Applied Study of a CES Utility Function Based on a Trial of a New Sakhalin Spruce Product－Integrating Economics and Science－

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Abstract

The goal of this study was to derive the optimal production quantity and optimal price for a Sakhalin spruce-based product not yet on the market by inserting the change in cortisol concentration (ug/dl) into a CES-type utility function. In the past research has been conducted without a concrete determination of utility levels for consumers. In this study, based on cardinal utility (an accurate measurement of the utility level), we calculate consumer utility based on the experiment and show a method to calculate the optimum production quantity and price for a new product that cannot yet be marketed. This has the effect of simplifying marketing efforts.

Sakhalin spruce is a coniferous evergreen tree that grows naturally in Hokkaido, Japan. Unlike other tree species, however, which are used for a variety of purposes, it currently has little use as a marketable material. In this study, trials were performed on test subjects of two new products (Sakhalin spruce juice and Sakhalin spruce lotion) which were not yet on the market. Since the concentration of cortisol (a type of stress hormone) in the saliva of the subjects is different after the trial as compared to before it, this change was measured and defined as the utility level. The trials were conducted on 28 subjects at Rakuno Gakuen University in the city of Ebetsu, Hokkaido.

The cortisol concentration is high when stress levels are high and low when stress levels are low. From the results of the trial, based on traditional consumer behavior theory, we were able to determine the combination of production quantity and price for which the cortisol concentration change was highest.

The utility function derived from the Sakhalin spruce juice and Sakhalin spruce lotion trials is as follows.

$$u = (1.3844{q_1}^{0.7223} + 1.6149{q_2}^{0.7223})^{\frac{0.2510}{}}$$

The numerical representation of stress changes in this study indicated that the scent of Sakhalin spruce has a stress-reducing effect. The study has verified from an economic point of view the conclusion of Yukari, Daigo et al. (2017) that "the scent of Sakhalin spruce has a stress-reducing effect."

Although Sakhalin spruce grows abundantly in the mountain forests of Hokkaido, there is little demand for it thus far as a product. In order to promote the effective use of natural resources, it is the hope of the author to encourage efforts toward the development of Sakhalin spruce-based products.

Body

1. Introduction

1-1 Objective

The Sakhalin spruce, genus Piecea, family Pinaceae, is an evergreen conifer native to Hokkaido, parts of the Tohoku region, the South Kuril islands, and Sakhalin. According to the regional forestry plan, its growth is slow, with the time taken from planting to felling (the standard rotation age) standing at around 60 years. By contrast, that of the Japanese larch is 30 years. Currently, although demand for Sakhalin spruce plantations is low, it is frequently planted. This is because it grows even in poor conditions such as volcanic ash and coastal sand dunes. Among planted trees in Hokkaido, it lies in third place behind the Sakhalin fir and the Japanese larch.

As such, it would be desirable to find a socially productive use for the tree, and harvest it proactively. Felling the trees is also essential to improve the forest environment. At present, however, no effective way of using Sakhalin spruce has been found, and the trees are cut down for lack of any alternative. The Hokkaido Wood Products List, published by the Hokkaido Department of Fisheries and Forestry, carries all the wood products produced in Hokkaido. A survey conducted by the authors showed that the list for 2016 contained 197 products, out of which only 4 were listed as Sakhalin spruce. Sakhalin spruce grows abundantly in Hokkaido's forests, but it is clear how little demand for it there is as a wood product.

Since 2014, there have been efforts to use it not only as a wood product, but also for medical applications. Functionality studies are being conducted of the wood components that Sakhalin spruce contains. This is part of a trend to cultivate new demand for the tree, and new products are in fact being developed, although they remain small in number. One of these is essential oil extracted from Sakhalin spruce components, while

another is a juice (named Ashoro Onneto Blue) that uses Sakhalin spruce as a fragrance.

However, these new products are largely unknown to consumers, and there is no tangible market for them. Accordingly, no sales strategy using marketing has been devised, and it has not been possible to deduce optimal production quantities and pricing. This paper, therefore, will show what kind of analysis producers should perform to determine production quantities and pricing in these kinds of circumstances, where marketing analysis cannot be carried out. This paper's originality, in theoretical terms, is as follows.

Previous economic analyses have been conducted while we are still unable to concretely estimate consumer utility. Here, we assume cardinal utility, in which utility can be concretely measured, and by calculating the utility that consumers obtain from their use of the new products, we derive optimal production volume and pricing.

