005, Holt and Balagtas 2009) and for other goods (Ueda and Frechette 2002, Muhammad 2011). Moschini and Meilke (1989) documented structural changes associated with the peak of beef consumption and claimed that significant gains in poultry productivity and subsequent reductions in real retail prices represented a change in the structure of meat demand. The relationship between changes in budget shares of primary products and structural changes in demand is also documented in Muhammad (2011). In a study of milk consumption in New York (Ueda and Frechette 2002), the null hypothesis of a constant demand structure was strongly rejected by both parametric and nonparametric methods.

As noted, the U.S. whitefish import market is a good example of the dramatic changes occurring in seafood demand. Trade data on whitefish in the U.S. market, presented in Table 1 (fish species) and Table 2 (fish source), provide two main insights. First, the market share of tilapia has increased rapidly since it was introduced to the U.S. market in the early 1990s, and it began to dominate the market in 2008. Market shares of the wild species (cod, haddock, and pollock) have declined substantially during the same period. Second, regarding sources of wild whitefish, China replaced Canada and Iceland as the largest supplier within a very short period (see Table 2). Moreover, because whitefish occupy a separate market with little or no substitution with respect to other species (Asche, Gordon, and Hannesson 2002, 2004, Nielsen, Smit, and Guillen 2009), it is reasonable to analyze whitefish without explicitly accounting for

Table 1. U.S. Whitefish Imports by Species

Year	Imports (million USD)	Market Share (percent)				Total Volume (thousand tonnes)
		Cod	Haddock	Pollock	Tilapia	
1994	509	55.0	20.9	19.0	5.0	173
1995	540	53.3	17.4	23.0	6.3	182
1996	566	46.0	16.6	29.8	7.6	202
1997	620	52.9	16.6	22.5	8.0	213
1998	654	48.7	15.9	27.4	8.1	206
1999	813	48.4	14.4	27.1	10.1	237
2000	740	48.8	14.4	23.1	13.7	229
2001	646	45.9	14.1	20.2	19.8	205
2002	770	44.6	13.6	19.1	22.6	237
2003	794	40.4	11.9	17.4	30.4	253
2004	871	37.9	11.1	16.8	34.2	284
2005	1,021	32.4	10.9	18.1	38.5	316
2006	1,130	31.1	11.4	14.8	42.7	325
2007	1,224	29.7	10.6	13.9	45.8	336
2008	1,357	24.8	8.3	12.8	54.1	326
2009	1,301	19.6	8.9	18.0	53.5	341
2010	1,460	18.0	10.4	13.9	57.7	372
2011	1,541	21.2	11.6	12.8	54.4	357

Note: Data are from the U.S. National Marine Fisheries Service.

Table 2. U.S. Wild Whitefish Imports by Source

Year	Wild Whitefish (Cod, Haddock, and Pollock) from Top Three Suppliers				Top Three Total (value share percent)	Total Volume (thousand tonnes)
	Imports (million USD)	Market Share (percent)				
		Canada	Iceland	China		
1990	531	77.16	21.62	1.22	78.23	193
1991	562	67.07	28.26	4.67	72.20	194
1992	413	60.53	30.09	9.38	70.40	163
1993	371	43.27	44.49	12.23	73.07	160
1994	327	33.08	53.39	13.53	67.54	158
1995	328	33.26	46.04	20.70	64.73	166
1996	356	33.25	41.22	25.53	68.07	183
1997	362	34.34	42.17	23.49	63.57	188
1998	394	32.03	38.75	29.22	65.53	179
1999	484	30.90	39.94	29.16	66.24	199
2000	456	31.50	34.02	34.47	71.33	189
2001	392	30.57	31.75	37.68	75.62	149
2002	457	26.36	30.01	43.63	76.68	170
2003	434	26.82	27.35	45.83	78.49	163
2004	472	21.76	26.20	52.03	82.44	171
2005	534	14.97	21.40	63.63	85.08	181
2006	556	12.55	21.06	66.39	86.00	167
2007	586	11.16	16.92	71.93	88.27	162
2008	551	12.25	13.06	74.69	88.45	146
2009	538	12.51	11.96	75.53	89.03	158
2010	531	11.93	13.81	74.26	86.07	157
2011	602	9.29	10.79	79.92	85.68	164

Note: Data are from the U.S. National Marine Fisheries Service.

other species. We estimate import demand using an inverse almost-ideal demand system (IAIDS) model. The inverse demand model is a useful tool for examining consumer demand for aquatic products given the sluggish response of suppliers of such products due to constraints associated with biological production processes and the perishability of seafood products. We further incorporate Moschini and Meilke's (1989) transition function in the demand system to test a multi-regime time path and use a discrete, one-time structural change as a special case.

