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An Assessment of Dynamic Behavior in the U.S. Catfish Market: An Application of the Generalized Dynamic Rotterdam Model

Andrew Muhammad and Keithly G. Jones

The generalized dynamic Rotterdam model was used in estimating U.S. demand for disaggregated catfish. The overall goal was to examine habit persistence in consumption and to determine the adjustment process in demand. Results indicated that it took up to 1 month for catfish-product demand to fully adjust to changes in expenditures and prices. Additionally, habit persistence played a role in demand where present consumption of a given product was positively affected by past consumption of that product. Consequently, U.S. catfish demand was significantly more elastic in the long-run.

Key Words: catfish, demand, dynamics, partial adjustment, Rotterdam model

JEL Classifications: C51, Q11, Q13, Q17

Incorporating dynamics in empirical demand models is necessary when the long-run relationships among economic variables are of interest. While static demand models are often used to model consumer behavior, in many cases the responsiveness of consumption to changes in expenditures and prices may not be instantaneous, but partially adjust over several periods. To account for this occurrence which is often attributed to habit persistence and/or inventory adjustment behavior on the part of consumers, dynamic demand models have been employed in a number of studies (See Arnade, Pick, and Vasavada, 1994; Balcombe and Davis, 1996; Blanciforti and Green, 1983; Brown and Lee, 1992; Karagiannis, Katranidis, and Velentzas, 2000; Quagrainie, 2003; and Sexauer, 1977). The conventional approach has been to include lag terms as demand determinants or to use an error correction model. Some studies have provided a theoretical foundation for dynamic demand structures. This is discussed further in the next section. More recently, Bushehri (2003) showed how a generalized dynamic Rotterdam model may be derived from the neoclassical intertemporal utility maximization problem. Since Bushehri (2003) provides no empirical application, this study examines the empirical performance of the generalized dynamic Rotterdam model in estimating U.S. demand for differentiated catfish products.

Previous studies have considered the demand for a type of fish differentiated by product cut (e.g., fillets, steaks, etc.) and product form (e.g., fresh or frozen). These include tuna demand

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(Chiang, Lee, and Brown, 2001), salmon demand (Asche, Bjørndal, and Salvanes, 1998), and cod demand (Gordon and Hannesson, 1996). Quagrainie (2003) and Hanson, Hite, and Bosworth (2001) considered the importance of product cut in determining catfish demand; however, neither study considered the product form.

The primary objective of this paper is to assess the dynamic behavior in the U.S. market for disaggregated catfish products where the overall goal is to determine if changes in consumption are instantaneous or adjust over several periods. To achieve this objective, the generalized dynamic Rotterdam model is used in estimation, and unlike previous catfish demand studies, both product cut and form are considered in analysis. Specific objectives of this paper are as follows. First, U.S. catfish demand is estimated accounting for noninstantaneous adjustments in consumption given changes in expenditures and prices. Following Brown and Lee (1992), the appropriate adjustment period is determined using likelihood ratio tests. Second, demand estimates are then used to derive short-run and long-run expenditure, compensated and uncompensated price elasticities.

The remainder of this paper is organized as follows. A review of the dynamic demand literature is provided in the following section. The third section gives an overview of the U.S. catfish industry, with particular focus on U.S. processor sales and catfish imports. Previous catfish demand studies are reviewed as well. In the fourth section, the empirical model is presented, and in the penultimate section, empirical results are given where the test for the appropriate adjustment period and short-run and long-run elasticities are highlighted. The paper closes with a brief summary and concluding remarks.

Dynamic Models and Analysis

Holt and Goodwin (1997) note that although progress has been limited, a number of studies have looked at the role and nature of dynamics in demand. Notably, Pollak (1970) investigated a theoretical model of consumer behavior based on habit formation using a modified Bergson family of utility functions. Empirical models that build on the theory of habit formation include Pollak and Wales (1969), Anderson and Blundell (1983), and Blanciforti and Green (1983). Houthakker and Taylor (1970) also developed a dynamic model in which past consumption influenced present consumption through a state variable termed a psychological stock of habit. Their model was the first to incorporate both the effect of inventories and the influence of habits arising from past consumption or current demand. They showed how such a demand system is obtained from utility maximization.

Sexauer (1977) contended that Houthakker and Taylor (1970) in their dynamic framework did not take into consideration the time dimension. He argued that the stock coefficient is a conceptual function of the time dimension of the data and that the importance of habit formation relative to inventory adjustment decreases as the time period analyzed decreases. Consequently, the frequency of the data determines the predominance of the stock or habit effect. Sexauer (1977) results showed that habit formation dominates for annual data while the stock effect dominates for higher frequency data such as quarterly or monthly data. Using a Houthakker-Taylor type model to evaluate meat and poultry demand, Wohlgenant and Hahn (1982) suggest that although the frequency of the data influences the stock and habit effect, the ability of consumers to vary both their inventory and consumption patterns is also important. They showed that even with high frequency data, the stock effect was less dominant for chicken, while more dominant for beef and pork.

Bushehri (2003) notes that although Houthakker and Taylor (1970) incorporated dynamic structures into a static demand system, their model was not derived from the intertemporal utility maximization problem. Bushehri (2003) laid out a theoretical framework and the derivation of a generalized dynamic Rotterdam model from the intertemporal utility maximization problem, but stopped short of fitting the model to empirical data.