Specifically, we performed a consumption experiment with two goods: the Sakhalin spruce juice mentioned previously, and a Sakhalin spruce lotion (a commercially available lotion containing the previously mentioned essential oils extracted from Sakhalin spruce), measuring the concentration of the stress hormone cortisol in saliva before and after consumption of the products. The concentration of cortisol, one of the stress hormones, is high in times of high stress, and low in times of low stress. A reduction of cortisol levels, in other words, the relief of stress, is taken as an appreciation utility. Based on traditional theories of consumer behavior and using that data as a utility level, we will find the combination of production volume and price that maximizes utility out of the consumption levels of the two goods, as seen from changes in cortisol concentration.

Large corporations aside, small and medium-sized businesses with low marketing capacity are unable to produce accurate benchmarks for production volume and pricing when trying to manufacture and sell new products. This paper presents a method for these companies to find optimal production volume in terms of social usefulness. This is a development study using a new marketing model that integrates economics and science, determining the optimal production volume of a product in circumstances where marketing analysis cannot be performed.

Note 1: At the stage when a new product has just been developed, profit maximization does not come into consideration. Accordingly, producer theory is not required, and only consumer theory will be used.

Note 2: Cortisol is a corticosteroid hormone secreted by the endocrine system that is

responsible for regulating organisms' physiological processes. Because it is released suddenly at times of stress, it is used as an indicator for measuring stress. It has recently become possible to collect it from saliva, so it is often used in field research.

1-2 Previous Studies

There are few studies which have provided concrete measurements of cardinal utility, and still less any studies in economics which have measured utility using cortisol levels in saliva.

In terms of studies that promote the use of experiments in economics, we have Takeuchi, K., 2014, who stressed their necessity in this field. However, despite expressing interest in developments in game theory, he did not advocate for experiments in traditional utility maximization economic theory. This paper, however, will promote experimental research within traditional economic theory. One example of an empirical study in cardinal utility is Katsushi Mizuno, et al, 2016, which succeeds in measuring cardinal utility in the Japanese forestry industry. In addition, as a premise for an experiment measuring utility by changes in cortisol concentration, it has already been shown, by studies including Yukari Daigo, 2017, that the scent of Sakhalin spruce has a stress-relieving effect.

2. Economic Model and Experiment

2-1 CES Utility Function

A CES production function with homogeneity of degree μ is shown in (1).

- $u = (\alpha_1 {q_1}^{-\beta} + \alpha_2 {q_2}^{-\beta})^{-\frac{\mu}{\beta}}$ (1)

u is cardinal utility, q_1 is the consumption of the first good, q_2 is the consumption of the second good, p_1 is the price of the first good, p_2 is the price of the second good, and by defining its degree as μ, we get a function that can accurately measure cardinal utility.

2-2 Experiment

We conducted a field experiment for two goods: the Sakhalin spruce juice (below, the "juice") and the Sakhalin spruce lotion (below, the "lotion"). The experiment was conducted on January 14th 2017 in a laboratory at Rakuno Gakuen University, located in Ebetsu, Hokkaido. Subjects were recruited arbitrarily, and included students and teaching staff. The number of subjects present on the day was 28, and broke down as shown in Table 1.

The experiment was conducted by having the subjects follow steps 1, 2, and 3.

Table 1 - Subject Breakdown

AGE	15 – 19	20 – 24	25 – 29	30 – 34	35 – 39	60 – 64	65 – 69	Total
Men	2	6	1	2	0	1	1	13
Women	5	7	1	1	1	0	0	15

Step 1

Each subject is given a imaginary budget of 300 yen. The subjects then buy juice (50cc) and lotion (1 coat) so as to use up their provided 300 yen budget entirely. Subjects were free to buy any amount of each good within the confines of their budget.

The 28 subjects were divided into 3 groups. The goods, 50cc of juice and 1 coat of lotion, were priced differently for each group.

Group 1 was assigned 9 subjects, with juice (50cc) priced at 100 yen and lotion (1 coat) priced at 50 yen. Group 2 was assigned 11 subjects, with juice (50cc) priced at 50 yen and lotion (1 coat) priced at 100 yen. Group 2 was assigned 8 subjects, with juice (50cc) priced at 100 yen and lotion (1 coat) priced at 100 yen. This is summarized below.

Table 2 - Experiment Parameters

Group	Juice (50 cc)	Lotion (1 coat)	Subjects
Group 1	100 yen	50 Yen	9
Group 2	50 Yen	100 yen	11
Group 3	100 yen	100 yen	8

Premise: Each subject uses up their 300 yen budget entirely, but is free to buy any combination of goods.

