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# A Demand Analysis of the Krill Fisheries in Japan using an Almost Ideal Demand System

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【abstract】
In this study, we use an almost ideal demand system to estimate the price and expenditure elasticities of domestic krill fishery products. The quantity and price of all domestic krill fishery products in the Iwate and Miyagi prefectures of Japan are analyzed. Since krill fishery products are consumed in recreational fishing, we use expenditure on leisure as the expenditure variable. Additionally, since many typhoons hit Japan, the number of typhoon landfalls is used as the instrumental variable for the expenditure endogeneity problem. Estimated expenditure elasticities are between 0.73 and 1.28, and significant own-price elasticities are -1.33 and -0.88 in two markets in Miyagi. Cross-price elasticities show that the products of Miyagi and Iwate markets are substitute goods, while those within Miyagi are complementary goods.

【keywords】
North pacific krill, AIDS, elasticity, instrumental variable

## 1. Introduction

Two krill species are caught by commercial fisheries, the Antarctic krill (Euphausia superba) and the North Pacific krill (Euphausia pacifica) (Nicol and Endo (1997)). Both krill species are used in recreational fishing as bait in addition to the fact that they are pivotal species to the ecosystem of oceans. They occupy a "the central position in the food web between the phytoplankton and large vertebrate predators" (Nicol and Endo, 1997). While the Antarctic krill is caught by multiple countries and managed by the Convention of Antarctic Marine Living Resources (CCAMLR), the North Pacific krill (domestic krill, hereafter) is caught and managed only in Japan. A rich body of literature exists on the ecology, management, and economics of the Antarctic krill (Nicol *et al.* (2012), Nicol and Endo (1997), Watters *et al.* (2013)). However, few studies exist on the ecology and management of domestic krill (Endo (2000), Nicol and Endo (1997)), and, to the best of our knowledge, none on it is economics.

Domestic krill products are mostly used as bait in recreational fishing or consumed by humans. Approximately 85% of the domestic krill products are frozen for recreational fishing bait and approximately 15% dried for human consumption (Niinuma (2019), personal communications, June 18). Domestic krill dryers cost between 0.1 and 0.2 billion yen, and a few companies have installed these dryers. Thus, for many companies, instant shifting from frozen domestic krill products to dried domestic krill products is not possible (Hamada and Hitokabe (2019), personal communications, June 18 and 19). When used as recreational fishing bait, domestic krill products, are loaded into sabiki rigs. A sabiki rig consists of several small golden hooks and feathers that act as a small baitfish. Jigging these small golden hooks yield in catching multiple live baits at once and allow you to put them into your baitwells with the least amount of harm done to them. Domestic krill products can also be used as ground bait targeting relatively smaller fish such as the horse mackerel or sardine. Domestic krill products can also be used in aquaculture. However, the domestic krill is too expensive for aquaculture industry, considering that import price from China is approximately 35 yen/kg while average price of domestic krill is more than 50 yen for usual year (Goto (2019), personal communications, June 19). Thus, farmers are not willing to buy domestic krill as fish food. Wholesalers try to sell stocked frozen krill within a year to avoid deadstock and to reduce the costs of running their freezers. The krill products can also be imported from China; however, their quality is not high (some foreign particles are mixed, and the color is not red enough to attract fish as bait or make colored farmed seabream) (Goto (2019), personal communications, June 19). Therefore, the import of krill is not regarded as a good alternative to domestic krill and has less impact on the domestic krill market unless the domestic krill price goes down to too low, which is extraordinary case.

The Antarctic krill can also be imported to Japan. The Antarctic krill is larger than and more expensive the domestic krill. It is mainly used as bait for larger fish species (e.g., seabream or sea bass). These fish species are targeted by intermediate or expert anglers. Assuming that domestic krill is mainly consumed at the entry-level of recreational fishing, we assume domestic krill can rarely be substituted for other similar products.

The catch of domestic krill is dependent on how the frontier of the Oyashio Current

Table 1 List of Variable in AIDS Estimation

| Variables | Explanation |
|---|---|
| Main variables | |
| Price ($P_i^t$) | Average weekly price of market m, (North Iwate, Kamaishi, Ofunato in Iwate, Kesennuma, Onagawa, and Shizugawa in Miyagi). |
| Shares of sales ($w_i^t$) | Weekly weight of sales in each port out of the 6 ports' total sales. |
| Expenditure (x) | Monthly expenditure for fishing (or other leisure) activities. |
| Seasonal dummies | |
| Weekly dummies | Weekly dummy (5 business days) from the opening. |
| Yearly dummies | Dummies of 2017, 2018, and 2019 (outlying years). |
| Instrumental variables | |
| Landed Typhoon | The number of typhoons that hit Japan in the last year. |

moves south against the warm Kuroshio Current (Endo (2000)), and unlike the other fisheries, the level of stock is not determined by the amount that krill fisheries catch. Accordingly, we assume that the demand for the domestic krill markets does not interlink other markets such as foreign markets or Antarctic krill markets, and complete within the domestic market. It is also not affected by its stock level (no stock externality to market). We also assume the domestic krill markets are competitive since the krill fisheries consist of sole proprietors. We structure our model based on these assumptions.

This study aims to estimate dockside demand for the domestic krill. To estimate the demand, we employ almost ideal demand system (AIDS) because the krill distribution and is completed and competitive within domestic eight producer markets. Under competitive markets, a demand is formed by consumer's willingness to buy products (prices), quality, substitutes, disposable income, and other many factors, following the law of demand. We previously conducted a semi-structured interview with buyers at landing markets in Iwate Prefecture in 2019. According to the interview, the buyer tries to obtain the amount of krill based on the order by krill wholesalers that are also ordered by retailers (private communications, A processing company). Also the krill fishers communicate with buyers during operation to determine the amount of catch. Krill industry is small and closed industry, and few other distribution channels exist. It follows that the market power is vested in the consumers. Thus, we assume the demand is determined by a price that consumers determined since the krill markets are assumed competitive. Possible substitute goods such as imported krill or Antarctic krill do not mainly affect domestic krill markets, and substitution effect is limited to domestic landing markets. Thus, krill landing market is suitable to apply a complete demand system model across landing market. The AIDS is originally developed by

Deaton and Muellbauer (1980) and a variety of demands for Japanese fishery products is estimated using AIDS (Ariji (2013), Eales et al. (1997), Eales and Wessells (1999), Johnson et al. (1998), Sakai et al. (2009), Tonsor and Marsh (2007), Wakamatsu and Miyata (2016a), Wessells and Wilen (1994), (1993)).