Demand for Whitefish Imports in the U.S. Market

The U.S. whitefish import market is complex. Many species compete with one another and many source countries compete for market share. Cod, haddock, and pollock have traditionally been the primary whitefish species imported by the United States. Recently, however, new aquaculture-based species such as tilapia have entered the market and gained a significant share (Table 1). It is far from obvious which market segments are most affected and which established species experience the keenest competition from new ones (Asche, Roll, and Trollvik 2009). In addition, substitution between wild and farmed species has been widely discussed (Gordon, Salvanes, and Atkins 1993, Asche, Bjørndal, and Young 2001, Norman-López and Asche 2008, Nielsen, Smit, and Guillen 2009, Tveterås et al. 2012). In the present study, we analyze the U.S. market for imports of three wild species (cod, haddock, and pollock) and for tilapia, the most important new farmed species of whitefish.²

As shown in Table 1, U.S. whitefish imports increased fairly steadily from a low of 509 million U.S. dollars (USD) in 1994 to a high of 1,541 million USD in 2011 with most of the increase attributable to tilapia. The whitefish market is attractive for new aquaculture products such as tilapia because it involves a large number of product forms that often are processed (Asche, Roll, and Trollvik 2009). According to the data, imports of the wild whitefish species (measured by value) fluctuated significantly; import values between 1994 and 2001 ranged from 483 million to 731 million USD. Although cod remained the most important wild whitefish species, its market share fell gradually, winding up at about 21 percent in 2011, the same year in which the overall value of whitefish imports was greatest. Fluctuations in shares held by the wild whitefish species tended to compensate for each other to a large extent during the last decade, as one would expect given the high degree of market integration (Asche, Gordon, and Hannesson 2002, 2004).

In terms of sources of imported wild whitefish (Table 2), the market has been concentrated in three source countries—Canada, Iceland, and China. Those three top suppliers made up about 80 percent of total wild whitefish imports to the United States throughout the sample period. In the earlier years, Canada and Iceland were the major suppliers. China had only 1.2 percent in 1990, but that share trended steadily upward in subsequent years. China became the leading supplier in 2000 and increasingly dominated the market thereafter.

² Of the various pollock products imported by the United States, Alaskan Pollock has been the dominant species with a value share that exceeded 80 percent during the last decade.

Theoretical Model

Numerous studies have employed inverse demand models to study price formation for fish, including Eales, Durham, and Wessells (1997), Lee and Kennedy (2008), Xie, Kinnucan, and Myrland (2009), and Nguyen (2012). Although comparisons of various types of inverse demand models have not yet produced consensus, the LAIDS model developed by Eales and Unnevehr (1994) and Moschini and Vissa (1992) is by far the most commonly used version. More recently, Goodwin, Harper, and Schnepf (2003) and Holt and Balagtas (2009) employed that model to evaluate the effects of structural change on demand.

A standard LAIDS model with quantity as the explanatory variable can be expressed as

$$(1) \quad w_{it} = \alpha_i + \beta_i \log Q_t + \sum_j \gamma_{ij} \log q_{jt}$$

where $i (= 1, 2, \dots, n)$ represents the market good in the n -dimensional demand system, w_{it} is the expenditure share of good i , Q_t is a nonlinear aggregate quantity index, q_{jt} is the quantity of good j consumed (imported), and the remaining expressions are parameters to be estimated. Among the parameters, γ_{ij} ($i \neq j$) measures substitutability (the Antonelli substitution effect) between the i th and j th goods, which is of particular interest here.

The nonlinear aggregate quantity index, Q_t , can be replaced with a linear index. To capture seasonal effects, which are likely to be important for aquatic production, we incorporate seasonal dummies (D_s) in equation 1. This parameterization gives rise to the following specification:

$$(2) \quad w_{it} = \alpha_i + \beta_i \log Q_t^* + \sum_j \gamma_{ij} \log q_{jt} + \sum_s \phi_{is} D_{st}$$

where

$$\log Q_t^* = \sum_k w_{kt} \log q_{kt}$$

(the Divisia volume index).

When we estimate the empirical model corresponding to equation 2, our underlying assumption is that the parameters are constant during the sample period used. As we discussed earlier, new products and/or newcomers in the market of interest could cause a structural change in importers' preferences, which could subsequently lead to changes in some or all of the demand parameters.

Methods of estimating structural change in demand systems have evolved over time. They fall roughly into two categories distinguished by the assumption about the nature of the structural change analyzed: (i) a discrete, one-time structural change or (ii) a smooth structural change over time. In general, a smooth structural change represented by various transition functions has been used most often since the advent of econometric techniques. In a study of demand for meat, Dahlgran (1987) tested an exponential changing path, Moschini and Meilke (1989) applied a switching regression model to represent gradual change, and Holt and Balagtas (2009) developed a demand model with nonmonotonic structural changes. For the case in this study, we presume that structural change would be driven by introduction of a new species (tilapia)

and/or a new trader (China). Considering the persistent growth of the volume of tilapia traded and China's market share, a transition function representing a nonmonotonic structural change is probably inappropriate. Consequently, we follow Moschini and Meilke (1989) and allow for a multi-regime time path for the demand parameters after assuming the presence of monotonic structural changes.