Step 2

The variables for the utility function (1) in this economic study are defined as follows:

Utility (u) was defined as the ratio of the change in cortisol concentration levels (sg/dL). Cortisol concentration (sg/dL) is the amount of cortisol (sg) found in 100ml of saliva.

The unit of consumption of the first good (q_1) was set as 50cc of juice.

The unit of consumption of the second good (q_2) was set as 1 coat of lotion.

The units of consumption for the first (q_1) and second (q_2) goods were handled unchanged as "units". For example, if a subject bought 100cc of juice, this amounts to a purchase of two units of juice (50cc), and is represented as two units. If they bought 3

coats of lotion, this amounts to a purchase of three units of lotion (1 coat), and is represented as three units.

Step 3

Before beginning the experiment, saliva was taken from each subject and stored. Storage was performed in accordance with the objective of measuring cortisol concentration (sg/dL), after which the field experiment began. Consumption of the goods signifies drinking the juice or applying the lotion. After the experiment, saliva was taken once more from each subject, then stored appropriately. Concentrations of cortisol (sg/dL) were measured to see what changes had taken place from before to after the experiment. Analysis was then performed by fitting the ratio of this change into the economic theory as utility derived through consumption of the goods.

2-3 Experiment Results

The table shows, for each group, the results of the measurements of cortisol concentrations (sg/dL) taken before and after the experiment. The A/B column shows the ratio of the change from before to after the experiment. The smaller this value, the more stress was relieved (see footnote).

Table 3 - Results of cortisol concentration (sg/DL) measurements

1) Group 1 Juice (50cc) 100 yen, Lotion (1 coat) 50 yen

Sex	Juice (50 ml)	Lotion (1 coat)	Before	After	A/B	B/A
Woman	1	4	0.0470	0.0792	1.6878	0.592504089
Man	1	4	0.1516	0.0796	0.5250	1.904906978
Man	2	2	0.1627	0.0729	0.4482	2.231207323
Woman	1	4	0.1546	0.0697	0.4506	2.219075754
Woman	1	4	0.1638	0.1239	0.7564	1.321999463
Woman	2	2	0.1382	0.0662	0.4790	2.087626428
Woman	2	2	0.1327	0.0543	0.4094	2.442560786
Man	2	2	0.0841	0.0759	0.9016	1.109144602
Man	3	0	0.4666	0.0944	0.2024	4.940432109

2) Group 3 Juice (50cc) 50 yen, Lotion (1 coat) 100 yen

Sex	Juice (50 ml)	Lotion (1 coat)	Before	After	A/B	B/A
Man	2	2	0.1672	0.0946	0.5654	1.768771428
Woman	2	2	0.1260	0.0923	0.7329	1.364471628
Woman	2	2	0.2598	0.0973	0.3744	2.671020827
Woman	2	2	0.0549	0.0500	0.9115	1.097116061
Woman	1	2	0.3592	0.1745	0.4859	2.058242351
Man	1	2	0.0786	0.0832	1.0583	0.944876171
Man	2	2	0.1879	0.0467	0.2487	4.020334192
Woman	2	2	0.2635	0.1436	0.5448	1.835577575
Woman	2	2	0.0739	0.0634	0.8575	1.166196988
Man	2	2	0.0672	0.0726	1.0805	0.925501789
Man	1	2	0.1078	0.0684	0.6344	1.576212528

3) Group 3　　Juice (50cc) 100 yen, Lotion (1 coat) 100 yen

Sex	Juice (50 ml)	Lotion (1 coat)	Before	After	A/B	B/A
Man	1	2	0.0304	0.0594	1.9538	0.511821398
Man	2	1	0.3207	0.1431	0.4462	2.241006023
Man	1	2	0.1931	0.1061	0.5496	1.819476866
Man	2	1	0.4095	0.1457	0.3558	2.810533036
Woman	2	1	0.2180	0.1026	0.4706	2.124991443
Woman	1	2	0.2948	0.0943	0.3199	3.125794128
Woman	2	1	0.5586	0.1839	0.3292	3.037344257
Woman	3	0	0.0468	0.0553	1.1804	0.847173154

The above represents the change in cortisol concentrations (sg/dL) after purchase and consumption of the goods, and in this economic experiment, will be considered a value equivalent to utility (u). We will conduct the economic analysis based on this data.

3. Calculation

3-1 Demand function

- $\ln\frac{p_2}{p_1} = .1540 - .2777\ln\frac{q_2}{q_1}$
- By solving lna for a, we obtain the following result.

