Econometric Analysis of the Japanese *Sake* Economy

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Preface

This dissertation is a quantitative analysis of several topics related to the *sake* economy, which the author has been working on since his master's program. I would like to thank the many people who provided support and guidance in the writing of this dissertation. The author would like to thank his mentor at the Faculty of Economics, Professor Teruo Nakatsuma, for his guidance and encouragement, which led him to pursue a career as a researcher. Professor Nakatsuma provided not only suggestions on how to use data and estimation methods, but also guidance from various perspectives on analytical methods via bayesian modeling. In addition, Professor Hiroki Kawai, Professor Tatsuo Tanaka, Professor Ryo Nakajima, and Professor Koji Ishibashi gave me a wide range of advices through the presentation of industrial organization. Furthermore, in the econometrics seminar, Professor Daisuke Nagakura, Professor Tatsuyoshi Okimoto, Professor Takahiro Hoshino and Professor Shota Katayama provided me with a variety of advices on theories and methods for data analysis. I also received very useful advice from Professor Tsutomu Fujii (Fukushima University) and Mr. Makoto Nakakita (Riken) in writing this dissertation. I would like to express my sincere gratitude to my father, who supported me to the end even though I wanted to quit my studies due to work conflicts. Finally, I would like to thank the employees of the company of which I am CEO for giving me the time to do my research.

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Chapter 1

Introduction

A wide variety of alcoholic beverages are currently consumed in Japan. Among the various types of alcoholic beverages that exist in Japan, there is one that has been handed down since ancient times and is unique to Japan. It is named *sake*-Japanese rice wine. Most Japanese people have either drunk sake or know the name of sake even if they have never had it. *Sake* is not only consumed on a daily basis, but is also frequently used for ceremonial occasions. For instance, wedding and funeral gifts, gifts for close friends and business partners, and so on. Although *sake* is a very familiar product in our daily lives, little is known about its economic reality. It is normally difficult to find information on the actual history of *sake*, its current status, and how *sake* breweries are trying to manage their business.

Figure 1.1: The *Sake* Brewery of the Author

The author is currently the CEO of *sake* brewery in Figure 1.1, and the current domestic situation regarding its management is quite severe. This year (2024) marks the sixth year since the author started working for a *sake* brewery, and when he started working, the brewery's business situation was not so good. This is because most of the main products at that time were low-quality *sake* that were supposed to be supplied cheaply and in large volumes. As a result, most products were sold to consumers and distributors at prices lower than cost. There were two main questions that why had they kept prices so low and why were they brewing only low-quality *sake*. The author asked these questions to the previous CEO, other *sake* breweries, *sake* guilds, and business partners, but received no clear answers from any of them. The only thing they had in common was that the price, quality, and logistics were based on a long-established tradition. The first motivation for writing this dissertation was to clarify why the *sake* business and industry environment had become such difficult environments.

Next, the author decided to develop a new *sake* product to improve the financial condition of the company. Since raising the price of the old low quality *sake* would be difficult, the author decided to create a higher quality *sake* with a higher price. However, a new problem arose here. It is not clear how much to price for quality. As before, the author inquired about this as well with the relevant authorities, but did not receive a clear response.Rather, some of them advised that the cheaper the better, no matter how high the quality, because if the price is low enough, the customers will purchase *sake*. On the other hand, there were *sake* breweries in other regions that were brewing high quality, high value-added *sake* and earning a profit, but the pricing varied from one brewery to another. Our second motivation for writing this dissertation was to identify structures of *sake* pricing.

Based on the findings from this research, the author worked to improve the management of the brewery and succeeded in overcoming its loss-making structure. Unfortunately, however, in the management of a *sake*. brewery, it is impossible to continue to grow as a company if it only deals with the domestic market, even if it can overcome its loss-making structure by restructuring its product lineup. The Japanese *sake* market in Japan is currently shrinking year by year, and it is difficult to increase sales significantly any further. On the contrary, the international *sake* market continues to expand year after year. The export environment surrounding *sake* have been improved. The number of restaurants serves *sake* increased as a result of the registration of Japanese food as a UNESCO Intangible Cultural Heritage in 2013. In addition, the economic growth in some countries may lead to a preference for high-end imported alcohol beverages. However, when it came time for the author to commit to the *sake* export business, it was very difficult to determine what kind of products to export to which countries would be profitable. Of course, it was possible to obtain some information on the export situation and markets by country from business partners and the Japan External Trade Organization (JETRO), which was all qualitative information, and there were no reports that provided quantitative analysis. Our third motivation for writing this dissertation was to conduct a quantitative analysis of sake exports and to examine the market trend by country. In summary, our motivation for this dissertation is as follows.

1. A survey on the history of *sake*
2. Empirical analysis of *sake* pricing in domestic market
3. Empirical analysis of *sake*export industry

Chapter 2 details the economic history and technological development of sake in response to the first motivation. As a result, it was found that the reason why inexpensive and low-quality products continue to be sold in the current *sake* market is that the food shortage triggered by the war in the 1940s led to the establishment of a low-cost brewing system that did not require the use of large amounts of rice, and price controls in the 1950s. Even if the food shortage solved, that the vestiges of this system continue to this day. On the other hand, *sake* brewing technology has steadily developed. Thus it was confirmed that current brewing equipment can brew high quality, high value-added *sake*.

Chapter 3 describes an empirical analysis of *sake* pricing to solve the second motivation. This research formulates a hedonic pricing model for Japanese rice wine, *sake*, via hierarchical Bayesian modeling, estimating it with a Markov chain Monte Carlo (MCMC) method.The data used in the estimation are obtained from Rakuten, the largest online shopping site in Japan. Flavor indicators, premium categories, rice breeds, and regional dummy variables are used as pricing factors. The Bayesian estimation of the model employs an ancillarity-sufficiency interweaving strategy(ASIS) to improve the sampling efficiency of MCMC. The estimation results indicate that Japanese consumers value sweeter *sake* more and the price reflects the cost of pre-processing rice only for the most luxurious category. No distinctive differences are identified among rice breeds or regions in the hedonic pricing model.

Chapters 4 and 5 provide a study of the third motivation.

In chapter 4, we discuss an empirical analysis of *sake* export. In recent decades, *sake* exports to international countries have developed tremendously. *Sake* exports to other countries are increasing in both volumes and unit values.In this study, we analyzed the export environment for *sake*, using unbalanced panel datasets by country via hierarchical Bayesian modeling, estimating it with a Markov chain Monte Carlo (MCMC) method. As in chapter 3, estimation of the model is computed by ASIS method for the improvements of sampling efficiency of MCMC. The results of estimated *sake* volumes show there were some significant individual effects by countries and UNESCO registration. The study also confirmed the existence of different trends in *sake* exports from one country to another. Moreover, it was found that this differed largely from country to country before and after the UNESCO registration. Next, we conducted an analysis of macro factors and monthly effects that might be related to exports, which also provided implicative results.We performed a similar analysis for unit values and found various implications for individual effects, trends, macro factors, and monthly effects. In addition to this, our analysis reflects the existence of regional differences in the sake export industry. We conducted the same analysis as above, splitting regions into the *Nada* region, which has traditionally large firms and the others with small and medium-sized firms scattered throughout the regions. As a result, the *Nada* region showed similar results to the aggregated results with respect to the volume of exports. In contrast, no monthly changes in unit values could be observed in the *Nada* region. For the other regions, the results show a higher trend than the aggregated results before and after the UNESCO registration, while the effect of exchange rate on both volume and unit value is different from the aggregated results. From these results, we identified regional heterogeneity in the products relative to *sake* exports.

In chapter 5, we tested for structural breaks related to *sake*, imports in the US.

The amount of alcoholic beverages consumed in the US is increasing every year, and in fact, imported alcoholic beverages are responsible for the majority of alcoholic beverages consumed in the US.Among these, the volume and value of *sake* imports exceed those of other imported alcoholic beverages.To establish these developments, it is well known that distributors and breweries of *sake* made various commercial efforts. In addition, there might be other factors behind this trend include changes in the manufacturing environment due to legal revisions and changes in economic policy. To the best of our knowledge, however, there are no studies which researched empirically when and how structural break occurred in *sake* import in the US. In our study, we developed a structural break model to explain breaks of volumes and unit values with some macroeconomic factors based on Bai and Perron (BP) methods. As a result, we found that there are several breaks which caused by political and commercial changes for volumes and unit values. Especially, we were able to confirm that the properties of the *sake* goods in the US. liquor market have changed from lower-class goods to higher-class goods over the past few decades. In addition, We made similar estimates for the *Nada* region and the other regions as in Chapter 4. As a result, we identified regional heterogeneity in structural break points.

Finally, we conclude this dissertation with conclusions in Chapter 6.

Chapter 2

History of Japanese *Sake* and its Technological Development

2.1 Economic History of *Sake*

Sake has been consumed since the ancient times. According to the description of the Japan Sake and Shochu Makers Association, the oldest record of *sake* appeared in a third-century Chinese history book called Gishi Wajinden (jp) or Weizhi Worenzhuan (ch) as ”Human propensity loves to drink sake”. At that time, the Chinese who visited Japan wrote a record that Japanese people drunk it mainly at funeral parties[1]. Akiyama (1994) speculates that active trade activities took place between China and Japan from the end of the 2nd century to the beginning of the 3rd century, and that *sake*-making techniques may have been introduced from China at the same time as rice cultivation was introduced to Japan from China.In Japanese old historical record called *Harimano kuni fudoki*, the description, Japanese *sake* appeared in seventh century. In 689, the Japanese government established a department to manage the logistics of alcoholic beverages. It means that that *sake* at this time was still only consumed by the wealthy people in special ceremonies and events. *Sake* production and distribution networks subsequently expanded. As Japanese old legal codes *Engishiki* commented alcohol consumption of ordinary people, by the 10th century *sake* became popular even in the ordinary people.

[1] https://japansake.or.jp/sake/en/basic/japanese-sake-history/

Engishiki also described how *sake* was brewed. The*Engishiki* also describes how *sake* is brewed, and although it is a very simple method compared to modern breweries, it showed a prototype of modern brewing. Nonetheless, *sake* especially the fragrant and qualified one was still a luxury item for the aristocracy, while *sake* for the ordinary people had a harsher and more muddy taste[2].

After 12^{th} century, The environment around *sake* production changed drastically. Then, Japan entered the Kamakura period (1185-1333), the birth of the samurai government liberated logistics of various goods and product. *sake* was no exception. Before the Kamakura, the so-called 'official' products were almost exclusively monopolized by the imperial court and only cheap *sake* was distributed to the ordinary people. In the Kamakura, when the right to brew *sake* was transferred from the imperial court to temples and shrines, the amount of *sake* production increased significantly. According to Sakaguchi (1964), it is said that until then there was no idea to merchandise *sake* , but when temples and shrines started treating *sake* as a commodity and distributing it, it quickly became popular with a large number of people in cities such as *Kyoto*. It should be noted, however, that until the 13h century, the brewing and selling of *sake* was exclusively monopolized by temples, shrines and the samurai class.

Such a situation changed drastically in the 14th century. Private sector began to participate in brewing and selling, which until then had been carried out exclusively by temples and shrines. One of the most impressive cases was in the *Fushimi* area of Kyoto in which *sake* breweries, as we know them today, emerged, and they brewed and sold *sake* products by themselves. The samurai regime initially tried to crack down on them, but it gradually shifted towards allowing their business to tax them. The background of this shift consisted in a change of samurai government. The samurai regime in the Kamakura period took a very strict stance against breweries, but the following samurai regime was constantly at war and wanted to secure financial resources to compensate for the severe shortage of financial resources by allowing commerce instead of suppressing breweries and by taxing them[3].This deregulation led to a rapid increase in the number of *sake* breweries, and by the 15th century, Kyoto was full of a large number of breweries.

[2]Details are describe in https://japansake.or.jp/sake/en/basic/japanese-sake-history/

[3]These political changes are mainly researched by Koizumi (2000) and Yoshida (2015)

They formed *sake* guilds for brewing and marketing.

Sake guilds came to make the conflicts with subcontractors such as *koji* guilds. Koizumi (1984) states that this conflict with *koji* guilds was so fierce that it eventually led to a request for military service, and as the result, the *sake* breweries merged the *koji* makers. It means that they established a unique brewing system to manage everything from raw material processing to bottling. This system is inherited by modern *sake* breweries. The breweries in Kyoto were developing and flourishing in this way, and *sake* brewing in other regions followed it. What we call 'local *sake* ' today began to emerge in that historical background in the 15th century.

Meanwhile, conflicts in the commercial sphere between private guilds, and temples and shrines were intensifying. Such situation changed dramatically from the 16^th century. Oda Nobunaga and Toyotomi Hideyoshi harshly suppressed political powers of temples and shrines and merged them into the samurai ruling system. It meant that their economic activities declined significantly. Samurai regimes increasingly sought to stabilize and expand the economic sphere under their political power by protecting commerce and guaranteeing business in the *rakuichi rakuza* system. As the result, by the end of the 16^{th} century, temples and shrines entirely lost the concession of the brewing and selling of *sake*. The *sake* industry had completely shifted to the private sector[4].

In the 17^{th} century, the period known as the Edo period got started. The Tokugawa shogunate ruled Japan for about 300 years in the stabilized way. Japan at that time was recognized as a country of producing gold. At the beginning of the 17^{th} century, in the Land of Gold, the monetary economy began to develop to a greater extent. Large volumes of coins made of gold came into circulation in the market. Following this monetary economy, the *sake* industry also took another giant leap forward during this period. Some breweries began to move away from their previous system based on small companies. By purchasing large volumes of rice from the market, they brewed and sold *sake* for the broader area. In 1657, the Tokugawa shogunate established a new license system to control *sake* tax. This license guaranteed the right to brew *sake* for the designated *sake* breweries and set a maximum amount of rice to be used at the same moment. Kato (1977)

[4]For more information on the *sake* industry during this period, see Kato (1977) and Yuzuki (1987)

and Yoshida (2015) argues that the Tokugawa shogunate was flexible in the operation of this licensing system. If the rice harvest was not sufficient in a year, new breweries were banned from licensing system. However, if there was a good harvest in a different year, licenses of brewing and selling were granted to everyone as long as they applied for the license. While implementing this licensing policy, the Tokugawa shogunate issued a regulation to prohibit the brewing of *sake* in the autumn. Kato (1977) found that this prohibition had two purposes. The first purpose was to improve *sake* quality. As we describe the details in chapter 3, due to its nature, *sake* is considered to be brewed purpose was to finish the rice harvest before starting brewing. It led to determine the quantity of rice for the brewing after checking the yield of rice harvest. As the result, this regulation limited *sake* brewing in the winter season. Sake breweries began to find the labor among farmers, who had less work during the winter season. They formed a specialized group of sake brewing with techniques. This group was led by a leader called *Toji*. This *Toji* system continues to this day. Koizumi (2000) states this *Toji* system rapidly spread in the other regions, by adapting to the local climate. There were also major changes in logistics of the transportation of *sake*. Until the 16th century, the transportation of *sake* was carried mainly by horse-drawn wagons. With the development of marine transportation technology, shipments became more active from the 17th century. By the 18th century, the shipping transportation became almost common. At the same moment, the containers used to store *sake* changed from jars and pots to wooden vats and barrels. This change allowed *sake* breweries for safer transportation. Yoshida (2015) argues that in the 17th century, it took about one month to transport goods from Edo (Tokyo) to Osaka, but by the 18th century, it took only two weeks. Accordingly, the production area of *sake* shifted from Kyoto to *Nada* of Hyogo, because *Nada* was much closer to the port. As for *Nada*, we will describe this area in the more detailed in Chapter 4. Briefly speaking, *Nada* was good to get water suitable for *sake* brewing, and its location near the port was advantageous for the distribution of *sake*. Consequently, by the 18th century, the center of *sake* brewing completely shifted from Kyoto to *Nada*. *Sake* became a popular product for daily consumption, rather than a product used only for religious ceremonies as in the past.

