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Estimation of the Market Competitiveness of Kelp by Municipality in Hokkaido

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Abstract

Japanese cuisine, “konbu” (kelp) is an essential ingredient as a raw material for dashi and other Japanese foods. Nine types of kelp are harvested in Japan and the type and use vary by region, including “Rausu konbu” or “Rishiri konbu,” which are named after the harvest location, and traded under their brand name. Even in other areas, kelp is currently competing with the region as a de facto brand. Although kelp from different regions is not completely substitutable, there is competition in each region for a given kelp type. In this paper, based on price and production volume data of 20 municipalities in Hokkaido, which produces more than 80% of total kelp production in Japan, we estimate the competitiveness of each region, using a discrete/continuous model. The results of the analysis reveal that not only well-known brands such as “Rausu konbu” and “Rishiri konbu” but also some areas with large production volumes, have a degree of competitiveness that is not affected by annual fluctuations of production volumes. This tendency is confirmed by the stability of market competitiveness even in subsamples of the sample period. In some areas, due to a decrease in prices and increased production, a slight change in competitiveness occurred.

Keywords: kelp, discrete/continuous model, market competitiveness, Hokkaido

1. Introduction

In 2011, Japan overtook France as the country with the most three-star Michelin restaurants, and in 2018, Tokyo enjoyed the title of the city with the world’s most three-star restaurants. On December 4, 2013, the United Nations Education, Science, and Culture agreed to register Washoku as an intangible cultural heritage. The Japanese word “Washoku” refers to traditional Japanese cuisine, which varies by region and has evolved through many centuries of political, economic, and social change. Traditional Japanese food is based on flavors from seasonal ingredients and other dishes. Side dishes are often composed of fish, vegetable pickles, and soups. In general, seafood is most often baked, but sometimes consumed raw as sashimi and sushi. Seafood and vegetables are also deep-fried in cooking oil to produce tempura. Apart from rice, other staple foods are noodles such as “soba” and “udon.” Japanese kelp is one of the most important ingredients in Japanese cuisine. For example, “Dashi,” which contains kelp, is a main ingredient in “Umami” soup in many Japanese recipes. Kelp can also be eaten directly as, for example, salted kelp.

In Japan, nine types of kelp are harvested. Table 1 describes the use of each type by harvested area. These types include “Rausu konbu” and “Rishiri konbu”, which are traded at high prices as brand names. In other areas, the production area is effectively treated as a brand, and competes with other production areas. In this way, kelp in each area is not completely substitutable. Various types of kelp are used in different ingredients but are treated as one kelp in state and local statistics. We focus on the differences in the types of kelp produced in each region, and we will analyze the substitutability of different kinds of kelp by analyzing the market competitiveness of kelp for each region. At present, such economic analysis has not been performed, and it is considered an important analysis in considering kelp production as an industry in the future. This is the main purpose of this paper.

Table 1. Types of kelp and their use

Japanese name	Scientific name	Use
Ma *konbu*	*Saccharina japonica*	Other uses for *dashi konbu** include thinly shaved processed products such as *oboro konbu** and white hair *konbu**, as well as *shiraita konbu** used in *battera***, a typical Osaka sushi** dish.
Oni *konbu*	*Saccharina japonica* var. *diabolica*	The highest quality *dashi konbu* is used in restaurants. Main uses include *udon*** soup, *oden***, seasoning for hot pot dishes, and *tsukudani***. It is also suitable for human consumption, and the Hokuriku region, especially Toyama Prefecture, is a major consumer area.
Rishiri *konbu*	*Saccharina japonica* var. *ochotensis*	Useful as a *dashi konbu* for *kaiseki*** cuisine and stews. It is also the most expensive and common *dashi konbu* in Kyoto, and has a wide range of uses, including *senmaizuke***, *boiled tofu***, and *konome-ni***. Its flesh is hard, so it can also be used as an ingredient in high-grade *oboro konbu* and *tororo konbu*.
Hosome *konbu*	*Saccharina japonica* var. *religiosa*	Because the cut end is whiter than any other *konbu*, it is often processed into *oboro konbu* and *tororo konbu*.
Mitsuishi *konbu*	*Saccharina angustata*	Suitable for dishes where you can eat kelp itself, such as kelp rolls*, *tsukudani*, and *oden* seeds. It is also consumed in large quantities in the Kanto region, where it is commonly used as kelp for *dashi*.
Gagome *konbu*	*Saccharina sculpera* (Synonyms: *Kjellmaniella crassifolia*, *Saccharina crassifolia*)	Mainly used for *natto* kelp, and Matsumae pickles**. It is not used for removing *dashi*, so the price is low compared with other kelp. Recently, it was discovered that it contains a viscous polysaccharide called "*fucoidan*" in higher amounts than other kelp, and that it seems to act as a so-called functional ingredient, so the price skyrocketed.
Naga *konbu*	*Saccharina longissima*	Because of its softness, it is commonly used for items such as kelp rolls. It has been used as a substitute for vegetables since ancient times, and in addition to being chopped up and eaten as a salad, it goes very well with pork, so it is often used in stir-fried dishes.
Gakkara *konbu*	*Saccharina coriacea*	Main use is for processing, such as in *tsukudani*, salt-blown kelp*, and *battera***.
Nekoashi *konbu*	*Arthrothamnus bifidus*	Mainly used as an ingredient for *tororo konbu* and *oboro konbu*. It was also known as a raw material for potassium iodide, which is essential for medicines and reagents. Like *Gagome*, it contains a large amount of a viscous polysaccharide called *fucoidan*, so its price has skyrocketed and it is becoming difficult to obtain.

Note. * Names of kelp products; ** Names of Japanese dishes.

Data sources: Japan Kelp Association (1986, 2023).

In this paper, the competitiveness of each region is estimated using discrete/continuous models based on data on the prices and production volumes of 20 municipalities in Hokkaido. The reasons for selecting these 20 municipalities are as follows. According to Ministry of Agriculture, Forestry and Fisheries (2023), in Japan, kelp production was 33 million lbs (14,970t) in 2021, of which, 28.25 million lbs (12,816t) were produced in Hokkaido. Hokkaido is one of the main islands of Japan and is located at the northern end of the archipelago, and kelp produced in Hokkaido accounts for over 85% of overall production in Japan. In addition to domestic production, only a small amount, 3.61 million lbs (1,637t), was imported into Japan in 2021. Therefore, analyzing the kelp market in Hokkaido is important for understanding the structure of the Japanese kelp market.

Additionally, according to Hokkaido Fisheries Statistics (Fisheries and Forestry Department, Hokkaido, 1989-2020), there are data on production volumes for each municipality, although some areas have extremely small production levels, which might produce a relatively large measurement error. The GDP of Hokkaido is 3.6% of the total GDP of Japan, but it accounts for about 20% of the country's fishery production. Of this production, kelp is the main product, accounting for about 7.1% of total fishery production, and in 2023, kelp production was valued at 20.5 billion yen (~US$ 1.4 billion).