- a=1.1665
- Using these values, we obtain the following values from the parameter relationships for the parameters in formula (1).
-
- b+1＝0.7223
- $\alpha_1 = 1/(b+1) = 1.3844$
- $\alpha_2 = a/(b+1) = 1.6149$
- $\beta = -(b+1) = -0.7223$

Table 4　Maximum likelihood estimation

Log likelihood = -21.795097　　Number of obs　=　26

	Coef.	Std. Err.	Z value	P>|z|	[95% Conf. Interval]
LNQ	-.2777835	.1715068	-1.62	0.105	-.6139307 .0583637
_cons	.154028	.1188767	1.30	0.195	-.078966 .387022
/sigma	.5595259	.0775923	7.21	0.000	.4074478 .7116039

By STATA.

3-2　CES utility function

In Table 3, which shows the results of the cortisol concentration (sg/dL) measurements, A/B shows to what extent the levels of stress hormone had decreased after the experiment in comparison to before. This value is less than 1 if cortisol concentration (sg/dL) falls, and above 1 if it increases. The reduction in stress hormone can be thought of as a reduction function, and while this is easy to understand, this economic analysis uses the reciprocal of A/B. This is because of the premise that the larger the utility (u), the larger the "appreciation" is. Consequently, we wish to fit the

reduction in cortisol concentrations (sg/dL), representing a reduction in stress, into an increase function. In other words, by substituting A/B into utility (u), the larger the value of utility (u, representing appreciation), the larger the relaxing effect was.(NOTE1) This is substituted into the basic consumer theory equation.
Take the logarithm of both sides of equation (1).

$$\ln u = -\frac{1}{\beta} \times \mu \ln(\alpha_1 {q_1}^{-\beta} + \alpha_2 {q_2}^{-\beta})$$

Using the values of α1, α2, and ß obtained previously and the experimental data to make an estimate, we get the following.

- $\ln u = 0.3450 \ln(\alpha_1 {q_1}^{-\beta} + \alpha_2 {q_2}^{-\beta})$
  (4.9832)
  R2=0.4790 s =0.5567

μ = 0.2491

Utility function

- $u = (1.3844 {q_1}^{0.7223} + 1.6149 {q_2}^{0.7223})^{\frac{0.2510}{0.7223}}$

The above equation is the utility function obtained from this study's field experiment.

3-4 Analysis - Collaboration among producers is effective as an initial strategy

It may be anticipated that, if it becomes more widely known how useful Sakhalin spruce is, a number of companies and organizations will work to develop products that use it. For example, in 2014, there was only one company making Sakhalin spruce essential oils, but as of 2017, there are three that manufacture and sell them. Moreover, several companies are confirmed to be planning future sales, even though they are not currently under production.

Releasing Sakhalin spruce products is important in that it will increase social recognition of Sakhalin spruce's usefulness, encourage the desire of consumers to buy Sakhalin spruce products (stimulating demand for Sakhalin spruce). However, at the initial stage, when developing products that contain completely new ingredients like Sakhalin spruce, it may be best to defer the pursuit of profit. For producers, too, it will involve dealing with a completely new product. As well the necessity of stimulating consumer demand, they will need to, among other things, cultivate new markets and

investigate how useful the product can be. In this sense, , at the first stages of product development, it would be preferable for companies and organizations to collaborate with each other rather than compete. By cooperating together and sharing information, it will be easy to build WIN-WIN relationships.

This would be beneficial not only from the producers' perspective, but also from that of society as a whole, because it will raise consumers' utility level more effectively. For example, it would be best if the price of goods was standardized as far as possible between producers, a combination of goods decided on, as with good 1 and good 2 in this experiment, then a fixed amount of production carried out based on discussions between the producers. In the event that companies produce similar goods that require similar consumption, then they may have no choice but to compete with each other, so a situation where companies divide roles between them , producing and selling different products would be ideal. By doing this, as well as creating new demand for Sakhalin spruce, they can also increase consumer utility for society as a whole.

$$q_1=(0.7223u^{4.1493}-0.8572q_2^{0.7223})^{1.3838}$$

The u in this equation is the utility that we want to produce for society, so we add in the target value here. We must also consider the combination of good 1 (q_1) and good 2 (q_2).

What combination of goods to develop, and produce is down to the manufacturers, and it is hoped that they consider the social situation, look at what consumers are asking for, and make their decisions as appropriate.

$$Y=p_1q_1+p_2q_2$$

The Y term in this equation is consumers' social budget. In other words, it is the budget that society as a whole is prepared to spend on Sakhalin spruce utility (u). If we know this Y, it can be solved for q_1 and q_2. q_1 and q_2 are the optimal production volumes for the initial period that will allow consumers to become aware of the products.