In the 19^{th} century, the *sake* industry reached a turning point again. Due to the

Meiji Restoration, the Tokugawa Shogunate came to an end and a modern government was established. They sought tax revenue for the modern nation in the form of currency, rather than the rice form that had been used until then. The expansion and reinforcement of the collection of taxes was important to stabilize the nation's finances. For *sake* , Meiji government took a policy to increase the number of sake breweries. This was the turning point for modern *sake* brewing in national-wide level. Yuzuki (1987) shows that there were 27,702 breweries in 1881. Figure 2.1 shows the *sake* production licenses issued in the Meiji era. The Meiji government actively encouraged the acquisition of brewing licenses, which differed greatly from the previous practice of allowing *sake* brewing upon application.

The tax rate on alcohol continued to increase along with subsequent wars such as the Sino-Japanese War (1894) and the Russo-Japanese War (1904). In particular, in order to carry out the Russo-Japanese War, the government forced the entire nation to pay heavy taxes. The *sake* tax was intensively strengthened as a good source of taxation. By the turn of the 20^{th} century, sake tax revenues accounted for 36% of total national tax revenues. Due to the heavy taxes, many *sake* breweries were constrained to abolish their business. The number of *sake* breweries decreased to 11,438 in 1904. In 20^{th}, *sake* began to be sold in the form of glass bottles, and the trend of consuming *sake* in glass bottle at home began to spread among ordinary families. What we cannot overlook is the development of highly refined rice technology and the appearance of new rice called *YamadaNishiki* in the 1920s. These details will be explained in chapter 3[5]. The foundations of modern *sake* brewing were established before the 1940s. However, the *sake* industry faced its greatest crisis in the 1940s, when the Pacific War began in 1941 and Japan was plagued by food shortages. Rice was completely rationed, and *sake* breweries were ordered to stop their business by the government. After the war, the serious circumstances in the defeat caused the proliferation of very poor quality moonshine. The government began to take various policies in response. In 1949, a method of increasing the volume of *sake* with the addition of alcohol, along with the addition of sugars and organic acids, got started (triple increasing brewing). Yoshida (2013) states that Japan was finally able to get rid

[5]more details on Kanzaki (1991)

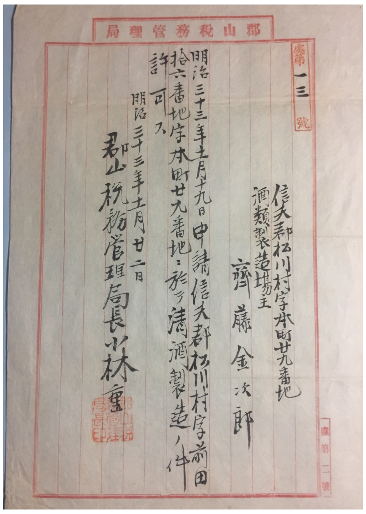
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Figure 2.1: *Sake* License Given in Meiji era

of moonshine after the recovery of economy due to the special arms procurement boom caused by the Korean War in 1950. In 1952, the rationing system of alcoholic beverages was abolished. However, because the food situation at the time prioritized the supply of rice for eating, the production of rice-based *sake* was sluggish. To make matters worse, a large amount of fake sake (equivalent to 60% of all sake in 1951) was produced and consumed. The standardized sales price system for *sake* was abolished in 1964[6].

The struggles of sake in the 20th century and beyond will be discussed in detail in Chapter 4, but it is undeniable that the low quality of sake and the price controls that were triggered by the food shortage have led to the low profit structure of sake breweries that has continued to this day. Development Bank of Japan (2013) claims that there was originally a chance to go back to brewing in the old days after the food shortage was resolved, but this distorted system has continued as a result of prioritizing the sale of large volumes of *sake*[7]. However, the cost of brewing sake has naturally increased over the years, resulting in a shrinking market and an increase in the number of low-profit *sake* breweries.

[6]These details are described in Koizumi(1984)

[7]The reason for prioritizing quantity was that the type of *sake* that could be brewed depended on how much was brewed, as will be discussed in more details in Chapter 5.

Figure 2.2: Steaming Rice machine

2.2 Technological Development of *Sake*

While we have discussed the economic development of the *sake* industry, brewing technology has also made great strides. Kato (1987) argues that the use of steamed rice for brewing had already been practiced since the 8th century, but it is believed that the process of steaming and the necessary rice washing was established to some extent in the 16th century. How well the rice is steamed during this steaming process will determine whether it will make a good *sake* or not. In Japan, the introduction of continuous rice steaming machines in the 1960s dramatically stabilized the rice steaming process. Figure2.2 shows the newest one. The next is *koji.* According to Koizumi (1984), the process of applying a large amount of *koji.* to steamed rice originated in the 12th century and later. Since the 20^{th} century, research on *koji.* has progressed rapidly, and it has become common practice to mix steamed rice with *koji.* at a high temperature (40°C) without lowering the temperature of the steamed rice.Until now, most workrooms dedicated to *koji* were wooden, but nowadays there are an increasing number of stainless steel ones as Figure 2.3. Then the tank is injected with *koji*, water, and additional rice to ferment. The starch in the rice is broken down into sugar by the enzymes in the *koji.* (saccharification), and the sugar is converted into alcohol by the yeast (fermentation). These two fermentations take place simultaneously, or parallel double

Figure 2.3: *Koji* Workingroom

Figure 2.4: Fermentation Tank

fermentation, is one of the characteristics of *sake* (we will describe this detail on chapter 3). In the past, most tanks were made of wood, but the manufacturing environment changed dramatically with the invention of enameled tanks in the 20^th century. Koizumi (1984) and Akiyama(1994) argue that introducing enameled tanks greatly reduced the risk of sake going bad during the brewing process. Recently, an increasing number of *sake* breweries are using enamel tanks with jackets wrapped around them as Figure 2.4 to pass cold water through for more detailed issue control. Finally,ater fermentation is complete, the sake is sterilized by spraying it with high-temperature steam. This process is called *Hiire* in Japanese, and called pasteurization. The term derives from the scientist Pasteur's discovery of the effects of high-temperature pasteurization, but Yuzuki (1987) claims that high-temperature pasteurization for *sake* already existed in the 15th century as far back as recorded. Pasteurization is believed to have been carried out multiple times from the 16^th to the 18^th century. Until the 1990s, it was common practice to sterilize twice, but now, due to technological innovation, machines like the one shown in Figure 2.5 are being introduced that can adequately maintain quality with only one

Figure 2.5: Pasteurizaer

pasteurization. As we have mentioned, *sake* has been an indispensable product for the Japanese people and has undergone major economic and technological innovations, but it is currently in the midst of a major crisis for the aforementioned reasons. In order to overcome this crisis, *sake* breweries are engaged in various economic activities, which will be quantitatively analyzed in Chapter 3 and thereafter.

Chapter 3

Hierarchical Bayesian Hedonic Regression Analysis of Japanese Rice Wine: Is the Price Right?

3.1 Introduction

The worldwide spread of the novel coronavirus COVID-19 since early 2020 inflicted severe damage on the alcoholic beverage industry. Demand for alcoholic beverages such as beer and wine sharply declined across the globe due to forced closures of bars and restaurants and prohibitions on indoor dining. Japanese rice wine, *sake*, is no exception. Since the first case of COVID-19 was reported in January 2020, to prevent the spread of coronavirus nationwide, the Japanese government repeatedly declared a state of emergency, shutting down bars and restaurants or ceasing the sale of alcoholic beverages. Because bars and restaurants are major buyers of *sake*, the Japanese *sake* breweries suffered the loss of a great portion of usual sales revenue. This decline in demand for *sake* was further worsened by record-high bar and restaurant closures. According to a survey conducted by the Ministry of Agriculture, Forestry and Fisheries (MAFF), this resulted in domestic shipments of *sake* falling by 11% in 2020 from the previous year.

Under this unprecedented adverse business environment, Japanese *sake* breweries are struggling to identify alternative channels for *sake* sale. One promising alternative is e-commerce. Due to state-imposed restrictions on outside activities[1], the frequency and the volume of the online purchases of food and other necessities dramatically increased. For instance, Rakuten, Japan's largest e-commerce conglomerate, experienced solid growth in their sales revenue from the first to the fourth quarter of 2020 and it is on track to post its highest operating profit in the first quarter of 2021. Given the fact that consumers have preferred to purchase goods and have them delivered rather than leaving their homes and risking possible COVID-19 infection, Japanese *sake* breweries may need to establish new online sales channels and supply more products for home consumption to compensate for the loss of bar and restaurant sales.

Although the shift to the e-commerce market seems to be a plausible strategy, its successful execution is a different matter. The Japanese *sake* industry mainly consists of family-owned small and medium-sized enterprises and their decision making continues to be based on experience and intuition. Most managers have limited expertise regarding marketing strategy in general and proper product pricing in particular. Furthermore, most *sake* breweries sell majority of their product through wholesalers and have insufficient experience in direct sale. Simply put, managers tend to follow the practices established by their parents and maintain the same old long-term relationships with wholesalers for decades. Given the prevalent old-fashioned management style in the Japanese *sake* industry, data-driven pricing of *sake* is inconceivable. Therefore, to help the Japanese *sake* industry adopt a more sophisticated marketing strategy, we propose to formulate a hedonic pricing model for *sake* in this study.

Since the seminal work by Rosen (1974), the hedonic pricing approach has been widely applied to various goods. As for alcoholic beverages, Ashenfelter (1986) first developed a hedonic pricing model for Bordeaux wine, and Nerlove (1995) estimated a hedonic pricing model for the Swedish wine market and found that the rank of vintage, wine color, and the amount of sugar in wine had significant effects on the price of wine. Moreover, Faye and Le Fur (2019) found that coefficients in the hedonic regression possibly varied over time for Bordeaux wine. As for Asian wine markets, Hu and Baldin (2018) found that

[1]Unlike other countries, the Japanese government did not impose a strict lockdown upon the population. Nonetheless, the Japanese people were encouraged to limit non-essential outside activities and stay in their homes during the COVID-19 pandemic.

specific characteristics of quality strongly affected wine price in the Chinese wine market while Galati et al. (2017) conducted a hedonic analysis of the Japanese wine market. In addition to wine, some researchers analyzed beer, cider and scotch whiskey in the hedonic approach. For beer, Blackmore et al. (2020) found that visual effects such as the color of the label had a significant impact on beer prices while Jaeger et al. (2019) claimed that differentiation of segments to emotion and cognition was important in the beer market. For cider, some studies (e.g., Le Fur and Outreville (2021), Outreville and Le Fur (2019)) found that production characteristics were important in cider prices. For scotch whiskey, Moroz and Pecchioli (2021) investigated the effect of vintage.Following these studies, we include taste indicators of *sake* in the hedonic pricing model as explanatory variables, which are explained in Section 2.

Besides the quality of wine, several previous studies examined the impact of grape breeds and producing regions on the price of wine. As for grape breeds, Ginsburgh et al. (2013), Jones and Storchmann (2001), Chevet et al. (2011) among others examined the relationship between wine prices and grape breeds, and concluded that the prices were significantly affected by grape breeds. As for producing regions, Oczkowski (1994), Horowitz (2002), Schamel and Anderson (2003), Costanigro (2006), Galizzi (2007), Corsi and Strom (2013), and Brentari et al. (2014) among others concluded that wine production areas had a significant impact on the price. Corsi and Storm (2013) also found that consumers tended to purchase wine at a higher price if it was manufactured with organic farming.

Following the previous studies, we also include rice breeds and producing regions in the hedonic model of *sake* prices. Although there exist numerous studies about the hedonic pricing approach to various alcoholic beverages, virtually no hedonic analyses of the Japanese *sake* market have been conducted as far as the authors knows. In the literature, the hedonic pricing model has been supposed to be a linear regression of the log price in many applications. Although some studies such as Nerlove et al. (1995) employed the Box-Cox transformation or other nonlinear regressions to avoid misspecification, we adopted the traditional linear specification because our study is the first attempt on hedonic pricing of *sake*. Extension to nonlinear specifications is reserved for a future study.

The organization of this chapter is as follows. Section 2 describes the basic information regarding *sake* for those who are unfamiliar with this traditional Japanese liquor, outlining *sake*'s unique flavor characteristics. The data set used to estimate the hedonic pricing model is also introduced. Section 3 presents the hierarchical Bayesian modeling of *sake* prices and outlines the Bayesian Markov chain Monte Carlo (MCMC) estimation procedure, with more details regarding this approach provided in Appendix. Section 4 delineates the hypotheses tested and interprets the estimation results. Finally, in Section 5, we summarize our new findings and discuss their implications for breweries and distributors of *sake*.

3.2 Taste Determinants and Other Factors for *Sake* Pricing

Prior to introducing the candidates for explanatory variables in the hedonic pricing regression of *sake*, we will now describe the key aspects of the brewing process and the determinants of the taste. *Sake* is a traditional Japanese liquor brewed from rice. It is slightly yellow-colored, which is similar to white wine, and contains 13 to 16% alcohol. *Sake* is made from rice, *koji*, yeast, and water.[2] Some breweries add brewed alcohol to *sake* as a post-production taste enhancement to lower production costs. This study does not include this type of *sake* because such *sake* is a mass-produced cheap liquor that may not be suitable for analyzing the relationship between price and the quality. As such, this research focuses on *sake* without the post-production addition of alcohol, which is known as *junmai*, which means "pure rice" in Japanese.

One of the key materials, *koji*, is a kind of mold that decomposes rice starch into sugar. This process of sugar creation is called saccharification. The addition of yeast produces alcohol from the sugar created by *koji*, in a process called fermentation. Saccharification and fermentation in the *sake* brewing process proceed in parallel. This parallel fermentation generates a unique flavor known as *umami*, which is created by a rich amount of amino acids. In contrast, in the beer brewing process, malt is first saccharified into wort,

[2] A comprehensive guide to *sake* is available at https://japansake.or.jp/sake/en/basic/

and this wort is fermented into alcohol with the help of yeast. Figure 3.1 summarizes the four taste components of *sake*, beer, and wine. In each panel of Figure 3.1, the top bar is for wine, the middle bar is for beer ,and the bottom bar is for *sake*. The upper-left panel shows the amount of alcohol by percentage, which is often referred to as alcohol by volume (ABV) in the Japanese *sake* industry, showing that *sake* has the highest ABV. The upper-right panel with the title "Extract" presents a bar chart regarding the amount of sugar by percentage. There is no distinctive difference among three liquors, other than variation being highest for wine and the average level being lower for beer. The bottom-left panel shows that *sake* contains more amino acids than the other types of liquor, but the acidity of *sake* is lower than that of wine, as shown in the bottom-right panel. Given these observations, the following indicators were chosen as explanatory variables in the hedonic pricing regression[3]:

- ABV
- *sake* meter value (SMV)
- acidity

SMV is related to the amount of sugar in *sake* and takes either a positive or negative value. A higher SMV indicates a lower amount of sugar; thus *sake* with a higher (lower) SMV tastes drier (sweeter).