We estimate the market competitiveness of each of these 20 municipalities and examine how the type of kelp harvested and scale of production affect market competitiveness. Figure 1 shows the location of each municipality. These municipalities produced 26.49 million pounds (12,015 tons) in 2021, with 28.25 million pounds being produced in Hokkaido in total; thus, these 20 municipalities produced over 90% of the total production in Hokkaido and over 80% of the total production in Japan. Figure 2 shows the average prices of kelp, and Figure 3 shows the average production volumes in these 20 municipalities. These figures also show the main types of kelp produced. These regions produce five major kinds of kelp. Recently, Hakodate city merged with three towns, Toi town, Esan town, and Minami-Kayabe town, and the former city area for which statistics are reported by Hokkaido Fisheries Statistics are indicated as the "former" municipalities. (In the map in Figure 1, these points are indicated as one point as 3, 4, 5, 6.) The municipality list and the types of kelp harvested in each municipality are shown in Table 2. Figures 2 shows that the prices and production volumes of kelp vary between regions and also show the changes in prices and production volumes between the first half (1989-2005) and second half (2006-2019) of the period in each region. Their changes were relatively small compared with the differences in prices and production volumes between regions. The price of kelp was highest in Rausu, followed by Rebun town, which produces Rishiri *konbu*, which is sent to Rebun town. Notably, the price of kelp from Shiriuchi town is lower than that in other regions. Production volumes in former Minami-Kayabe town and Nemuro city are larger than those in other areas, followed by Erimo town and Hamanaka town.

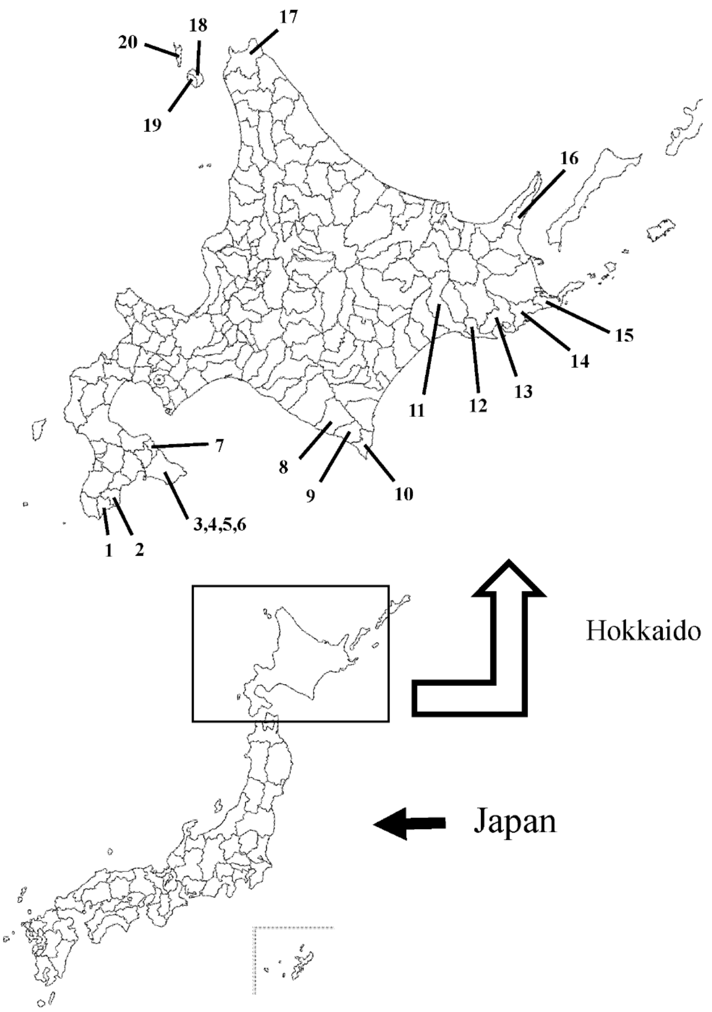

Figure 1. Map of Hokkaido and Japan (numbers in map correspond to the numbers of municipalities in Table 2)

Source: https://www.geospatial.jp/ckan/dataset/hokkaidoshirochizukani/resource/1ca78add-298e-47ed-8548-e823371fd429?inner_span=True and the authors add the information about the municipalities.

We estimate the market competitiveness of kelp by municipality in Hokkaido using a discrete/continuous model and data from 1989 to 2020. This analysis may clarify the relationship between market competitiveness and prices. We investigate if the differences in prices shown in Table 2 automatically indicate the market competitiveness of each municipality. Regarding the market competitiveness of each municipality considering the changes in production, we follow Yoshino's (1997) approach, which is based on Hanemann (1984), and extend it using a price equation with aggregated variables.

Table 2. List of municipalities (cities and villages) and average real price and types

No.	Municipalities	Average real price 1989-2020	Average real price 1989-2005	Average real price 2006-2020	Produced types of kelp
1	Fukushima town	19.667	20.975	18.185	Ma *konbu*
2	Shiriuchi town	10.367	12.208	8.280	Ma *konbu*
3	Former Hakodate city	18.760	18.645	18.890	Ma *konbu*
4	Former Toi town	17.153	17.756	16.469	Ma *konbu*
5	Former Esan town	18.765	20.289	17.038	Ma *konbu*, Mitsuishi *konbu*, Gagome *konbu*
6	Former Minami-Kayabe town	15.269	15.446	15.067	Ma *konbu*
7	Shikabe town	15.973	16.000	15.943	Ma *konbu*
8	Urakawa town	13.735	13.575	13.916	Mitsuishi *konbu*
9	Samani town	14.554	14.507	14.607	Mitsuishi *konbu*
10	Erimo town	14.066	13.820	14.344	Mitsuishi *konbu*
11	Kushiro city	12.115	12.310	11.894	Naga *konbu*
12	Kushiro town	12.326	12.387	12.257	Naga *konbu*
13	Akkeshi town	12.089	11.965	12.229	Naga *konbu*, Oni *konbu*
14	Hamanaka town	11.602	11.688	11.504	Naga *konbu*, Nekoashi *konbu*, Atsuba *konbu*
15	Nemuro city	12.634	12.685	12.576	Naga *konbu*, Nekoashi *konbu*, Atsuba *konbu*
16	Rausu town	29.998	32.772	26.854	Oni *konbu*
17	Wakkanai town	21.962	21.130	22.906	Rishiri *konbu*
18	Rishiri-Fuji town	22.738	22.896	22.559	Rishiri *konbu*
19	Rishiri town	24.317	25.154	23.367	Rishiri *konbu*
20	Rebun town	26.559	27.129	25.913	Rishiri *konbu*

Note. Real prices are measured in 100 yen units in 2015 prices per kg (1 kg = 2.2046 lbs). In October 2024, 100 yen = US$ 0.67.

Data sources: Fisheries, and Forestry Department, Hokkaido (1989–2020). *Fisheries* Statistics and Japan Kelp Association (2023) and calculated by authors.

The results of the analysis reveal that not only well-known brands such as “Rausu konbu” and “Rishiri konbu” but also some areas with large production, have a degree of competitiveness that is not affected by annual fluctuations in production. This finding is very important to understand the market competitiveness of kelp, and it is clear that high prices do not automatically indicate high competitiveness. This is an important finding to consider the changes in production in the future and the change in the price of kelp. This tendency is confirmed by the stability of market competitiveness even when the sample period is divided. In some areas, due to a decrease in prices and increased production, a slight change in competitiveness was seen.

This study is organized as follows. In the next section, we survey some previous studies on kelp and related products. Then, we introduce our discrete/continuous model in Section 3. Using this model, we conduct empirical analysis based on data for 20 municipalities to examine the relative market competitiveness in each municipality in Section 4. Additionally, we split the estimation period to examine whether the relative market competitiveness changes between subsamples in section 5. Finally, in Section 6, we present our results and examine some remaining issues. Appendix describs the details of the derivation of price equation.

2. Survey of Related Works

Before proceeding to the empirical analysis, we first provide a short survey of related studies of kelp. Kelp has been studied together with other seaweeds or marine algae. The use of seaweed as a type of food was surveyed by Mouritsen et al. (2019) and Nayar and Bott (2014). Buschmann et al. (2017) surveyed the state of kelp cultivation around the world. In Japan, Murata and Nakazoe (2001) examined kelp production and its use and Nisizawa et al. (1987) focused on the ways in which kelp was eaten. Olson (1987) also examined kelp production in Japan, focusing on Minami-Kayabe town, which is included in the present study.

