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U.S. Shrimp Market Integration

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Abstract *Recent supply shocks in the Gulf of Mexico—including hurricanes, the Deepwater Horizon oil spill, and the seasonal appearance of a large dead zone of low oxygen water (hypoxia)—have raised concerns about the economic viability of the U.S. shrimp fishery. The ability of U.S. shrimpers to mediate supply shocks through increased prices hinges on the degree of market integration, both among shrimp of different sizes classes and between U.S. wild caught shrimp and imported farmed shrimp. We use detailed data on shrimp prices by size class and import prices to conduct a co-integration analysis of market integration in the shrimp industry. We find significant evidence of market integration, suggesting that the law of one price holds for this industry. Hence, in the face of a supply shocks, prices do not rise; instead, imports of foreign farmed fish increase.*

Key words Seafood trade, market integration, environmental shocks.

JEL Classification Code Q22.

Introduction

Shrimp is the world's most valuable seafood product, accounting for 17% of the global seafood trade in 2006 (FAO 2009). Although more than half of the world's shrimp are now farmed, significant wild shrimp fisheries remain in many parts of the world, including the Gulf of Mexico and along the East Coast of the U.S. Figure 1 depicts global shrimp production broken down by farmed and wild. Production of wild shrimp increased in recent decades, but leveled off in 2003 at just over 3 million metric tons. Farmed shrimp production increased at even faster rates and reached a production of 3.5 million metric tons in 2009 for a combined global supply of over 6.6 million metric tons. This increased production has fueled an increased trade in shrimp. As for most farmed species,

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markets in the EU, Japan, and the U.S. have been the most targeted, since these are the markets with the highest willingness to pay.

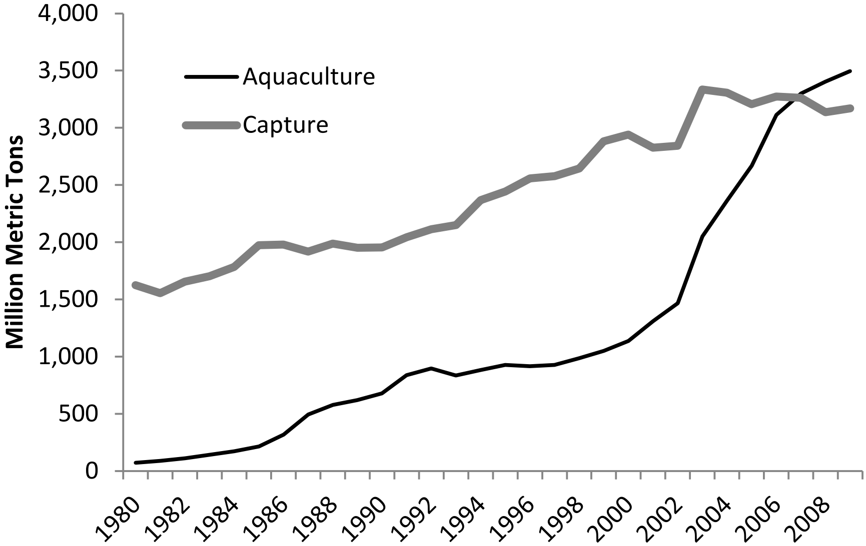

Figure 1. Global Shrimp Production by Production Method

Consumption of shrimp in the U.S. reflects the global surge in shrimp production. Shrimp ranked first in 2004 U.S. per capita seafood consumption at 4.2 pounds, nearly a pound more than the second ranked seafood category (canned tuna with 3.3 pounds per capita) (Committee on Nutrient Relationships in Seafood 2007). In 2010, shrimp consumption remained high at 4.0 pounds per capita compared to 2.7 pounds per capita of canned tuna, and consumption of all fillets and steaks aggregated across species amounted to only 5.0 pounds per capita (National Marine Fisheries Service 2011). Much of this consumption comes from imported farm-raised shrimp, as the U.S. has developed into the world's largest shrimp import market (Anderson 2003). In 1980, domestic shrimp had a 43% market share, but that share declined to 12% by 2001 (Mukherjee and Segerson 2011). In spite of declining market share, the U.S. still maintains a large wild shrimp fishery, with 80% caught in the Gulf of Mexico (Mukherjee and Segerson 2011). The U.S. domestic shrimp fishery has three main species: brown, pink, and white, the largest being brown. Brown shrimp landings in the Gulf over the past decade ranged from 33,000 to 71,000 metric tons with landed value between $137 and $355 million. For pink, landings ranged from 2,300 to 6,900 metric tons with landed value between $10 and $39 million. For white, landings ranged from 37,000 to 67,000 metric tons with landed value between $141 and $252 million.[1]