Our study estimates krill demand across landing markets using AIDS, which is rare for literature that use demand system model. However, one study exists such that Thong (2012) applied a demand system model for international mussel trade markets to estimate the demand of each country's market, and it is of important to the domestic krill industry to understand the demand and the characteristics of krill goods.

## 2. Methodology

### 2-1. Data

To estimate demand, it is necessary to obtain the quantity and price of krill landings for each market and consumer expenditure on krill. We collected landing quantities and prices of all the ports that land krill (Miyako, Yamada, Otsuchi, Kamaishi, and Ofunato in the Iwate Prefecture, Kesen-numa, Onagawa, and Shizugawa in the Miyagi Prefecture). Daily data from February 25, 2013 to April 20, 2019 was obtained. Table 2 shows overall descriptive statistics of krill landing market in Japan. Average price of krill for 7 years ranges from 51 to 61 yen/kg. Ofunato occupies 30% of market share which is the highest following Onagawa (20%). Depending on the arrival and departure of krill near the coastline, the fishing season usually starts at the end of February and ends at the end of April, which makes the number of days at sea different for each year. Iwate Prefecture, located in northern Miyagi Prefecture, usually starts fishing earlier than Miyagi Prefecture because a herd of krill comes from the north along the Oyashio Current. Fishing operations are irregularly closed once every several operational days owing to production adjustment for price collapse and the rough weather conditions in the winter. This short closure is mainly concurrent in the same prefecture, but not in others. Since this short closures create many missing values and make analysis difficult with the daily data, we converted the data from daily to weekly, each of which consists of five business days from the opening day of the year. The three landing ports in the Iwate prefecture (Miyako, Yamada, and Otsuchi) are relatively small in scale, and many missing values exist in these ports. For this reason and since the ports are adjacent to each other, we regarded (summed up) them as one regional market (North Iwate, hereafter). Combining these ports helped to deal with the technical issues of estimation.

Table 2　Descriptive Statistics of Krill Landing Market in Japan

| | Iwate Prefecture | | | Miyagi Prefecture | | |
|---|---|---|---|---|---|---|
| | North Iwate | Kamaishi | Ofunado | Kesen-Numa | Onagawa | Shizugawa |
| Vessels (vessels/week) | 68.3 | 32.4 | 123.1 | 80.6 | 99.4 | 62.4 |
| | (41.0) | (11.4) | (47.3) | (50.3) | (63.8) | (40.0) |
| Landing (Kg/week) | 375,443 | 206,612 | 777,431 | 418,578 | 577,488 | 334,151 |
| | (247,485) | (96,608) | (380,941) | (285,641) | (401,529) | (238,089) |
| Value (JPY/week) | 21,600,000 | 12,300,000 | 44,000,000 | 19,400,000 | 27,500,000 | 15,300,000 |
| | (19,100,000) | (9,837,457) | (27,300,000) | (14,800,000) | (18,500,000) | (12,000,000) |
| Share of values | 16.2% | 8.5% | 30.4% | 13.6% | 20.6% | 10.7% |
| | (0.16) | (0.05) | (0.12) | (0.08) | (0.12) | (0.06) |
| Price (JPY/Kg/week) | 58.7 | 61.0 | 63.2 | 51.8 | 56.3 | 51.7 |
| | (40.5) | (40.9) | (39.6) | (28.4) | (28.6) | (30.4) |

Note: Values in parentheses are standard deviation.

The average prices and quantities of landing prices were calculated using the obtained data.

A demand analysis usually needs monetary variable that control the expense on the commodity. This study aims to estimate the demand at landing markets, and thus landing value is usually used for the expenditure variable. However, considering endogenous aspect of expenditure, expense on the landing market are affected by expense on leisure fishing. Hence, we collected expense on leisure fishing as proxy data of krill expenditure. We obtained the data from the statistics bureau of Japan, which included expenditure on non-durable goods for leisure (Ministry of Internal Affairs and Communications, 2019)(1). Results of the model using expense on leisure fishing and the model using total landing value are compared in Appendix B, and we found that the results are quite similar, and that the model using expense on leisure fishing has more significant explanatory variable for expense to the dependent variable.

## 2-2. Almost Ideal Demand System

We constructed the AIDS model for the krill fisheries to estimate the demand following Lecocq and Robin (2015), using code “aidsills”(2) in STATA 15.1. The asymptotic variance-covariance matrix is estimated to obtain standard errors in the package, following Blundell and Robin (1999). The equation of the model for this study is as follows:

$$w_{it} = \alpha_i + \gamma_i' \boldsymbol{p}_t + \beta_i \{x_t - a(\boldsymbol{p}_t, \boldsymbol{\theta})\} + u_{it}. \qquad (1)$$

$w_{it}$ is the share of landing $w_{it}$ on market $i = 1, \ldots, 6$ at a time point $t = 1, \ldots, 49$. $x_{it}$ is the log-total expenditure on fishing (leisure), vector $\boldsymbol{p}_t$ is the log price, and $u_{it}$ is an error term. The nonlinear price aggregator in the equation above is given by:

$$a(\boldsymbol{p}_t, \boldsymbol{\theta}) = \alpha_0 + \boldsymbol{\alpha}'\boldsymbol{p}_t + \frac{1}{2}\boldsymbol{p}_t{}'\boldsymbol{\Gamma}\boldsymbol{p}_t.$$

vectors denote $\boldsymbol{\alpha} = (\alpha_1, \dots, \alpha_N)'$, $\boldsymbol{\beta} = (\beta, \dots, \beta_N)'$, $\boldsymbol{\Gamma} = (\gamma, \dots, \gamma_N)'$, and $\boldsymbol{\theta}$ denote the set of all parameters. The list of variables is presented in Table 1.