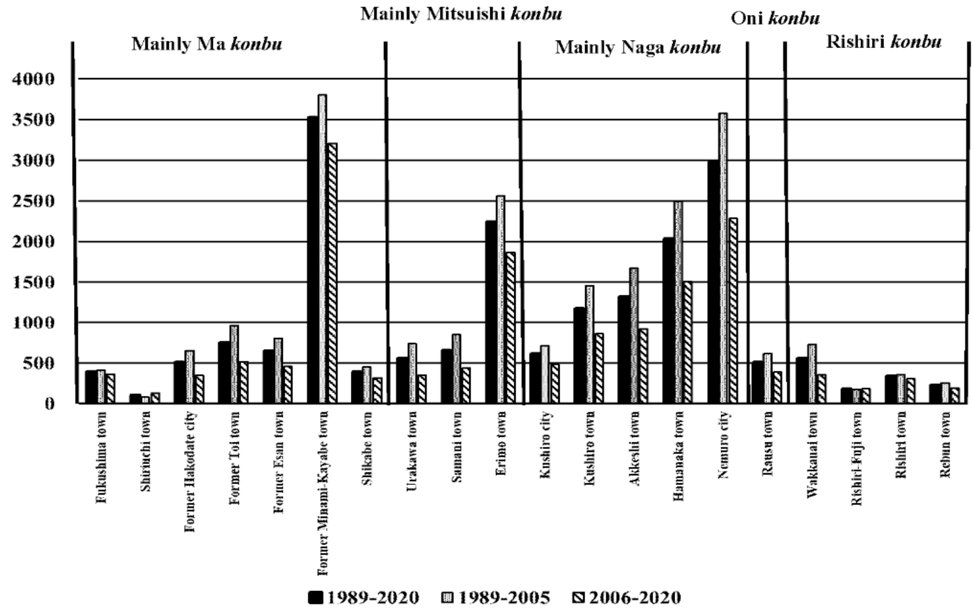

Figure 2. Average production volumes of kelp by municipality: Production is measured in tons (1 ton = 2204.6 lbs)

Data sources: Fisheries, and Forestry Department, Hokkaido (1989–2020). Fisheries Statistics and calculated by authors.

Aakre et al. (2021) and Redway and Combet (2023) associated seaweed consumption to iodine intake, and Mouritsen et al. (2012) studied its relationship with "*umami*" and "*dashi*" in Nordic cuisine. There are also studies on specific kelp species, for example, the economic use of giant kelp in Chile by Camus et al. (2019) and regional variations in the economic value of sugar kelp in the USA by Heidkamp et al. (2022). Although the focus of those studies closely relates to ours, they did not adopt an econometric approach to analysis.

Regarding consumer demand, several studies have used conjoint analysis, for example, Loureiro and McCluskey (2000) for veal, van den Lans and van Ittersum (2001) for olive oil, and Jaffry et al. (2004) for seafood. Loureiro and Umberger (2007) measured variations in the willingness-to-pay (WTP) for steak meat. With a focus on seaweed, Li et al. (2021) measured the WTP for certain seaweed-based products and Lucas et al. (2019) for certain types of seaweeds. These studies on consumer demand were based on survey data of individual consumers. This approach differs from Yoshino (1997), Nair et al. (2005), and others, which extended Hanemann's (1984) focus on estimating an aggregated demand function.

3. Price Equation from a Discrete/Continuous Model

In this section, we analyze how regional competitiveness varies across regions using the aggregated discrete/continuous model developed by Yoshino (1997), based on Hanemann's (1984) model, but using an indirect utility function and deriving the price equation with aggregated data. Originally, Hanemann's model assumed that consumers' brand choice and volume of demand were determined simultaneously. Empirical applications of this model include Yoshino (1997), Richards (2000), Nair et al. (2005), and Ishida and Fukushige (2010). In this paper, following the model that Yoshino (1997) extended using price equations with aggregated data, we explain the discrete/continuous model proposed by Hanemann (1984). This model is also introduced in Dub é (2019) and Ganddhi and Nevo (2021 as a representative model that explains discrete demand, including the choice of consumer brands. Recently, several other applications have appeared. Bergquist and Dinerstein (2020) applied this model to agricultural markets in Kenya, Hanemann et al. (2024) to energy demand, Ngoc and Nishiuchi (2023) to motorcycle ownership, Pellegrini et al. (2022) to multiple herbicide use in cropland. and Song and Chintagunta (2007) to households purchasing laundry detergents and fabric softeners. However, most of these studies applied this model to microdata. The most important extension of Hanemann's model is that of Yoshino (1997) to a price equation with aggregated data.

Following the derivation of the price equation by Yoshino (1997) and Ishida and Fukushige (2010), the following price equation for p_i is derived:

$$p_i = {}^{1}/_{\rho}\,(ln\,N + ln\,\theta + \eta m) + \bar{\varphi}_i + \mu\,ln\,X_i + \left(\mu - \frac{1}{\rho}\right) ln\,X + \gamma\mu$$

where p_i is the price of the *i*th local product, X_i is the demand for the *i*th local product, X is the total demand for all local products, m is the consumers' total budget, and N is the total number of consumers. Most of the parameters come from the Hanemann (1984) setting for the price of the *i*th brand (p_i), its competitive power (φ_i), and the consumers' conditional indirect utility function $v^*(p_i - \varphi_i, m)$, which is introduced by Yoshino (1997) as follows:

$$v^*(p_i - \varphi_i, m) = -\frac{exp(-\eta m)}{\eta} + \frac{\theta}{\rho} exp[-\rho(p_i - \varphi_i)]$$

where θ, η and ρ are constants and satisfy $\theta > 0\ and\ \eta \neq 0$. Additionally, Yoshino (1997) introduces the relationship $\varphi_i = \bar{\varphi}_i + \varepsilon_i$, where φ_i is the competitive power of the *i*th product and $\bar{\varphi}_i$ and ε_i are its nonstochastic and stochastic part, respectively. Then, $\bar{\varphi}_i$ represents the consumers' expected market competitiveness of the *i*th local product, $\rho, \theta,$ and η are parameters from the consumers' indirect utility function and μ is the parameter from the distribution function of the error term in the consumers' choice decision. Details of the derivation are described in the Appendix.

In our empirical analysis, a new parameter for the relative levels of competitiveness of the *i*th local product is introduced as:

$$\alpha_i = \bar{\varphi}_i - \bar{\bar{\varphi}}$$

where $\bar{\bar{\varphi}}$ is the average of $\bar{\varphi}_i$ for all the local products and all the $\bar{\varphi}_i's$ are assumed to be constant over time. Then, an equation of the prices for the *i*th local product at time point *t* is derived:

$$p_{it} = {}^1/_\rho\,(ln\,N_t + ln\,\theta + \eta m_t) + \alpha_i + \bar{\bar{\varphi}} - \mu\,ln\,X_{it} + \left(\mu - \frac{1}{\rho}\right) ln\,X_t + \gamma\mu$$

Because N_t and m_t are unobservable but might vary over time, we reparametrize as:

$$\xi_t = \frac{1}{\rho}(lnN_t + ln\theta + \eta m_t) + \gamma\mu + \bar{\bar{\varphi}}$$

and

$$\psi = \mu - \frac{1}{\rho},$$

and then, adding the error term u_{it}, the equation to be estimated becomes:

$$p_{it} = \xi_t + \alpha_i - \mu\,ln\,X_{it} + \psi\,ln\,X_t + u_{it}$$

We estimate this equation using the data.