Understanding how integrated markets for domestic wild-caught shrimp fisheries are with markets for farmed shrimp imports is important for several reasons. First, the rapid increase in farmed shrimp production coupled with large domestic wild-caught fisheries has created trade disputes in the EU and U.S. The U.S., for example, enacted trade restrictions on shrimp from a group of six named countries (all in Asia or Latin

[1] < http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html>.

America) in 2004 after domestic fishermen filed anti-dumping complaints against several shrimp exporting countries (Keithly and Poudel 2008). Second, disease has been an issue for farmed shrimp. Reduced growth rates in farmed shrimp production in the 1990s can largely be attributed to white spot disease (Anderson 2003). Third, there are significant environmental shocks that affect the supply of domestic wild-caught shrimp. For U.S. shrimp fishermen, hypoxia—most notably the seasonal dead zone in the Gulf of Mexico—has been a reoccurring phenomenon that potentially influences aggregation, production, and the size distribution of shrimp (Craig 2012; Huang, Smith, and Craig 2010; Huang *et al.* 2012). Hurricanes Katrina and Rita caused significant shrimp supply disruptions through destruction of shrimp vessels and processing facilities (Buck 2005), while rising fuel prices are particularly costly for wild-caught shrimp because trawling is fuel-intensive (Ran, Keithly, Kazmierczak 2011). Moreover, costs of complying with the U.S. requirement for shrimp trawlers to use turtle excluder devices decreased domestic supply (Mukherjee and Segerson 2011). The degree of market integration affects how these environmental and economic stressors affect prices. The impact of all of these stressors (trade, production costs, disease, and environmental) will have a strong impact on the price determination process if the markets are not integrated, while the impact will be weaker in a larger, more integrated shrimp market. The rationale is that consumers can substitute other species (or substitute across wild or farmed) if the supply of one species becomes scarce due to a production shock.

Despite being the world's most important aquaculture species and comparably significant global capture landings, there are relatively few studies shedding light on the price determination process for shrimp. Vinuya (2007) is an exception, indicating that there is a global market for farmed shrimp. We investigate the extent of the shrimp market by testing for market integration using prices. Time series analysis of market integration has been used for a number of seafood products in recent decades. It is particularly useful when there is a large number of products/markets of interest, as demand analysis in such cases is not feasible (Asche, Gordon, and Hannesson 2004). Time series analysis can also be a flexible approach by allowing tests across geographically distinct markets, different species, and different product forms. If prices are stationary, ordinary regression analysis can be used (Squires, Herrick, and Hastie 1989; Asche, Gordon, and Hannesson 2004). But if prices are nonstationary, cointegration analysis is the appropriate econometric tool.[2]

The article is divided into sections describing the data, the time-series methods used for the empirical tests of market integration, the results, and finally, discussion of the implications for the shrimp market.

Data

Our data set consists of monthly prices covering the period June 1990 through December 2008. The prices of brown, pink, and white shrimp, by size, are for the Gulf of Mexico shrimp fishery and are computed by aggregating daily landings values and quantities that are recorded in NOAA's SHRCOM database. SHRCOM is the primary source of microdata used for fisheries management in the Gulf of Mexico. The import prices are U.S. import prices from the U.S. Department of Commerce <www.st.nmfs.noaa.gov/st1/trade>.

Shrimp size is measured as the number of shrimp per pound. Hence, a higher number implies a smaller average size. In the raw data, prices are available for the three species in eight size categories for a total of 24 price time series. Figure 2 shows the prices by size

[2] Since most seafood prices are found to be nonstationary, cointegration is the most commonly used empirical tool to test for market integration (Gordon, Salvanes, and Atkins 1993; Bose and McIlgrom 1996; Gordon and Hannesson 1996; Asche, Bremnes, and Wessells 1999; Asche 2001; Jaffry *et al*. 2000; Asche *et al*. 2005; Nielsen 2005; Nielsen *et al*. 2007; Norman-López and Asche 2008; Nielsen, Smit, and Guillen 2009; Norman-López 2009).

class for brown shrimp. Price series for pink and white shrimp appear similar (Asche *et al.* 2011). In all cases, larger sizes are more valuable per pound, and there is substantial variation in the price level by size. However, price development of the different sizes appears to follow a common trend. Within each species, price increases (decreases) for one size tend to translate into price increases (decreases) for each of the other sizes. Visually, figure 2 suggests market integration, which we formally test in the results section.