At the beginning of the brewing process of *sake*, grains of rice are threshed and polished so that only the inner part of a rice grain is used for saccharification and fermentation. This is because the inner part contains more amount of starch than the peripheral part. Polishing rice grains further makes *sake* taste smoother. The downside of this polishing process is that it increases production cost by discarding a substantial portion of rice that could otherwise be used. Thus, the portion of rice that is polished is a key factor that determines both the flavor of *sake* and its production cost. This variable is measured

[3]Although it is preferable to include the amount of amino acids in the hedonic pricing regression, this consideration was excluded from the study due to limitations in data availability.

[4]The authors appreciate the National Research Institute of Brewing for kindly supplying Figure 3.1 and allowing its reprint.

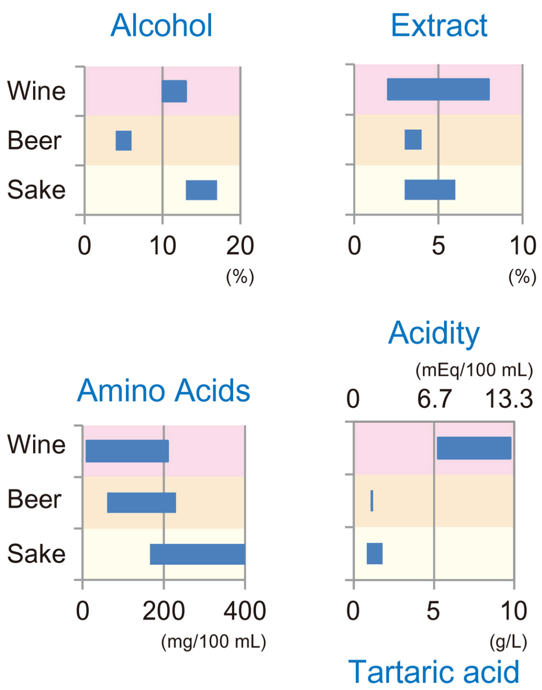

Figure 3.1: Liquor Taste Comparison[4]

through a polishing rice ratio (PRR); for instance, 50% PRR indicates that the outer half portion of the rice grain is discarded.

Related to PRR, the MAFF of Japan prescribes three categories of *sake*, including *jumnai*, *junmai ginjo*, and *junmai dai ginjo*. As previously noted, *junmai* is made from rice without the addition of post-production alcohol. There is no specific requirement on PRR to be classified as *junmai*; thus, it is regarded as a regular type of *sake* made purely from rice. The next category *junmai ginjo* is destined for the premium *sake* market. *Ginjo* literally means "premium brewing" in Japanese. To be categorized as *junmai ginjo*, *sake* must be *junmai*, i.e., without the addition of post-production alcohol, and the PRR must be no more than 60%. In addition, Akiyama (1994) argues that *sake* categorized as *ginjo* should be fermented for around a month. For the fermentation process must be kept for a certain periods to produce the appropriate aroma for *ginjo*. The last *junmai dai ginjo* designation represents the super-premium category. *Dai* means "great" in Japanese. To be classified as *junmai dai ginjo*, the PRR must be no more than 50%. For convenience, the following abbreviations will be used for these categories:

Table 3.1: Classes of Pure Rice *Sake*

Class	*Junmai Dai Ginjo* (DG)	*Junmai Ginjo* (JG)	*Junmai* (JM)
Maximum PRR	50%	60%	None

Source: Akiyama (1994) pp. 4–7

- *junmai* (JM)
- *junmai ginjo* (JG)
- *junmai dai ginjo* (DG)

Given the above categorization, DG is expected to be the most expensive luxury *sake*, followed by JG, and JM to be the cheapest. To analyze how this categorization contributes the price differentiation among JM, JG, and DG, dummy variables are used in the hedonic pricing regression to represent these categories. Cross-product terms between each category dummy and PRR are also added to the regression to assess differences in sensitivity to PRR among categories.

Unlike mass-produced cheap *sake*, the *ginjo*-type premium *sake* (DG and JG) is painstakingly crafted by a *toji* (brew master) who supervises the entire brewing process. Since most *sake* breweries are family-owned small businesses, they cannot afford to hire their own brew masters, so they outsource the task to freelance brew masters who have traditionally formed independent guilds. According to the Japan Sake and Shochu Makers Association (2021), there are 19 such guilds in Japan. In the past, knowledge and skills in *sake* brewing were a tightly held secret from the public; thus, making it necessary for breweries to hire brew masters from one of the existing guilds each season. This tradition remains today, even after an AI-monitored brewing system and other innovations have made it possible to produce *ginjo*-type premium *sake* without the help of traditional brew masters. Therefore, the quality of *sake* can differ region-to-region because it is subject to the skills and the preferences of the brew masters who belong to different regional guilds. Furthermore, some argue that regional climate differences may also affect the quality of *sake*, though with the introduction of fully automated temperature and humidity control in the brewing process, this may no longer be the case.

Regional dummy variables have been introduced into the hedonic pricing regression to investigate these parameters.

Rice breeds are included as the final factor in the hedonic pricing regression of *sake*. Of course, rice is the most important material of *sake*. Although some breeds of cooking rice have been used for *sake* brewing, *ginjo*-type premium *sake* is almost exclusively made from a *sake*-specific breed of rice, which is called *sakamai* (*sake* rice) in Japanese.

One of the most commonly used *sakamai* is *Yamadanishiki*, which is mainly grown in the western Japan, whereas rice farmers in the eastern Japan mainly grow *Gohyakumangoku*. *Omachi* and *Miyamanishiki* are also popular breeds, though they are cropped in smaller quantities than *Yamadanishiki* or *Gohyakumangoku*. *Omachi* is primarily cultivated in the western regions, while *Miyamanishiki* is mostly grown in the eastern regions. Moreover, some locally grown breeds of *sakamai* are also used by local breweries in *sake* brewing, but it is difficult for non-local breweries to purchase such breeds. As for the purchase price, in general, *Yamadanishiki* is the most expensive and *Omachi* follows. *Gohyakumangoku* and *Miyamanishiki* are the next most expensive, and local *sakamai* is the cheapest. Especially, the purchase price of *Yamadanishiki* costs almost twice as much as the purchase price of local *sakamai*[5]. Dummy variables for the four major breeds of *sakamai* are included as explanatory variables in the hedonic pricing model:

- *Yamadanishiki* (YM)
- *Gohyakumanngoku* (GH)
- *Omachi* (OM)
- *Miyamanishiki* (MY)

When all four dummy variables equal zero, this means that the corresponding *sake* is produced from a locally grown breed of *sakamai*.

In summary, the following explanatory variables are included in the hedonic pricing regression model of *sake* in this study with the number of observations (403).

[5]We obtained this information on material prices from an interview with the Japan Sake and Shochu Makers Association

Taste indicators:

- PRR (403)
- ABV (403)
- *sake* meter value (SMV) (403)
- acidity (403)

Premium categories:

- *junmai ginjo* (JG) dummy (134)
- *junmai dai ginjo* (DG) dummy156)
- JG dummy × PRR (134)
- DG dummy × PRR (156)

Rice breeds:

- *Yamadanishiki* (YM) dummy (110)
- *Gohyakumanngoku* (GH) dummy (59)
- *Omachi* (OM) dummy (41)
- *Miyamanishiki* (MY) dummy (33)

Regional effects:

- prefecture dummies for the following 29 prefectures:

Hokkaido (18)	*Aomori* (12)	*Miyagi* (17)	*Akita* (18)	*Yamagata* (45)
Fukushima (25)	*Ibaragi* (10)	*Tochigi* (23)	*Gunma* (12)	*Saitama* (6)
Chiba (5)	*Niigata* (38)	*Ishikawa* (7)	*Fukui* (9)	*Nagano* (14)
Gifu (18)	*Shizuoka* (11)	*Aichi* (6)	*Mie* (3)	*Shiga* (9)
Osaka (3)	*Hyogo* (9)	*Nara* (10)	*Wakayama* (8)	*Shimane* (8)
Okayama (9)	*Hiroshima* (23)	*Yamaguchi*(8)	*Kochi* (19)	

The data for the above variables, along with *sake* prices, were retrieved on August 6, 2021, using an API provided by Rakuten. The data set consists of 403 brands. We

Table 3.2: Descriptive Statistics

	Price	PRR	ABV	SMV	Acidity	Price	PRR	ABV	SMV	Acidity
	Total					**DG**				
Mean	2394	0.53	15.8	2.36	1.56	3860	0.43	15.9	1.25	1.44
SD	1924	0.09	0.9	5.12	0.31	2788	0.07	0.77	4.74	0.23
Max	22000	0.8	19	27	3.6	22000	0.5	18	13	2.5
Min	1034	0.18	11	-36	1	1365	0.18	14	-36	1
	JG					**JM**				
Mean	1782	0.55	15.9	1.98	1.6	1500	0.61	15.5	4.18	1.66
SD	283	0.03	0.84	5.1	0.32	235	0.05	1.05	5.14	0.35
Max	2992	0.6	18	20	3.6	2536	0.8	19	27	3.5
Min	1078	0.45	13	-21	1	1034	0.5	11	-20	1.1

Table 3.3: Correlation Matrix

	PRR	ABV	SMV	Acidity
PRR	1.000	-0.137	0.1967	0.289
ABV	-0.137	1.000	0.218	-0.006
SMV	0.197	0.219	1.000	-0.170
Acidity	0.289	-0.006	-0.170	1.000

chose this date because August was the most difficult month to produce *sake* due to the high temperature and few seasonal or special products were made. For this reason, we expect that only regular types of *sake* are sold at the online shopping site. We only used the data of *sake* sold by the bottle of 720 ml because the widest variety of products are available in this size of bottle. Note that the data set used here reflects only information on how online retailers who operate on Rakuten's online shopping site set the prices of their products. This is a notable limitation. The descriptive statistics of *sake* prices, PRR, ABV, SMV, and acidity are summarized in Table 3.2.

As expected, DG is the most expensive and has the lowest PRR and acidity; whereas, JM is the cheapest and has the highest PPR and acidity. JG is somewhere in between. SMV is lower for DG and JG than JM. These observations suggest that premium *sake* such as DG and JG tends to taste sweeter than less expensive JM. As for ABV, no significant differences are noted among the three categories.

When estimating a linear regression model by the OLS method, we have to check whether it suffers from severe multicolinearlity or not. Alin (2010) suggested checking the correlation matrix among the explanatory variables to detect multicolinearlity. Table 3.3 shows the correlation matrix among the explanatory variables in the hedonic pricing regression model (the dummy variables are excluded). From Table 3.3, we can safely say that there is no severe multicollinearity among the variables. Moreover, to make estimation of the regression model more robust, we estimate (3.3) via hierarchical Bayesian modeling. We will explain this method in Section 3.

The main goal of this study is to identify key determinants in pricing *sake*. To establish hypotheses for statistical inference on the relationship between the price of *sake* and the potential candidates for determinants presented in Section 2, we interviewed Professor Tsutomu Fujii[6], who is currently affiliated with Faculty of Food and Agricultural Sciences, Fukushima University, and was the supervisor of the Department of Quality and Evaluation Research Division in the National Research Institute of Brewing. In his former career, he evaluated the quality of various kinds of *sake* as a judge for the Annual Japan Sake Awards, which is the most traditional and prestigious *sake* competition. Based on his knowledge and experience, Professor Fujii suggested the following "conventional wisdom" in the *sake* industry related to the signs of the coefficients in the hedonic pricing regression:

Taste indicators:

- H1 The coefficient for PRR will be negative because lowering PRR costs more.
- H2 The coefficient for ABV will be positive because a higher ABV is an essential factor for the fragrance of DG and JG.
- H3 The coefficient for SMV will be negative because lower SMV leads to higher quality for *junmai*.

[6] Details on his academic achievements are available at https://researchmap.jp/read0005781

H4 The coefficient for the acidity will be negative. If the acidity is higher than 1.7, such *sake* is no longer classified in DG or JG.

Premium categories:

H5 The coefficient for JG dummy should be positive because of the PRR cap (it must be no more than 60%), as noted in Section 2.

H6 The coefficient for DG dummy should also be positive for the same reason as H5.

H7 For both the JG dummy × PRR and the DG dummy × PRR, the coefficient will be negative for the same reason as H5 and H6.

Rice breeds: *blue*

H8 The *Yamadanishiki* (YM) dummy should be positive because YM is the most suitable *sakamai* for brewing DG and JG.

H9 The *Gohyakumanngoku* (GH) dummy will not have a positive impact.

H10 The *Omachi* (OM) dummy will have a positive impact.

H11 The *Miyamanishiki* (MY) dummy will not have a significant impact.

Regional effects:

H12 There will be no clear difference among prefectures regarding regional effects because contemporary brewing technologies are almost universally used throughout Japan, as noted in Section 2.

3.3 Hierarchical Bayesian Modeling of the Hedonic Pricing Regression

This section will first introduce the hierarchical Bayesian modeling of the hedonic pricing regression of *sake* developed for this research. Suppose y_i is the log price of *sake* brand $i \in \{1, \dots, N\}$ and a dummy variable is defined as $d_{\star j}^{(i)}$, $\star \in \{R, B\}$,

$$d_{\star j}^{(i)} = \begin{cases} 1, & \text{if } \{\text{(R)egion, (B)reed}\} \text{ of } \textit{sake} \text{ brand } i \text{ is } j; \\ 0, & \text{otherwise,} \end{cases}$$

where "Region" refers to the prefecture where sake brand i is produced and "Breed" represents the rice breed from which the *sake* brand is made. As for the regional dummy variable d_{Rj}^{i}, all dummy variables for 29 prefectures are included. For this reason, the constant term from the regression is excluded to avoid multicollinearity. As for the breed dummy variable d_{Bj}^{i}, any local rice breeds are treated as the base breed; that is, $d_{\star j}^{i} = 0$ for all j if *sake* brand i is made from a local rice breed. Further, suppose $\{x_{ki}\}_{k=1}^{K}$ are explanatory variables, including taste indicators (PRR, ABV, SMV, and acidity), dummy variables for premium categories (DG dummy and JG dummy), and the cross-product terms (DG dummy×PRR and JG dummy×PRR). The hedonic pricing regression model is formulated as

$$y_i = \sum_{j=1}^{N_R} d_{Rj}^{(i)} \alpha_{Rj} + \sum_{j=1}^{N_B} d_{Bj}^{(i)} \alpha_{Bj} + \sum_{k=1}^{K} x_{ik} \beta_k + \epsilon_i, \quad \epsilon_i \sim \mathcal{N}(0, \sigma_\epsilon^2), \tag{3.1}$$

where $N_R = 29$ (the number of prefectures analyzed), $N_B = 4$ (the number of rice breeds), and $K = 8$ (the number of other explanatory variables) in the study. By introducing the following notations:

$$\boldsymbol{D}_\star = \begin{bmatrix} d_{\star 1}^{(1)} & \cdots & d_{\star N_\star}^{(1)} \\ \vdots & \ddots & \vdots \\ d_{\star 1}^{(N)} & \cdots & d_{\star N_\star}^{(N)} \end{bmatrix}, \quad \boldsymbol{\alpha}_\star = \begin{bmatrix} \alpha_{\star 1} \\ \vdots \\ \alpha_{\star N_\star} \end{bmatrix}, \quad \star \in \{R, B\},$$

$$\boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_N \end{bmatrix}, \quad \boldsymbol{X} = \begin{bmatrix} x_{11} & \cdots & x_{1K} \\ \vdots & \ddots & \vdots \\ x_{N1} & \cdots & x_{NK} \end{bmatrix}, \quad \boldsymbol{\beta} = \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_K \end{bmatrix}, \quad \boldsymbol{\epsilon} = \begin{bmatrix} \epsilon_1 \\ \vdots \\ \epsilon_N \end{bmatrix},$$

the regression model (3.1) is rewritten as

$$\boldsymbol{y} = \boldsymbol{D}_R \boldsymbol{\alpha}_R + \boldsymbol{D}_B \boldsymbol{\alpha}_B + \boldsymbol{X}\boldsymbol{\beta} + \boldsymbol{\epsilon}, \quad \boldsymbol{\epsilon} \sim \mathcal{N}\left(\boldsymbol{0}_N, \sigma_\epsilon^2 \boldsymbol{I}_N\right), \tag{3.2}$$

where $\mathbf{0}_N$ is the $N \times 1$ zero vector and $\boldsymbol{I}_N$ is the $N \times N$ identity matrix. Similar expressions will be used for zero vectors and identity matrices with different shapes. Furthermore, by defining

$$\boldsymbol{Z} = \begin{bmatrix} \boldsymbol{D}_R & \boldsymbol{D}_B & \boldsymbol{X} \end{bmatrix}, \quad \boldsymbol{\delta} = \begin{bmatrix} \boldsymbol{\alpha}_R \\ \boldsymbol{\alpha}_B \\ \boldsymbol{\beta} \end{bmatrix},$$

we have

$$\boldsymbol{y} = \boldsymbol{Z}\boldsymbol{\delta} + \boldsymbol{\epsilon}, \quad \boldsymbol{\epsilon} \sim \mathcal{N}\left(\mathbf{0}_N, \sigma_\epsilon^2 \boldsymbol{I}_{NT}\right). \tag{3.3}$$