We have longitudinal observations with M individuals and T length of time and estimate this equation by least squares with (two-way) dummy variables $DT_t's$ and $DI_i's$:

$$p_{it} = \sum_{t=1}^{T} \xi_t\, DT_t + \sum_{i=1}^{M} \alpha_i^* DI_i - \mu lnX_{it} + \psi lnX_t + u_{it} \quad (1)$$

Table 3. Summary statistics

Variable	Mean	Variance	Minimum	Maximum
Real price	17.232	15.268	5.1057	45.429
Xi	982.38	584.5	36	5543
lnXi	6.4192	6.3708	3.5835	8.6203
X	21033	20431	12886	33341
lnX	9.9198	9.9244	9.4639	10.415

Note. Calculated by authors.

Table 3 presents the summary statistics and Table 4 the results of estimating equation (1). We also present the estimation results of a seemingly unrelated regression (SUR) model, suggested by Yoshino (1997). In the SUR estimates, we constrained the coefficient of production volume of each local product and overall production to be the same for all regions. For our least squares with dummy variable (LSDV) estimation, the error terms for each region are assumed not to be mutually independent with each other, and the SUR estimates admit correlations between the error terms. However, our sample period is sufficiently long to estimate whether the variance–covariance matrix of the error term is nonsingular so that we can apply the generalized least squares method.

Table 4. Estimation results for 1989-2020

Variable	Model 1	Model 2	Model 3
lnXi	–3.03621**	–2.58265**	–2.53841**
	(–5.655)	(–6.683)	(–3.609)
lnX	4.65837**	8.80076**	2.55847**
	(5.893)	(8.621)	(5.529)
Estimation method	LSDV	LSDV	SUR
Time dummies	No	Yes	–
Individual dummies	Yes	Yes	–
R-squared	0.650	0.835	–
Durbin–Watson	1.397	1.316	–

Note. * significant at 5%, ** significant at 1%. *t*-values are in parentheses. Calculated by authors.

4. Estimation of Market Competitiveness by Municipalities

Before reviewing the estimation results, we describe the data used in this paper. The production volume and production value of kelp for each region can be obtained from the Hokkaido Fisheries Statistics, where the price per ton is estimated by dividing the production value by the production volume in tons. In some municipalities where production volumes are low, because the price estimate is expected to be affected significantly by any measurement or rounding errors in the production volumes, we selected 20 municipalities with production volumes of at least 100 tons in 2020 to estimate the price equation. Additionally, to ensure that we obtained real price data, the Bank of Japan's Corporate Goods Price Index (2015 base) for dried tangle was used as a deflater. Then, the price could be considered as the real price per 10 kg at 2015 prices. The production value and volume of each municipality and the total production volume in Hokkaido were obtained from Hokkaido Fisheries Statistics.

Table 4 presents the estimation results of equation (1) using data for 1989-2020. In the panel data estimates, in addition to the results with one-way individual dummy variables (Model 1), the results using two-way dummy variables (Model 2) are reported. Model 3 is the SUR model. The estimation results for the coefficient of production in each municipality are similar in the three models, but the coefficients of total production in Hokkaido vary greatly depending on the inclusion of dummy variables and whether SUR estimation is used. When SUR is used, the coefficient of determination differs substantially for each municipality; however, these results are not reported here. For the LSDV estimation, the coefficient of determination of the model with two-way dummy variables is high. This suggests that market competitiveness fluctuates over time, but changes captured by the time dummy are common across all municipalities. Therefore, it does not affect the relative market competitiveness between municipalities because the fluctuations affect only the average market competitiveness at each time point. The reported Durbin–Watson statistic is calculated using the residuals from the panel data, so we cannot confirm or deny the possibility of serial correlation in the error term (Note 1).

Figure 3 shows the estimated relative market competitiveness of each municipality assuming that the overall average is zero. At first, the relative market competitiveness of each municipality does not vary significantly across the estimation methods of LSDV, LSDV with time dummy, and SUR. Regarding the differences between municipalities, Figure 3 clearly shows that Oni *konbu* has the highest market competitiveness and Rishiri *konbu* the second highest; thus, the municipalities where these types of kelp are produced also have high market competitiveness. This result is obtained to some extent by comparing the prices in Table 2. When calculating market competitiveness from the estimation results of equation (1), it depends not only on prices but also on local production volumes. This fact suggests that the difference in market competitiveness between regions also depends on the differences in rarity due to differences in production volumes in each region. Compared with the average price, Shiriuchi town and Rishiri-Fuji town have relatively low market competitiveness. In particular, Rishiri-Fuji town suggests that the price is higher than Wakkanai city, but the market competitiveness is lower. These results might be due to the low production volumes of these towns. Similare results are also shown in comparison between former Esan town and former Minami-Kayabe town. This difference may also reflect the fact that the production volume in former Minami-Kayabe town is much higher than that in former Esan town and other municipalities. In this way, by estimating market competitiveness not only in comparison at a simple price but also in consideration of production, it has become possible to clarify the difference in market competitiveness for each municipality that is not reflected in the price.

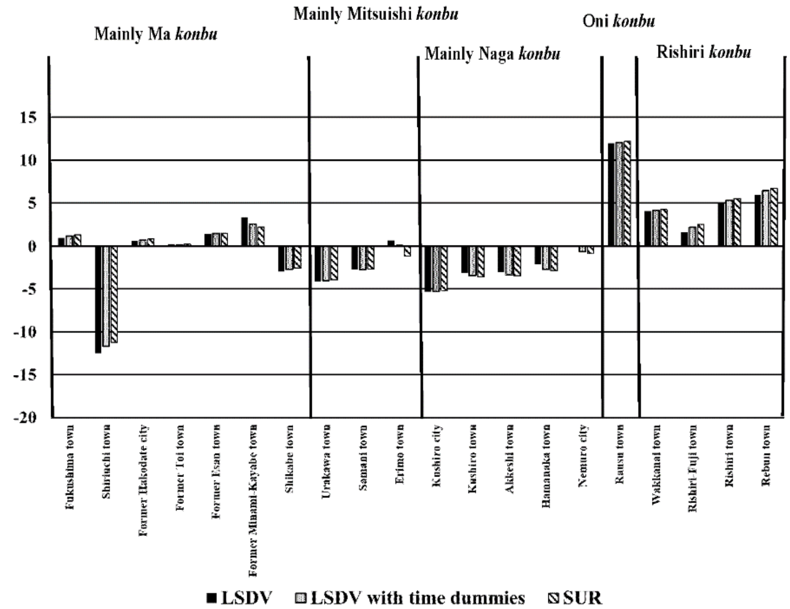

Figure 3. Estimated regional market competitiveness 1989-2020

Source: Estimated by authors.