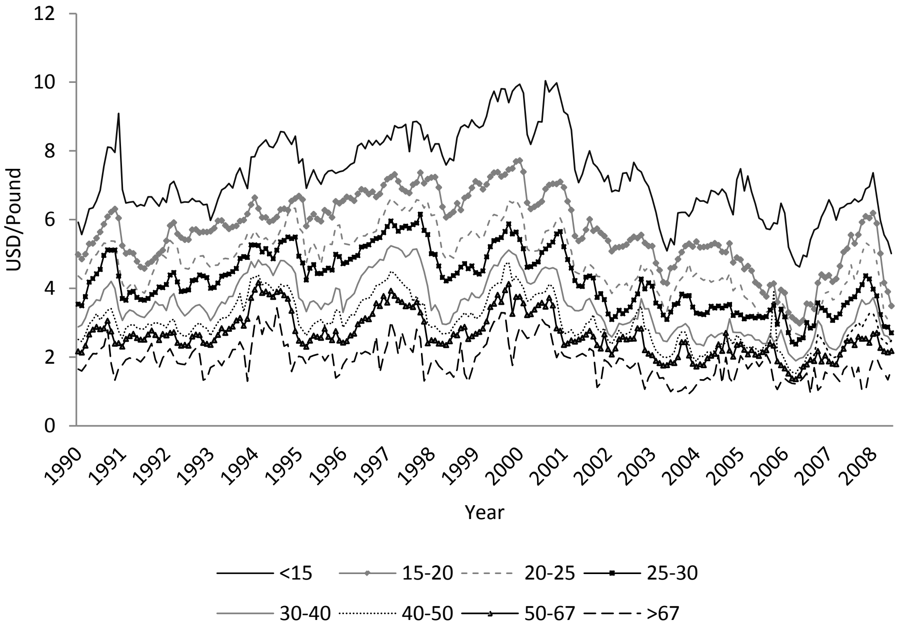

Figure 2. Monthly Prices of Gulf of Mexico Brown Shrimp in Different Size Classes

To compare the price development of U.S. shrimp with imports, different weight classes are aggregated to avoid the curse of dimensionality.[3] This weighting is done by constructing a Fisher price index for each of the three species. For imported shrimp, the category "shell-on frozen" is used. This category is the closest to the largest volumes for domestically produced shrimp because it is relatively unprocessed. In contrast, products like breaded shrimp or shrimp in frozen meals contain significant added value that could distort inferences about market integration.

Before conducting formal tests of market integration, the time series properties of the prices must be investigated. The results from Augmented Dickey-Fuller (ADF) tests are reported in table 1. Nearly all of the individual size-based price series are nonstationary in levels but stationary in first differences. The exceptions are small brown shrimp and very large pink shrimp that appear stationary in levels. All indexed prices are nonstationary in levels but stationary in first differences. The price series are, accordingly, integrated of order one, and cointegration analysis is the appropriate tool. This finding is as expected and in line with what is found for most seafood prices.

[3] Hendry (1995) provides a good discussion of the curse of dimensionality in time series analysis.