A number of alternative specifications for dynamic models have been explored in the literature. Holt and Goodwin (1997) used a generalized inverse almost ideal demand system (AIDS) model in which all parameters in the distance function were augmented with lagged consumption levels in order to incorporate persistence effects. They showed that habit effects could be incorporated in a non linear, non additive way in the distance function of an inverse AIDS model. Brown and Lee (1992) extended the differential demand system or Rotterdam model to include lagged consumption through translation parameters. The translation model maximizes an indirect utility function and then applies a differential approach. In their model, the translation parameters are weighted by the share of total expenditures committed to a good. Based on the premise that commodity prices follow a distributed lag process, Balcombe and Davis (1996) used a canonical cointegration regression procedure for estimating the AIDS model. Karagiannis, Katranidis, and Velentzas (2000) used an error correction version of the AIDS model. Jones et al. (2008) used a CBS demand system where demand determinants included present and past log changes in exogenous variables.

Catfish Demand in the United States

The catfish industry is the largest aquaculture industry in the United States. In 2008, 514.9 million pounds of farm-raised catfish were processed at a sales value (farm level) of $389.3 million (U.S. Department of Agriculture -National Agricultural Statistics Service, 2009). This production came from 163,100 water acres with 94% of all U.S. acreage located in Mississippi (55%), Arkansas (19%), Alabama (14%), and Louisiana (4%). Additional production areas include California, North Carolina, and Texas. In 2008, catfish producers in Mississippi, Arkansas, Alabama, and Louisiana produced 252.4 million, 83.7 million, 131.6 million, and 15.4 million pounds of catfish, respectively, valued at $191.8, $62.8, $92.1, and $11.8 million, respectively. Direct sales to processors accounted for 94.8% of total sales of food-size catfish in the United States (U.S. Department of Agriculture- National Agricultural Statistics Service, 2009).

Catfish is one of the top six preferred fish and seafood products by U.S. consumers with a 0.88 lb per capita consumption level in 2007. The top five seafood products are shrimp (4.10 lbs), canned tuna (3.10 lbs), salmon (2.36 lbs), pollock (1.73 lbs), and tilapia (1.14 lbs). U.S. catfish consumption increased by 57% during the period 1990–2004, while consumption levels for shrimp and salmon doubled over the same period. Since 2004, however, per capita consumption decreased from 1.09 lbs to its current level (National Fisheries Institute, 2009).

Table 1 reports U.S. sales of processed catfish and prices from 1996 through 2008. In 2008, U.S. catfish expenditures (domestic and imported) were $771.2 million. This was an increase of 3% when compared with the previous year ($750.3 million) and a 36.4% increase when compared with 1996 ($565.2 million). In terms of quantity, U.S. sales were 353.5 million lbs in 2008, which was an increase of 4.7% and 47.7% when compared with the previous year and 1996, respectively.

Overall, processed catfish sales in the United States have been increasing since 1996. However, expenditures declined during the 2001−2004 period. This was in part due to legislation forbidding non Ictaluridae families of fish from being classified as catfish from 2002 to 2004 (Hanson and Sites, 2007). Consequently, imports of Vietnamese basa and tra were not counted among catfish imports during this period. U.S. "catfish" imports from Vietnam were valued at $21.5 million in 2001, but in 2002, 2003, and 2004, imports were valued at only $12.4, $5.2, and $7.7 million, respectively. The National Marine Fisheries Service began listing catfish-like species among catfish imports once again in June 2004. The next year (2005), imports from Vietnam were valued at $18.4 million. This suggests that total imports from Vietnam were higher than what was reported from 2002 to 2004.

The decline in total catfish expenditures during 2001–2004 was also due to relatively low prices at the processor level. For instance, fresh and frozen fillet prices in 2000 were $2.74/lb and $2.61/lb, respectively. However, both reached lows in 2002 and 2003. In 2003, fresh fillet prices fell to a low of $2.48/lb, and in 2002, frozen fillet prices reached a low of $2.39/lb. This had a significant affect on expenditures particularly since fillets accounted for about 70% of domestic catfish sales.

Table 1. U.S. Catfish Sales (expenditure, quantity, and price): 1996–2008

			Price ($/lb)						
			Fresh			Frozen			
Year	Expenditure ($000)	Quantity (000lbs)	Whole	Fillet	Other	Whole	Fillet	Other	Imports
1996	565,208	239,642	1.68	2.87	1.79	1.99	2.78	1.88	1.29
1997	592,699	262,701	1.55	2.75	1.67	1.93	2.63	1.76	1.50
1998	652,100	282,780	1.59	2.80	1.72	1.94	2.69	1.73	1.55
1999	691,535	296,089	1.59	2.81	1.64	1.99	2.76	1.69	1.65
2000	720,235	305,376	1.66	2.86	1.68	2.03	2.83	1.65	1.50
2001	691,283	314,410	1.57	2.74	1.60	1.98	2.61	1.63	1.26
2002	670,729	327,793	1.32	2.52	1.51	1.84	2.39	1.54	1.28
2003	661,724	324,745	1.35	2.48	1.52	1.84	2.41	1.44	1.26
2004	697,174	315,984	1.56	2.71	1.71	1.95	2.62	1.46	1.28
2005	721,414	330,011	1.59	2.83	1.69	2.00	2.67	1.50	1.14
2006	811,189	358,813	1.68	3.07	1.75	2.15	2.91	1.59	1.49
2007	750,262	336,880	1.69	3.15	1.68	2.17	2.92	1.39	1.59
2008	771,172	353,483	1.63	3.13	1.65	2.16	2.89	1.52	1.55

Source: National Agricultural Statistical Service and National Marine Fisheries Service.