For the above model (3.3), the likelihood of unknown parameters $(\boldsymbol{\delta}, \sigma_\epsilon)$ is given by

$$p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon) \propto (\sigma_\epsilon^2)^{-\frac{N}{2}} \exp\left[-\frac{1}{2\sigma_\epsilon^2}(\boldsymbol{y} - \boldsymbol{Z}\boldsymbol{\delta})^\intercal(\boldsymbol{y} - \boldsymbol{Z}\boldsymbol{\delta})\right] \tag{3.4}$$

$$\propto (\sigma_\epsilon^2)^{-\frac{N}{2}} \exp\left[-\frac{\sum_{i=1}^N e_i^2}{2\sigma_\epsilon^2}\right], \tag{3.5}$$

where $e_i = y_i - \sum_{j=1}^{N_R} d_{Rj}^{(i)} \alpha_{Rj} - \sum_{j=1}^{N_B} d_{Bj}^{(i)} \alpha_{Bj} - \sum_{k=1}^{K} x_{ik}\beta_k$. Two different forms of the likelihood, (3.4) and (3.5), will be used to derive the conditional posterior distribution of each parameter.

The prior distribution of $\boldsymbol{\delta}$ and σ_ϵ is assumed to be:

$$\boldsymbol{\delta} \sim \mathcal{N}\left(\boldsymbol{\mu}, \boldsymbol{\Sigma}\right), \quad \boldsymbol{\mu} = \begin{bmatrix} \mu_R \mathbf{1}_{N_R} \\ \mu_B \mathbf{1}_{N_B} \\ \boldsymbol{\mu}_\beta \end{bmatrix}, \quad \boldsymbol{\Sigma} = \begin{bmatrix} \sigma_R^2 \boldsymbol{I}_{N_R} & & \\ & \sigma_B^2 \boldsymbol{I}_{N_B} & \\ & & \boldsymbol{\Sigma}_\beta \end{bmatrix}, \tag{3.6}$$

$$\sigma_\epsilon \sim \mathcal{C}^+(0, s_\epsilon), \tag{3.7}$$

where $\mathcal{C}^+(0, s_\epsilon)$ stands for the half-Cauchy distribution:

$$p(\sigma_\epsilon|s_\epsilon) = \frac{2s_\epsilon}{\pi(\sigma_\epsilon^2 + s_\epsilon^2)}, \quad \sigma_\epsilon > 0, \quad s_\epsilon > 0, \tag{3.8}$$

and s_ϵ takes a preset value as a hyper-parameter. Note that the prior distribution (3.6) is equivalent to

$$\alpha_{\star i} \sim \mathcal{N}(\mu_\star, \sigma_\star^2), \quad i \in \{1, \dots, N_\star\}, \quad \star \in \{R, B\}, \tag{3.9}$$

$$\boldsymbol{\beta} \sim \mathcal{N}(\boldsymbol{\mu}_\beta, \boldsymbol{\Sigma}_\beta), \quad j \in \{1, \dots, K\}. \tag{3.10}$$

We further assume the prior distribution of $\mu_\star$ and $\sigma_\star$ in (3.6) are

$$\mu_\star \sim \mathcal{N}(\varphi_\star, \tau_\star^2), \quad \sigma_\star \sim \mathcal{C}^+(0, s_\star), \quad \star \in \{R, B\}, \tag{3.11}$$

where ($\varphi_\star, \tau_\star$, and $s_\star$) are also hyper-parameters, which are fixed at preset values. Gelman (2006) suggests that the half-Cauchy distribution (3.8) is more suitable as the prior distribution for the variance parameter in a hierarchical model such as $\sigma_\star$ in (3.11). Finally, prior distributions (3.6), (3.7), (3.9) – (3.11) are summarized into the joint prior distribution of $\boldsymbol{\theta} = (\boldsymbol{\delta}, \mu_R, \sigma_R, \mu_B, \sigma_B, \sigma_\epsilon)$:

$$\begin{aligned} p(\boldsymbol{\theta}) &= p(\boldsymbol{\delta}|\mu_R, \sigma_R, \mu_B, \sigma_B, \boldsymbol{\mu}_\beta \boldsymbol{\Sigma}_\beta) \\ &\quad \times p(\mu_R|\varphi_R, \tau_R) p(\sigma_R|s_R) p(\mu_B|\varphi_B, \tau_B) p(\sigma_B|s_B) p(\sigma_\epsilon|s_\epsilon). \end{aligned} \tag{3.12}$$

For brevity in mathematical expressions, dependency on the hyper-parameters was ignored in the prior distribution (3.12) as $p(\boldsymbol{\theta})$. By applying Bayes' theorem to the likelihood (3.4) and prior distribution (3.12), the posterior distribution of $\boldsymbol{\theta}$ is:

$$p(\boldsymbol{\theta}|\mathcal{D}) \propto p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon) p(\boldsymbol{\theta}), \quad \mathcal{D} = (\boldsymbol{y}, \boldsymbol{Z}). \tag{3.13}$$

Unfortunately, the posterior distribution (3.13) and the posterior statistics of $\boldsymbol{\theta}$ cannot be analytically evaluated as moments and intervals. Instead, they are evaluated using the MCMC method called Gibbs sampler. In this research, we improved this algorithm by ancillarity-sufficiency interweaving strategy (ASIS). See the Appendix for the derivation of each conditional posterior parameters and how to evaluate posterior statistics by MCMC method. Then we describe ASIS method to improve the algorithm in appendix and prior distributions we set.

3.4 Results

Table 3.4 presents the estimation results via hierarchical Bayesian modeling with all dummies. This table includes the names of variables, point estimates (posterior mean) of the coefficients, the posterior standard deviations of the coefficients as "SD", and the 90% intervals[7] as "90%". As the confidence interval in OLS estimation, the sign of the

[7] We use the highest posterior density interval for interval estimation.

Table 3.4: Estimation Results 1

Variables	Coefficients	SD	90% Interval				
PRR	-0.355	0.502	[-1.195,0.457]	*Saitama*	7.206	0.417	[6.533,7.905]
ABV	0.021	0.016	[-0.007,0.047]	*Chiba*	7.230	0.411	[6.553,7.905]
SMV	-0.006	0.003	[-0.011,-0.001]	*Niigata*	7.284	0.407	[6.607,7.944]
Acidity	0.011	0.049	[-0.068,0.091]	*Ishikawa*	7.287	0.413	[6.601,7.954]
JG	0.180	0.465	[-0.568,0.962]	*Fukui*	7.183	0.412	[6.496,7.849]
DG	2.484	0.346	[1.906,3.047]	*Nagano*	7.160	0.411	[6.485,7.837]
JG×PRR	-0.097	0.808	[-1.443,1.212]	*Gifu*	7.171	0.406	[6.506,7.840]
DG×PRR	-4.128	0.614	[-5.155,-3.136]	*Shizuoka*	7.248	0.410	[6.561,7.910]
YM	0.024	0.033	[-0.025,0.082]	*Aichi*	7.178	0.411	[6.492,7.843]
GH	-0.014	0.037	[-0.077,0.044]	*Mie*	7.216	0.411	[6.534,7.885]
OM	0.022	0.044	[-0.046,0.098]	*Shiga*	7.210	0.411	[6.536,7.888]
MY	-0.039	0.044	[-0.111,0.027]	*Osaka*	7.235	0.414	[6.565,7.925]
Hokkaido	7.261	0.402	[6.594,7.916]	*Hyogo*	7.259	0.411	[6.594,7.948]
Aomori	7.216	0.411	[6.560,7.911]	*Nara*	7.223	0.413	[6.548,7.906]
Miyagi	7.204	0.407	[6.526,7.864]	*Wakayama*	7.200	0.408	[6.514,7.859]
Akita	7.203	0.410	[6.534,7.883]	*Shimane*	7.214	0.413	[6.531,7.891]
Yamagata	7.097	0.407	[6.434,7.774]	*Okayama*	7.172	0.413	[6.498,7.857]
Fukushima	7.183	0.408	[6.511,7.855]	*Hiroshima*	7.223	0.412	[6.560,7.913]
Ibaragi	7.205	0.409	[6.529,7.878]	*Yamaguchi*	7.142	0.412	[6.459,7.814]
Tochigi	7.239	0.41	[6.562,7.907]	*Kochi*	7.230	0.407	[6.553,7.890]
Gunma	7.156	0.413	[6.488,7.845]				

Table 3.5: Estimation Results 2

Variables	Coefficients	SD	90% Interval	Variables	Coefficients	SD	90% Interval
PRR	-0.489	0.501	[-1.326,0.32]	YM	7.233	0.409	[6.579,7.921]
ABV	0.023831	0.016713	[-0.004,0.051]	GH	7.210	0.408	[6.548,7.884]
SMV	-0.005365	0.003022	[-0.010,-0.000]	OM	7.166	0.405	[6.492,7.819]
Acidity	0.029781	0.048119	[-0.050,0.107]	MY	7.221	0.410	[6.54,7.894]
DG	2.415	0.346	[1.846,2.977]	Others	7.204	0.405	[6.550,7.877]
JG	0.039	0.470	[-0.7372,0.803]				
DG×PRR	-4.040	0.616	[-5.041,-3.024]				
JG×PRR	0.148	0.813	[-1.150,1.521]				

coefficient is inferred to be inconclusive if the corresponding 90% interval includes zero. Conversely, if the entire 90% interval is on the positive (negative) region, we conclude that the corresponding coefficient is positive (negative).

First, the hypotheses regarding taste indicators (H1 – H4) are tested. The point estimate of PRR is negative, while that of ABV is positive. Although these estimates are consistent with H1 and H2, their signs are inconclusive because the 90% interval includes zero for both cases. The coefficient for SMV is conclusively negative, supporting H3. The coefficient for acidity is negative, but it is inconclusive because the 90% interval includes zero, which means that H4 is not supported. These results imply that lower SMV (sweeter *sake*) is more valued in the online market but other flavor indicators have negligible impact on price.

Next, H5 – H7, which are related to the influence of premium categories on the price, are examined. In Table 3.4, the sign of the JG dummy coefficient is ambiguous, but that of the DG dummy is positive and substantial, so H6 is supported, but H5 is not. This means the DG dummy has some significant effect on the price while the JG dummy has little effect. As for H7, the sign of the coefficient of the cross term JG×PRR is inconclusive but that of DG×PRR is conclusively negative. Therefore, as "super premium" *sake*, DG seems to have a distinctive PRR-price profile, in which the intercept is positive (DG is more expensive than JM and JG), and the slope is negative (lower PRR leads to a higher

Table 3.6: Estimation Results 3

Variables	Coefficients	SD	90% Interval	Variables	Coefficients	SD	90% Interval
PRR	-0.351	0.504	[-1.175,0.477]	*Niigata*	7.250	0.408	[6.575,7.916]
ABV	0.022	0.0164	[-0.005,0.049]	*Ishikawa*	7.258	0.413	[6.565,7.932]
SMV	-0.005744	0.003	[-0.010,-0.001]	*Fukui*	7.15	0.412	[6.469,7.826]
Acidity	0.011186	0.048	[-0.068,0.091]	*Nagano*	7.121	0.410	[6.446,7.797]
DG	2.530352	0.343	[1.967,3.098]	*Gifu*	7.141	0.405	[6.459,7.795]
JG	0.198169	0.467	[-0.579,0.955]	*Shizuoka*	7.22	0.410	[6.540,7.893]
DG×PRR	-4.1962	0.609	[-5.189,-3.185]	*Aichi*	7.148	0.410	[6.471,7.823]
JG×PRR	-0.1177	0.811	[-1.471,1.193]	*Mie*	7.187	0.411	[6.502,7.860]
Hokkaido	7.229728	0.402	[6.5681,7.898]	*Shiga*	7.186	0.411	[6.496,7.851]
Aomori	7.186	0.410	[6.506,7.864]	*Osaka*	7.209	0.414	[6.525,7.889]
Miyagi	7.178	0.407	[6.510,7.852]	*Hyogo*	7.233	0.411	[6.553,7.906]
Akita	7.169	0.409	[6.515,7.867]	*Nara*	7.199	0.413	[6.53,7.888]
Yamagata	7.061	0.406	[6.379,7.720]	*Wakayama*	7.174	0.410	[6.513,7.860]
Fukushima	7.147	0.407	[6.478,7.822]	*Shimane*	7.188	0.413	[6.515,7.880]
Ibaragi	7.17	0.409	[6.486,7.838]	*Okayama*	7.149	0.413	[6.473,7.834]
Tochigi	7.207	0.410	[6.548,7.902]	*Hiroshima*	7.196	0.411	[6.5158,7.874]
Gunma	7.121	0.412	[6.451,7.813]	*Yamaguchi*	7.111	0.412	[6.453,7.8118]
Saitama	7.172	0.417	[6.490,7.866]	*Kochi*	7.204	0.407	[6.556,7.900]
Chiba	7.195	0.410	[6.523,7.876]				

Table 3.7: Estimation Results 4

Variables	Coefficients	SD	90% Interval
PRR	-0.475	0.502	[-1.295,0.355]
ABV	0.026	0.017	[-0.003,0.053]
SMV	-0.006	0.004	[-0.011,-0.001]
Acidity	0.033	0.049	[-0.046,0.114]
const	7.159	0.404	[6.49,7.815]
DG	2.467	0.344	[1.914,3.043]
JG	0.049	0.468	[-0.712,0.832]
DG×PRR	-4.124	0.612	[-5.118,-3.108]
JG×PRR	0.138	0.812	[-1.152,1.522]

price).