The transition function (h_t) as defined by Moschini and Meilke (1989) and the modified LAIDS model are represented by the following equations.

$$(3) \quad w_{it} = \alpha_i + \xi_i h_t + (\beta_i + \lambda_i h_t) \log Q_t^* + \sum_j (\gamma_{ij} + \lambda_{ij} h_t) \log q_{jt} + \sum_s (\phi_{is} + \vartheta_{is} h_t) D_{st}$$

$$(4) \quad h_t \begin{cases} = 0 & \text{for } t = 1, \dots, \tau_1 \\ = (t - \tau_1) / (\tau_2 - \tau_1) & \text{for } t = \tau_1 + 1, \dots, \tau_2 - 1 \\ = 1 & \text{for } t = \tau_2, \dots, T \end{cases}$$

In the transition function (h_t), 1, $\tau_1 + 1$, and τ_2 are starting points for three regimes. The wedge between τ_2 and τ_1 reflects the transitory nature of the demand system. When $\tau_2 \neq \tau_1 + 1$, the model becomes a multi-regime switching regression model with two stable regimes and one transition regime in between. When $\tau_2 = \tau_1 + 1$, the number of regimes is reduced to two, indicating a one-time structural change. In that case, the demand model with a one-time structural change is nested in a multi-regime switching regression model. Thus, another advantage of a demand model accompanied by a transition function (as shown in equation 4) is that the hypothesis test of a one-time change versus smooth changes is a byproduct of the process of identifying τ_1 and τ_2 .

The demand theory implies the following parameter restrictions.

$$(5a) \quad \sum_{j=1}^n \lambda_{ij} = 0, \quad \sum_{j=1}^n \gamma_{ij} = 0 \quad (\text{homogeneity})$$

$$(5b) \quad \gamma_{ij} = \gamma_{ji}, \quad \lambda_{ij} = \lambda_{ji} \quad (\text{symmetry})$$

$$(5c) \quad \sum_{i=1}^n \alpha_i = 1, \quad \sum_{i=1}^n \beta_i = \sum_{i=1}^n \gamma_{ij} = 0, \quad \sum_{i=1}^n \phi_{is} = 0, \quad (\text{adding-up})$$

$$\sum_{i=1}^n \zeta_i = 0, \quad \sum_{i=1}^n \lambda_i = \sum_{i=1}^n \lambda_{ij} = 0, \quad \sum_{i=1}^n \vartheta_{is} = 0$$

Estimated parameters from the demand system can be used to derive price flexibilities with respect to scale (the Divisia volume index) and quantity. The Marshallian price flexibilities are given as

$$(6a) \quad f_i = -1 + \frac{\beta_i + h_t \lambda_i}{w_i} \quad (\text{scale flexibility})$$

$$(6b) \quad f_{ij} = -\delta_{ij} + \frac{\gamma_{ij} + h_t \lambda_{ij}}{w_i} + \frac{\beta_i + h_t \lambda_i}{w_i} w_j \quad (\text{price flexibility})$$

where $\delta_{ij} = 1$ for $i = j$ (i.e., f_{ii} = the own-price flexibility) and $\delta_{ij} = 0$ otherwise (i.e., f_{ij} = the uncompensated cross-price flexibility). The computed flexibilities represent price responsiveness in the first ($h_t = 0$) and third ($h_t = 1$) regimes. Since the flexibilities are a function of the expenditure shares, the flexibilities will change as demand for tilapia / whitefish from China increases even if we do not find evidence of a structural change. In the second regime, the transition function (h_t) is not constant, indicating a changing pattern of demand response.

A flexibility can be explained in a similar manner as an elasticity (Anderson 1980, Barten and Bettendorf 1989, Eales and Unnevehr 1994). The scale flexibility (f_i) describes the sensitivity of an expenditure-normalized price to changes in an aggregate quantity index. A product is considered to be a necessity if its scale flexibility is less than one in absolute value and to be a luxury otherwise (Park and Thurman 1999). A price flexibility (f_{ij}) measures the extent to which the i th normalized price responds to a 1 percent increase in the volume of the j th product. In the case of $i \neq j$, a larger negative f_{ij} in absolute value indicates that the i th product's price is more sensitive to changes in the j th product quantity and that there is a more complementary relationship.

A comparison of demand flexibilities before and after structural change can shed light on how the structural changes affect the market. However, first we must evaluate the pattern of structural change using statistical tests. Thus, we test the structural changes with respect to seasonal, scale, and Antonelli effects via the following hypotheses.

$$(7a) \quad \theta_{is} = 0 \quad i = 1, \dots, n; s = 1, 2, 3.$$

H_N : constant seasonal effects

$$(7b) \quad \lambda_i = 0 \quad i = 1, \dots, n.$$

H_N : constant scale effects

$$(7c) \quad \lambda_{ij} = 0 \quad i = 1, \dots, n; j = 1, \dots, n.$$

H_N : constant Antonelli effects

$$(7d) \quad \theta_{is} = \lambda_i = \lambda_{ij} = 0 \quad s = 1, 2, 3; i = 1, \dots, n; j = 1, \dots, n.$$

H_N : no structural change in the coefficients

These hypotheses are tested using a likelihood-ratio test.