$\alpha_0$ in the price aggregator is not identified, nor is any other arbitrary fixed price, including zero in the estimation. $\alpha_0$ is usually set to be slightly less than the log of the lowest price of $x_t$ (Poi (2012)), and in our data, $\ln(\min(x))$ is 8.53. Thus, $\alpha_0$ was set to 8 as an arbitrary price. The estimated prices did not vary with other arbitrary prices between 0 and 10. We also set three conditions to run AIDS: additivity condition, where $\beta_i$ and $\gamma_i$ sum to zero, and $\alpha_i$ sum to one over all the equation; homogeneity condition, where the effect of estimates of log price sum up to zero within each equation; and symmetry condition, where a parameter $\gamma_i$ on budget share *j* equals $\gamma_j'$ on budget share *i*, as follows: $\sum \alpha_i = 1$ , $\sum \beta_i = 0 \sum \gamma_{ij} = 0$ , $\gamma_{ij} = \gamma_{ji}$.

In this study, we introduce weekly and yearly dummy variables, ***s***. The weekly dummy consists of five business days, from the day it opened to when it closed, except for the last period(3). The first week is the base and is dropped from the equation. While landing price was relatively smooth from 25 to 79 yen/kg in the earlier period from 2013 to 2016, the price moves steeply: from 62 to 185 yen/kg in 2017: from 65 to 1715 in 2018, and from 30 to147 yen/kg in 2019. Accordingly we introduce yearly dummy of 2017, 2018, and 2019. The variable ***s*** is set as $\boldsymbol{\alpha}_t = \boldsymbol{A}\boldsymbol{s}_t$, $\boldsymbol{A} = (\boldsymbol{\alpha}_i')$.

Expenditure elasticity is given by $e_i = \beta_i / w_i + 1$ , and uncompensated and compensated price elasticities are given by $e_{ij}^u = \frac{\gamma_{ij} - \beta_i \alpha_j + \beta_i \gamma_j \boldsymbol{p}}{w_i} - \delta_{ij}$, and $e_{ij}^c = e_{ij}^u + e_i w_j$, respectively (Lecocq and Robin, 2015). $\delta_{ij}$ is the Kronecker delta ($\delta_{ij} = 1\ if\ i = j, \delta_{ij} = 0\ if\ i \neq j$). The compensated price elasticity indicates the pure price effect, in which the time point is compensated for the expenditure effect of a price change (Green and Alston (1990)).

## 2-3. Introduction of an instrumental variable

Regression analyses often suffer from endogeneity issues, and the introduction of instrumental variables (IVs) is necessary to cope with endogeneity. In fisheries, IVs of weather conditions are popular for coping with endogeneity (Angrist, Graddy, and Imbens (2000), Angrist and Krueger (2001)). In this study, we used the number of typhoon landfalls in the previous year. When typhoons hit Japan, fishing activities cease, which reduces expenditure related to fishing activities. The decrease in the expenditure affect demand for kill as fishing baits. Typhoons usually hit Japan from Summer to Fall, which affect recreational fishing activities. The decrease in demand affected by the typhoons indirectly reduces the upcoming demand for krill in the next year. In the endogeneity problem, the error term $u_{it}$ may be correlated with the log total expenditure on fishing, $x_t$. If correlated, these variables may cause biases in the estimation. Using IVs and the augmented regression technique, equation (1) can be augmented with the error vector, $\hat{\boldsymbol{v}}_t$, which can be predicted from the reduced form of the estimation for $x_t$. The augmented regression is estimated in three-stage least-square estimator (Lecocq and Robin(2015)). The error term is rewritten as $u_{it} = \boldsymbol{\rho}_i \hat{\boldsymbol{v}}_t + \varepsilon_{it}$ which is an orthogonal decomposition, and $E(\varepsilon_{it}|x_t) = 0$. The significance of the coefficient of $\hat{\boldsymbol{v}}_t$ shows the results of the exogeneity test.

## 3. Results

### 3-1. Result of Estimation

Table 3 shows the estimation results of the AIDS model. Some weekly and yearly dummies show the statistical significance that increases or decreases the number of sales in the markets. The result of instrumental regression is shown in Appendix C. The IV of the number of typhoons that hit Japan significantly explains the expense on leisure including fisheries and coped with endogeneity (the exogeneity test was insignificant). Also, AIDS estimation result (Table 3) show that variable of typhoon landfalls are not significant, which means IV is only effective to expenditure variable, but not to demand for krill. Hence, this estimation is considered to satisfy exclusion restriction. The result also shows significant market shares in each market at 1% of significance level (shown in Table 4), which supports the premise of AIDS model that change in price determines market share.

Expenditure elasticities in the Iwate prefecture are 1.28 (North Iwate), 1.27 (Ofunato), and those in the Miyagi prefecture are 0.74 (Kesen-numa), 0.88 (Onagawa), 0.81 (Shizugawa), respectively with 1% significant level (Table 4). According to the results, the krill in Iwate prefecture is a relatively a luxury commodity, and that in Miyagi prefecture is a necessary commodity.

As for own-price elasticities, the krill products in Kamaishi show -1.48 (uncompensated) at a 10% level of significance, while Onagawa and Shizugawa show -1.5 (uncompensated) and -0.99 (uncompensated) at 1% level.