Table 1
Augmented Dickey Fuller Unit Root Tests Shrimp Series

		Level		1st Difference	
Series	Weight Class	Constant	Trend	Constant	Trend
Brown	<15	–1.583	–2.217	–4.245**	–4.342**
	15–20	–1.176	–2.398	–4.453**	–4.632**
	20–25	–1.636	–2.853	–6.546**	–7.805**
	25–30	–1.069	–2.768	–7.302**	–7.382**
	30–40	–1.821	–3.312	–11.14**	–11.14**
	40–50	–2.540	–3.523*	–3.595**	–3.588*
	50–67	–2.466	–3.138	–13.51**	–13.49**
	>67	–2.802	–3.790*	–3.740**	–4.321**
Pink	<15	–4.672**	–4.753**	–7.707**	–7.689**
	15–20	–2.053	–2.081	–11.62**	–11.59**
	20–25	–2.199	–2.591	–16.02**	–16.00**
	25–30	–1.720	–2.238	–15.86**	–15.84**
	30–40	–1.956	–2.359	–14.44**	–14.42**
	40–50	–2.478	–2.466	–4.847**	–4.861**
	50–67	–2.113	–2.680	–9.537**	–9.519**
	>67	–2.965*	–3.577*	–7.519**	–7.611**
White	<15	–1.217	–2.116	–6.897**	–6.512**
	15–20	–0.7487	–2.014	–3.756**	–3.884*
	20–25	–1.767	–3.107	–9.597**	–9.696**
	25–30	–1.207	–2.441	–4.067**	–4.113**
	30–40	–1.851	–3.217	–4.394**	–4.472**
	40–50	–1.803	–2.848	–4.019**	–4.040**
	50–67	–2.546	–3.384	–7.075**	–10.63**
	>67	–2.368	–3.350	–4.266**	–4.279**
Brown Fisher	–	–2.091	–3.242	–4.579**	–4.038**
Pink Fisher	–	–2.069	–2.678	–11.35**	–11.33**
White Fisher	–	–1.311	–2.385	–4.360**	–4.399**
Import Fisher	–	–1.350	–2.469	–4.867**	–7.143**

Note: * rejection at 5%; ** rejection at 1%.

Methods[4]

Let p_{1t} be the price in one market and p_{2t} the price in another. The basic relationship of interest for investigating market integration using time-series price data is the following:

$$\ln p_{1t} = \alpha + \beta \ln p_{2t}, \tag{1}$$

where α is a constant term that captures differences in the levels of the prices, and β indicates the relationship between the prices. If $\beta = 0$, there is no relationship between the prices, whereas if $\beta = 1$ the prices are proportional. When prices are proportional, the relative price is stationary, a phenomenon known as the Law of One Price (LOP). If β differs from zero but is not equal to one, there is a relationship between the prices, but the

[4] This section largely follows Asche, Gordon, and Hannesson (2004).

relative price is not constant. Equation (1) describes the situation when prices adjust immediately. However, there is often a dynamic adjustment pattern, which can be captured with lags of the two prices (Ravallion 1986; Slade 1986). Even when dynamics are introduced, the long-run relationship will have the same form as equation (1).

Since the late 1980s economists have known that traditional econometric tools cannot be used when price series are non-stationary; standard statistical theory for inference breaks down in these situations (Engle and Granger 1987). Cointegration analysis is then the appropriate tool to infer causal long-run relationships between non-stationary time series. There are two common approaches to test for cointegration: the single equation-based Engle-Granger test and the Johansen test (Johansen 1988). Given that the price series are nonstationary and integrated of the same order, the Engle-Granger test is performed by estimating equation (1) and testing whether the residuals are stationary. Stationary residuals indicate that the two price series are cointegrated.

The Johansen test is appropriate for a system of prices, and accordingly allows for more than one long-run relationship. Moreover, it allows for hypothesis testing on the parameters in the cointegration vector and exogeneity tests. The Johansen method is based on a vector autoregressive error correction model (VECM). With a vector, $\boldsymbol{P_t}$, containing the n prices, to test for cointegration the system can be written as:

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Pi_k P_{t-k} + \mu + e_t. \tag{2}$$

The matrix Π contains the parameters in the long-run relationships (the cointegration vectors). Given r cointegrating vectors, one can factorize $\Pi_k = \alpha\beta'$, where both α and β are $(n \times r)$ matrices. The β-matrix contains the cointegrating vectors and α the adjustment parameters. We use the trace test to determine the rank of Π. Tests with respect to the structural relationship between prices (markets) are tests of restrictions on the parameters in the cointegrating vectors, β. Information about the existence of a central market is formally conducted through exogeneity tests on the α coefficients and through examination of the integrating factors.