As for rice breeds, none of the four dummy variables, YM, GH, OM, and MY, elicited a conclusively positive or negative coefficient; thus, H8 and H10 are not supported, while H9 and H11 are somewhat consistent with the data.

Finally, regional effects from *Hokkaido* to *Kochi* are compared in Table 3.4. All estimates are positive and range from 7.0 to 7.3, but no statistically noticeable differences are found among them; hence, H12 is supported. To obtain more robust results, we conducted two additional regression analyses: a model with rice breed dummies only and a model with prefecture dummies only. Estimation results of the model only with rice breed dummies are shown in Table 3.5 and those of the model only with prefecture dummies are shown in Table 3.6. These tables imply that the sign and significance of each coefficient does not change remarkably in either model specification. From these three tables, we may conclude that either producing prefecture or rice breed has little impact on *sake* prices. As the final robustness check, we estimated the simplest model in which four taste indicators (PRR, ABV, SMV and acidity), DG, JG and the cross terms DG×PRR and JG×PRR are used as explanatory variables. Estimation results in Table 3.7 indicate that estimated coefficients hardly differ from the other model specifications.

In summary, the estimation results in Table 3-6 suggest the following findings.

1. Lower SMV leads to a higher price in general, which may indicate that Japanese consumers prefer sweeter *sake*.
2. As it is categorized as DG, “super premium” *sake* has a strongly positive impact on the price.
3. DG with lower PRR tends to be priced higher, which may reflect the cost of the polishing process in addition to flavor improvement.
4. Both rice breed and producing prefecture have negligible impact on the price of *sake*.

3.5 Discussion

In this study, we estimated a hedonic pricing regression model for Japanese rice wine, *sake*, with data obtained from Rakuten’s online shopping site. Taste indicators, premium categories, rice breeds, and regional dummies were used as explanatory variables in the hedonic pricing regression model as possible determinants of *sake* prices. To obtain more stable estimation results, the hedonic pricing regression model was constructed via hierarchical Bayesian modeling and was estimated with the MCMC method. We also utilized ASIS to enhance the efficiency of the sampling algorithm.

In the estimated hedonic pricing regression model, the amount of sugar, which is negatively related to SMV, has a positive impact on the price; thus it can be inferred that Japanese consumers prefer sweeter *sake*. PRR has a negative impact on the price only if the *sake* is categorized as *junmai dai ginjo* (DG) “super premium” *sake*. This may imply that the costly polishing process is justified only for the most luxury category. DG was also found to be priced higher than other less luxury *sake*. Although some flavor indicators seem to influence *sake* prices, rice breeds and producing prefectures appear to have little to do with them. These results do not depend on whether regional dummies and/or rice breed dummies are excluded from the model or not.

These findings enable us to provide some helpful advice for *sake* breweries and distributors. For example, the finding that the impact of rice breeds on *sake* prices is limited may allow breweries to lower production costs by using cheaper materials. As mentioned in Section 2, YM, GH, OM and MY are more expensive than the other regional *sakamai*. Many breweries have used YM and the other three major *sakamai* especially for DG and JG due to long-standing practice, but the estimated coefficients in the hedonic pricing regression model suggests that such practice may no longer make sense.

Another helpful finding is that DG, “super premium” *sake*, has a strongly positive effect on the price, witch could improve the production portfolio of breweries. As we discussed the definition of *ginjo* in Section 2, one requirement for *ginjo* is that it should be fermented for a month. This requirement greatly drives up production costs because the efficiency of tank rotation is much lower than non-luxury *sake*, *junmai*. The cost difference between DG and JG, on the other hand, is mainly due to the difference in PRR. As a result, the cost difference between DG and JG is less than the difference between JG and *junmai* in practice. Thus, breweries may benefit more by increasing DG production and reducing JG production.

Our findings are also useful for marketing and promotion of *sake* in the e-commerce market. For instance, when distributors promote *sake*, they must place more emphasis on DG because it can be sold with a solid premium. Furthermore, they can adjust the price of *sake* based on whether it is sweeter or drier. In addition, it may be a futile attempt to raise the price based on producing regions or rice breeds because they have little impact on the price.

COVID-19 still threatens the *sake* brewing industry in Japan. The revenues of bars and restaurants have not yet returned to the pre-pandemic level. We believe that a shift to the e-commerce market is vital and a proper pricing strategy is essential for the *sake* brewing industry. We hope that findings and implications of this study will be of some help for the industry.

3.6 Appendix: Conditional Posterior Distributions and ASIS Algorithm

In this appendix, we first derive the conditional posterior distributions of the parameters in (3.13) and then describe the algorithm of general Gibbs sampler. Then we describe the ASIS method, which improves the MCMC algorithm.

The conditional posterior distribution of $\boldsymbol{\delta}$ is derived by applying Bayes' theorem to the likelihood (3.4) and the prior distribution of $\boldsymbol{\delta}$ (3.6) as follows:

$$\begin{aligned} p(\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}}) &\propto p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon) p(\boldsymbol{\delta}|\boldsymbol{\mu}, \boldsymbol{\Sigma}) \\ &\propto \exp\left[-\frac{1}{2\sigma_\epsilon^2}\left\{(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})^\intercal(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})\right\}\right] \times \exp\left[-\frac{1}{2}(\boldsymbol{\delta}-\boldsymbol{\mu})^\intercal\boldsymbol{\Sigma}^{-1}(\boldsymbol{\delta}-\boldsymbol{\mu})\right] \\ &= \exp\left[-\frac{1}{2}\left\{\sigma_\epsilon^{-2}(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})^\intercal(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta}) + (\boldsymbol{\delta}-\boldsymbol{\mu})^\intercal\boldsymbol{\Sigma}^{-1}(\boldsymbol{\delta}-\boldsymbol{\mu})\right\}\right]. \end{aligned} \tag{3.1}$$

By completing the square in (3.1), we have

$$\begin{aligned} &\sigma_\epsilon^{-2}(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})^\intercal(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta}) + (\boldsymbol{\delta}-\boldsymbol{\mu})^\intercal\boldsymbol{\Sigma}^{-1}(\boldsymbol{\delta}-\boldsymbol{\mu}) \\ &= \boldsymbol{\delta}^\intercal\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)\boldsymbol{\delta} - 2\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)^\intercal\boldsymbol{\delta} + \text{const} \\ &= \left(\boldsymbol{\delta} - \left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right) \\ &\quad \times \left(\boldsymbol{\delta} - \left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right) + \text{const}, \end{aligned}$$

where "const" indicates that the term is independent of $\boldsymbol{\delta}$. Then, by dropping "const", we rearrange the conditional posterior distribution of (3.1) as

$$\begin{aligned} p(\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}}) \propto \exp\Bigg[-\frac{1}{2}&\left(\boldsymbol{\delta} - \left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right) \\ &\times \left(\boldsymbol{\delta} - \left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\Bigg]. \end{aligned} \tag{3.2}$$

(3.2) is rewritten as

$$\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}} \sim \mathcal{N}\left(\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right), \left(\sigma_\epsilon^{-2}\boldsymbol{Z}^\intercal\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\right), \tag{3.3}$$

which is the conditional posterior distribution $p(\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}})$ used in the Gibbs sampler.

Next, we derive the conditional posterior distributions of $\mu_\star$, $\star \in \{R, B\}$. By applying

Bayes' theorem to (3.9) and (3.11), we have

$$\begin{aligned}
p(\mu_\star|\mathcal{D},\boldsymbol{\theta}_{-\mu_\star}) &\propto p(\boldsymbol{\alpha}_\star|\mu_\star,\sigma_\star)p(\mu_\star|\varphi_\star\tau_\star)\\
&\propto \exp\left[-\frac{\sum_{i=1}^{N_\star}(\alpha_{\star i}-\mu_\star)^2}{2\sigma_\star^2}-\frac{(\mu_\star-\varphi_\star)^2}{2\tau_\star^2}\right]\\
&\propto \exp\left[-\frac{1}{2}\left\{\left(\sigma_\star^{-2}N_\star+\tau_\star^{-2}\right)\mu_\star^2-2\left(\sigma_\star^{-2}\sum_{i=1}^{N_\star}\alpha_{\star i}+\tau_\star^{-2}\varphi_\star\right)\mu_\star\right\}\right]\\
&\propto \exp\left[-\frac{1}{2}\left(\sigma_\star^{-2}N_\star+\tau_\star^{-2}\right)\left(\mu_\star-\frac{\sigma_\star^{-2}\sum_{i=1}^{N_\star}\alpha_{\star i}+\tau_\star^{-2}\varphi_\star}{\sigma_\star^{-2}N_\star+\tau_\star^{-2}}\right)^2\right]. \qquad (3.4)
\end{aligned}$$

Therefore the conditional posterior distribution $p(\mu_\star|\mathcal{D},\boldsymbol{\theta}_{-\mu_\star})$ is derived as

$$\mu_\star|\mathcal{D},\boldsymbol{\theta}_{-\mu_\star}\sim\mathcal{N}\left(\frac{\sigma_\star^{-2}\sum_{i=1}^{N_\star}\alpha_{\star i}+\tau_\star^{-2}\varphi_\star}{\sigma_\star^{-2}N_\star+\tau_\star^{-2}},\frac{1}{\sigma_\star^{-2}N_\star+\tau_\star^{-2}}\right). \qquad (3.5)$$

In order to derive the conditional posterior distributions of $\sigma_\star^2$, $\star\in\{R,B\}$ and σ_ϵ^2, we utilize the property that a half Cauchy random variate $U\sim\mathcal{C}^+(0,s)$ is expressed in a mixture form:

$$U^2|V\sim\mathcal{IG}\left(\frac{1}{2},\frac{1}{V}\right),\quad V\sim\mathcal{IG}\left(\frac{1}{2},\frac{1}{s^2}\right), \qquad (3.6)$$

where $\mathcal{IG}(a,b)$ stands for the inverse gamma distribution:

$$p(x|a,b)=\frac{b^a}{\Gamma(a)}x^{-(a+1)}e^{-\frac{b}{x}}. \qquad (3.7)$$

See Wand, Ormerod, Padoan, and Frühwirth (2011) and Makalic and Schmidt (2016) for more details. By introducing a latent variable $\xi_\star$, the half Cauchy distribution in (3.11) is rearranged as

$$\sigma_\star^2|\xi_\star\sim\mathcal{IG}\left(\frac{1}{2},\frac{1}{\xi_\star}\right),\quad \xi_\star\sim\mathcal{IG}\left(\frac{1}{2},\frac{1}{s_\star^2}\right). \qquad (3.8)$$

Given $\xi_\star$, we can derive the conditional posterior distribution of $\sigma_\star^2$ from (3.9) and (3.8) as

$$\begin{aligned}
p(\sigma_\star^2|\mathcal{D},\boldsymbol{\theta}_{-\sigma_\star^2},\xi_\star) &\propto p(\boldsymbol{\alpha}_\star|\mu_\star,\sigma_\star^2)p(\sigma_\star^2|\xi_\star)\\
&\propto (\sigma_\star^2)^{-\frac{N_\star}{2}}\exp\left[-\frac{\sum_{i=1}^{N_\star}(\alpha_{\star i}-\mu_\star)^2}{2\sigma_\star^2}\right]\times(\sigma_\star^2)^{-\left(\frac{1}{2}+1\right)}\exp\left(-\frac{1}{\xi_\star\sigma_\star^2}\right)\\
&\propto (\sigma_\star^2)^{-\left(\frac{N_\star+1}{2}+1\right)}\exp\left[-\frac{\frac{1}{2}\sum_{i=1}^{N_\star}(\alpha_{\star i}-\mu_\star)^2+\xi_\star^{-1}}{\sigma_\star^2}\right], \qquad (3.9)
\end{aligned}$$

that is,

$$\sigma_\star^2|\mathcal{D},\boldsymbol{\theta}_{-\sigma_\star},\xi_\star \sim \mathcal{IG}\left(\frac{N_\star+1}{2},\frac{\sum_{i=1}^{N_\star}(\alpha_{\star i}-\mu_\star)^2}{2}+\frac{1}{\xi_\star}\right). \tag{3.10}$$

Given $\sigma_\star^2$, on the other hand, the conditional posterior distribution of $\xi_\star$ is derived as

$$\begin{aligned} p(\xi_\star|\sigma_\star^2) &\propto p(\sigma_\star^2|\xi_\star)p(\xi_\star|s_\star^2) \\ &\propto \xi_\star^{-\frac{1}{2}}(\sigma_\star^2)^{-\left(\frac{1}{2}+1\right)}\exp\left(-\frac{1}{\xi_\star\sigma_\star^2}\right)\times \xi_\star^{-\left(\frac{1}{2}+1\right)}\exp\left(-\frac{1}{\xi_\star s_\star^2}\right) \\ &\propto \xi_\star^{-(1+1)}\exp\left(-\frac{\sigma_\star^{-2}+s_\star^{-2}}{\xi_\star}\right), \end{aligned} \tag{3.11}$$

which is the inverse gamma distribution:

$$\xi_\star|\sigma_\star^2 \sim \mathcal{IG}\left(1,\frac{1}{\sigma_\star^2}+\frac{1}{s_\star^2}\right). \tag{3.12}$$

Finally, we derive the conditional posterior distribution of σ_ϵ^2 and ξ_ϵ. With the mixture form of a half Cauchy distribution (3.6), we can rearrange (3.7) as

$$\sigma_\epsilon^2|\xi_\epsilon \sim \mathcal{IG}\left(\frac{1}{2},\frac{1}{\xi_\epsilon}\right), \quad \xi_\epsilon \sim \mathcal{IG}\left(\frac{1}{2},\frac{1}{s_\epsilon^2}\right), \tag{3.13}$$

where ξ_ϵ is a latent variable. In the same manner as (3.10), we can derive the conditional posterior distribution of σ_ϵ^2 from (3.5) and (3.13) as

$$\begin{aligned} p(\sigma_\epsilon^2|\mathcal{D},\boldsymbol{\theta}_{-\sigma_\epsilon^2}) &\propto p(\boldsymbol{y}|\boldsymbol{Z},\boldsymbol{\delta},\sigma_\epsilon^2)p(\sigma_\epsilon^2|\xi_\epsilon) \\ &\propto (\sigma_\epsilon^2)^{-\frac{N}{2}}\exp\left(-\frac{\sum_{i=1}^N e_i^2}{2\sigma_\epsilon^2}\right)\times(\sigma_\epsilon^2)^{-\left(\frac{1}{2}+1\right)}\exp\left(-\frac{1}{\xi_\epsilon\sigma_\epsilon^2}\right) \\ &\propto (\sigma_\epsilon^2)^{-\left(\frac{N+1}{2}+1\right)}\exp\left(-\frac{\frac{1}{2}\sum_{i=1}^N e_i^2+\xi_\epsilon^{-1}}{\sigma_\epsilon^2}\right), \end{aligned} \tag{3.14}$$

which is the inverse gamma distribution:

$$\sigma_\epsilon^2|\mathcal{D},\boldsymbol{\theta}_{-\sigma_\epsilon},\xi_\epsilon \sim \mathcal{IG}\left(\frac{N+1}{2},\frac{\sum_{i=1}^N e_i^2}{2}+\frac{1}{\xi_\epsilon}\right). \tag{3.15}$$

By replacing $\sigma_\star^2$, $\xi_\star$ and $s_\star^2$ with respectively σ_ϵ^2, ξ_ϵ and s_ϵ^2 in the derivation of (3.12), we obtain the conditional posterior distribution of ξ_ϵ as

$$\xi_\epsilon|\sigma_\epsilon^2 \sim \mathcal{IG}\left(1,\frac{1}{\sigma_\epsilon^2}+\frac{1}{s_\epsilon^2}\right). \tag{3.16}$$

Since all conditional posterior distributions (3.3), (3.5), (3.10), (3.11), (3.15) and (3.16) are standard ones, it is straightforward to set up the MCMC algorithm for generating $\boldsymbol{\theta}$ from the posterior distribution (3.13). Thus, a Gibbs sampler algorithm method can be adopted to generate pseudo-random numbers of $\boldsymbol{\theta}$ from the posterior distribution (3.13) for applying the Monte Carlo integration to evaluate the posterior statistics, including the posterior mean, the posterior standard deviation, and the interval estimation. In the Gibbs sampler, ($\boldsymbol{\delta}, \mu_R, \sigma_R, \mu_B, \sigma_B$, and σ_ϵ) are generated one by one in Steps 1 – 6.