Table 3 The estimation results

| | NI | Kama | Ofuna | Kesen | Ona | Shizu |
|---|---|---|---|---|---|---|
| $\gamma$ | | | | | | |
| North Iwate | 0.07 | 0.006 | -0.16 | -0.14 | 0.19 | 0.04 |
| Kamaichi | 0.01 | -0.04 | -0.087 | 0.047 | 0.09 | -0.02 |
| Ofunato | -0.16 | -0.09 | 0.056 | 0.054 | 0.003 | 0.13 |
| Kesennuma | -0.14 | 0.05 | 0.054 | 0.15 | -0.06 | -0.05 |
| Onagawa | 0.19*** | 0.09*** | 0.003 | -0.06 | -0.13* | -0.1*** |
| Shizugawa | 0.04 | -0.02 | 0.13 | -0.05 | -0.1 | 0.001 |
| $\beta$ | | | | | | |
| Expenditure | 0.04 | -0.02 | 0.08* | -0.04 | -0.03 | -0.02 |
| $\rho$ | | | | | | |
| Typhoons | 0.21 | 0.12 | 0.047 | 0.11 | -0.40 | -0.087 |
| $\alpha$ | | | | | | |
| Weekly dummy | | | | | | |
| week 2 | 0.02 | 0.005 | -0.05 | 0.02 | 0.01 | 0.001 |
| week 3 | 0.034 | 0.004 | -0.04 | 0.02 | -0.03 | 0.001 |
| week 4 | -0.001 | -0.01 | -0.09** | 0.05* | 0.032 | 0.03* |
| week 5 | -0.06** | -0.029 | -0.13*** | 0.06** | 0.10** | 0.06*** |
| week 6 | -0.028 | 0.014 | -0.040 | 0.038 | -0.0093 | 0.025 |
| week 7 | -0.07** | 0.002 | -0.15*** | 0.09*** | 0.05 | 0.07*** |
| Yearly dummy | | | | | | |
| 2017 | 0.06 | 0.04 | 0.07 | -0.04 | -0.10* | -0.02 |
| 2018 | 0.19*** | 0.05 | 0.25*** | -0.13*** | -0.26*** | -0.09*** |
| 2019 | 0.05* | 0.02 | 0.04 | -0.02 | -0.08** | -0.004 |
| Constant | 0.21* | 0.001 | 0.56*** | 0.01 | 0.18 | 0.04 |
| R-Square | 0.79 | 0.65 | 0.68 | 0.57 | 0.7 | 0.72 |

Note 1) ***, **and * indicate significant level at 1, 5, and 10 %.

Note 2) Typhoons denotes typhoon landfalls.

Note 3) NI stands for North Iwate, Kama for Kamaishi, Ofuna for Ofunato, Ona for Onagawa, Shizu for Shizugawa.

Table 4 The estimated elasticities

| | Predicted share | Expenditure elasticity | Own-price elasticities Uncompensated | Own-price elasticities Compensated |
|---|---|---|---|---|
| North Iwate | 0.126*** | 1.281*** | -0.525 | -0.363 |
| Kamaishi | 0.073*** | 0.734* | -1.478* | -1.424 |
| Ofunato | 0.288*** | 1.265*** | -0.945 | -0.58 |
| Kesennuma | 0.155*** | 0.740*** | -0.009 | 0.106 |
| Onagawa | 0.235*** | 0.876*** | -1.531*** | -1.325*** |
| Shizugawa | 0.122*** | 0.813*** | -0.982*** | -0.883** |

Note: ***, **and * indicate significant level at 1, 5, and 10 %.

Table 5 The estimated cross-price elasticities

| | Onagawa | |
|---|---|---|
| | Uncompensated | Compensated |
| North Iwate | 1.465*** | 1.767*** |
| Kamaishi | 1.306** | 1.478*** |
| Shizugawa | -0.763*** | -0.571** |

Note: *** and ** indicate significant level at 1 and 5 %.

The cross-price elasticities in Table 5 show significant relationships between Onagawa and North Iwate, Kamaishi, and Shizugawa. These relationships suggest that the krill in Onagawa is a substitute for that in North Iwate and Kamaishi, while it is a complementary good of Shizugawa.

### 3-2. Checking Market linkage

Given that there are few significant cross-price elasticities, there is a possibility that krill markets are not integrated, and thus we checked market linkage for the domestic krill market. We checked prices series of respective markets with unit root tests, and bivariate cointegration tests. As a result of unit root test, each price is in a non-stationary process, but in a first difference stationary process (Appendix D). The price series in a non-stationary process are tested by Johansen test for cointegration. The test result are shown in Figure 1, which indicates that almost all markets are integrated around Kesennuma and Onagawa (detailed statistics are shown in Appendix E).

| | Miyoko | Yamada | Otsuchi | Kamaishi | Ofunato | Kesen | Onagawa |
|---|---|---|---|---|---|---|---|
| Miyako | | | | | | | |
| Yamada | ✓ | | | | | | |
| Otsuchi | | | | | | | |
| Kamaishi | | | | | | | |
| Ofunato | | | | | | | |
| Kesen | ✓ | ✓ | ✓ | ✓ | ✓ | | |
| Onagawa | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Shizugawa | | | ✓ | | ✓ | ✓ | |

Figure 1 Cointegrated markets within domestic krill markets

Note: Checks indicates the markets are cointegrated.

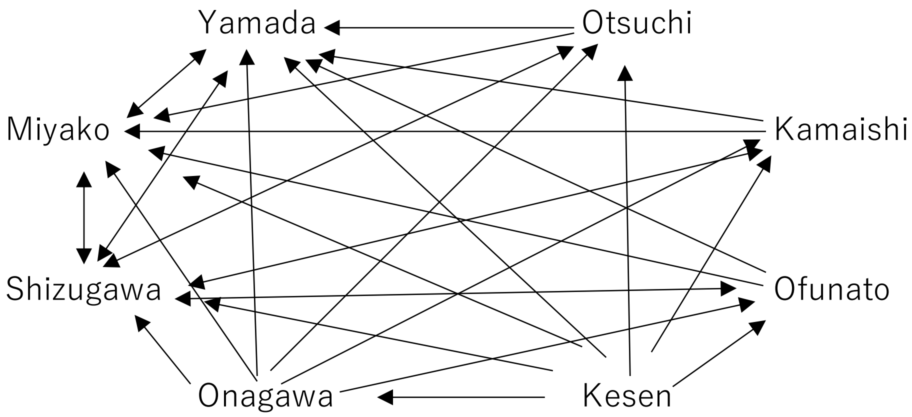


Figure 2 Granger causality test with first differenced prices

We also conducted Granger causality tests at level prices (see Appendix F). Arrows in Figure 2 indicate Granger causality. For example, an arrow pointing from Otsuchi to Yamada means that Otsuchi Granger-causes Yamada. Double headed arrow such as Yamada and Miyako means Yamada Granger-causes Miyako and vice versa.