Figure 1 shows the expenditure shares by catfish product from January 1996 to January 2009. The share of U.S. catfish expenditures allocated to catfish imports was relatively small throughout most of the data period. In fact, imports accounted for less than 1% of total expenditures prior to mid1999. Import expenditures were as high as 5% in mid2001, but as expected, were relatively lower during the period when many catfish-like species were not counted among imports. Since mid2004, import expenditure shares increased from about 3% to over 25% in late 2006 and early 2007. From 2007 through 2009, imports have accounted for

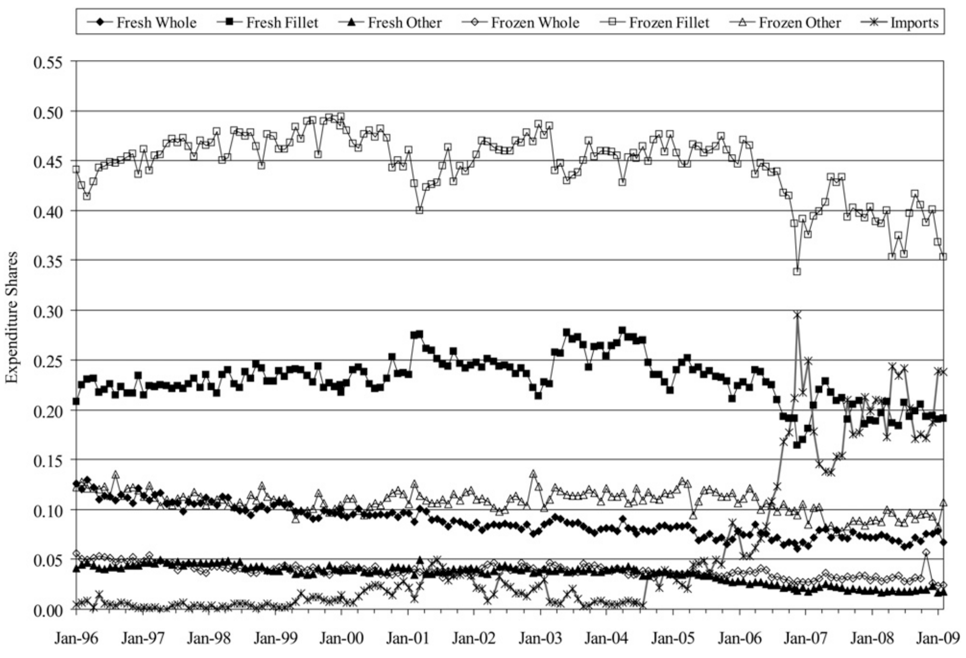

Figure 1. Expenditure Shares by Catfish Product: January 1996 to January 2009 (Source: National Agricultural Statistical Service, National Oceanic and Atmospheric Administration)

anywhere from 15 to 25% of total U.S. expenditures. With the rise in imports, the share of expenditures allocated to domestic fresh fillets decreased from over 25% to about 19%, and the share of expenditures allocated to domestic frozen fillets decreased from over 45% to about 39%. Although expenditure shares for the remaining products have also been declining, compared with domestic fillets, they were relatively steady throughout the data period.

Harvey and Blayney (2002) reported that increased import competition has negatively affected the U.S. catfish industry. Lower-priced imports of catfish and catfish-like species substitute for domestic catfish, which significantly affect catfish demand dynamics (Quagrainie and Engle, 2006). Despite labeling restrictions on basa, tra, and other non Ictaluridae fish, and antidumping duties imposed on catfish from Vietnam, catfish imports continue to flourish.

Within the past two decades a number of studies have analyzed catfish demand dynamics and marketing. Quagrainie (2003) used a dynamic AIDS model to derive long run estimates of demand for three catfish products (whole, fillet, and other). His interest was to evaluate the rate of adjustment of catfish buyers to changes in real prices and expenditures. He found that only about 16% of the adjustment in demand took place instantaneously, with full adjustment taking place within a 2-month period where the relatively quick rate of adjustment suggested a low cost of adjustment in the U.S. catfish market. He also found that products with greater value-added were more own-price and expenditure elastic as evidenced by fillets being own-price elastic while whole fish was own-price inelastic.

Kumar, Quagrainie, and Engle (2008) surveyed households in selected cities to see what could be gleaned from understanding the factors that influence the frequency of purchase of catfish by U.S. households. Respondents who preferred fresh catfish were likely to purchase catfish more often than respondents who purchased frozen catfish. This supported earlier findings in Kinnucan, Nelson, and Hiariay (1993) and Hanson, Rauniyar, and Herrmann (1994). Both studies showed that the frequency of purchase was influenced by both quality and perception where freshness is often deemed an indicator of quality. However, Gempesaw et al. (1995) found that the decision to purchase fish had less to do with quality attributes, but rather the need to add variety to the diet.

Houston and Ermita (1992) noted that changes in catfish consumption differed between national and regional markets. They further reported that catfish consumption demonstrated significant habit formation, with habits persisting in the southern region of the United States and consumption increasing with age.

Generalized Dynamic Rotterdam Model

The generalized dynamic Rotterdam model is used to model U.S. catfish demand. Bushehri (2003) illustrates how the generalized dynamic Rotterdam model may be derived from the intertemporal utility maximization problem. This section is limited to the model derivations and the specification of the empirical form. Readers are referred to Boyer (1983) and Bushehri (2003) for a more complete treatment of the underlining theory.

Given the intertemporal utility maximization problem, we can define the optimal demand for the i^{th} good at time t as follows:

$$(1) \qquad q_i(t) = g_i(x(t),\mathbf{p}(t),\mathbf{h}(t)).$$

$q_i(t)$ is the quantity of good i; g_i denotes the demand function; $x(t)$ is consumer expenditures; $\mathbf{p}(t)$ is an n-vector of prices where n denotes the total number of goods within the consumer's choice set; and $\mathbf{h}(t)$ is an n-vector of stock of habits. $\mathbf{h}(t)$ is a measure of past behavior at time t important to consumption choices in period t.[1]

[1] Bushehri (2003) notes that the general demand specification Equation (1) requires an additional stage in the consumer budgeting process. The conventional utility tree approach assumes that consumers first allocate total expenditures across product groups and then allocate group expenditures across goods within groups. To arrive at Equation (1), it must be assumed that at the initial stage of the budgeting process, consumers allocate lifetime wealth to specific time periods (pre-allocated expenditures) and that expenditures are allocated across goods (or product groups) without reconsidering the intertemporal optimization problem. Otherwise, demand at time t would be a function of lifetime wealth and not time-specific expenditures.