Gibbs sampler for the hierarchical Bayesian regression model

Step 1. Draw $\boldsymbol{\delta}$ from the conditional posterior distribution $p(\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}})$.

Step 2. Draw μ_R from the conditional posterior distribution $p(\mu_R|\mathcal{D}, \boldsymbol{\theta}_{-\mu_R})$.

Step 3. Draw σ_R from the conditional posterior distribution $p(\sigma_R|\mathcal{D}, \boldsymbol{\theta}_{-\sigma_R})$.

Step 4. Draw μ_B from the conditional posterior distribution $p(\mu_B|\mathcal{D}, \boldsymbol{\theta}_{-\mu_B})$.

Step 5. Draw σ_B from the conditional posterior distribution $p(\sigma_B|\mathcal{D}, \boldsymbol{\theta}_{-\sigma_B})$.

Step 6. Draw σ_ϵ from the conditional posterior distribution $p(\sigma_\epsilon|\mathcal{D}, \boldsymbol{\theta}_{-\sigma_\epsilon})$.

Note that $\boldsymbol{\theta}_{-x}$ indicates that a parameter x is excluded from $\boldsymbol{\theta}$. Each step generates a new value of the parameter from the conditional posterior distribution, replacing the current value with the new one before moving on to the next step. The loop of Steps 1-6 is started from an arbitrary initial point of $\boldsymbol{\theta}$ and repeated until the generated sample paths of the parameters are stabilized. This initial sampling is known as "burn-in" in the literature. In our experience, the plain vanilla Gibbs sampler tends to generate highly correlated unstable sample paths, which may be caused by the fact that the hedonic pricing regression (3.3) includes many dummy variables. Therefore, to improve the efficiency of random number generation in the Gibbs sampler, ancillarity-sufficiency interweaving strategy (ASIS) proposed by Yu and Meng (2011) is applied so that the sample paths of the parameters generated will be stabilized faster. For this purpose, we treat $\{\alpha_{\star i}\}_{i=1}^{N_\star}$,

$\star \in \{R, B\}$, as latent variables and introduce the following transformation:

$$\begin{aligned} \tilde{\alpha}_{\star i} &= \alpha_{\star i} - \mu_\star, \quad i \in \{1, \dots, N\}, \\ \tilde{y}_i &= y_i - \sum_{j=1}^{N_R} d_{Rj}^{(i)} \tilde{\alpha}_{Rj} - \sum_{j=1}^{N_B} d_{Bj}^{(i)} \tilde{\alpha}_{Bj}. \end{aligned} \tag{3.17}$$

Then we can rewrite the regression model (3.1) as

$$\tilde{y}_i = \mu_R + \mu_B \sum_{j=1}^{N_B} d_{Bj}^{(i)} + \sum_{k=1}^{K} x_{ik}\beta_k + \epsilon_{it}, \quad \epsilon_{it} \sim \mathcal{N}(0, \sigma_\epsilon^2), \tag{3.18}$$

because $\sum_{j=1}^{N_R} d_{Rj}^{(i)} = 1$ holds for any $i \in \{1, \dots, N\}$. Note that $\sum_{j=1}^{N_B} d_{Bj}^{(i)} = 0$ if product i is the base brand; otherwise $\sum_{j=1}^{N_B} d_{Bj}^{(i)} = 1$. The basic idea behind ASIS is that the efficiency of the Gibbs sampler depends on which specification (3.1) or (3.18) we use but it is not clear which one is better in practice. Yu and Meng (2011) proposed to combine two equivalent Gibbs samplers to improve the efficiency of the sampling algorithm.

In order to construct the ASIS algorithm, let us derive the conditional posterior distributions of the parameters in (3.18). By defining

$$\tilde{\boldsymbol{y}} = \begin{bmatrix} \tilde{y}_1 \\ \vdots \\ \tilde{y}_N \end{bmatrix}, \quad \tilde{\boldsymbol{D}} = \begin{bmatrix} 1 & \sum_{j=1}^{N_B} d_{Bj}^{(1)} \\ \vdots & \vdots \\ 1 & \sum_{j=1}^{N_B} d_{Bj}^{(N)} \end{bmatrix}, \quad \tilde{\boldsymbol{Z}} = \begin{bmatrix} \tilde{\boldsymbol{D}} & \boldsymbol{X} \end{bmatrix}, \quad \tilde{\boldsymbol{\delta}} = \begin{bmatrix} \mu_R \\ \mu_B \\ \boldsymbol{\beta} \end{bmatrix},$$

we have

$$\tilde{\boldsymbol{y}} = \tilde{\boldsymbol{Z}}\tilde{\boldsymbol{\delta}} + \boldsymbol{\epsilon}, \quad \boldsymbol{\epsilon} \sim \mathcal{N}(\boldsymbol{0}_N, \sigma_\epsilon^2 \boldsymbol{I}_N). \tag{3.19}$$

From (3.9) and (3.11), we obtain the prior distribution of $\tilde{\boldsymbol{\delta}}$ as

$$\tilde{\boldsymbol{\delta}} \sim \mathcal{N}\left(\tilde{\boldsymbol{\mu}}, \tilde{\boldsymbol{\Sigma}}\right), \quad \tilde{\boldsymbol{\mu}} = \begin{bmatrix} \varphi_R \\ \varphi_B \\ \boldsymbol{\mu}_\beta \end{bmatrix}, \quad \tilde{\boldsymbol{\Sigma}} = \begin{bmatrix} \tau_R^2 & & \\ & \tau_B^2 & \\ & & \boldsymbol{\Sigma}_\beta \end{bmatrix}. \tag{3.20}$$

In the same manner as (3.1), we can derive the conditional posterior distribution of $\tilde{\boldsymbol{\delta}}$ from likelihood (3.4) and the prior distribution (3.20) as

$$\begin{aligned} p(\tilde{\boldsymbol{\delta}}|\mathcal{D}, \boldsymbol{\theta}_{-\tilde{\boldsymbol{\delta}}}) &\propto p(\tilde{\boldsymbol{y}}|\tilde{\boldsymbol{Z}}, \tilde{\boldsymbol{\delta}}, \sigma_\epsilon) p(\tilde{\boldsymbol{\delta}}|\tilde{\boldsymbol{\mu}}, \tilde{\boldsymbol{\Sigma}}) \\ &\propto \exp\left[-\frac{1}{2}\left\{\sigma_\epsilon^{-2}(\tilde{\boldsymbol{y}} - \tilde{\boldsymbol{Z}}\tilde{\boldsymbol{\delta}})^\intercal(\tilde{\boldsymbol{y}} - \tilde{\boldsymbol{Z}}\boldsymbol{\delta}) + (\tilde{\boldsymbol{\delta}} - \tilde{\boldsymbol{\mu}})^\intercal \tilde{\boldsymbol{\Sigma}}^{-1}(\tilde{\boldsymbol{\delta}} - \tilde{\boldsymbol{\mu}})\right\}\right]. \end{aligned} \tag{3.21}$$

By completing the square, (3.21) is rewritten as

$$p(\tilde{\boldsymbol{\delta}}|\mathcal{D},\boldsymbol{\theta}_{-\tilde{\boldsymbol{\delta}}}) \propto \exp\left[-\frac{1}{2}\left(\tilde{\boldsymbol{\delta}} - \left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{y}} + \tilde{\boldsymbol{\Sigma}}^{-1}\tilde{\boldsymbol{\mu}}\right)\right)\left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1}\right) \times \left(\tilde{\boldsymbol{\delta}} - \left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{y}} + \tilde{\boldsymbol{\Sigma}}^{-1}\tilde{\boldsymbol{\mu}}\right)\right)\right]. \tag{3.22}$$

From (3.22), we derive the conditional posterior distribution of $\tilde{\boldsymbol{\delta}}$ as

$$\tilde{\boldsymbol{\delta}}|\mathcal{D},\boldsymbol{\theta}_{-\boldsymbol{\delta}} \sim \mathcal{N}\left(\left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{y}} + \tilde{\boldsymbol{\Sigma}}^{-1}\tilde{\boldsymbol{\mu}}\right), \left(\sigma_\epsilon^{-2}\tilde{\boldsymbol{Z}}^\intercal\tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1}\right)^{-1}\right). \tag{3.23}$$

Note that, except for $\tilde{\boldsymbol{\delta}}$, the conditional posterior distributions for the rest of the parameters are the same as in (3.1). Thus the ASIS algorithm is given as follows.

ASIS for the hierarchical Bayes regression model

Suppose $\boldsymbol{\theta}^{(r)}$ is the r-th draw of $\boldsymbol{\theta}$ in the ASIS algorithm.

Step 1 Given $\boldsymbol{\theta}^{(r)}$, draw $(\mu_R^{(r+0.5)}, \sigma_R^{(r+0.5)}, \mu_B^{(r+0.5)}, \sigma_B^{(r+0.5)}, \boldsymbol{\beta}^{(r+0.5)}, \sigma_\epsilon^{(r+0.5)})$ via the Gibbs sampler with the conditional posterior distributions (3.3), (3.5), (3.10), (3.11), (3.15) and (3.16), and compute

$$\tilde{\alpha}_{\star i}^{(r+0.5)} = \alpha_{\star i}^{(r+0.5)} - \mu_\star^{(r+0.5)}, \quad i \in \{1,\dots,N\}, \quad \star \in \{R, B\},$$

and obtain $\boldsymbol{\theta}^{(r+0.5)}$.

Step 2 Given $\boldsymbol{\theta}^{(r+0.5)}$, draw $(\mu_R^{(r+1)}, \sigma_R^{(r+1)}, \mu_B^{(r+1)}, \sigma_B^{(r+1)}, \boldsymbol{\beta}^{(r+1)}, \sigma_\epsilon^{(r+1)})$ via the Gibbs sampler with the conditional posterior distributions (3.10), (3.11), (3.15), (3.16) and (3.23), and compute

$$\alpha_{\star i}^{(r+1)} = \tilde{\alpha}_{\star i}^{(r+0.5)} + \mu_\star^{(r+1)}, \quad i \in \{1,\dots,N\}, \quad \star \in \{R, B\},$$

and obtain $\boldsymbol{\theta}^{(r+1)}$.

Step 1 is the Gibbs sampler based on (3.1) while **Step 2** is the alternative sampler based on (3.18). The above ASIS algorithm uses two equivalent samplers in tandem so that the efficiency of random number generation will be improved. Finally, in this research, we set the hyper-parameters in the prior distributions (3.7), (3.9) – (3.11) as

$$\boldsymbol{\mu}_\beta = \mathbf{0}_K, \quad \boldsymbol{\Sigma}_\beta = 100\boldsymbol{I}_K, \quad s_\epsilon = 1,$$
$$\varphi_\star = 0, \quad \tau_\star^2 = 100, \quad s_\star = 1, \quad \star \in \{R, B\}.$$

The number of the initial burn-in iterations for the Gibbs sampler was 5,000, and then we generated 50,000 sets of parameters from the posterior distribution (3.13).

Chapter 4

Empirical Research on Japanese *Sake* Export

4.1 Introduction

Japanese rice wine (*sake*) consumption in Japan reached its peak in the late 20th century, and *sake* has become a part of daily life for almost all Japanese people. Since then, however, the business environment for the *sake* brewing industry has been drastically deteriorated. An overview of the *sake* brewing industry published by the Japanese National Tax Administration Agency depicts a gloomy picture of this industry. According to the overview, the amount of *sake* consumption peaked (1.77 million kl) in 1973 and then has been decreasing for more than 40 years. Currently, it is only 23% (0.41 million kl) of what it was at its heyday. The share of *sake* among the total consumption of alcoholic beverages has also continued to decline from 28% at its high in 1973 to 7% at present.

We think there are two main factors that trapped the *sake* brewing industry in such a difficult situation: (a) aging and shrinking population in Japan and (b) availability of competing alcoholic beverages. Although the first factor affects virtually all industries in Japan, the *sake* brewing industry is more severely hit by the aging population because the older people tend to drink less alcoholic beverages than the younger in general. The second factor is mostly related to twin deregulation: (a) lifting tariffs and quotas on imported alcoholic beverages and (b) relaxing restrictions upon retailers of alcoholic beverages. The former greatly increased the import of wine and whiskey while the latter made beer a tough domestic competitor against *sake*. Since typical beer cans (350 or 500 ml) are less bulky and much lighter than traditional 1.8-liter bottles of *sake*, retail stores, which are allowed to sell alcoholic beverages thanks to the deregulation, prefer to beer over *sake*.

We think two major shifts are necessary for the *sake* brewing industry to overcome a no-win situation, namely fierce competition with other alcoholic beverages in the shrinking domestic market. The first change is to shift to high-end products. As mentioned in the previous chapter, the *sake* breweries are now gradually shifting their production from low-end *sake* (e.g., *junmai*) to high-end ones (e.g., *ginjo* and *daiginjo*). We believe the *sake* breweries must accelerate this shift further. The second change is to shift to the oversea market. The Japanese population will keep aging and shrinking in a foreseeable future. Given this inevitable demographic trend, the *sake* breweries must look for the oversea market where the population is still younger and growing.

The second shift may be facilitated by the first one. The people outside Japan has become aware of Japanese traditional cuisine, *washoku*, especially since it was included in UNESCO's Intangible Cultural Heritage List in 2013. Given the growing awareness for Japanese cuisine, the oversea market is ripe to import more *sake* since it is an inseparable ingredient of Japanese cuisine. Moreover, since Japanese cuisine tends to be more expensive in the oversea market than the domestic market, *sake* breweries could sell high-end *sake* more to oversea Japanese restaurants that serve the wealth class who can afford expensive dinners than their domestic counterparts. In our opinion, more *sake* breweries should devote their management resources to brew high-end *sake* and open up the overseas market to overcome the current hardship they are faced with.