5. Stability of market competitiveness

To examine whether market competitiveness may be changing, we reestimate equation (1) using subsamples. We divide the sample period into 1989-2005 and 2006-2020, and estimate equation (1) for each (Note 2). Table 5 presents the results using data from 1989-2005 (Models 1a and 2a) and shows that the Durbin–Watson statistic is relatively high, but that the coefficient for total production in Hokkaido is not significant. This coefficient is the estimates of $\mu - {}^{1}/_{\rho}$, so it depends on the sizes of the parameters, even when both of μ and ${}^{1}/_{\rho}$ are not zero. The coefficient of determination is higher than that for the full sample. Models 1b and 2b are estimated using data for 2006–2020, for which the Durbin–Watson statistic is close to 1, suggesting serial correlation in the error term. To cope with this possibility, we estimate Models 1c and 2c, which add a partial adjustment mechanism to equation (1). The partial adjustment mechanism assumes that the change of price from t–1 to t is part (τ) of the difference between the ideal price level at t ($p_{it}{}^{*}$) and the price at t–1:

$$p_{it} - p_{i,t-1} = \tau\left(p_{it}{}^{*} - p_{i,t-1}\right)$$

where $0 \le \tau \le 1$ and the ideal price level is assumed to be:

$$p_{it}{}^{*} = \sum_{t=1}^{T} \xi_t \, DT_t + \sum_{i=1}^{M} \alpha_i^{*} DI_i - \mu lnX_{it} + \psi lnX_t$$

Table 5. Estimation results of LSDV for 1989-2005 and 2006-2020

Variable	Model 1a	Model 2a	Model 1b	Model 2b	Model 1c	Model 2c
Period	1989–2005	1989–2005	2006–2020	2006–2020	2006–2020	2006–2020
lnXi	–4.56020**	–3.38786**	–1.99895*	–1.47479*	–1.47479**	–3.78472**
	(–5.751)	(–6.003)	(–2.022)	(–2.092)	(–2.990)	(–3.390)
lnX	1.04565	–3.20642	8.20346**	22.3178**	2.64743	43.9391**
	(0.645)	(–1.761)	(4.289)	(10.54)	(0.810)	(9.826)
Real price (–1)	–	–	–	–	0.517129**	0.449558**
					(10.53)	(9.010)
Time dummies	No	Yes	No	Yes	No	Yes
Individual dummies	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.685	0.856	0.667	0.842	0.775	0.884
Durbin–Watson	1.830	1.760	1.007	0.907	–	–
Durbin's *t*-test	–	–	–	–	−4.409**	−1.193

Note. * significant at 5%, ** significant at 1%. *t*-values are in parentheses. Estimated by authors.

Using these two equations and adding an error term, we obtain:

$$\mathrm{p}_{it} = (1-\tau)\mathrm{p}_{i,t-1} + \tau\left(\sum_{t=1}^{T}\xi_t\,\mathrm{DT}_t + \sum_{i=1}^{M}\alpha_i^* DI_i - \mu lnX_{it} + \psi lnX_t\right) + \mathrm{u}_{it}$$

and estimate this by ordinary least squares. Model 1c, which does not include a time dummy, assumes that the coefficients of all time dummies ξ_t are zero. In Models 1c and 2c, the possibility of serial correlation in the error term is tested using Durbin's *t* test (Note 3) instead of the Durbin–Watson statistic because the lagged dependent variable is used as an explanatory variable. The results indicate the presence of serial correlation in Model 1c, but no serial correlation in Model 2c. The coefficient of determination is slightly higher than that of Model 2b, and all coefficients, including the coefficient of the lagged dependent variable, are estimated to be statistically significant.

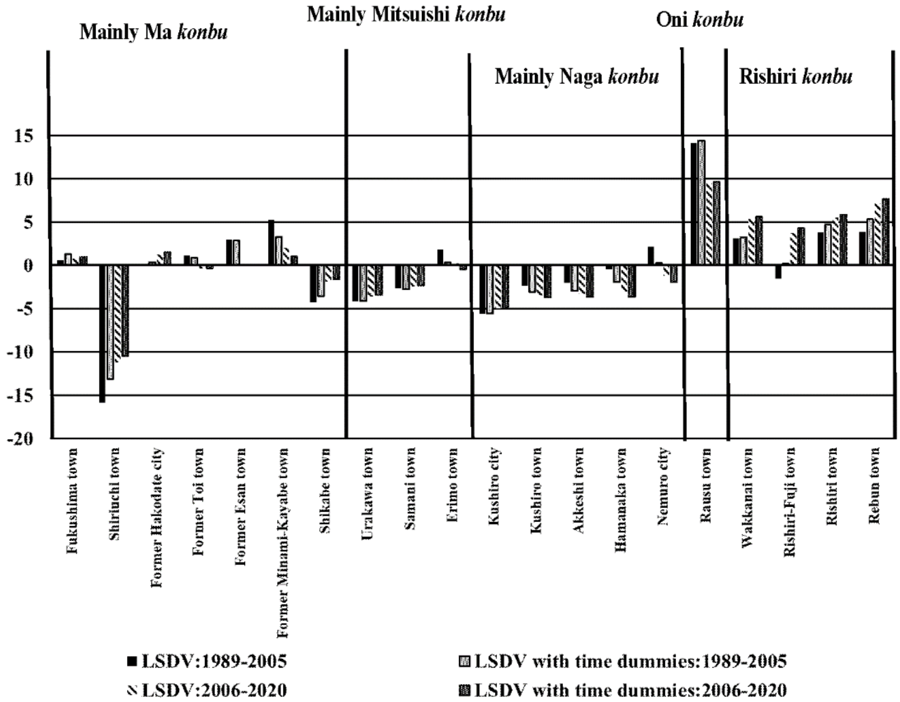

Figure 4. Estimated regional market competitiveness 1989-2005 and 2006-2020

Source: Estimated by authors.

From our estimation results, when comparing the first and second subsamples, market competitiveness has increased in some regions and declined in others. Because the estimates of market competitiveness are relative values across the 20 municipalities for each estimation period, these estimates cannot be compared easily. However, comparisons within the estimated relative market competitiveness in each estimation period, it is suggested that the results differ depending on whether to consider partial adjustment mechanism. Next, using the coefficient of determination, we compare the results of the LSDV model with time dummies for the first subsample (Model 2a) and the results of the LSDV/partial adjustment model with time dummies for the second subsample (Model 2c).

The results in Figure. 4 show that the relative competitiveness of Shiriuchi town is similar in the first and second subsamples, whereas that of Rausu town is lower in the second subsample. This change for Rausu town occurs along with a fall in price in the second subsample, which can be observed in Table 1. Similar changes are evident in other municipalities such as Esan town, Rishiri town, and Rebun town. To summarize the relative changes between estimation periods, we rank average prices and market competitiveness in Table 6. For the five highest- and five lowest-ranked municipalities for each period, the bolded municipalities are ranked within the top- or bottom-five municipalities for both prices and market competitiveness. Based on this table, one characteristic fact is that market competitiveness is ranked relatively high in the former Minami-Kayabe town, Erimo town, and Nemuro city compared with their price rankings. As noted, their relatively large production volumes may affect their market competitiveness. Another finding is that Rausu town, Rishiri town, Rishiri-Fuji town, and Rebun town, which are producing areas of Oni *konbu* or Rishiri *konbu*, have high rankings for both price and market competitiveness, but their relative market competitiveness is decreasing, which might be the result of changes in household tastes. In other words, a shift in taste from Oni *konbu* and Rishiri *konbu* to other kelps may have occurred over time. Although this result is interesting, we cannot verify it with our data. Additionally, the change in market competitiveness may also reflect a change in the composition of the kelp harvested in the area, but again our data do not allow us to confirm this.