To illustrate, consider the case with only two price series, A and B. Assume that the two price series are nonstationary but cointegrated and that one lag is sufficient to capture the dynamics. The price relationships (suppressing the error terms) can be represented as:

$$\begin{bmatrix} \Delta p_t^A \\ \Delta p_t^B \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \begin{bmatrix} b_1 & b_2 \end{bmatrix} \begin{bmatrix} p_{t-1}^A \\ p_{t-1}^B \end{bmatrix}. \tag{3}$$

If $b_1 = -b_2$, the prices are proportional and the LOP holds. Usually, b_1 is normalized, so that the null hypothesis is $b_2 = -1$. The parameters α_i measure the impact of deviations from the long-run relationship and are normally denoted as the adjustment speed or factor loadings. In a system with n price series and r stochastic trends, there can be at most r exogenous variables (Johansen and Juselius 1994). With the structure expected in efficiently functioning commodity markets, n–1 cointegrating vectors and *one* stochastic trend are expected (Asche, Bremnes, and Wessells 1999; Gonzalez-Rivera and Helfand 2001).

Empirical Results

The sheer number of prices in the different shrimp size categories and species makes it virtually impossible to investigate the degree of market integration in one large system due to the curse of dimensionality. Moreover, Asche and Guttormsen (2001) note that prices for different weight classes are likely to be proportional; if that is the case, they can be aggregated using the Generalized Composite Commodity Theorem of Lewbel (1996). We thus commence our analysis by testing for market integration for each of the three species where prices by size are available. We then investigate the relationships among the three species and imports.

For the separate species, the most interesting issue is whether the market is fully integrated or whether different price determination processes by size exist. Supply shocks could affect different size classes differently due to spatio-temporal dynamics of the fishery and the individual life histories of species. Separate markets for each size would suggest that shocks that affect one size class would not propagate through to other size classes. This outcome, in turn, would affect the level of price compensation in the affected market. We thus use Engle-Granger tests for the size classes within each species and start out by imposing proportionality; *i.e.*, $\beta = 1$ in equation (1). If this hypothesis is rejected, we continue to test for cointegration without this restriction to distinguish the case of imperfect market integration from no market integration.

The results of the Engle-Granger test are reported in table 2. For nearly all price pairs, the null hypothesis of nonstationarity is rejected. The only exceptions are for the smallest size classes that constitute small shares of the total landings. Hence, we conclude that for all three species, there is strong evidence of a common price determination process and that prices move proportionally over time. This conclusion implies that one can construct an aggregate price for each species.

To investigate the relationships among the prices of the three species and the import price, a Johansen test is used. Here we used the indexed prices depicted in figure 3. The number of lags is chosen using the AIC and is found to be 14. A set of dummies is included to account for seasonality. The likelihood ratio test of Johansen and Juselius (1990) indicates that the constant term should be included in the cointegrating vectors.

The cointegration tests are reported in table 3. The results indicate that the system with four prices contains three cointegrating vectors and accordingly one common stochastic trend. This result is very robust with respect to model specification.

Normalized into bivariate relationships, the β matrix containing the cointegrating vectors is given as:

$$\beta = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ -1.113 & -0.990 & -1.124 \\ -0.000 & -0.000 & -0.001 \end{bmatrix}.$$

The *b* parameters are all relatively close to one, indicating that prices are close to proportional and the LOP approximately holds. A test for this hypothesis is distributed as $\chi^2(3)$, and gives a test statistic of 4.595. Accordingly, with a *p*-value of 0.204, this hypothesis is not rejected.

Trade restrictions on some named countries that are introduced to protect domestic producers must influence the relationship between domestic price and import price if they are to have any effect. This can be determined by testing for structural breaks in the price relationships (Asche 2001). We do not find evidence of any structural breaks in the relationships, as the test for a break in January 2000 gives a *p*-value of 0.720 and the test of a structural break in January 2005 gives a *p*-value of 0.803. This supports the conclusion of Keithly and Poudel (2008), who concluded that the trade restrictions led primarily to a reallocation of trade patterns, with little benefit to domestic producers.