This causality suggests a price at one market will reflect on the other market in the next business week. Figure 2 graphically demonstrates Granger causality relationship between markets. It clearly illustrates Kesennuma and Onagawa take market leadership because they Granger-cause almost every market. Kesennuma is also unaffected market by any other market as well as Onagawa.

## 4. Conclusion

Considering that the herd of krill advances from the north to the south, Iwate experiences the peak of catch earlier than Miyagi. On the other hand, Miyagi lands more towards the closure since the peak comes later.

The estimated expenditure elasticities (more than one in Iwate and less than one in Miyagi) suggest that Iwate markets are relatively sensitive to the trend of recreational fishing activities. In particular, typhoons negatively affect the expenditure, which makes the Iwate krill market more unstable compared to that of Miyagi. Expectedly, Miyagi is less sensitive to the trend of recreational fishing, presumably because more krill is dried for human consumption in Miyagi (Hamada (2019), personal communications, June 18), which reduces the risk of influence by recreational fishing.

Price elasticities in Miyagi are more significant and elastic than those in Iwate. The fishing vessels in Iwate designate each vessel's landing port at the beginning of the fishing season, while those in Miyagi are not restricted to their landing ports (Niinuma (2019), personal communications, June 18). This may make the own-price elasticities in Miyagi relatively more elastic to the demand because Miyagi can take action based on the market price at the landing ports.

Cross-price elasticities indicate that krill in the same prefecture are complimentary, while that in the other prefecture is a substitute. This may be because the fishing operation coincides in the same prefecture, but does not in the other. In addition, the advancement of krill from the north to south may be another reason (Endo (2000)). In 2018, krill did not advance to the fishing area of Miyagi. As a result, buyers in Miyagi bought krill from Iwate, and prices in Iwate surged up to three times the average annual market price (Minato (2019), personal communications, June 20).

According to the results of cointegration test and Granger causality test, Kesennuma and Onagawa are linked to each other, but either market does not affect the other in a short-run. Kesennuma and Onagawa take a price leadership to every market, the domestic markets are partially integrated around Kesennuma and Onagawa. This results support main analysis of this study. We did not find many significant cross-elasticities in the AIDS model. This is not because the domestic krill market are not integrated, but because the markets are integrated around two big markets including Onagawa and Kesennuma. Even though there is a short-run.

In this study, we conducted our analysis based on the assumption that the krill markets are competitive, and that its price is given. However, this assumption sometimes fails to capture reality. Our estimation resulted in few significant elasticities, which may be caused by the model choice based on the assumption that price determines quantity. Sometimes supply determines price in small markets or the markets where one or more supplier are large enough to affect the market price. Some studies use an inverse demand function assuming that price is not given (Barten and Bettendorf (1989), Thong (2012)), while others assume price determines supply (Ariji (2013), Wakamatsu and Miyata (2016b)). This study did not adopt an inverse demand system model, but the further study that adopts an Inverse AIDS model may increase robustness of our estimation.

## Notes

(1) The data used for the expenditures are from the monthly household expenditures of two or more households for non-durable goods in the education and entertainment category. This is because krill is primarily used as fishing bait, and is expected to fall

into the non-durable goods of recreational fishing category. Since fishing tackle falls into the other athletic durable goods category of the education and entertainment category, we used that of non-durable goods as a proxy of the expenditure on krill. The monthly expenditure on fishing is extended to weekly for estimation. The weekly production between February and May represents the production of the whole year while weekly expenditure does a part of a year. However, the figure in Appendix A shows the expenditure has seasonal trend in a year, and the disparity between February and May is very little, and thus we assume the expenditure not only represent the corresponding months, but also the corresponding year.

(2) This study employed *aidsills* estimator because this estimator provide us with consistent unbiased estimates of parameters by iterating least square regressions. This estimator is based on Seemingly Unrelated Regression (SUR), but the estimator can obtain unbiased estimates by iterating a series of SUR or OLS (Blundell and Robin, 1999). *aidsills* also treats with a quadratic relationship between log-total expenditure and share of sales in each market (Engel curve), since AIDS model assumes linear, but Engel curve is often non-linear or quadratic in reality. The relationship is not quadratic in this study, and thus, a linear model is employed.

(3) Since fishing seasons differ across years, the seventh week (last week) include days between day 36 to the end of fishing seasons.

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Appendix A

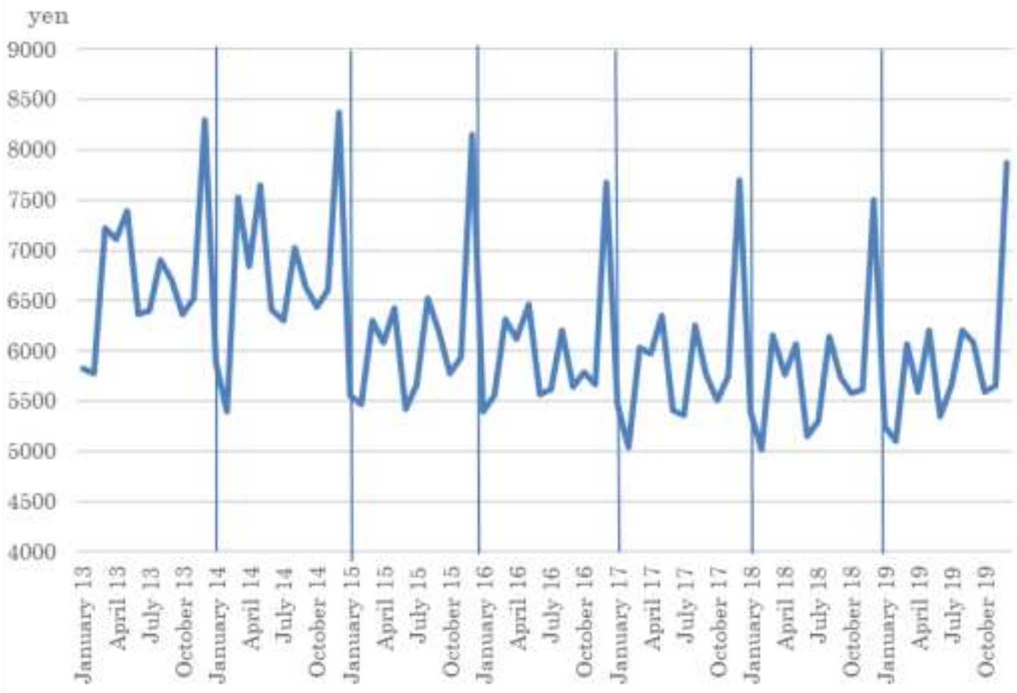


Figure A　Household Expenditure on non-durable goods for other recreation/leisure

## Appendix B

Table B Comparison between Model using Expense on Leisure Fishing and Model using Total Landing Value