Moreover, in regard to pricing, although it is preferable for producers to cooperate as far as possible, the discretion of each company will naturally take precedence. It is also necessary to consider laws such as antitrust regulations, so there are limits to complete cooperation between producers, including things such as determining production volume or uniform pricing by agreement. However, we want to emphasize that a certain level of cooperation between producers would help not only them, but also increase

consumer utility for society as a whole.

4. Summary

This economic model is characterized by its use of changes in cortisol concentration levels (sg/dL) in saliva, measured as an indicator for stress, as the utility value (u) in a CES utility function. In order to attach an economic value to a product, Sakhalin spruce, that is unexplored as a raw material, we conducted a field experiment to find the optimal production volume for products developed using Sakhalin spruce as an ingredient. As well as providing a function to determine the socially optimal production volume of Sakhalin spruce products, we have shown that in the initial stages of product development, it would be more efficient for companies to work in partnership. We think that this will be one future direction for manufacturers developing new products.

Sakhalin spruce is the 4th most planted tree in Hokkaido, and most of these trees are approaching the time for periodic thinning. However, the timber obtained from periodic thinning is thinner and weaker than that obtained from final cutting, so it cannot be used as material for building. As well as its slow maturation time, other disadvantages that Sakhalin spruce possesses include its many knots, which make it unpleasing aesthetically, its abundant sap, which makes it difficult to cut, and the fact that even when sawed, the wood is not attractive to look at. Currently, it is easy to imagine that Sakhalin Spruce has no particular appeal as timber. If it has no appeal, it will not be valued, and demand for it will not arise. However, the companies and organizations developing Sakhalin spruce products that we have introduced here have focused not on using it as timber, but on its constituents. Although it is also important to produce demand for the tree as timber, first discovering its other values and using that as an opportunity to emphasize its qualities is another possible method. If it is understood that the ingredients extracted from Sakhalin spruce have some appeal, then its appeal as timber will also rise. A rise in the tree's appeal means a rise in demand for it.

Increasing the appeal of the wood and thereby raising demand will lead to stimulation of the forestry industry as a whole. Japan's forest coverage is about 70% (i.e., approximately 70% of the land area is forested). The world's forest coverage is about 70%, so relative to other countries, Japan is surrounded by over twice the amount of forest. Among developed nations, it is third behind Finland and Sweden. Moreover, Japan is currently approaching the use period for its timber. Trees planted after the end of the war have grown, and have just reached the appropriate age for felling. Because it takes many years for trees to grow and be felled, in terms of an abundance of forestry resources, this is an opportunity that arrives once every few decades. Japan is said to be

a country without natural resources, but this does not apply to its forests. These resources have not been effectively used because the forestry industry has not been stimulated. Increasing demand for timber and encouraging the forestry industry would doubtless act as a following wind that would grow the Japanese economy.

In this field experiment, we have focused on essential oils from Sakhalin spruce, or products such as juices that use components of Sakhalin spruce as fragrance. Hearing this might lead us to believe that although there is value in using Sakhalin spruce components as fragrance, there is none in using the wood as timber. However, this is not the case. These Sakhalin spruce components are fine substances that the trees give off under normal circumstances, scientifically extracted. That is to say, the benefit of Sakhalin spruce fragrance in reducing stress hormones can be said to be an essential benefit of the Sakhalin spruce tree. Indeed, while thin trunks of Sakhalin spruce may be unsuitable for use as building timber, they could possibly be used as materials for some interior fittings. They could almost certainly be used as material for furniture. For people living in stressful urban environments, Sakhalin spruce, with its proven stress relief benefits, might appear a very attractive good. When people hear wood, wood used for building and furniture may come to mind, but components such as essential oils also have many possible applications. Getting away from the traditional demand for wood and looking at it from new perspectives, such as the use of its components, can cultivate new demand. The effective use of Sakhalin spruce is surely a typical example of this.

In the initial stages, until new products are developed and demand for them established, it is important for producers to cooperate in order to maximize social utility for consumers. One issue that remains, however, is building optimal economic models for the medium-to-long term. In other words, we must calculate the optimal production volume for when the initial stage is complete and each company starts to pursue its own profits. This economic model has assumed a friendly cooperation between companies, and in the initial stages this is easy to establish. However, there is no guarantee that it will happen, and the chances of it continuing into the medium-to-long term are small. To further this research, it is also necessary to investigate optimal production volumes and decision models for when each company is pursuing its own profits.

Footnote

(NOTE1)This value represents utility, but because the utility function is an increase function, we have used the reciprocal of A/B (B/A) as the utility term u.

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