Pollak and Wales (1992, pp. 105–106) note that the stock of habits can be measured by past consumption of good i and other related goods.

Differentiating Equation (1) with respect to time yields:

$$\dot{q}_i = \frac{\partial g_i}{\partial x(t)}\dot{x} + \sum_{j=1}^{n}\frac{\partial g_i}{\partial p_j(t)}\dot{p}_j + \sum_{j=1}^{n}\frac{\partial g_i}{\partial h_j(t)}\dot{h}_j. \tag{2}$$

Note that for any variable y, $\dot{y} = \mathrm{d}y(t)/\mathrm{d}t$. If we divide both sides of Equation (2) by $q_i(t)$, and multiply the first, second, and third terms on the right hand side by $x(t)/x(t)$, $p(t)/p(t)$, and $h(t)/h(t)$, respectively, with some manipulation we get the following growth equation:

$$\frac{\dot{q}_i}{q_i(t)} = \eta_i\frac{\dot{x}}{x(t)} + \sum_{j=1}^{n}\eta_{ij}\frac{\dot{p}_j}{p(t)} + \sum_{j=1}^{n}\phi_{ij}\frac{\dot{h}_j}{h_j(t)}. \tag{3}$$

Note that η_i is the expenditure elasticity and η_{ij} is the uncompensated price elasticity. $\phi_{ij} = (\partial g_i/\partial h_j)(h_j/g_i)$ is the responsiveness of the quantity demanded for good i to changes in the stock of habit for good j.

Lastly, we can substitute the Slutsky equation for the uncompensated price elasticity η_{ij} and multiply both sides of Equation (3) by the i^{th} budget share $w_i = p_iq_i/\sum_i p_iq_i$.[2] This yields the following demand equation:

$$\begin{aligned} w_i\frac{\dot{q}_i}{q_i(t)} &= \sum_{j=1}^{n} w_i\phi_{ij}\frac{\dot{h}_j}{h_j(t)} + w_i\eta_i \\ &\times\left[\frac{\dot{x}}{x(t)} - \sum_{j=1}^{n} w_j\frac{\dot{p}_j}{p(t)}\right] \\ &+ \sum_{j=1}^{n} w_i\eta_{ij}^{*}\frac{\dot{p}_j}{p(t)}. \end{aligned} \tag{4}$$

without the stock of habits term, $\sum_j w_i\phi_{ij}(\dot{h}_j/h_j(t))$, Equation (4) is similar to the absolute price version of the Rotterdam model in Theil (1980) and Theil and Clements (1987), where the term in brackets is the change in real expenditures and the last term is the impact of prices on quantity demanded.

To put Equation (4) in empirical form, continuous changes are replaced with discrete time changes. Theil (1980, pp. 105–106) and Bushehri (2003) suggest the one-period difference, which is used in most demand studies. Monthly data were used for this analysis and the demand for catfish is highly seasonal. To remove the seasonality from the data, the 12th difference was used (Duffy, 1990; Lee, 1988; Seale, Marchant, and Basso, 2003). Thus, the changes in quantities and prices are approximated as follows:

$$\Delta q_t = \log q_t - \log q_{t-12} \approx \dot{q}/q(t) \quad \text{and}$$
$$\Delta p_t = \log p_t - \log p_{t-12} \approx \dot{p}/p(t).$$

The term in brackets in Equation (4) is equal to the Divisia volume index. This term is replaced with a discrete measure of the Divisia volume index (ΔQ_t) where (Theil, 1980, pp. 11–12)

$$\begin{aligned} \Delta Q_t &= \sum_{i=1}^{n}\bar{w}_i\Delta q_{it} \approx \Delta x_t - \sum_{j=1}^{n}\bar{w}_j\Delta p_j \\ &\approx \dot{x}/x(t) - \sum_{j=1}^{n} w_j(\dot{p}_j/p(t)). \end{aligned} \tag{5}$$

Bushehri (2003) suggests the following habit specification for discrete time periods:

$$\sum_{j=1}^{n}\phi_{ij}\frac{\dot{h}_j}{h_j(t)} = \alpha_i^{*} + \sum_{k=1}^{p}\sum_{j=1}^{n}\alpha_{ijk}\Delta q_{jt-k}, \tag{6}$$

where $\sum_k\sum_j\alpha_{ijk}\Delta q_{jt-k}$ is a distributed lag of the quantities consumed in log-differenced form. The empirical specification of habit persistence (6) is for the most part ad hoc and comparable to lag structures assumed in previous studies. For instance, the difference between this specification and the lag structure used by Brown and Lee (1992) is that cross-lag effects were not considered by Brown and Lee (1992).