Fortunately, as shown in Figure 4.1, the export of *sake* has been drastically increasing during the last three decades. It is worth noting that the growth in the volume of export was faster than the value of export. As if to confirm the fact, the growth rate of the unit export price has been much more rapid than the growth rate of the export volume. This indicates that *sake* is becoming more and more expensive every year in the overseas market. According to the Japanese National Tax Administration Agency, the average export unit price was 1,323 JPY, which is almost double the average domestic price of

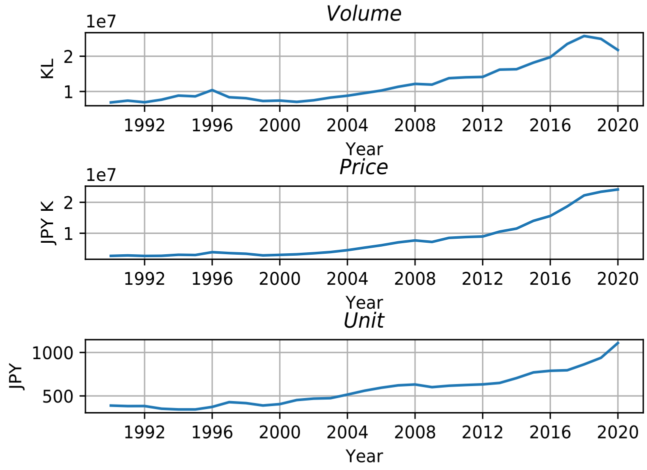

Figure 4.1: Japanese *Sake* Export

736 JPY.

One possible factor that may contribute this development is the aforementioned inclusion of Japanese cuisine on UNESCO's Intangible Cultural Heritage List in 2013. Shinato and Kato (2020) argues that the Japanese government began promoting *sake* after the UNESCO registration. Kishi (2018) notes that after the UNESCO registration, the number of restaurants serving Japanese food internationally doubled compared to before the registration. According to the Japan External Trade Organization (JETRO), there used to be only a few restaurants in China that served Japanese cuisine, but since the UNESCO registration, combined with the economic boom due to the Beijing Olympics in 2008, the number of Japanese restaurants has increased to 900 in Shanghai and 500 in Beijing. Moreover, according to JETRO, the consumption of cheap *sake*, which used to be mainly from major affiliated companies, has been on the rise in Taiwan since 2015 as more department stores and specialty shops retail high-end *sake*. The UNESCO registration might also make a significant impact in the U.S. market. Japanese cuisine rapidly spread in North America in the 2010s[1].

Another factor for the growth in export is a widening price gap between the domestic market and the oversea market. Japan suffered from stagnation and deflation for the

[1] We will explain this development in the next chapter

last three decade. Other countries, on the other hand, other countries have experienced inflation in the same period. In addition, depreciation of the Japanese yen since the beginning of the Quantitative and Qualitative Easing (QQE) policy by the Bank of Japan in 2013 also contributed this trend. As a result, the price gap in alcoholic beverages between Japan and other countries has been widening and it help the sale of *sake* in the oversea market.

In any case, the future is not a simple continuation of the past. Therefore it is essential to understand what kinds of factor determine the trend of *sake* export as we observed in Figure 4.1 so that the Japanese *sake* breweries could sustain the current upward trend of *sake* export in the future. To the best of our knowledge, however, there are no previous studies on *sake* export. In this chapter, we conduct a panel data regression analysis of *sake* export to Japan's major trade partners and investigate the influences of socio-economic variables upon *sake* export.

Although we could not find any previous studies on *sake* export, there are several studies on export of other alcohol beverages in the literature. For example, Bouët et al. (2017) showed that income elasticity of demand had a significant impact on Cognac export. Bargain (2020) found that income and price effects of French wine export to China were different by wine-growing regions in France. Cardebat and Figuet (2019) argued that appreciation of the euro increased the share of premium wines in French wine export.

Following the previous studies on alcoholic beverages, we adopt a log-log model specification for the key variables in the panel data regression model. Since the number of countries in the panel data is rather small (we have only five countries as described in the next chapter), we apply hierarchical Bayesian modeling to the panel data regression model and estimate it with an efficient Markov chain Monte Carlo (MCMC) method called an ancillarity-sufficiency interweaving strategy (ASIS) to improve the sampling efficiency of MCMC. In the next section, we will describe the data used in the analysis and elaborate the estimation procedure in detail.

The organization of this chapter is as follows. Section 2 presents the datasets we used for our empirical research and explains the estimation procedure. Section 3 shows the estimation results of panel data regression models for volumes and unit values of *sake* export and discuss their implications on the influences of socio-economic variables upon *sake* export. Section 4 explores possible heterogeneity in the export structure between *Nada*, the major *sake* brewing region in Japan, and the rest of the country. Finally, Section 5 summarizes the findings of our research and concludes the chapter.

4.2 Datasets and Estimation Procedure

For our empirical analysis of *sake* export, based on data availability, we set the sample period from 1995 to 2021 and choose five major importing countries: China, Hong Kong, Singapore, Taiwan and the United States. These five countries have been continuously importing *sake* from Japan during the sample period and the export to them accounts for around 60% of the total volume of *sake* export during the sample period.

In our analysis, we consider a panel data regression model for the five countries. The dependent variable is ether export volume or export unit value (export value divided by export volume) of each country. Common independent variables for all countries are (a) export unit value (*Unit*), (b) consumer price index (*CPI*), (c) nominal exchange rate (*NER*), and (d) monthly seasonal dummy variables excluding January. The first three variables are based on Bargain (2020) and Bouët et al. (2017). We will see how they influence each country's *sake* export. To control mutual influences among different currencies, we use Nikkei Currency Indices in place of nominal exchange rates. Since we use log-log specification for panel data regression models, the dependent variable, *Unit*, *CPI* and *NER* are in the natural logarithm. For a regression model of the export unit value, *Unit* will be dropped since it is used as the dependent variable. Table 4.1 shows the descriptive statistics of these variables. Note that the panel data is unbalanced.

As explained in Chapter 2, *sake* brewing is inherently seasonal. It is very sensitive to the temperature which exhibits seasonal fluctuations. Like the temperature, the rice harvest is also seasonal. To capture possible seasonal fluctuations in *sake* export, we add monthly seasonal dummy variables to the panel data regression model, though we exclude the dummy variable for January to avoid multicollinearity.

In addition to the common independent variables, we introduce country-specific constant terms and time trends to the panel data regression model. To capture heterogeneity

Table 4.1: Descriptive Statistics

Variables	mean	std	max	min	N
Unit (All)	0.829	0.189	1.193	0.359	1,601
Unit (China)	0.604	0.299	1.768	0.176	313
Unit (Hongkong)	0.977	0.664	3.405	0.301	323
Unit (Singapore)	0.908	0.400	2.797	0.401	323
Unit (Taiwan)	0.383	0.158	1.108	0.184	319
Unit (US)	0.829	0.189	1.193	0.359	323
CPI (All)	113.074	51.856	278.802	64.300	1,601
CPI (China)	102.587	3.210	120.700	97.900	313
CPI (Hongkong)	78.963	11.943	102.200	64.300	323
CPI (Singapore)	85.778	11.342	104.439	70.681	323
CPI (Taiwan)	88.477	7.082	101.240	75.040	319
CPI (US)	208.935	34.532	278.802	150.900	323
Exchange (All)	96.722	12.821	124.809	59.576	1,601
Exchange (China)	82.533	10.807	101.504	59.576	313
Exchange (Hongkong)	107.669	9.177	123.485	92.900	323
Exchange (Singapore)	90.937	8.558	104.249	79.548	323
Exchange (Taiwan)	105.201	7.383	124.809	93.225	319
Exchange (US)	96.935	8.464	115.333	81.484	323
Quantity (All)	152,700	156,920	10,579,000	146	1,601
Quantity (China)	112,970	168,590	807,200	146	313
Quantity (Hongkong)	114,760	58,597	363,650	26,647	323
Quantity (Singapore)	31,689	17,509	114,700	6,060	323
Quantity (Taiwan)	200,320	141,830	1,025,700	1,620	319
Quantity (US)	303,110	164,920	1,057,900	53,207	323
Price (All)	126,790	174,040	1,240,500	213	1601
Price (China)	107,760	211,260	1,240,500	213	313
Price (Hongkong)	143,400	179,000	1,141,400	10,207	323
Price (Singapore)	33,497	34,896	228,930	3,208	323
Price (Taiwan)	73,073	50,845	325,420	1,425	319
Price (US)	274,980	192,890	1,225,700	26,308	323

Table 4.2: Model Specifications

	Model I	Model II
Constant Term	Country-specific	Country-specific
Time Trend	Country-specific	Country-specific
$UNESCO_{dummy}$	$\times$	Country-specific
$UNESCO_{trend}$	$\times$	Country-specific
Unit	Common	Common
CPI	Common	Common
NER	Common	Common
Seasonal Dummy	Common	Common

among countries, the constant term and the slope of the time trend are allowed to be different among the countries. In the literature, several studies found supportive evidence for such heterogeneity. For example, Fogarty (2008) and Nelson (2013) found that EU countries had different trends on elasticity values of alcohol beverages. Lombardi et al. (2016) also showed that the trends of bottled wine shipments within EU varied by countries. Bargain (2020) applied a time trend to export models of alcoholic beverages. Mitchell (2016) found that time-dependent taste changes played a significant role in determining wine and beer demand in EU. Connolly et al. (2023) showed that short-time trends had some significant impact on beer sales in Connecticut, the U.S., after the beer sales was admitted even on Sunday. Hart and Altson (2020) found that historical trends of alcohol consumption in the U.S. differed from geographical factors, like regions or states.

Furthermore, to analyze the effect of the UNESCO registration of Japanese cuisine, we add the UNESCO dummy variable and the UNESCO time trend to the model. The UNESCO dummy variable takes 1 after the registration and takes 0 before while the UNESCO time trend starts from 2013-03 and ends in 2021-12. We also allow the coefficient of these variables to be different among countries to capture the heterogeneity in *sake* export.

Table 4.2 summarizes two model specifications we consider for the panel data regression model. Model I is the base model to examine the impacts of the key variables on *sake* export. Model II is for checking the influence of the UNESCO registration of Japanese cuisine. These models are expressed as the following panel data regression model

$$\begin{aligned} &y_{it} = \boldsymbol{w}_t' \boldsymbol{\gamma}_i + \boldsymbol{x}_{it}' \boldsymbol{\beta} + \epsilon_{it}, \quad \epsilon_{it} \overset{\text{i.i.d.}}{\sim} \mathcal{N}(0, \sigma_\epsilon^2), \\ &i \in \{1, \dots, N\}, \quad t \in \{1, \dots, T_i\}, \end{aligned} \tag{4.1}$$

where

- y_{it} — export volume or unit value of *sake* to the i^{th} country in the t^{th} period;
- $\boldsymbol{w}_t$ — a vector of the constant term and the time trend in the t^{th} period;
- $\boldsymbol{x}_{it}$ — a vector of the common independent variables of the i^{th} country in the t^{th} period.

In Equation (4.1), Japanese *sake* breweries export their *sake* to N countries and we have T_i periods of data on *sake* export to the i^{th} country. In out study, $N = 5$ (China, Hong Kong, Singapore, Taiwan and the United States) and T_i of each country is shown in Table 4.1. $\boldsymbol{\gamma}_i$ in Equation (4.1) includes the intercept (constant term) and slope of the country-specific time trend of the i^{th} country to capture the heterogeneity among countries. In case of Model II, it also include the intercept and slope corresponding a possible regime shift before and after the UNESCO registration of Japanese cuisine in 2013. $\boldsymbol{\beta}$ in Equation (4.1) includes the regression coefficients for the common independent variables including monthly seasonal dummy variables.

Then, defining vectors and matrices as

$$\boldsymbol{y}_i = \begin{bmatrix} y_{i1} \\ \vdots \\ y_{iT_i} \end{bmatrix}, \quad \boldsymbol{W}_i = \begin{bmatrix} \boldsymbol{w}_1 \\ \vdots \\ \boldsymbol{w}_{T_i} \end{bmatrix}, \quad \boldsymbol{X}_i = \begin{bmatrix} \boldsymbol{x}_{i1} \\ \vdots \\ \boldsymbol{x}_{iT_i} \end{bmatrix}, \quad \boldsymbol{\epsilon}_i = \begin{bmatrix} \epsilon_{i1} \\ \vdots \\ \epsilon_{iT_i} \end{bmatrix},$$

the regression model of Equation (4.1) corresponding to the *sake* export to the i^{th} country can be summarized as

$$\boldsymbol{y}_i = \boldsymbol{W}_i \boldsymbol{\gamma}_i + \boldsymbol{X}_i \boldsymbol{\beta} + \boldsymbol{\epsilon}_i, \quad \boldsymbol{\epsilon}_i \sim \mathcal{N}(\boldsymbol{0}_{T_i}, \sigma_\epsilon^2 \boldsymbol{I}_{T_i}), \tag{4.2}$$

where $\mathbf{1}_{T_i}$ is a $T_i \times 1$-vector whose elements are all ones, $\mathbf{0}_{T_i}$ is a $T_i \times 1$-vector whose elements are all zeros, and $\boldsymbol{I}_{T_i}$ is the T_i-dimensional identity matrix. Finally, stacking up vectors and matrices as

$$\boldsymbol{y} = \begin{bmatrix} \boldsymbol{y}_1 \\ \vdots \\ \boldsymbol{y}_N \end{bmatrix}, \quad \boldsymbol{W} = \begin{bmatrix} \boldsymbol{W}_1 & & \\ & \ddots & \\ & & \boldsymbol{W}_N \end{bmatrix}, \quad \boldsymbol{X} = \begin{bmatrix} \boldsymbol{X}_1 \\ \vdots \\ \boldsymbol{X}_N \end{bmatrix},$$

$$\boldsymbol{Z} = \begin{bmatrix} \boldsymbol{W} & \boldsymbol{X} \end{bmatrix}, \quad \boldsymbol{\epsilon} = \begin{bmatrix} \boldsymbol{\epsilon}_1 \\ \vdots \\ \boldsymbol{\epsilon}_N \end{bmatrix}, \quad \boldsymbol{\gamma} = \begin{bmatrix} \boldsymbol{\gamma}_1 \\ \vdots \\ \boldsymbol{\gamma}_N \end{bmatrix}, \quad \boldsymbol{\delta} = \begin{bmatrix} \boldsymbol{\gamma} \\ \boldsymbol{\beta} \end{bmatrix},$$

the regression model for all N countries is summarized as

$$\boldsymbol{y} = \boldsymbol{W\gamma} + \boldsymbol{X\beta} + \boldsymbol{\epsilon} = \boldsymbol{Z\delta} + \boldsymbol{\epsilon}, \quad \boldsymbol{\epsilon} \sim \mathcal{N}\left(\mathbf{0}_T, \sigma_\epsilon^2 \boldsymbol{I}_T\right), \quad T = \sum_{i=1}^{N} T_i. \tag{4.3}$$

Next, we set up the posterior distribution to conduct a hierarchical Bayesian analysis on the regression model in Equation (4.1). Since the conditional distribution of $\boldsymbol{y}$ under a given $\boldsymbol{Z}$ in Equation (4.3) is $\mathcal{N}(\boldsymbol{Z\delta}, \sigma_\epsilon^2 \boldsymbol{I})$, the likelihood of the unknown parameter $(\boldsymbol{\delta}, \sigma_\epsilon)$ is

$$p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon) \propto (\sigma_\epsilon^2)^{-\frac{T}{2}} \exp\left[-\frac{1}{2\sigma_\epsilon^2}(\boldsymbol{y} - \boldsymbol{Z\delta})'(\boldsymbol{y} - \boldsymbol{Z\delta})\right] \tag{4.4}$$

$$\propto (\sigma_\epsilon^2)^{-\frac{T}{2}} \exp\left[-\frac{\sum_{i=1}^{T_i} e_{it}^2}{2\sigma_\epsilon^2}\right], \quad e_{it} = y_{it} - \boldsymbol{w}_t'\boldsymbol{\gamma}_i - \boldsymbol{x}_{it}'\boldsymbol{\beta}. \tag{4.5}$$

We assume the following prior distribution for the parameter $(\boldsymbol{\delta}, \sigma_\epsilon)$.

$$\boldsymbol{\delta} \sim \mathcal{N}(\boldsymbol{\mu}, \boldsymbol{\Sigma}), \quad \boldsymbol{\mu} = \begin{bmatrix} \mathbf{1}_N \otimes \boldsymbol{\mu}_\gamma \\ \boldsymbol{\mu}_\beta \end{bmatrix}, \quad \boldsymbol{\Sigma} = \begin{bmatrix} \boldsymbol{I}_N \otimes \boldsymbol{\Sigma}_\gamma & \\ & \boldsymbol{\Sigma}_\beta \end{bmatrix}, \tag{4.6}$$

$$\sigma_\epsilon \sim \mathcal{C}^+(0, s_\epsilon), \tag{4.7}$$

where $\otimes$ is the Kronecker product, $\boldsymbol{\Sigma}_\gamma$ is supposed to be diagonal, and $C^+(\cdot)$ is a half-Cauchy distribution,

$$p(\sigma_\epsilon|s_\epsilon) = \frac{2s_\epsilon}{\pi(\sigma_\epsilon^2 + s_\epsilon^2)}, \quad \sigma_\epsilon > 0, \quad s_\epsilon > 0.$$

We assume the half-Cauchy distribution as Gelman (2006) recommended for hierarchical models.