Table 6. Ranking of prices and market competitiveness

Rank	Price	Market competitiveness	Price	Market competitiveness	Price	Market competitiveness
	1989–2020	1989–2020	1989–2005	1989–2005	2006–2020	2006–2020
1	***Rausu town***	***Rausu town***	***Rausu town***	***Rausu town***	***Rausu town***	***Rausu town***
2	**Rebun town**	**Rebun town**	**Rebun town**	**Rebun town**	**Rebun town**	Former Minami-Kayabe town
3	**Rishiri town**	**Rishiri town**	**Rishiri town**	**Rishiri town**	**Rishiri town**	**Wakkanai town**
4	Rishiri-Fuji town	**Wakkanai town**	Rishiri-Fuji town	Former Minami-Kayabe town	**Wakkanai town**	**Rebun town**
5	**Wakkanai town**	Former Minami-Kayabe town	**Wakkanai town**	**Wakkanai town**	**Rishiri-Fuji town**	**Rishiri town**
6	Fukushima town	Rishiri-Fuji town	Fukushima town	Former Esan town	Former Hakodate city	Erimo town
7	Former Esan town	Former Esan town	Former Esan town	Fukushima town	Fukushima town	Nemuro city
8	Former Hakodate city	Fukushima town	Former Hakodate city	Former Toi town	Former Esan town	Rishiri-Fuji town
9	Former Toi town	Former Hakodate city	Former Toi town	Erimo town	Former Toi town	Former Hakodate city
10	Shikabe town	Former Toi town	Shikabe town	Former Hakodate city	Shikabe town	Fukushima town
11	Former Minami-Kayabe town	Erimo town	Former Minami-Kayabe town	Nemuro city	Former Minami-Kayabe town	Hamanaka town
12	Samani town	Nemuro city	Samani town	Rishiri-Fuji town	Samani town	Former Toi town
13	Erimo town	Hamanaka town	Erimo town	Hamanaka town	Erimo town	Former Esan town
14	Urakawa town	Shikabe town	Urakawa town	Samani town	Urakawa town	Akkeshi town
15	Nemuro city	Samani town	Nemuro city	Akkeshi town	Nemuro city	Kushiro town
16	**Kushiro town**	**Akkeshi town**	**Kushiro town**	**Kushiro town**	Kushiro town	Samani town
17	**Kushiro city**	**Kushiro town**	**Kushiro city**	Shikabe town	Akkeshi town	Shikabe town
18	**Akkeshi town**	Urakawa town	**Shiriuchi town**	Urakawa town	**Kushiro city**	Urakawa town
19	Hamanaka town	**Kushiro city**	Akkeshi town	**Kushiro city**	Hamanaka town	**Kushiro city**
20	**Shiriuchi town**	**Shiriuchi town**	Hamanaka town	**Shiriuchi town**	**Shiriuchi town**	**Shiriuchi town**

6. Conclusion

In this study, we estimated the market competitiveness of the Hokkaido-produced kelp industry and investigated the degree of regional competition using a discrete/continuous model. According to the empirical results, higher market competitiveness exists in the regions that produce Oni *konbu* or Rishiri *konbu*, and where the production volume of the region is high, namely former Minami-Kayabe town, Erimo town, and Nemuro city. When we checked the stability of the market competitiveness by dividing the sample period, some regions experienced a reduction in market competitiveness while concurrently lowering their price levels, whereas others increased their competitiveness while concurrently lowering their production volumes. However, the change appears to be relatively small and gradual.

The most important result is that the market competitiveness of each region in the kelp market depends not only on the difference in price depending on the type of kelp but also on the production volume of each region. In multiple areas, multiple types of kelp are harvested, and how the types of kelp, production volumes, and regional-specific competitiveness are related to market competitiveness are areas for future research. To address these issues, it will be necessary to obtain data on the production volume and price for each type of kelp in each region.

Authors Contributions

Prof. Mori was responsible for data collection, Prof. Fukushige and Prof. Mori were jointly responsible for hypotheses formulation, literature review, study design, and the methods used and research results.

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Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Notes

Note 1. However, if there exists serial correlation in the error term, the estimated coefficients are still estimated results of unbiased estimators.

Note 2. Even if we split the sample period into three subperiods, we can estimate the market competitiveness for each municipality. However, as the estimates of the coefficients on which market competitiveness is based vary for each municipality, there are only 10 subsamples, even if the existence of other explanatory variables is ignored. This implies that the degree of freedom in estimating market competitiveness is likely to be almost the same as the case taking the average of the 10 observations. We decided that it would be appropriate to divide the entire sample period into two subperiods, allowing for approximately 15 degrees of freedom.

Note 3. Durbin (1970) proposed this test originally. Also see Godfrey (1978).

Appendix A

Derivation of price equation

We assume that the kelp industry in each region is competitive, and that competition occurs between the municipalities of Hokkaido. This paper analyzes market competitiveness econometrically based on the differentiated demand structure of consumers for a product in the municipalities. This derivation is based on the assumptions and theoretical explanation by Hanemann (1984) and original additional assumptions by Yoshino (1997). Most of the steps for the derivation process depend on Ishida and Fukushige (2010). First, following Hanemann (1984), we introduce the utility function for consumers as:

$$u = u\{x, \varphi_1(b_1, \varepsilon_1), \varphi_2(b_2, \varepsilon_2), \cdots \varphi_I(b_I, \varepsilon_I), z\}$$

where $x = (x_1, x_2, \cdots, x_I)$ is a vector of the levels of consumption of the product in each municipality, φ_i is the competitive power of the product in each municipality, b_i is the attribute of the product in each municipality, ε_i is a random variable, and z is total expenditure on all other goods. Assuming that the competitive power of the product in each municipality, φ_i, depends on the attributes of the product in each municipality, b_i, we consider differences in utility between consumers to be differences in the attitudes of consumers toward the product in each municipality b_i expressed as a function of φ_i.

Next, following Hanemann (1984), we assume that consumers choose only one product in municipality *i*, where $i = 1,2, \ldots, I$. Consumers compare the conditional indirect utility of each product in each municipality and choose only the one that maximizes their utility. The conventional utility function obtained in this manner is expressed as:

$$v = max[\tilde{v}_1, \tilde{v}_2, \cdots, \tilde{v}_I] \tag{A1}$$

where $\tilde{v}_i = \tilde{v}_i[p_i, \varphi_i(b_i, \varepsilon_i), m]$ represents the conditional indirect utility function when the consumer chooses the product in municipality *i*. We express the conditional utility function where the consumer chooses a product in the *i*th municipality as $u_i = \bar{u}_i[x_i, \varphi_i(b_i, \varepsilon_i), z]$. The consumer chooses (x_i, z) to maximize his/her conditional utility subject to the budget constraint $p_i x_i + z \leq m$ and the nonnegativity conditions $x_i \geq 0$ and $z \geq 0$, where p_i is the price of a product in municipality *i* and *m* is household income. Below, we derive the probability that the consumer chooses a product in the *i*th municipality and provides the conditional demand function.

Hanemann (1984) assumed that the following bivariate utility function expresses the conventional utility function of consumers:

$$u(x, \varphi, z) = u^*(\sum x_i, z + \sum \varphi_i x_i)$$

Using this assumption, we express the utility where a product in municipality *i* is selected as $u_i = u_i^*(x_i, z + \varphi_i x_i)$. Now we define $w_I = x_i$, $w_{II} = z + \varphi_i x_i$, and assume that u^* is quasi-concave in w_I or w_{II}. Then, where a product in municipality *i* is selected, the conditional demand, other expenditure, and indirect utility functions are as follows:

$$\tilde{x}_i = w_I^*(p_i - \varphi_i, m)$$
$$\tilde{z} = w_{II}^*(p_i - \varphi_i, m) - \varphi_i w_I^*(p_i - \varphi_i, m) \tag{A2}$$

$$\tilde{v}_i = \tilde{v}^*{}_i(p_i - \varphi_i, m).$$

Because the conditional indirect utility function is a decreasing function of the difference between the price of a product in municipality i (p_i) and its competitive power (φ_i), the consumer chooses a product that minimizes $p_i - \varphi_i$ and the probability that the consumer chooses a product in municipality i is expressed as:

$$\begin{aligned}\pi_i &= Pr\{p_i - \varphi_i \le p_i - \varphi_i, j = 1,2,\dots,I\}\\ &= Pr\{\varepsilon_j + \bar{\varphi}_i - p_j \le \varepsilon_i + \bar{\varphi}_j - p_j, j = 1,2,\dots,I\}\\ &= Pr\{\varepsilon_j + (\bar{\varphi}_i - p_j) - (\bar{\varphi}_j - p_j) \le \varepsilon_i,, j = 1,2,\dots,I\}\\ &= Pr\{\varepsilon_j + \lambda_j - \lambda_i \le \varepsilon_i,, j = 1,2,\dots,I\} \qquad \text{(A3)}\end{aligned}$$

where $\varphi_i(b_i, \varepsilon_i) = \bar{\varphi}_i + \varepsilon_i$ and $\lambda_i = \bar{\varphi}_i - p_i$, $i = 1,2,\cdots,I$. The relation $\varphi_i = \bar{\varphi}_i + \varepsilon_i$ was introduced by Yoshino (1997), where φ_i is the competitive power of the ith product and $\bar{\varphi}_i$ and ε_i are its nonstochastic and stochastic part, respectively.