| | Model using Leisure Fishing Expense for Expenditure | | | | | | Model using Total Landing Value for Expenditure | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NI | Kama | Ofuna | Kesen | Ona | Shizu | NI | Kama | Ofuna | Kesen | Ona | Shizu |
| *γ* | | | | | | | | | | | | |
| North Iwate | 0.07 | 0.006 | -0.16 | -0.14 | 0.19 | 0.04 | 0.06 | 0.021 | -0.18 | -0.14 | 0.20 | 0.03 |
| Kamaichi | 0.01 | -0.04 | -0.087 | 0.047 | 0.09 | -0.02 | 0.02 | -0.07 | -0.059 | 0.054 | 0.07 | -0.02 |
| Ofunato | -0.16 | -0.09 | 0.056 | 0.054 | 0.003 | 0.13 | -0.18 | -0.06 | 0.046 | 0.040 | 0.027 | 0.13 |
| Kesennuma | -0.14 | 0.05 | 0.054 | 0.15 | -0.06 | -0.05 | -0.14 | 0.05 | 0.040 | 0.15 | -0.07 | -0.04 |
| Onagawa | 0.19*** | 0.09*** | 0.003 | -0.06 | -0.13* | -0.1*** | 0.20*** | 0.07** | 0.03 | -0.07 | -0.13 | -0.10*** |
| Shizugawa | 0.04 | -0.02 | 0.13 | -0.05 | -0.1 | 0.001 | 0.03 | -0.02 | 0.13 | -0.04 | -0.10 | 0.002 |
| *β* | | | | | | | | | | | | |
| Expenditure | 0.04 | -0.02 | 0.08* | -0.04 | -0.03 | -0.02 | 0.04 | -0.02 | 0.07 | -0.02 | -0.02 | -0.04 |
| *ρ (IV)* | | | | | | | | | | | | |
| Typhoons | 0.21 | 0.12 | 0.047 | 0.11 | -0.40 | -0.087 | -0.021 | -0.0013 | -0.019 | 0.030 | -0.031 | 0.042 |
| *α* | | | | | | | | | | | | |
| Weekly dummy | | | | | | | | | | | | |
| week 2 | 0.02 | 0.005 | -0.05 | 0.02 | 0.01 | 0.001 | 0.0087 | 0.010 | -0.078* | 0.025 | 0.014 | 0.019 |
| week 3 | 0.034 | 0.004 | -0.04 | 0.02 | -0.03 | 0.001 | 0.017 | 0.012 | -0.073 | 0.038 | -0.019 | 0.024 |
| week 4 | -0.001 | -0.01 | -0.09** | 0.05* | 0.032 | 0.03* | -0.021 | -0.0055 | -0.13*** | 0.064* | 0.043 | 0.050*** |
| week 5 | -0.06** | -0.029 | -0.13*** | 0.06** | 0.10** | 0.06*** | -0.073** | -0.026 | -0.16*** | 0.075** | 0.10** | 0.080*** |
| week 6 | -0.028 | 0.014 | -0.040 | 0.038 | -0.0093 | 0.025 | -0.033 | 0.015 | -0.052 | 0.046 | -0.0076 | 0.031* |
| week 7 | -0.07** | 0.002 | -0.15*** | 0.09*** | 0.05 | 0.07*** | -0.087** | 0.0062 | -0.17*** | 0.10*** | 0.061 | 0.088*** |
| Yearly dummy | | | | | | | | | | | | |
| 2017 | 0.06 | 0.04 | 0.07 | -0.04 | -0.10* | -0.02 | 0.042 | 0.045*** | 0.019 | -0.0094 | -0.083** | -0.014 |
| 2018 | 0.19*** | 0.05 | 0.25*** | -0.13*** | -0.26*** | -0.09*** | 0.16*** | 0.060*** | 0.19*** | -0.095*** | -0.24*** | -0.082*** |
| 2019 | 0.05* | 0.02 | 0.04 | -0.02 | -0.08** | -0.004 | 0.037 | 0.022 | 0.012 | -0.0060 | -0.068** | 0.0042 |
| Constant | 0.21* | 0.001 | 0.56*** | 0.01 | 0.18 | 0.04 | -0.13 | 0.20 | -0.090 | 0.27 | 0.39 | 0.36** |
| R-Square | 0.79 | 0.65 | 0.68 | 0.57 | 0.7 | 0.72 | 0.79 | 0.65 | 0.70 | 0.57 | 0.71 | 0.73 |

Note: NI stands for North Iwate, Kama for Kamaishi, Ofuna for Ofunato, Ona for Onagawa, Shizu for Shizugawa. *, **, and *** denotes 10, 5, and 1% of statistical significance levels.