Empirical Model and Data

We use the IAIDS model to estimate effects of structural change in the U.S. whitefish market distinguished by species and source country. The IAIDS model is analogous to any ordinary demand system and can be derived from a multi-stage budgeting process based on a weak separability assumption. Moreover, the complete demand system generally represents an allocation of expenditures that satisfies the budget constraint (Pollack and Wales 1992). If the various imported whitefish products (cod, haddock, pollock, and tilapia) are components in a target group in some budgeting stage,

a species-differentiated demand system can be accordingly derived. If, on the other hand, importers allocate a budget for purchasing wild whitefish (an aggregate of cod, haddock, and pollock) across multiple exporting countries, the model generates a source-differentiated demand system for imported wild whitefish at an aggregated level.³

When we apply the empirical model to whitefish, the species-differentiated demand system consists of four equations, one for each species (cod, haddock, pollock, and tilapia). The source-differentiated demand system for aggregated wild whitefish consists of three equations, one for each import source (Canada, Iceland, and China). Given the dynamic behavior typical of frequently reported time-series data (Moschini and Meilke 1989), the two sets of empirical equations are expressed in the first-difference form to alleviate the problem of nonstationarity.

We formulate the empirical specification of the U.S. whitefish IAIDS model differentiated by species or source as

$$(8) \Delta w_{it} = \xi_i + \beta_i \Delta \log Q_t^* + \lambda_i \Delta (h_t \log Q_t^*) + \sum_j \gamma_{ij} \Delta \log q_{jt} + \sum_j \lambda_{ij} \Delta (h_t \log q_{jt}) \\ + \sum_s \phi_{is} D_{st} + \sum_s \vartheta_{st} \Delta (h_t D_{st}) + u_{it}$$

where i represents species in the species-differentiated model and supplier in the source-differentiated model and u_i is the independently and identically distributed (i.i.d.) error term. The intercept ξ_i in the first-difference demand equation accounts for autonomous shifts in demand due to changes in taste and other trend-type phenomena (Deaton and Muellbauer 1980). All of the other terms have been previously defined.

The data on the value and quantity of U.S. whitefish imports comes from the U.S. National Marine Fisheries Service (www.nmfs.gov) and the U.S. International Trade Commission. The data set covers the first quarter of 1994 (1994:Q1) through the fourth quarter of 2011 (2011:Q4) for the species-differentiated demand model and 1990:Q1 through 2011:Q4 for the source-differentiated demand model.⁴ Import values are reported in U.S. dollars and import quantities are reported in kilograms, resulting in a unit of USD price per kilogram (value divided by quantity for each month). For each quarter, the expenditure share of the i th product (w_i) is calculated by dividing its import value by the total value of imports in the quarter. Tilapia had only a 5.0 percent share in 1990 and came to dominate the market with a share of more than 50 percent by 2011. China entered the U.S. market with only a 0.9 percent share in 1990 and increased its presence to about a 20 percent share in 1995 and about an 80 percent share in 2011.

³ The import demand system for aggregated wild whitefish may suffer from aggregation bias since differences between varieties within the group are ignored. But demand systems confined to an individual species also may bias the estimates due to interactions between those products (Yang and Koo 1994). Asche, Gordon, and Hannesson (2002, 2004) identified a well-integrated whitefish market in France and determined that the whitefish market was global. In the present study, the bundle of prices for individual species of wild whitefish can be characterized using a composite price index.

⁴ The data period employed for the species-differentiated demand model is short to avoid a potential lack of reporting of tilapia imports early in the study period.

Empirical Results

When estimating the first-difference IAIDS models, the first step is to identify the path of the structural change—the parameters (τ_1 and τ_2) in the transition function. Following Moschini and Meilke (1989), we estimate the system of equations with all plausible combinations of τ_1 and τ_2 . Our comparison of the regression results relies on an Akaike information criterion (AIC) generated from the iterative seemingly-unrelated regression procedure. In the estimation, we impose general parameter constraints (homogeneity and symmetry) and drop one equation from the system to avoid singularity.