Following Hanemann (1984), we now assume that the random variables, ε_i, $i = 1,2,\cdots,I$, are independently and identically distributed according to the extreme value distribution. Their cumulative distribution function is $F(\varepsilon_i) = exp[-exp(-\varepsilon_i/\mu)]$, where μ is a nonnegative parameter. Hence, their joint cumulative distribution function is given as:

$$F(\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_I) = exp[-\textstyle\sum_{h=1}^{I} exp(-\varepsilon_h/\mu)]. \qquad \text{(A4)}$$

From equation (A4), the derivative of $F(\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_I)$ with respect to the ith argument is:

$$F^i(\varepsilon_1, \varepsilon_2, \cdots, \varepsilon_I) = \frac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp\left[-\sum_{h=1}^{I} exp(-\varepsilon_h/\mu)\right]$$

Then equation (A3) and (A4) implies $F(\varepsilon_i + \lambda_i - \lambda_1, \varepsilon_i + \lambda_i - \lambda_2, \cdots, \varepsilon_i + \lambda_i - \lambda_I)$ as

$$\begin{aligned}F^i(\varepsilon_i + \lambda_i - \lambda_1, \varepsilon_i + \lambda_i - \lambda_2, \cdots, \varepsilon_i + \lambda_i - \lambda_I) &= \tfrac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp[-\textstyle\sum_{h=1}^{I} exp\{(-\varepsilon_i - \lambda_i + \lambda_h)/\mu\}]\\ &= \tfrac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp[-exp\{(-\varepsilon_i - \lambda_i)/\mu\}\textstyle\sum_{h=1}^{I} exp\{(\lambda_h)/\mu\}]\\ &= \tfrac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp[-exp\{-\varepsilon_i/\mu\}\, exp\{-\lambda_i/\mu\}\textstyle\sum_{h=1}^{I} exp\{(-\lambda_h)/\mu\}]\\ &= \tfrac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp[-\beta_i\, exp\{-\varepsilon_i/\mu\}] \qquad \text{(A5)}\end{aligned}$$

where $\beta_i = exp(-\lambda_i/\mu)\sum_{h=1}^{I} exp(\lambda_h/\mu)$ and

$$\frac{1}{\mu}[exp(-\varepsilon_i/\mu)]\, exp[-exp\{-\varepsilon_i/\mu\}]$$

is the density function of the Gumbel distribution with parameters 0 and μ. We can rewrite as

$$\begin{aligned}&\frac{1}{\mu}\{\exp(-\varepsilon_i/\mu)\}\exp[-\beta_i \exp\{-(\varepsilon_i/\mu)\}]\\ &= \frac{1}{\mu}\{\exp(-\ln\beta_i)\}[\exp\{-(\varepsilon_i/\mu - \ln\beta_i)\}]\exp[-\exp\{-(\varepsilon_i/\mu - \ln\beta_i)\}].\end{aligned}$$

By integrating equation (A5) with ε_i, we obtain probability π_i and the following multivariate logit model:

$$\begin{aligned}\pi_i &= \int_{-\infty}^{\infty} F^i(\varepsilon_i + \lambda_i - \lambda_1, \varepsilon_i + \lambda_i - \lambda_2, \cdots, \varepsilon_i + \lambda_i - \lambda_I)\, d\varepsilon_i\\ &= \int_{-\infty}^{\infty}\frac{1}{\mu}[exp\{-\ln\beta_i\}]\left[exp\left\{-\left(\frac{\varepsilon_i}{\mu} - \ln\beta_i\right)\right\}\right] exp\left[-exp\left\{-\left(\frac{\varepsilon_i}{\mu} - \ln\beta_i\right)\right\}\right] d\varepsilon_i\\ &= [exp\{-\ln\beta_i\}]\int_{-\infty}^{\infty}\frac{1}{\mu}\left[exp\left\{-\left(\frac{\varepsilon_i}{\mu} - \ln\beta_i\right)\right\}\right] exp\left[-exp\left\{-\left(\frac{\varepsilon_i}{\mu} - \ln\beta_i\right)\right\}\right] d\varepsilon_i\\ &= [exp\{-\ln\beta_i\}]\int_{-\infty}^{\infty}\frac{1}{\mu}\left[exp\left\{-\left(\varepsilon_i - \frac{\mu\ln\beta_i}{\mu}\right)\right\}\right] exp\left[-exp\left\{-\frac{(\varepsilon_i - \mu\ln\beta_i)}{\mu}\right\}\right] d\varepsilon_i\end{aligned}$$

$$= [exp\{-\ln\beta_i\}] = [exp\{\ln{\beta_i}^{-1}\}] = {\beta_i}^{-1}$$

$$= exp(\lambda_i/\mu)/\sum_{h=1}^{I} exp(\lambda_h/\mu) \tag{A6}$$

Next, we define set A_i as $A_i \equiv \{\varepsilon | v_i(p_i, \varphi_i, m) \geq v_j(p_j, \varphi_j, m), j = 1,2,\cdots, I\}$. From equations (5) and (6), we can obtain the conditional marginal density of ε_i as follows:

$$f_{\varepsilon_i|\varepsilon\in A_i}(\varepsilon_i) = F^i(\varepsilon_i + \lambda_i - \lambda_1, \varepsilon_i + \lambda_i - \lambda_2, \Lambda\ , \varepsilon_i + \lambda_i - \lambda_I)/\pi_i$$

$$= \exp(-\varepsilon_i/\mu)\exp\left[\frac{-\beta_i \exp(-\varepsilon_i/\mu)}{\mu}\right]$$

Furthermore, the moment-generating function of the following Gumbel distribution:

$$\frac{1}{\mu}[exp\{-(\varepsilon_i - \mu\ln\beta_i)/\mu\}]\, exp[-exp\{-(\varepsilon_i - \mu\ln\beta_i)/\mu\}]$$

is $E\{exp(t\varepsilon_i)|\varepsilon \in A_i\} = exp(t\mu\ln\beta_i)\,\Gamma(1-\mu t) = \beta_i^{\mu t}\Gamma(1-\mu t)$ and the mean of ε_i is

$$E\{\varepsilon_i|\varepsilon \in A_i\} = \mu\ln\beta_i + \gamma\mu = \mu(\ln\beta_i + \gamma)$$

where γ is Euler's constant (= 0.57722).