Given Equations (5) and (6), the empirical version of the dynamic Rotterdam model is expressed as follows:

$$\begin{aligned} \overline{w}_{it}\Delta q_{it} &= \gamma_i^{*} + \sum_{k=1}^{p}\sum_{j=1}^{n}\gamma_{ijk}\Delta q_{jt-k} + \theta_i\Delta Q_t \\ &+ \sum_{j=1}^{n}\pi_{ij}\Delta p_{jt} + \varepsilon_{it}, \end{aligned} \tag{7}$$

where $\overline{w}_{it} = 0.5(w_{it} + w_{it-12})$ which is the ith budget share averaged over periods t and $t - 12$; $\gamma_i^{*} = \overline{w}_{it}\alpha_i^{*}$; $\gamma_{ijk} = \overline{w}_{it}\alpha_{ijk}$; $\theta_i = \overline{w}_{it}\eta_i$; and $\pi_{ij} = \overline{w}_{it}\eta_{ij}^{*}$. γ_i^{*}, γ_{ijk}, θ_i and π_{ij} are parameters to be estimated and ε_{it} is a random disturbance term. Equation (7) suggests that the effects of

[2] The Slutsky equation is defined as $\eta_{ij} = \eta_{ij}^{*} - \eta_i w_j$, where η_{ij}^{*} is the compensated price elasticity and $w_j = p_jq_j/\sum_i p_iq_i$ is the budget share for good j.

habit on consumption is captured by past consumption where consumption of a particular good depends not only on present expenditures and prices but also on the past consumption of that good and all other related goods.

Demand theory requires the following restrictions on parameters:

$\sum_i \gamma_i^* = 0$, $\sum_i \gamma_{ijk} = 0$ for all j and k, $\sum_i \theta_i = 1$, $\sum_i \pi_{ij} = 0$ (adding-up);
$\sum_j \pi_{ij} = 0$ (homogeneity);
$\pi_{ij} = \pi_{ji}$ (symmetry); and
$\mathbf{\Pi}_{n\times n} = [\pi_{ij}]$ is negative semidefinite (negativity).

The Rotterdam model satisfies adding-up by construction. Homogeneity and symmetry are imposed on model estimates and statistically tested. The negative semidefinite property is verified by inspection.

Given the parameters in Equation (7), the short-run conditional expenditure and compensated price elasticities (Hicksian) are respectively defined as θ_i/w_i and π_{ij}/w_i. The short-run uncompensated price elasticity (Marshallian) is defined as $\pi_{ij}/w_i - \theta_i w_j/w_i$ (Seale, Sparks, and Buxton, 1992). The long-run expenditure elasticity, compensated price elasticity, and uncompensated price elasticity are respectively defined as (Bushehri, 2003):

$$\text{(8)} \qquad \eta_i^L = \frac{\theta_i}{w_i - \left(\sum_k \gamma_{ijk}\right)}$$

$$\text{(9)} \qquad \eta_{ij}^{*L} = \frac{\pi_{ij}}{w_i - \left(\sum_k \gamma_{ijk}\right)}$$

$$\text{(10)} \qquad \eta_{ij}^L = \frac{\pi_{ij}}{w_i - \left(\sum_k \gamma_{ijk}\right)} - \frac{\theta_i}{w_i - \left(\sum_k \gamma_{ijk}\right)} w_j.$$

Empirical Results

Theil (1980, p. 103) and Theil and Clements (1987, pp. 170–171) show that the Rotterdam model is a theoretically separable functional form. If a product group is separable (weak or strong) from other products groups, then the demand for the products within that group could be represented by a system limited only to those products.

Following the empirical examples of Chiang, Lee, and Brown (2001), Asche, Bjørndal, and Salvanes (1998), Gordon and Hannesson (1996), Quagrainie (2003), and Hanson, Hite, and Bosworth (2001), catfish is defined as a single product group made up of fresh and frozen product cuts and is assumed weakly separable from other product groups. Catfish imports, which are mostly frozen fillets, are treated as an individual product within the group, which implies that consumers are able to differentiate between domestic and imported catfish. While it can be argued that this may not be the case, source-differentiation is plausible in this instance given the implementation country-of-origin labeling (COOL). Although COOL legislation for seafood is fairly recent (April 2005), catfish imports above negligible levels are also fairly recent. In instances where COOL may not apply (e.g., restaurant sales), country-of-origin is still a factor for retailers and wholesalers. In this instance, the allocation of consumer expenditures to domestic catfish and imports is indirectly determined by the behavior of retailers and wholesalers.

The data used in this study were monthly and covered the time period January 1996 to January 2009. Domestic quantities at the processor level measured in 1,000 pounds and prices measured in dollars per pound were provided by the United States Department of Agriculture, National Agricultural Statistical Service (U.S. Department of Agriculture- National Agricultural Statistics Service, 2009). Domestic catfish was disaggregated into six processed products: fresh whole catfish, fillets, and other; frozen whole catfish, fillets, and other. The other category included steaks, nuggets, and other catfish products not elsewhere specified. Import quantities and prices were provided by the National Marine Fisheries Service and were an aggregation of all catfish from foreign suppliers.

Descriptive statistics for model variables are presented in Table 2. The average price of fresh whole catfish, fillets, and other catfish were \$1.58, \$2.83, and \$1.67/lb, respectively. The average price of frozen whole catfish (\$2.00/lb) was \$0.42 higher than the price of fresh whole catfish. The average price of frozen fillets and other catfish were \$2.70 and \$1.60/lb, respectively. Both were lower than their fresh counterparts by \$0.13 and \$0.07, respectively. Although imports are mostly fillets, they were

Table 2. Descriptive Statistics for U.S. Catfish Sales: January 1996 to January 2009