## Appendix C

Table C Instrumental Regression for Expenditure

| | | | | |
|---|---|---|---|---|
| Samples = | 43 | | R-square = | 0.90 |
| F(16, 26) = | 15.28 | | Adj. R-sq. = | 0.84 |
| | Coefficient | Std.err. | [95% Conf. | Interval] |
| *Log Price* | | | | |
| North Iwate | -0.04 | 0.09 | -0.22 | 0.14 |
| Kamaichi | 0.06 | 0.07 | -0.07 | 0.19 |
| Ofunato | -0.03 | 0.12 | -0.28 | 0.21 |
| Kesennuma | 0.04 | 0.09 | -0.14 | 0.22 |
| Onagawa | -0.04 | 0.04 | -0.12 | 0.05 |
| Shizugawa | -0.01 | 0.05 | -0.11 | 0.09 |
| *ρ (IV)* | | | | |
| typhoons | -0.19 *** | 0.02 | -0.23 | -0.15 |
| *Weekly dummy* | | | | |
| week 2 | 0.05 *** | 0.02 | 0.01 | 0.09 |
| week 3 | 0.05 *** | 0.02 | 0.01 | 0.10 |
| week 4 | 0.04 * | 0.02 | 0.00 | 0.08 |
| week 5 | 0.02 | 0.02 | -0.02 | 0.07 |
| week 6 | 0.02 | 0.02 | -0.03 | 0.06 |
| week 7 | 0.00 | 0.03 | -0.05 | 0.05 |
| *Yearly dummy* | | | | |
| 2017 | 0.04 | 0.03 | -0.02 | 0.11 |
| 2018 | -0.02 | 0.03 | -0.09 | 0.04 |
| 2019 | 0.00 | 0.02 | -0.05 | 0.05 |
| Constant | 9.04 *** | 0.10 | 8.84 | 9.25 |

Note: *, **, and *** denotes 10, 5, and 1% of statistical significance levels. Adj. R-sq denotes adjusted R-square.

## Appendix D

Table D  Results of Unit Root Tests (Augmented Dickey Fuller Tests)

| ADF | NOBS | lags | Trend | Drift | Trend(D1) | Drift(D1) | 10%Trend | 10%Drift | 1%Trend | 1%Drift |
|---|---|---|---|---|---|---|---|---|---|---|
| Miyako | 48 | 1 | -2.264 | -2.215 | -8.883 | -8.918 | -3.19 | -2.605 | -4.187 | -3.607 |
| Yamada | 48 | 1 | -2.282 | -2.276 | -5.874 | -5.852 | -3.19 | -2.605 | -4.187 | -3.607 |
| Otsuchi | 48 | 1 | -2.37 | -2.284 | -5.883 | -5.864 | -3.19 | -2.605 | -4.187 | -3.607 |
| Kamaishi | 48 | 1 | -2.351 | -2.265 | -5.739 | -5.727 | -3.19 | -2.605 | -4.187 | -3.607 |
| Ofunato | 48 | 1 | -2.153 | -2.125 | -5.706 | -5.69 | -3.19 | -2.605 | -4.187 | -3.607 |
| Kesennuma | 48 | 1 | -2.018 | -2.111 | -5.485 | -5.416 | -3.19 | -2.605 | -4.187 | -3.607 |
| Onagawa | 48 | 1 | -1.861 | -1.926 | -5.634 | -5.562 | -3.19 | -2.605 | -4.187 | -3.607 |
| Shizugawa | 48 | 1 | -1.92 | -1.974 | -6.015 | -5.956 | -3.19 | -2.605 | -4.187 | -3.607 |

Note 1) Trend and Drift in the first row show the results of Augment Dicky Fuller (ADF) test with a constant (drift) and a time trend dummy (trend) using level data. Trend(D1) and Drift(D1) show the result of ADF test with the first differenced data. 10% Trend, Drift and 1% Trend, Drift denote the criteria of significance for stationarity. All the series are stationary at first difference.

Note 2) While the number of observations (NOBS) is 48, there are some missing values in Miyako (45 obs), Yamada (44 obs), Kesennuma (43 obs), Onagawa (43 obs) and Shizugawa (43 obs). We imputed the missing values by predicting the price when the quantity of the market is zero using a simple inverse demand functions of Iwate and Miyagi markets (price of a market = landing at the market + all prices in the prefecture).

## Appendix E

Table E Result of Johansen test for cointegration

| Prices | Opt. Lags | Trace Statistics Rank=0 | Rank=1 | Rank |
|---|---|---|---|---|
| Miyako-Yamada | 3 | 25.6067 | 2.9517* | 1 |
| Miyako-Otsuchi | 1 | 49.8377 | 4.7745 | 2 |
| Miyako-Kama | 1 | 63.3195 | 5.3507 | 2 |
| Miyako-Ofuna | 1 | 47.8167 | 4.9737 | 2 |
| Miyako-Kesen | 1 | 42.2468 | 3.2354* | 1 |
| Miyako-Ona | 1 | 35.5979 | 3.1669* | 1 |
| Miyako-Shizu | 1 | 32.4727 | 4.3547 | 2 |
| Yamada-Otsuchi | 1 | 45.4131 | 4.8067 | 2 |
| Yamada-Kama | 1 | 60.9614 | 5.4038 | 2 |
| Yamada-Ofuna | 1 | 40.8116 | 5.0875 | 2 |
| Yamada-Kesen | 1 | 40.621 | 3.2331* | 1 |
| Yamada-Ona | 1 | 34.0387 | 3.0919* | 1 |
| Yamada-Shizu | 1 | 30.6208 | 4.2453 | 2 |
| Otsuchi-Kama | 1 | 32.6166 | 4.8232 | 2 |
| Otsuchi-Ofuna | 1 | 31.2471 | 4.9244 | 2 |
| Otsuchi-Kesen | 1 | 38.5511 | 3.4364* | 1 |
| Otsuchi-Ona | 1 | 31.0417 | 2.9754* | 1 |
| Otsuchi-Shizu | 2 | 38.9847 | 2.9062* | 1 |
| Kama-Ofuna | 1 | 33.0886 | 5.2108 | 2 |
| Kama-Kesen | 1 | 39.333 | 3.3367* | 1 |
| Kama-Ona | 1 | 31.2329 | 3.0351* | 1 |
| Kama-Shizu | 1 | 28.2348 | 3.8073 | 2 |
| Ofuna-Kesen | 1 | 38.4684 | 3.1895* | 1 |
| Ofuna-Ona | 1 | 30.8797 | 2.8850* | 1 |
| Ofuna-Shizu | 1 | 28.5706 | 3.6903* | 1 |
| Kesen-Ona | 1 | 30.7163 | 3.2510* | 1 |
| Kesen-Shizu | 1 | 36.4391 | 3.6320* | 1 |
| Ona-Shizu | 1 | 38.5206 | 4.226 | 2 |
| *Critical Value* | | *15.41* | *3.76* | |

Note 1) Kama denotes Kamaishi; Ofuna denotes Ofunato, Kesen denotes Kesennuma; Ona denotes Onagawa; Shizu denotes Shizugawa.