For the species-differentiated demand model, the combinations of τ_1 from 1995:Q4 through 2009:Q4 and τ_2 from 1996:Q1 through 2011:Q1 generate 1,821 sets of estimations. Based on the AIC values, the optimal $\hat{\tau}_1$ (= 1999:Q3) and $\hat{\tau}_2$ (= 2005:Q2) are identified. For the source-differentiated demand model, the combinations of τ_1 from 1990:Q4 through 2004:Q4 and τ_2 from 1991:Q1 through 2011:Q3 generate 3,052 sets of estimations. The AIC values indicate optimal $\hat{\tau}_1$ at 1995:Q4 and optimal $\hat{\tau}_2$ at 2008:Q1. These results suggest a rather long period of transition. It took about six years for the species-differentiated demand system to stabilize to a new equilibrium. The source-differentiated demand system required about twelve years to transition to the third regime, with a high share (75 percent) held by the new agent, China. One would in many cases expect transition processes of similar lengths by source and species. The large difference in adjustment times indicates that consumers do not associate specific species with particular countries.⁵

Before turning to the hypotheses tests and analysis of the results, we note that the insignificant intercepts in the two models (see Tables A1 and A2 in the Appendix, which is available from the authors) indicate a lack of increasing preferences and tastes for whitefish over time. The insignificant parameters of the Divisia volume index in some cases suggest homothetic preferences for the relevant products (Xie, Kinnucan, and Myrland 2009).⁶

Hypotheses Tests

We present the results of tests of hypotheses 7a through 7d in Table 3. Under the species-differentiated model, the null hypotheses of constancy of seasonal effects, scale effects, and Antonelli effects are rejected individually and jointly. Therefore, the IAIDS model must include the structural change to represent the formulation of prices. The magnitudes of the interaction terms ($h:\log q_i$)

⁵ A reviewer suggested that we consider an exponential transition function when testing the structural change. Following Dahlgran (1987) and Holt and Balagtas (2009), we defined a transition function with two regimes: one with a stable parameter and one with an exponential transition function. The AIC values indicated a first regime of eighteen months for the species model and twelve months for the source model. Corresponding optimal coefficients of the exponential function were 0.8 and 0.2. A higher value for this coefficient indicates more rapid convergence to unity. Thus, the transition functions also verify a long transition period following entry of a new exporting country.

⁶ The Newey-West covariance matrix was employed to correct for both simultaneous-equation bias and cross-equation correlation in the error terms. Homogeneity and symmetry were imposed, though both properties were rejected in preliminary tests. In the estimation, we dropped one equation from the system to avoid singularity; relevant coefficients for the dropped equation were recovered on the basis of demand constraints.

Table 3. Tests of Theoretical Restrictions Based on Log-likelihood Ratio

Hypothesis	Species-differentiated Model		Source-differentiated Model	
	No. of Restrictions	p-Value	No. of Restrictions	p-Value
Constant seasonal effects	9	< 0.001	6	< 0.001
Constant scale effects	3	< 0.001	2	0.449
Constant Antonelli effects	6	< 0.001	4	< 0.001
Constant coefficients of all variables	18	< 0.001	12	< 0.001

further reflect the economic significance of the effects of structural change (Table A1). As an example, the Antonelli coefficient of cod-tilapia is about -0.04 before structural change. The significant interaction term (-0.09) changes the magnitude of the corresponding Antonelli effect after the structural break to about -0.13 ($-0.04 - 0.09$), implying a strong complementarity relationship.

For the source-differentiated demand model, the test results show that both seasonal and Antonelli effects are subject to structural change. Although the hypotheses of constant scale effects cannot be rejected, the hypothesis of constancy of all coefficients in the system is rejected. The significant interaction terms for the quantity variables and the large magnitude of the interaction terms for the seasonal dummy variables (Table A2) further indicate that the demand parameters are sensitive to changes in the demand structure.

Flexibilities from the Species-differentiated Model

Given the lack of economic meaning in the estimated coefficients in the IAIDS model, we derive scale flexibilities (f_i) and price flexibilities (f_{ij}) using average expenditure shares from the first (pre-break) and third (post-break) regimes. The estimated flexibilities are presented in Table 4.

The resulting scale flexibilities are close to 1.0, ranging between -0.94 and -1.23 before the structural break and -0.93 to -1.03 after the break. This suggests nearly homothetic preferences in this market, especially for cod, haddock, and pollock, since the upper bounds are obtained for tilapia. Tilapia's scale flexibility is in decline between regimes whereas changes in the scale flexibilities for the wild species are modest. Since a negative scale flexibility of less than 1.0 indicates an expenditure-elastic demand (Park and Thurman 1999), the estimated flexibilities suggest that tilapia was the only species for which demand became more expenditure-elastic. The uneven distribution of benefit to each species from the increase in aggregate expenditure can, at least partly, explain the upward trend of tilapia's share over time.

Before the structural break, cod, the most prominent product at the time, had the largest own-price flexibility (-0.51). This implies that the price of cod is relatively flexible and responds to changes in the quantity of cod traded. Prices for haddock and pollock are less sensitive to own-quantity changes as they generated relatively small own-price flexibilities (-0.17 and -0.21 , respectively). In the case of tilapia, the positive estimate of own-price flexibility

is odd but would have been much more troubling if it were significant. The insignificant price flexibility for tilapia is probably due to its small share of the market prior to the structural break. After the break, when tilapia replaced cod as the dominant product in the market, its own-price flexibility (-0.50) is precisely estimated as the largest value in the system. Price flexibilities for the other three species tended to be less sensitive. Among the wild species, cod had the greatest reduction (-0.51 before the break versus -0.21 after the break).