At this stage, Yoshino (1997) introduces the consumers' conditional indirect utility function $v^*(p_i - \varphi_i, m)$ as:

$$v^*(p_i - \varphi_i, m) = -\frac{exp(-\eta m)}{\eta} + \frac{\theta}{\rho} exp[-\rho(p_i - \varphi_i)]$$

where θ, η, and ρ are constants and satisfy $\theta > 0 \quad and \quad \eta \neq 0$. Using equation (A2) and Roy's identity, we obtain a conditional demand function as follows:

$$\tilde{x}_i(p_i, \varphi_i, m) = w_I^*(p_i - \varphi_i, m) = -\frac{\partial v^*(p_i - \varphi_i, m)/\partial(p_i - \varphi_i)}{\partial v^*(p_i - \varphi_i, m)/\partial m} = \theta\, exp[-\rho(p_i - \varphi_i) + \eta m]$$

and using $\varphi_i = \bar{\varphi}_i + \varepsilon_i$ and $\lambda_i = \bar{\varphi}_i - p_i$, $i = 1,2,\cdots, I$ relationships, we can rewrite the demand function as

$$\tilde{x}_i(p_i, \varphi_i, m) = \theta\, exp[\rho\lambda_i + \eta m + \rho\varepsilon_i].$$

The expected value of $\tilde{x}_i$ is:

$$\begin{aligned}
E\{\tilde{x}_i|\varepsilon \in A_i\} &= \theta\exp(\rho\lambda_i + \eta m)E(\exp(\rho\varepsilon_i)|\varepsilon \in A_i) \\
&== \theta\exp(\rho\lambda_i + \eta m)\beta_i^{\mu\rho}\Gamma(1-\mu t) \\
&= \theta\exp(\rho\lambda_i + \eta m)\left(\exp(-\lambda_i/\mu)\sum_{h=1}^{I}\exp(\lambda_h/\mu)\right)^{\rho\mu}\Gamma(1-\rho\mu) \\
&= \theta\exp(\rho\lambda_i + \eta m)\exp\ \rho\mu(-\lambda_i/\mu)\left(\sum_{h=1}^{I}\exp(\lambda_h/\mu)\right)^{\rho\mu}\Gamma(1-\rho\mu) \\
&= \theta\exp(\rho\lambda_i + \eta m)\exp(-\lambda_i\rho)\left(\sum_{h=1}^{I}\exp(\lambda_h/\mu)\right)^{\rho\mu}\Gamma(1-\rho\mu) \\
&= \theta\exp(\eta m)\left(\sum_{h=1}^{I}\exp(\lambda_h/\mu)\right)^{\rho\mu}\Gamma(1-\rho\mu)
\end{aligned} \tag{A7}$$

To derive the empirical model, we also obtain $\widetilde{\ln x_i}$ as follows:

$$
\begin{aligned}
E\{\ln \tilde{x}_i | \varepsilon \in A_i\} &= \ln\theta + \rho\lambda_i + \eta m + \rho E\{\varepsilon_i | \varepsilon \in A_i\} \\
&= \ln\theta + \rho\lambda_i + \eta m + \rho\mu(\ln\beta_i + \gamma) \\
&= \ln\theta + \rho\lambda_i + \eta m + \rho\mu(\ln\exp(-\lambda_i/\mu) + \ln\sum_{h=1}^{I}\exp(\lambda_h/\mu) + \gamma) \\
&= \ln\theta + \rho\lambda_i + \eta m + \rho\mu(-\lambda_i/\mu + \ln\sum_{h=1}^{I}\exp(\lambda_h/\mu) + \gamma) \\
&= \ln\theta + \rho\lambda_i + \eta m - \lambda_i\rho + \rho\mu\left[\ln\sum_{h=1}^{I}\exp(\lambda_h/\mu) + \gamma\right] \\
&= \ln\theta + \eta m + \rho\mu\left[\ln\sum_{h=1}^{I}\exp(\lambda_h/\mu) + \gamma\right]
\end{aligned} \tag{A8}
$$

These are derivations of the individual demand functions of the discrete/continuous model proposed by Hanemann (1984).

Yoshino (1997) derived a price equation from the individual demand functions obtained in a discrete/continuous model. The main feature of Yoshino's (1997) model is that the competitive power and the logarithm of total production volume and the production volume in each municipality determine the price in each municipality. We derive the empirical model for estimation as follows. First, we define market share y_i with N consumers. If N is sufficiently large, using equations (A6) and (A7), we can rewrite the market share as follows:

$$
\begin{aligned}
y_i &= \frac{X_i}{X} \\
&= \frac{\pi_i N \cdot E\{x_i | \varepsilon \in A_i\}}{\sum_{j=1}^{I}\pi_j N \cdot E\{x_j | \varepsilon \in A_j\}} \\
&= \frac{\exp(\lambda_i/\mu)}{\sum_{h=1}^{I}\exp(\lambda_h/\mu)}
\end{aligned} \tag{A9}
$$

where X_i is the total demand for products in municipality i and X is the total demand for all products in each municipality. The total demand for all products in each municipality is expressed as:

$$
\begin{aligned}
X &= \sum_{j=1}^{I} X_j \\
&= \sum_{j=1}^{I}\pi_j N \cdot E\{x_i | \varepsilon \in A_i\} \\
&= N\theta\exp(\eta m)\left(\sum_{h=1}^{I}\exp(\lambda_h/\mu)\right)^{\rho\mu}\Gamma(1-\rho\mu)
\end{aligned}
$$

Taking the logarithm of X, we obtain:

$$
\begin{aligned}
\ln X &= \ln\left(\sum_{j=1}^{I} X_j\right) \\
&= \ln\left(\sum_{j=1}^{I}\pi_j\right) + \ln N + E\{\ln x_i | \varepsilon \in A_i\} \\
&= \ln N + \ln\theta + \eta m + \rho\mu\ln\sum_{j=1}^{I}\exp(\lambda_j/\mu) + \gamma\rho\mu
\end{aligned} \tag{A10}
$$

$ln \sum_{j=1}^{I} exp(\lambda_j/\mu)$ can be rewritten using (A9), because

$$ln\, X - ln\, X_i = ln(\textstyle\sum_{h=1}^{I} exp(\lambda_h/\mu)) - \lambda_i/\mu$$

and we obtain:

$$ln\, X = ln\, N + ln\, \theta + \eta m + \rho\mu(ln\, X - ln\, X_i + \lambda_i/\mu) + \gamma\rho\mu.$$

By solving equation (A10) for λ_i:

$$\lambda_i = {}^{1}/_{\rho}\,(ln\, X - ln\, N - ln\, \theta - \eta m - \rho\mu(ln\, X - ln\, X_i) - \gamma\rho\mu)$$
$$= -{}^{1}/_{\rho}\,(ln\, N + ln\, \theta + \eta m) + \left(\frac{1}{\rho} - \mu\right) ln\, X - \mu\, ln\, X_i - \gamma\mu$$

and p_i, using the relation $\lambda_i = \bar{\varphi}_i - p_i$, we obtain:

$$p_i = {}^{1}/_{\rho}\,(ln\, N + ln\, \theta + \eta m) + \bar{\varphi}_i - \mu\, ln\, X_i + \left(\mu - \tfrac{1}{\rho}\right) ln\, X + \gamma\mu \quad \text{(A11)}$$

Given that in actual empirical situations N_t and m_t are unobservable, we assume that N_t and m_t are constant over time by setting α_i as:$\alpha_i = \bar{\varphi}_i - \bar{\varphi}_I \;\; for \quad i = 1,2,\cdots,I-1$

$$\alpha_I = \tfrac{1}{\delta}(ln\, N + ln\, \theta + \eta m) + \gamma\mu + \bar{\varphi}_I \;\; for \quad i = I.$$

Finally, we obtain the equations for estimation as follows:

$$p_i = \alpha_i + \alpha_I - \mu\, ln\, X_i + (\mu - \frac{1}{\rho})\, ln\, X + u_i \quad for \quad i = 1,2,\ldots,I-1$$
$$p_I = \alpha_I - \mu\, ln\, X_I + (\mu - \tfrac{1}{\rho})\, ln\, X + u_I \quad \text{(A12)}$$

where u is the error term and α_i,α_I,μ, and ρ are parameters where α_i is the competitive power of brand *i* expressed as its difference from the competitive power of reference brand I.

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