Note 2) The values in the table shows Trace statistics of Johansen test for cointegration. Cointegration rank is determined when Trace statistics is lower than critical value at the corresponding rank. The bivariate relationship has market linkage when rank is one. * shows the Trace statistics is lower than the critical value.

Note 3) Optimal lag length is determined by SBIC or HQIC statistics.

## Appendix F

### Table F Results of Granger causality tests using level prices

| Equation | | chi2 | Prob |
|---|---|---|---|
| Miyako-Yamada | | | |
| p_Miyako | p_Yamada | 6.85 | 0.01 |
| p_Yamada | p_Miyako | 4.38 | 0.04 |
| Miyako-Otsuchi | | | |
| p_Miyako | p_Otsuchi | 11.92 | 0.00 |
| p_Otsuchi | p_Miyako | 0.27 | 0.61 |
| Miyako-Kamaishi | | | |
| p_Miyako | p_Kama | 9.32 | 0.00 |
| p_Kama | p_Miyako | 0.01 | 0.92 |
| Miyako-Ofuna | | | |
| p_Miyako | p_Ofuna | 8.90 | 0.00 |
| p_Ofuna | p_Miyako | 0.61 | 0.44 |
| Miyako-Kesennuma | | | |
| p_Miyako | p_Kesen | 35.00 | 0.00 |
| p_Kesen | p_Miyako | 0.56 | 0.45 |
| Miyako-Onagaga | | | |
| p_Miyako | p_Ona | 20.46 | 0.00 |
| p_Ona | p_Miyako | 1.94 | 0.16 |
| Miyako-Shizugawa | | | |
| p_Miyako | p_Shizu | 9.94 | 0.00 |
| p_Shizu | p_Miyako | 4.69 | 0.03 |

| Equation | | chi2 | Prob |
|---|---|---|---|
| Yamada-Otsuchi | | | |
| p_Yamada | p_Otsuchi | 7.47 | 0.01 |
| p_Otsuchi | p_Yamada | 0.02 | 0.89 |
| Yamada-Kamaishi | | | |
| p_Yamada | p_Kama | 5.25 | 0.02 |
| p_Kama | p_Yamada | 0.13 | 0.72 |
| Yamada-Ofunato | | | |
| p_Yamada | p_Ofuna | 4.35 | 0.04 |
| p_Ofuna | p_Yamada | 0.06 | 0.81 |
| Yamada-Kesennnuma | | | |
| p_Yamada | p_Kesen | 34.63 | 0.00 |
| p_Kesen | p_Yamada | 0.39 | 0.53 |
| Yamada-Onagwa | | | |
| p_Yamada | p_Ona | 20.11 | 0.00 |
| p_Ona | p_Yamada | 1.74 | 0.19 |
| Yamada-Shizugawa | | | |
| p_Yamada | p_Shizu | 9.23 | 0.00 |
| p_Shizu | p_Yamada | 4.16 | 0.04 |
| Otsuchi-Kamaishi | | | |
| p_Otsuchi | p_Kama | 0.02 | 0.89 |
| p_Kama | p_Otsuchi | 1.94 | 0.16 |

| Equation | | chi2 | Prob |
|---|---|---|---|
| Otsuchi-Ofunato | | | |
| p_Otsuchi | p_Ofuna | 0.47 | 0.49 |
| p_Ofuna | p_Otsuchi | 3.02 | 0.08 |
| Otsuchi-Kesennuma | | | |
| p_Otsuchi | p_Kesen | 30.07 | 0.00 |
| p_Kesen | p_Otsuchi | 0.02 | 0.88 |
| Otsuchi-Onagawa | | | |
| p_Otsuchi | p_Ona | 15.85 | 0.00 |
| p_Ona | p_Otsuchi | 1.62 | 0.20 |
| Otsuchi-Shizugawa | | | |
| p_Otsuchi | p_Shizu | 6.51 | 0.01 |
| p_Shizu | p_Otsuchi | 4.96 | 0.03 |
| Kamaishi-Ofunato | | | |
| p_Kama | p_Ofuna | 0.13 | 0.72 |
| p_Ofuna | p_Kama | 0.41 | 0.52 |
| Kamaishi-Kesennuma | | | |
| p_Kama | p_Kesen | 35.03 | 0.00 |
| p_Kesen | p_Kama | 0.08 | 0.78 |
| Kamaishi-Onagawa | | | |
| p_Kama | p_Ona | 17.87 | 0.00 |
| p_Ona | p_Kama | 1.33 | 0.25 |

| Equation | | chi2 | Prob |
|---|---|---|---|
| Kamaishi-Shizugawa | | | |
| p_Kama | p_Shizu | 7.63 | 0.01 |
| p_Shizu | p_Kama | 4.47 | 0.04 |
| Ofunato-Kesennuma | | | |
| p_Ofuna | p_Kesen | 30.34 | 0.00 |
| p_Kesen | p_Ofuna | 0.34 | 0.56 |
| Ofunato-Onagawa | | | |
| p_Ofuna | p_Ona | 15.00 | 0.00 |
| p_Ona | p_Ofuna | 2.44 | 0.12 |
| Ofunato-Shizugawa | | | |
| p_Ofuna | p_Shizu | 6.47 | 0.01 |
| p_Shizu | p_Ofuna | 5.73 | 0.02 |
| Kesennuma-Onagawa | | | |
| p_Kesen | p_Ona | 0.83 | 0.36 |
| p_Ona | p_Kesen | 5.84 | 0.02 |
| Kesennuma-Shizugawa | | | |
| p_Kesen | p_Shizu | 0.01 | 0.94 |
| p_Shizu | p_Kesen | 20.22 | 0.00 |
| Onagawa-Shizugawa | | | |
| p_Ona | p_Shizu | 2.86 | 0.09 |
| p_Shizu | p_Ona | 21.19 | 0.00 |

Note 1) The number of observation is 47 for each price series. The columns of Equation shows the market is Granger caused by the market in the second columns.

Note 2) chi2 denotes chi square statistics and Prob shows the p-value of the chi-square value.