Cross-price flexibility can be viewed as a measure of changes in marginal valuations in response to changes in the quantity of substitute goods (Goodwin, Harper, and Schnepf 2003). A high degree of flexibility in absolute terms indicates that a product faces strong competition and hence a large reduction in its marginal valuation following an increase in the quantity supplied by competitors. Before the structural change, tilapia was relatively sensitive to changes in quantities of competing products in the market with a cross-price flexibility of between -0.23 and -0.71 . However, tilapia had only a tiny effect on the price of the other products, which had cross-price flexibilities with respect to tilapia quantity of between -0.07 and -0.08 . Conversely, estimates of cross-price flexibilities after the structural break reveal that tilapia then played a more important role in formation of prices for the other products

Table 4. Estimated Scale and Marshallian Flexibilities in the Species-differentiated Model

Price of	With Respect to Scale	With Respect to Quantity of			
		Cod	Haddock	Pollock	Tilapia
Before Structural Break					
Cod	-0.993* (0.006)	-0.509* (0.011)	-0.152* (0.005)	-0.249* (0.005)	-0.084* (0.007)
Haddock	-0.941* (0.018)	-0.411* (0.021)	-0.171* (0.018)	-0.287* (0.016)	-0.072* (0.010)
Pollock	-0.991* (0.014)	-0.496* (0.014)	-0.207* (0.010)	-0.205* (0.010)	-0.083* (0.008)
Tilapia	-1.230* (0.05)	-0.705* (0.083)	-0.225* (0.035)	-0.350* (0.036)	0.055 (0.063)
After Structural Break					
Cod	-0.969* (0.017)	-0.211* (0.046)	-0.097* (0.026)	-0.152* (0.023)	-0.510* (0.037)
Haddock	-0.934* (0.038)	-0.114* (0.071)	-0.114* (0.076)	-0.146* (0.053)	-0.444* (0.060)
Pollock	-1.006* (0.030)	-0.0126* (0.042)	-0.106* (0.035)	-0.160* (0.035)	-0.477* (0.049)
Tilapia	-1.028* (0.011)	-0.0031* (0.020)	-0.102* (0.011)	-0.150* (0.012)	-0.500* (0.026)

Notes: Numbers in parentheses are asymptotic standard errors; * indicates significance at the $p < 0.05$ or less

and was relatively less affected by supplies of those products. In the new post-break equilibrium, when holding all other factors constant, a 1 percent increase in the quantity of tilapia traded would decrease prices of cod, haddock, and pollock by 0.51 percent, 0.44 percent, and 0.48 percent, respectively. Further inspection of the cross-price flexibilities between cod, haddock, and pollock yields a more interesting finding: competition between the wild whitefish species has declined as the cross-price flexibilities dwindled. This indicates that competition among the wild whitefish species was overwhelmed by the competition between wild whitefish and tilapia as the market share of tilapia gradually increased during the sample period.

Flexibilities from the Source-differentiated Model

Scale and uncompensated price flexibilities derived from the estimated coefficients of the source-differentiated demand model are reported in Table 5.

The scale flexibilities for whitefish from Canada and Iceland are quite close to 1.0 in absolute value. Goodwin, Harper, and Schnepf (2003), in a study of structural change in the fats and oils market in the United States, also found that scale effects were relatively insensitive to structural change. China's scale flexibility increased from -0.91 to -0.98 . After the structural change, the demand system tends to be more homothetic. Thus, the increasing scale of expenditures on imports would increase the share of each product by an equal proportion. Therefore, relative prices are the main determinants that drive the market's evolution.

Table 5. Estimated Scale and Marshallian Flexibilities in the Source-differentiated Model

Price of	With Respect to Scale	With Respect to Quantity from		
		Canada	Iceland	China
Before Structural Break				
Canada	-1.018* (0.019)	-0.593* (0.021)	-0.356* (0.017)	-0.069* (0.017)
Iceland	-1.001* (0.022)	-0.468* (0.024)	-0.360* (0.030)	-0.173* (0.032)
China	-0.911* (0.157)	-0.278 (0.150)	-0.584* (0.182)	-0.049 (0.195)
After Structural Break				
Canada	-1.096* (0.066)	-0.439* (0.167)	0.133 (0.151)	-0.790* (0.304)
Iceland	-1.050* (0.050)	0.127 (0.134)	-0.164 (0.189)	-1.013* (0.347)
China	-0.978* (0.046)	-0.102* (0.033)	-0.152* (0.050)	-0.725* (0.093)

Notes: Numbers in parentheses are asymptotic standard errors; * indicates significance at the $p < 0.05$ or less.