Product	Mean	Standard Deviation	Minimum	Maximum
	Price ($/lb)			
Fresh whole	1.58	0.13	1.24	1.81
Fresh fillet	2.83	0.22	2.44	3.33
Fresh other	1.67	0.10	1.40	1.90
Frozen whole	2.00	0.12	1.80	2.28
Frozen fillet	2.70	0.19	2.36	3.11
Frozen other	1.60	0.16	1.28	1.96
Imports	1.43	0.27	0.89	2.77
	Monthly Quantity (1,000 lbs)			
Fresh whole	3,213	458	2,227	4,467
Fresh fillet	4,712	808	3,075	6,815
Fresh other	1,215	293	568	2,156
Frozen whole	1,104	182	576	1,595
Frozen fillet	9,522	1,205	6,296	12,362
Frozen other	3,911	628	2,384	5,364
Imports	2,297	3,168	—	12,803
	Monthly Expenditure ($1,000)			
Fresh whole	5,040	699	3,733	7,022
Fresh fillet	13,236	1,882	9,054	18,903
Fresh other	2,012	453	920	3,385
Frozen whole	2,197	322	1,267	3,637
Frozen fillet	25,643	2,932	16,873	33,555
Frozen other	6,199	798	4,267	8,295
Imports	3,393	4,937	—	20,694
	Budget Share (%)			
Fresh whole	8.85	1.53	6.09	12.95
Fresh fillet	22.99	2.27	16.41	27.96
Fresh other	3.55	0.91	1.72	4.98
Frozen whole	3.85	0.65	2.37	5.69
Frozen fillet	44.59	3.20	33.82	49.39
Frozen other	10.80	1.14	7.77	13.59
Imports	5.37	7.43	0.00	29.54

significantly cheaper than U.S. catfish products. The average import price was $1.43/lb, which was less than the lowest priced U.S. product, fresh whole catfish.

Frozen fillets accounted for the largest expenditure share of catfish sales in the United States (44.6%). The next largest category was fresh fillets (23.0%). The other frozen category accounted for 10.8%, fresh whole catfish 8.9%, frozen whole catfish 3.9%, and other fresh catfish 3.6%. In more recent months, imports have accounted for as much as 29.50% of U.S. sales. However, throughout most of the data period imports accounted for a relatively small share where the average expenditure share was about 5.4%.

Estimation of the dynamic Rotterdam model was accomplished using the LSQ procedures in TSP (version 5.0), which uses the generalized Gauss-Newton method to estimate the parameters in the system (Hall and Cummins, 2005). Due to the adding-up property, the system of equations represented by (7) was singular and required that an equation be deleted for estimation. The frozen other equation was deleted for this purpose. However, as noted by Barten (1969), maximum likelihood estimates are invariant to the chosen deletion equation. Given that the Rotterdam model is in log-differential form, zero observations are problematic since the log of zero is undefined. While monthly catfish sales were mostly positive, in May 1997, catfish imports were zero. For estimation purposes this observation was set to one.

A dynamic model of lag-length k is nested within a model of lag-length $k + 1$. Thus, likelihood ratio (LR) tests can be used to test for the appropriate adjustment period (Brown and Lee, 1992). LR test results are presented in Table 3 and indicate that the static Rotterdam model without constants should be rejected in favor of the static model with constants. The significance of the constant terms suggests trends (in levels) in U.S. catfish demand (Seale, Marchant, and Basso, 2003). Results further indicate that the static model (with constants) should be rejected in favor of the one-period lag model, but there was little difference between the log-likelihood values for the two-period and one-period lag models. This suggests that the one-period model should not be rejected in favor of the two-period model and that it takes up to 1 month for demand to fully adjust to changes in expenditures and prices.[3]

Given the one-period lag model, a test was performed to determine if the cross-lag effects were symmetric (Ho: $\gamma_{ij} = \gamma_{ji}\ \forall i \neq j$). This hypothesis was rejected at any reasonable significance level. This implies (for example) that the impact of past fresh fillet consumption on frozen whole catfish consumption is not equal to the impact of past frozen whole catfish consumption on fresh fillet consumption.

A test was performed to determine if the own-lag effects were the only significant dynamic factors (Ho: $\gamma_{ij} = 0 \forall i \neq j$). This hypothesis would yield the lag specification in Brown and Lee (1992) and would imply that present consumption of a given product would be impacted by past consumption of that product only. This hypothesis was also rejected at any reasonable significance level.

[3] All models have homogeneity and symmetry imposed although both properties were rejected in preliminary tests.

Conditional demand estimates are presented in Table 4. Overall, the dynamic Rotterdam model performed reasonably well, where expenditures, prices, and past consumption in the previous month explained a significant percent of the variation in present consumption. All marginal share estimates or expenditure effects (θ_i) were positive and significant at the 1% level with the exception of frozen whole catfish, which was significant at the 5% level. These estimates indicated how a dollar increase in real catfish expenditures was allocated across the seven products. Given that fillets (fresh, frozen, and imports) are the more popular products, their marginal share estimates were relatively large when compared with the other catfish products. The marginal share estimates for domestic fresh and frozen fillets were 0.127 and 0.320, respectively, and the marginal share for imported fillets (imports) was 0.390.

With the exception of frozen whole catfish and imports, all own-price effects (π_{ii}) were negative and significant at the 1% level, which is consistent with economics theory. This also sufficiently ensures that the matrix of price effects is negative semidefinite, at least at the point of estimation. Of the seven catfish products, the own-price effects for fresh and frozen fillets (−0.238 and −0.239, respectively) were significantly greater than the own-price effects for the remaining products. Significant own-price estimates for the remaining products were: −0.064 (fresh whole), −0.027 (fresh other), and −0.044 (frozen other).

A number of cross-price estimates indicated significant competition between catfish products. Products that were competitive (substitutes) include: fresh whole catfish and fillets (0.084), fresh and frozen fillets (0.108), fresh other and frozen fillets (0.034), frozen fillets and other (0.034), and frozen fillets and imports (0.028). There were also significant complementary relationships between fresh whole and other catfish (−0.023), fresh and frozen whole catfish (−0.029), fresh fillets and imports (−0.016), and frozen other and imports (−0.015). The complementary relationships were relatively small in magnitude when compared with the competitive relationships.