Table 2
Cointegration Tests on Spreads of Species by Weight Class

Species	Spread	ADF	Spread	ADF	Spread	ADF	Spread	ADF
Brown	15 – 1520	–4.884**	1520 – 2530	–5.467**	2025 – 3040	–5.488**	2530 – 67	–4.294**
	15 – 2025	–4.494**	1520 – 2025	–4.941**	2025 – 4050	–5.089**	3040 – 4050	–8.601**
	15 – 2530	–3.915*	1520 – 3040	–5.906**	2025 – 5060	–5.015**	3040 – 5060	–7.010**
	15 – 3040	–4.601**	1520 – 4050	–4.800**	2025 – 67	–4.199**	3040 – 67	–3.275
	15 – 4050	–4.336**	1520 – 5067	–4.491**	2530 – 3040	–4.389**	4050 – 5060	–3.240
	15 – 5067	–3.862*	1520 – 67	–4.580**	2530 – 4050	–4.439**	4050 – 67	–3.206
	15 – 67	–3.996*	2025 – 2530	–5.265**	2530 – 5060	–4.321**	5060 – 67	–3.159
Pink	15 – 1520	–7.484**	1520 – 2530	–4.650**	2025 – 3040	–5.285**	2530 – 67	–6.431**
	15 – 2025	–4.561**	1520 – 2025	–3.788*	2025 – 4050	–4.442**	3040 – 4050	–4.344**
	15 – 2530	–7.773**	1520 – 3040	–6.025**	2025 – 5060	–3.600*	3040 – 5060	–4.368**
	15 – 3040	–6.153**	1520 – 4050	–5.403**	2025 – 67	–5.970**	3040 – 67	–7.338**
	15 – 4050	–6.507**	1520 – 5067	–4.445**	2530 – 3040	–5.102**	4050 – 5060	–5.193**
	15 – 5067	–5.569**	1520 – 67	–5.221**	2530 – 4050	–4.670**	4050 – 67	–6.635**
	15 – 67	–7.130**	2025 – 2530	–5.314**	2530 – 5060	–4.493**	5060 – 67	–9.303**
White	15 – 1520	–4.027**	1520 – 2530	–3.526*	2025 – 3040	–5.050**	2530 – 67	–5.267**
	15 – 2025	–3.478*	1520 – 2025	–3.458*	2025 – 4050	–4.361**	3040 – 4050	–5.807**
	15 – 2530	–3.770*	1520 – 3040	–4.159**	2025 – 5060	–4.210**	3040 – 5060	–6.085**
	15 – 3040	–4.043**	1520 – 4050	–4.030**	2025 – 67	–3.676*	3040 – 67	–5.998**
	15 – 4050	–3.712*	1520 – 5067	–4.265**	2530 – 3040	–5.178**	4050 – 5060	–6.692**
	15 – 5067	–4.013**	1520 – 67	–3.778*	2530 – 4050	–4.159**	4050 – 67	–3.311
	15 – 67	–3.386	2025 – 2530	–4.551**	2530 – 5060	–4.471**	5060 – 67	–3.129

Note: * rejection at 5%; ** rejection at 1%.

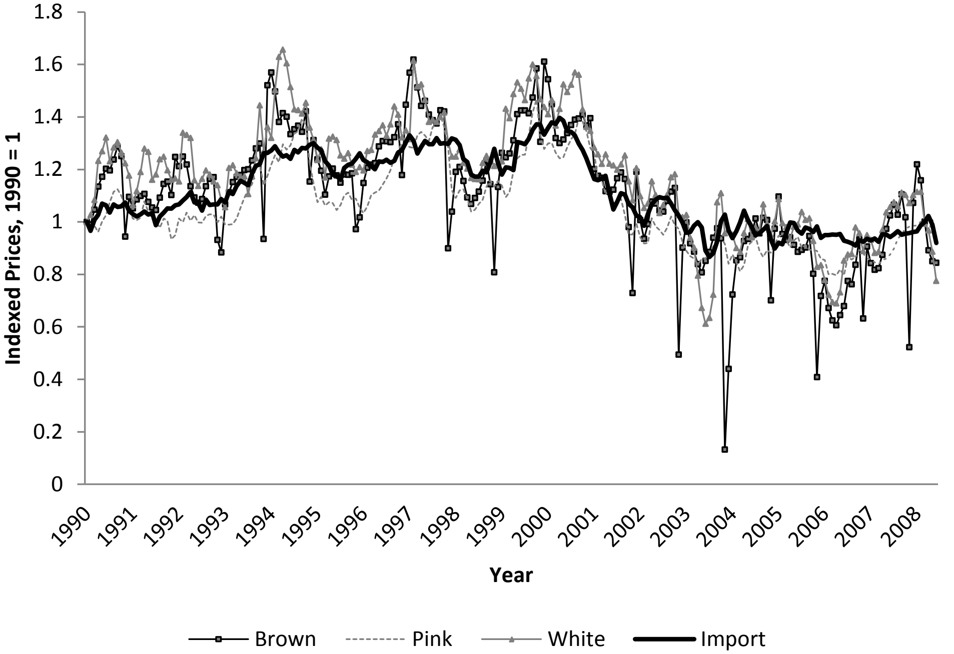

Figure 3. Monthly Fisher Index Prices and Import Prices for Shrimp

Table 3
Cointegration Analysis for Brown, Pink, White, and Imported Shrimp Prices