As with the pattern in the species-differentiated model, the dominant product in the source-differentiated model is associated with the largest own-price flexibility. China's own-price flexibility rose from -0.05 before the structural break to -0.73 after the structural break. This relatively flexible price (analogous to a price-inelastic demand) is related to the dominant market share achieved by China after the structural break. For Canada, own-price flexibility before and after structural change are not very different (-0.59 versus -0.44). However, Iceland's flexibility dropped from -0.36 to -0.16 and became insignificant.

In terms of cross-price flexibilities, the results are again similar to results from the species-differentiated model. They suggest that the dominant product (Canadian whitefish before the break and Chinese whitefish after the break) was less affected by other products and had more influence on those products. For example, a 1 percent increase in the quantity of whitefish imported from China after the structural break would reduce the price of fish imported from Canada and Iceland by 0.79 percent and 1.01 percent, respectively. Before the structural break, the price of Canadian whitefish would have dropped only 0.07 percent and the price of Icelandic whitefish would have fallen 0.17 percent. The interactions between whitefish from Canada and Iceland before the break are precisely estimated with cross flexibilities of -0.36 and -0.47 , respectively, indicating a substitute relationship. However, their interactions after the break are ambiguous given the positive but insignificant cross-price flexibilities.

Time-varying Marshallian Cross-flexibilities

The preceding analyses focus on flexibilities in the first (pre-change) and third (post-change) regimes. We further compute time-varying Marshallian cross-flexibilities for the second (transition) regime to illustrate the nature of the transition and the resulting time path. In the formula in 6b, the dummy variable remains constant only in the first ($h_t = 0$) and third ($h_t = 1$) regimes. In the second regime, calculation of the flexibilities for each market share includes a transition variable (h_t) that is not constant. The time-varying Marshallian cross-flexibilities are plotted in Figures 1 and 2.⁷

In the species-differentiated demand model, substitutability between wild whitefish species and tilapia is a fairly dynamic adjustment process. None of the time paths indicates a one-time structural change in cross-quantity effects. The time paths of price flexibilities for cod, haddock, and pollock with respect to the quantity of tilapia imported appear to follow similar tracks. However, tilapia's price flexibility with respect to the quantity of cod is dampened relative to its price flexibility with respect to haddock and pollock quantities. This loose relationship is consistent with the fact that cod, previously the most important wild species within the group, had lost the leading role to tilapia at the starting point of the third regime (2005:Q3).

The source-specific demand model captures a more dynamic time path in the price response of Canadian and Icelandic whitefish to changes in China's whitefish quantity. There is little fluctuation in China's price in response to changes in the quantity imported from Canada and Iceland. Thus, the longer transition period in the source-differentiated system is probably associated

⁷ We focus on the substitutability between tilapia and wild whitefish species and between China and the other two exporters. Figures describing other substitutability relationships are available upon request.

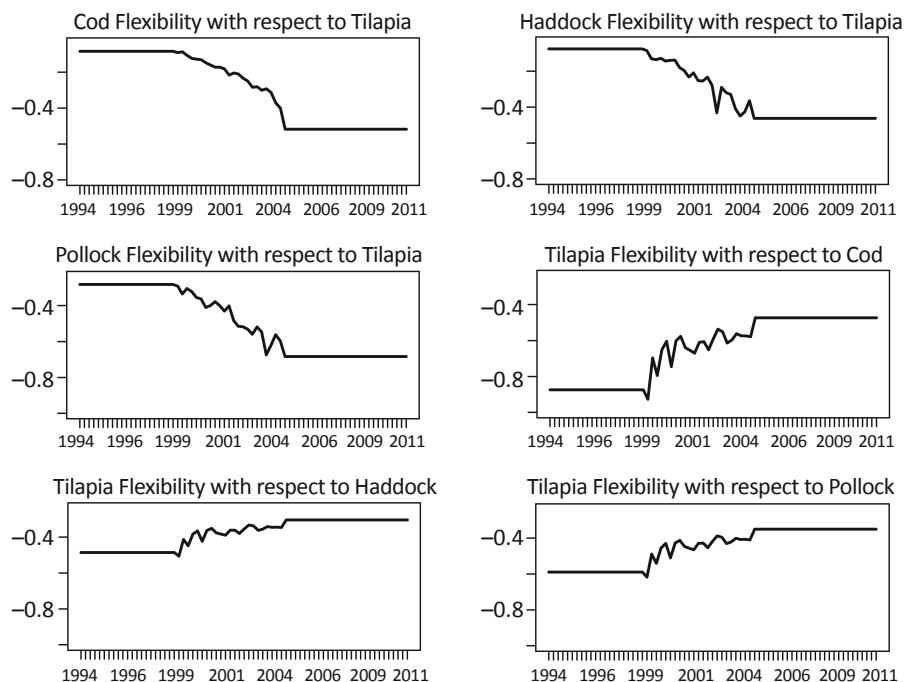


Figure 1. Cross-price Marshallian Flexibilities in Species-differentiated Demand Model