Table 3. Likelihood Ratio Tests Results

Models	Log-Likelihood Value	LR Statistic	p-Value
Two-period lag	3,036.10		
One-period lag	3,010.17	51.86	0.142 (42)[a]
Static (constants)	2,882.32	255.70	0.000 (42)
Static (no constants)	2,854.50	55.64	0.000 (6)
Additional Restrictions			
Symmetric lags	2,962.12	96.09[b]	0.000 (15)
Own-lags only	2,879.05	262.24[b]	0.000 (36)

All models have homogeneity and symmetry imposed.
[a] The number of restrictions is in parenthesis.
[b] The one-period lag model is the unrestricted model for this LR statistic.

The dynamic adjustment estimates are presented in Table 5 where the dynamic own-lag effects are presented along the diagonal. Sexauer (1977) notes that positive own-lag effects reflect habit persistence whereas negative effects reflect short-run inventory adjustments. All own-lag effects were significant and positive which suggest habit formation behavior. In other words, repeated consumption of a given catfish product increases preferences for that product resulting in even greater consumption in the future, ceteris peribus. Of the seven catfish products, the most significant habit effects were for fresh and frozen fillets (0.1384 and 0.1557, respectively). All others were small by comparison.

Recall that Wohlgenant and Hahn (1982) suggested that the ability of consumers to vary both their inventory behavior and consumption is important in determining the dominance of the stock or habit effect. Given the perishable nature of fish, it is not likely that consumers maintain significant catfish inventories on a monthly basis. Ladewig and Logan (1992) note that refrigerated catfish (stored at 32° to 38°F) should be consumed within 2 days and even frozen catfish (never thawed) stored at 0°F should be consumed within 3 months. Thus, the management of catfish stocks may be more applicable to weekly or daily sales data, particular since the average shelf life of channel catfish is about 5–7 days (Przybylski et al., 2006).

The sign and magnitude of the cross-lag effects depend on the relationship between products (substitutes versus complements) and the adjustment behavior of buyers (habits versus inventories). For example, if any two products are substitutes (complements) and unrelated to all other goods, we would expect their cross-lag effect to be negative (positive) given habit formation in demand. Note that the cross-price estimates indicated a competitive relationship between frozen fillets and most other catfish products (see Table 4). Likewise, the dynamic effects of past frozen fillet consumption on most products were negative. Since each product was related to more than one product the signs of the cross-lag estimates may not be consistent with the above stated in many cases. Regardless to sign, however, the cross-lag effects indicate that not only was past "own-product" consumption a significant determinant of demand but past "cross-product" consumption was also important.

The short-run and long-run expenditure and price elasticities are presented in Table 6. The short-run expenditure elasticities for frozen fillets (0.71) and frozen other (0.81) were relatively larger than the estimates for the remaining products except imports. It must be noted that the elasticities were evaluated at mean budget shares. The budget share for imports was about 5%, which resulted in the unusually large expenditure elasticity (7.89). Using a more recent budget share estimate (0.25), the expenditure elasticity is about 0.64. As expected, demand was more expenditure elastic in the long-run given habit formation behavior, particularly for fresh fillets where the expenditure elasticity was 0.549 in the short-run and 1.365 in the long-run. The same was

Table 4. Conditional Demand Estimates for Processed Catfish

	Price Coefficients π_{ij}							
	Fresh			Frozen				
Products	Whole	Fillet	Other	Whole	Fillet	Other	Imports	Marginal Share θ_i
Fresh								
Whole	−0.064 (0.011)***	0.084 (0.017)***	−0.023 (0.006)***	−0.029 (0.008)**	0.029 (0.019)	0.002 (0.005)	0.000 (0.002)	0.043 (0.006)***
Fillet		−0.238 (0.053)***	0.016 (0.014)	0.030 (0.019)	0.108 (0.049)**	0.017 (0.012)	−0.016 (0.005)***	0.127 (0.017)***
Other			−0.027 (0.007)***	−0.002 (0.007)	0.034 (0.015)**	0.006 (0.004)	−0.002 (0.002)	0.020 (0.005)***
Frozen								
Whole				−0.005 (0.014)	0.007 (0.017)	0.000 (0.005)	−0.001 (0.002)	0.012 (0.005)**
Fillet					−0.239 (0.063)***	0.034 (0.015)**	0.028 (0.010)***	0.320 (0.033)***
Other						−0.044 (0.009)***	−0.015 (0.003)***	0.088 (0.011)***
Imports							0.006 (0.012)	0.390 (0.041)***
Equation R^2	0.64	0.73	0.50	0.35	0.74	0.50	0.57	

Note: System $R^2 = 0.931$.
Asymptotic standard errors are in parentheses. Homogeneity and symmetry are imposed.
***, **, * Significance level = 0.01, 0.05, 0.10, respectively.