Rank	Eigenvalue	Trace Stat.	5% cv.	Max Eigenvalue Stat.	5% cv.
0	–	117.464*	62.99	47.485*	31.46
1	0.20411	69.979*	42.44	36.786*	25.54
2	0.16210	33.192*	25.32	25.203*	18.96
3	0.11412	7.9883	12.25	7.988*	12.52
4	0.03768				

Discussion

Using detailed monthly price data for shrimp of various sizes, we find significant evidence of integration in the U.S. shrimp market. We test for proportionality in relative prices using all possible price-pairs for different size classes, suggesting a common price determination process and that the prices move proportionally over time.

We then construct an aggregate price index for each of three species of domestic wild-caught shrimp and test for market integration between wild-caught shrimp and imports of farmed shrimp. We again find significant evidence of market integration.

The degree of market integration, both among size classes and across farmed and wild-caught shrimp has important implications for policy. First, in order for trade restrictions on imported shrimp from named countries to protect domestic producers, these restrictions must influence the relationship between domestic price and import price.

Market integration suggests that this does not occur, and trade restrictions act as a shift in the type of imports, by shifting to imports from non-named countries or of non-restricted shrimp (*i.e.*, processed shrimp), rather than helping domestic producers.

Second, if farmed shrimp are subject to supply shocks from disease, market integration implies that the domestic wild-caught fishery can replace supply from imports. The domestic industry would benefit through expanded production but not through higher prices. Given the wide range of domestic production and the influence of cost factors on supply, there is likely room for such expansion. However, a caveat is in order. A major global shock to farmed shrimp production that exceeds the magnitude of changes we observe in sample could lead to the breakdown of market integration.

Finally, market integration has significant implications for how domestic wild-shrimp fishermen can respond to certain environmental supply shocks. In North Carolina (a much smaller market than the Gulf of Mexico), there is evidence that hypoxia has decreased shrimp production in the range of 13% but has not increased prices (Huang, Smith, and Craig 2010; Huang *et al.* 2012). In the much larger Gulf of Mexico, there is emerging evidence that hypoxia decreases the supply of large shrimp and increases the supply of smaller shrimp, likely as a result of aggregation on the edge of hypoxic areas (Bennear, Kociolek, and Smith 2011; Craig 2012). Market integration suggests that the decreased supply of large shrimp cannot be offset by an increase in price. Rather, imports of larger farmed shrimp will increase to satisfy demand. Similarly, domestic supply shocks from hurricanes, oil spills, or fuel price spikes cannot be offset by price increases. In particular, market integration suggests that economic losses from a significant decrease in 2010 domestic shrimp production—assuming this decrease was caused by the Deepwater Horizon oil spill—was not likely offset by a price increase. Market integration thus has important implications for the long-run economic viability of the U.S. shrimp fishery. The losses from supply shocks are more consequential for producers, and the various shocks are additive as economic challenges to the fishery. But U.S. shrimp consumers are essentially unharmed. Market integration also implies that regional demand shocks (positive or negative) are felt by the entire industry, but their effects are dampened relative to how they would be felt in particular regions if markets were not integrated.

One important caveat to our findings is that we have examined market integration in a period (1990–2008) when shrimp imports increased dramatically. While we find significant market integration during this period, this integration could be recent and might not be found if looking at subsets of the time domain. That is, it may be that earlier portions of the time domain did not have market integration, and the implications for supply shocks during these times varied. Hypoxia has been documented in the Gulf for two decades, though detailed data are only available since the late 1990s. It may be that hypoxia had some ability to influence prices in the past, but no longer can due to the massive increase in imported shrimp.

A second caveat is to consider how the domestic wild-caught shrimp industry will react to the many economic stressors it faces. Currently, there is growing interest amongst American consumers in buying local food and wild-caught seafood in particular. The domestic shrimp industry is attempting to capitalize on this interest.[5] It remains to be seen whether domestic wild-caught shrimp producers will successfully segment the market and undo the market integration with imported farmed shrimp.

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