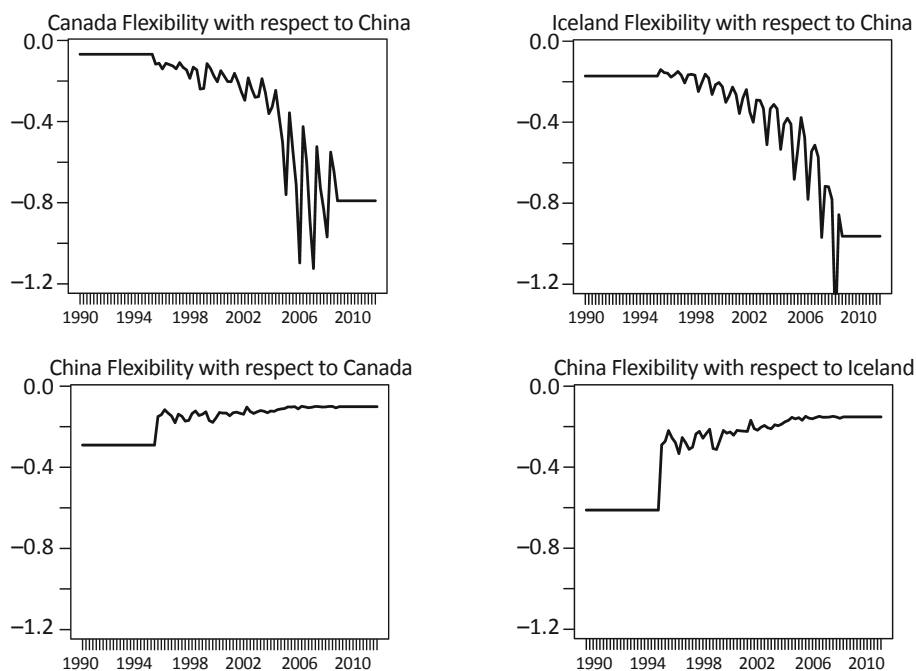


Figure 2. Cross-price Marshallian Flexibilities in Source-differentiated Demand Model

with a slower adjustment mechanism for prices in Canada and Iceland to the newcomer. Upon closer inspection, we find that China's price flexibilities with respect to quantities from Canada and Iceland represent a nearly one-time change, although the overall demand system undergoes a gradual switch according to the results of the hypotheses tests reported in the previous section.

Concluding Remarks

Although demand parameters for fisheries within a well-defined group of species or sources have been studied extensively, little attention has been given to potential structural changes in the demand for seafood. This is true despite the dramatic changes occurring in seafood markets over the past twenty years. Trade has increased, not only in terms of the quantity of seafood being exported but in the number of countries exporting it with new countries and fish species joining the market and particularly due to the advent of aquaculture (Tveterås et al. 2012). Unless one accounts for time-varying demand parameters, it is difficult to evaluate the impacts of new species and new sources. For example, the impact of the expansion of aquaculture on wild fish stocks depends on the interactions between those two types of species. Those impacts can be important. The seafood market has changed dramatically, affecting not only consumers but also operators through the supply chain (Valderrama and Anderson 2010, Larsen and Asche 2011).

Applying the inverse almost-ideal demand system model with Moschini and Meilke's (1989) multi-regime switching transition function, we investigated structural changes in demand at two levels in the whitefish market in the United States and consequently derived time-varying price flexibilities with respect to changes in quantities of whitefish imports. The significant parameters in the transition functions reject a one-time structural change. In response to the shock from entry of a new species (tilapia), a demand system confined to cod, haddock, pollock, and tilapia took six years to reach a new equilibrium. After entry of a new source country (China), a demand system confined to wild whitefish and distinguished by source country required about twelve years to stabilize to a new equilibrium. Consumers had a more persistent preference for products distinguished by source country.

These findings provide important information about the seafood market. Asche, Bjørndal, and Young (2001) indicated that the global seafood market is highly segmented with substitution occurring primarily within species groups. Despite the large increase in aquaculture production, studies have found little evidence of substitution between farmed and wild-caught fish for species other than salmon, and there is limited information regarding competition among farmed and wild-caught whitefish species despite the fact that tilapia now ranks fifth among species of seafood consumed in the United States. Our results also supplement findings by Roheim, Sudhakaran, and Durham (2012) from a survey regarding consumers' preferences for wild and farmed fish. The estimation results from our species-differentiated model reveal how the interaction in the demand for wild and farmed whitefish has changed. For example, the price of cod becomes significantly more sensitive to the quantity of tilapia imported. A 1 percent change in the volume of tilapia imported reduced the price for cod by only -0.08 percent prior to structural change but reduced it -0.51 percent after structural change. The stronger relationship between cod and tilapia supports the proposition that increasing quantities of the farmed

product (tilapia) will reduce the price of wild-caught products (cod), causing fishing efforts to dwindle. Not accounting for this type of structural shift may explain why it has been difficult, as noted by Norman-López and Asche (2008), to identify markets in which tilapia and other farmed species have won market share.

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