Table 5. Dynamic Adjustment Estimates

Products	Constant γ_i^*	Lag Coefficients γ_{ijk} (one-period lag effects)						
		Fresh			Frozen			
		Whole	Fillet	Other	Whole	Fillet	Other	Imports
Fresh								
Whole	−0.0018 (0.001)***	0.0209 (0.006)***	0.0094 (0.006)*	0.0046 (0.004)	0.0068 (0.004)*	−0.0160 (0.006)***	−0.0026 (0.004)	−0.0009 (0.000)**
Fillet	0.0032 (0.001)***	−0.0021 (0.016)	0.1384 (0.014)***	0.0165 (0.010)*	0.0188 (0.010)*	−0.0488 (0.015)***	−0.0313 (0.012)***	−0.0039 (0.001)***
Other	−0.0007 (0.000)*	−0.0162 (0.005)***	0.0071 (0.004)*	0.0198 (0.003)***	0.0024 (0.003)	−0.0050 (0.005)	−0.0057 (0.004)	−0.0008 (0.000)***
Frozen								
Whole	−0.0012 (0.000)***	−0.0036 (0.005)	0.0023 (0.005)	−0.0037 (0.003)	0.0102 (0.003)***	0.0083 (0.005)*	0.0009 (0.004)	−0.0006 (0.000)*
Fillet	−0.0007 (0.002)	−0.0370 (0.029)	−0.0288 (0.025)	0.0562 (0.019)***	0.0437 (0.019)**	0.1557 (0.028)***	−0.0207 (0.022)	−0.0004 (0.002)
Other	0.0001 (0.000)	−0.0028 (0.010)	0.0213 (0.008)**	0.0048 (0.006)	0.0142 (0.006)**	−0.0269 (0.009)***	0.0140 (0.007)*	−0.0007 (0.001)
Imports	0.0011 (0.003)	0.0409 (0.037)	−0.1498 (0.031)***	−0.0982 (0.024)***	−0.0961 (0.024)***	−0.0673 (0.036)**	0.0454 (0.027)*	0.0073 (0.002)***

Asymptotic standard errors are in parentheses.
***, **, * Significance level = 0.01, 0.05, and 0.10, respectively.

Table 6. Short-Run and Long-Run Demand Elasticities

	Short-Run Elasticities			Long-Run Elasticities		
	Expenditure	Hicksian Own-Price	Marshallian Own-Price	Expenditure	Hicksian Own-Price	Marshallian Own-Price
Fresh						
Whole	0.489	−0.725	−0.768	0.641	−0.950	−1.007
Fillet	0.549	−1.026	−1.154	1.365	−2.551	−2.868
Other	0.569	−0.757	−0.778	1.268	−1.687	−1.732
Frozen						
Whole	0.302[b]	−0.119[a]	−0.130[a]	0.411[b]	−0.162[a]	−0.177[a]
Fillet	0.714	−0.534	−0.854	1.093	−0.817	−1.308
Other	0.812	−0.411	−0.498	0.933	−0.472	−0.573
Imports	7.891	0.118[a]	−0.272[a]	9.257	0.138[a]	−0.319[a]

[a] Insignificant estimate.
[b] Significant at the 0.05 level; all others are significant at the 0.01 level.

true for frozen fillets (0.714–1.093) and fresh other (0.569–1.268).

Discussion of the short- and long-run own-price elasticities (Hicksian and Marshallian) is limited to the two main products, fresh and frozen fillets. Imports are excluded because while the current import share exceeds fresh fillets, the insignificant own-price estimate resulted in insignificant own-price elasticities. The Hicksian and Marshallian own-price elasticities for fresh fillets were about unity (−1.026 and −1.154, respectively) in the short-run. As expected, fresh fillet demand was significantly more elastic in the long-run where a percentage increase in price decreased the quantity demanded by about 2.55% (Hicksian) and 2.87% (Marshallian). For frozen fillets, the Hicksian own-price elasticity (−0.534) indicated that demand was inelastic in the short-run, and the short-run Marshallian own-price elasticity (−0.854) indicated that demand was relatively more elastic but still inelastic. In the long-run, frozen fillet demand was more elastic given habit formation. However, the increase (in absolute value) was not as great as fresh fillets. Whereas the own-price elasticities for fresh fillets increased 2.5 times in magnitude in the log-run, the Marshallian price elasticity for frozen fillets increased (in absolute value) by about 54% (−0.845 to −1.308).

The results show that fresh fillet demand was more elastic than the other fresh products, and frozen fillet demand was more elastic that the other frozen product. Additionally, when the total effect of prices are considered (Marshallian), the demand for fillets overall was relatively more elastic when compared with the other products. This was the case in both the short- and long-run and is consistent with Quagrainie (2003) who indicated that the demand for catfish was more price-elastic with added value.

Summary and Conclusion

Although Bushehri (2003) lays out a theoretical framework and derives a dynamic Rotterdam model from the intertemporal utility maximization problem, he stopped short of an empirical application. This paper provided an empirical application where the dynamic Rotterdam model was used in estimating the demand for disaggregated catfish in the United States. The overall objective was to assess dynamic behavior in the consumption of fresh and frozen domestic catfish products as well as catfish imports. Likelihood ratio tests indicated that the appropriate adjustment period for U.S. catfish demand was 1 month, and log likelihood values significantly decreased when a static model was assumed. These findings are consistent with Quagrainie (2003) who found an adjustment period of less than 2 months. Like Houston and Ermita (1992), our dynamic estimates suggested that habit formation played an important role in determining U.S. catfish demand where past consumption of a given product had a positive effect on the present consumption of that product. This was the case for all products in this study. Finally, dynamic estimates indicated that not only was past consumption of a given product important in determining present consumption, but past consumption of related products was also important.

Overall, the dynamic Rotterdam model performed reasonably well and the resulting estimates were fairly consistent with economic theory. As expected, there was a significant competitive relationship between fresh and frozen fillets, and given that imports were mostly frozen fillets, there was also a significant competitive relationship between imports and frozen fillets. Interestingly, the relationship between fresh fillets and imports was complementary and may be some indication that U.S. processors could specialize in fresh fillet production given the increase in frozen fillet imports. However, dynamic estimates did indicate that past consumption of imported catfish had a negative effect on the consumption of fresh domestic products, ceteris peribus. While the relative cheapness of imported catfish may have a positive effect on domestic fresh fillets given the conditional complementary relationship, increased consumption of imports could lead to decreased fresh fillet consumption in the future.

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