Note that the prior distribution in Equation (4.6) is equivalent to assuming

$$\begin{aligned} &\gamma_{ij} \overset{\text{i.i.d.}}{\sim} \mathcal{N}(\mu_{\gamma j}, \sigma_{\gamma j}^2), \quad i \in \{1, \ldots, N\}, \quad j \in \{1, \ldots, K\}, \\ &\boldsymbol{\beta} \sim \mathcal{N}(\boldsymbol{\mu}_\beta, \boldsymbol{\Sigma}_\beta), \end{aligned} \tag{4.8}$$

where γ_{ij} and $\mu_{\gamma j}$ are the j^{th} element of $\boldsymbol{\gamma}_i$ and μ_γ respectively, $\sigma_{\gamma j}^2$ is the j^{th} diagonal element of $\boldsymbol{\Sigma}_\gamma$, and K is the number of elements in $\boldsymbol{\gamma}$. $K = 2$ in Model I and $K = 4$ in Model II.

In the prior distribution of the parameter $(\boldsymbol{\delta}, \sigma_\epsilon)$, $(\boldsymbol{\mu}_\beta, \boldsymbol{\Sigma}_\beta)$ in Equation (4.6) and s_ϵ in Equation (4.7) are fixed to a specific value as hyperparameters. In the prior distribution of $\{\mu_{\gamma j}, \sigma_{\gamma j}\}_{j=1}^K$ in Equation (4.8), however, we set the following hierarchical prior distribution

$$\mu_{\gamma j} \sim \mathcal{N}(\varphi_\gamma, \tau_\gamma^2), \quad \sigma_{\gamma j} \sim \mathcal{C}^+(0, s_\gamma), \quad j \in \{1, \ldots, K\}, \tag{4.9}$$

and attempt to estimate it simultaneously with $(\boldsymbol{\delta}, \sigma_\epsilon)$ using a Bayesian approach.

The name "hierarchical Bayesian analysis" is derived from the use of this hierarchical prior distribution. One advantage of hierarchical Bayesian analysis is that the values of $\{\mu_{\gamma j}, \sigma_{\gamma j}\}_{j=1}^K$ in the prior distribution (4.8) are not fixed as hyperparameters, but can be estimated simultaneously with other parameters to construct a more flexible prior distribution. Another advantage of this type of approach is that the shrinkage method can be used to stabilize the estimation of individual effects. $(\varphi_\gamma, \tau_\gamma^2, s_\gamma)$ in Equation (4.9) are fixed to specific values as hyperparameters. In this study, we set the values of the hyperparameters $(\boldsymbol{\mu}_\beta, \boldsymbol{\Sigma}_\beta, \varphi_\gamma, \tau_\gamma^2, s_\gamma, s_\epsilon)$ as

$$\boldsymbol{\mu}_\beta = \mathbf{0}_{14}, \quad \boldsymbol{\Sigma}_\beta = 100\boldsymbol{I}_{14}, \quad \varphi_\gamma = 0, \quad \tau_\gamma^2 = 100, \quad s_\gamma = s_\epsilon = 1. \tag{4.10}$$

Note that the dimension of $\boldsymbol{\beta}$ is 14, which is equal to the number of the common independent variable (3) plus the number of monthly seasonal dummy variables (11).

In summary, we can conclude that the parameters to be estimated in the hierarchical Bayesian analysis of the regression model (4.1) for *sake* export are

$$\begin{aligned} \boldsymbol{\theta} &= \left(\boldsymbol{\delta}, \boldsymbol{\mu}_\gamma, \sqrt{\operatorname{diag}(\boldsymbol{\Sigma}_\gamma)}, \sigma_\epsilon\right) \\ &= (\boldsymbol{\gamma}_1, \ldots, \boldsymbol{\gamma}_N, \boldsymbol{\beta}, \mu_{\gamma 1}, \ldots, \mu_{\gamma K}, \sigma_{\gamma 1}, \ldots, \sigma_{\gamma K}, \sigma_\epsilon), \end{aligned}$$

and the posterior distribution of unknown parameters $\boldsymbol{\theta}$ is derived as

$$p(\boldsymbol{\theta}|\mathcal{D}) \propto p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon)p(\boldsymbol{\theta}), \quad \mathcal{D} = (\boldsymbol{y}, \boldsymbol{Z}), \tag{4.11}$$

where $p(\boldsymbol{y}|\boldsymbol{Z}, \boldsymbol{\delta}, \sigma_\epsilon)$ is the likelihood in Equation (4.4) and $p(\boldsymbol{\theta})$ is the product of the prior distributions in Equations (4.6), (4.7) and (4.9). Unfortunately, the posterior distribution 4.11 cannot be evaluated analytically. Therefore we will proceed with the hierarchical Bayesian analysis by using the Markov chain Monte Carlo (MCMC) method. The conditional posterior distribution of each parameter is derived as follows (see Appendix).

$$\boldsymbol{\delta}|\mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}} \sim \mathcal{N}\left(\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z} + \boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y} + \boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right), \left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z} + \boldsymbol{\Sigma}^{-1}\right)^{-1}\right), \tag{4.12}$$

$$\mu_{\gamma j}|\mathcal{D}, \boldsymbol{\theta}_{-\mu_{\gamma j}} \sim \mathcal{N}\left(\frac{\sigma_{\gamma i}^{-2}\sum_{i=1}^{N}\gamma_{ij} + \tau_\gamma^{-2}\varphi_\gamma}{\sigma_{\gamma j}^{-2}N + \tau_{\gamma j}^{-2}}, \frac{1}{\sigma_{\gamma j}^{-2}N + \tau_\gamma^{-2}}\right), \tag{4.13}$$

$$\sigma_{\gamma j}^2|\mathcal{D}, \boldsymbol{\theta}_{-\sigma_{\gamma j}}, \xi_{\gamma j} \sim \mathcal{IG}\left(\frac{N+1}{2}, \frac{\sum_{i=1}^{N}(\gamma_{ij} - \mu_{\gamma j})^2}{2} + \frac{1}{\xi_{\gamma j}}\right), \ \xi_{\gamma j}|\sigma_{\gamma j} \sim \mathcal{IG}\left(1, \frac{1}{\sigma_{\gamma j}^2} + \frac{1}{s_\gamma^2}\right), \tag{4.14}$$

$$\sigma_\epsilon^2|\mathcal{D}, \boldsymbol{\theta}_{-\sigma_\epsilon}, \xi_\epsilon \sim \mathcal{IG}\left(\frac{T+1}{2}, \frac{\sum_{i=1}^{N}\sum_{t=1}^{T_i}e_{it}^2}{2} + \frac{1}{\xi_\epsilon}\right), \ \xi_\epsilon|\sigma_\epsilon \sim \mathcal{IG}\left(1, \frac{1}{\sigma_\epsilon^2} + \frac{1}{s_\epsilon^2}\right), \tag{4.15}$$

where $\boldsymbol{\theta}_{-a}$ indicates that the parameter a is excluded from $\boldsymbol{\theta}$, and $\mathcal{IG}(a, b)$ is the inverse gamma distribution

$$p(x|a, b) = \frac{b^a}{\Gamma(a)}x^{-(a+1)}e^{-\frac{b}{x}}.$$

In the conditional posterior distribution of Equations (4.14)–(4.15), new latent variables $(\xi_{\gamma 1}, \ldots, \xi_{\gamma K}, \xi_\epsilon)$ are introduced. This is because $x \sim \mathcal{C}^+(0, a)$ is expressed as

$$x^2|z \sim \mathcal{IG}\left(\frac{1}{2}, \frac{1}{z}\right), \quad z \sim \mathcal{IG}\left(\frac{1}{2}, \frac{1}{a^2}\right), \tag{4.16}$$

and is used to derive Equations (4.14)–(4.15) (see Appendix for details).

The conditional posterior distributions in Equations (4.12)–(4.15) have all known efficient random number generation algorithms, such as the normal and inverse gamma distributions. Therefore Gibbs sampling can be used to generate parameters $\boldsymbol{\theta}$ from their posterior distribution. It turns out that a simple Gibbs sampling algorithm consisting of the conditional posterior distribution of Equations (4.12)–(4.15) is inefficient in drawing Monte Carlo samples from the posterior distribution when it was applied to the exported *sake* data used in this study. To overcome this inefficiency, we apply the ASIS proposed by Yu and Meng (2011) to $\{\boldsymbol{\gamma}_i\}_{i=1}^N$. To demonstrate the ASIS algorithm used in this study, we first assume that $(\boldsymbol{\gamma}_1, \ldots, \boldsymbol{\gamma}_N, \mu_{\gamma 1}, \ldots, \mu_{\gamma K})$ are generated by Gibbs sampling, and consider the following transformation.

$$\tilde{\boldsymbol{\gamma}}_i = \boldsymbol{\gamma}_i - \boldsymbol{\mu}_\gamma, \quad \tilde{y}_{it} = y_{it} - \boldsymbol{w}_t' \tilde{\boldsymbol{\gamma}}_i, \quad i \in \{1, \ldots, N\}, \quad t \in \{1, \ldots, T_i\}. \tag{4.17}$$

Then Equation (4.1) is rewritten as

$$\tilde{y}_{it} = \boldsymbol{w}_t' \boldsymbol{\mu}_\gamma + \boldsymbol{x}_{it}' \boldsymbol{\beta} + \epsilon_{it}, \quad \epsilon_{it} \overset{\text{i.i.d.}}{\sim} \mathcal{N}(0, \sigma_\epsilon^2). \tag{4.18}$$

Thus Equation (4.18) becomes

$$\tilde{\boldsymbol{y}} = \tilde{\boldsymbol{Z}} \tilde{\boldsymbol{\delta}} + \boldsymbol{\epsilon}, \ \boldsymbol{\epsilon} \sim \mathcal{N}(\boldsymbol{0}_T, \sigma_\epsilon^2 \boldsymbol{I}_N), \ \tilde{\boldsymbol{y}} = \begin{bmatrix} \tilde{y}_{11} \\ \vdots \\ \tilde{y}_{NT_N} \end{bmatrix}, \ \tilde{\boldsymbol{Z}} = \begin{bmatrix} \boldsymbol{w}_{11}' & \boldsymbol{x}_{11}' \\ \vdots & \vdots \\ \boldsymbol{w}_{NT_N}' & \boldsymbol{x}_{NT_N}' \end{bmatrix}, \ \tilde{\boldsymbol{\delta}} = \begin{bmatrix} \boldsymbol{\mu}_\gamma \\ \boldsymbol{\beta} \end{bmatrix}, \tag{4.19}$$

Then the conditional posterior distribution of $\tilde{\boldsymbol{\delta}}$ is obtained as

$$\tilde{\boldsymbol{\delta}} | \mathcal{D}, \boldsymbol{\theta}_{-\boldsymbol{\delta}} \sim \mathcal{N}\left(\left(\sigma_\epsilon^{-2} \tilde{\boldsymbol{Z}}' \tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1} \right)^{-1} \left(\sigma_\epsilon^{-2} \tilde{\boldsymbol{Z}}' \tilde{\boldsymbol{y}} + \tilde{\boldsymbol{\Sigma}}^{-1} \tilde{\boldsymbol{\mu}} \right), \left(\sigma_\epsilon^{-2} \tilde{\boldsymbol{Z}}' \tilde{\boldsymbol{Z}} + \tilde{\boldsymbol{\Sigma}}^{-1} \right)^{-1} \right), \tag{4.20}$$

$$\tilde{\boldsymbol{\mu}} = \begin{bmatrix} \varphi_\gamma \boldsymbol{1}_N \\ \boldsymbol{\mu}_\beta \end{bmatrix}, \quad \tilde{\boldsymbol{\Sigma}} = \begin{bmatrix} \tau_\gamma^2 \boldsymbol{I}_N & \\ & \boldsymbol{\Sigma}_\beta \end{bmatrix},$$

by exactly the same procedure with Equation (4.12): thus, the Gibbs sampling with the addition of ASIS can be summarized as follows[2].

Step 1 Given the sth generated $\boldsymbol{\theta}^{(s)}$, apply Gibbs sampling based on Equations (4.12)–(4.15) to generate $\boldsymbol{\theta}^{(s+0.5)}$ and compute

$$\tilde{\boldsymbol{\gamma}}_i^{(s+0.5)} = \boldsymbol{\gamma}_i^{(s+0.5)} - \boldsymbol{\mu}_\gamma^{(s+0.5)}.$$

Step 2 Given $\boldsymbol{\theta}^{(s+0.5)}$, apply Gibbs sampling based on Equations (4.20) and (4.14)–(4.15) to generate $(\boldsymbol{\beta}^{(s+1)}, \mu_{\gamma 1}^{(s+1)}, \ldots, \mu_{\gamma K}^{(s+1)}, \sigma_{\gamma 1}^{(s+1)}, \ldots, \sigma_{\gamma K}^{(s+1)}, \sigma_\epsilon^{(s+1)})$, and compute

$$\boldsymbol{\gamma}_i^{(s+1)} = \tilde{\boldsymbol{\gamma}}_i^{(s+0.5)} + \boldsymbol{\mu}_\gamma^{(s+1)}.$$

[2] In short, the prior distribution of $\tilde{\boldsymbol{\delta}}$ is $\mathcal{N}(\tilde{\boldsymbol{\mu}}, \tilde{\boldsymbol{\Sigma}})$.

In this study, we use this Gibbs sampling to generate a Monte Carlo sample $\{\boldsymbol{\theta}^{(s)}\}_{s=1}^{S}$ of $\boldsymbol{\theta}$ from the posterior distribution, and conduct the hierarchical Bayesian analysis of *sake* export.

4.3 Hypotheses and Estimation Results

We consider the following hypotheses with reference to the previous studies.

H1 The trend of *sake* export may exhibit heterogeneity among countries as demonstrated for other alcoholic beverages.

H2 *Unit*, *CPI* and *NER* may have a significant impact on *sake* export. According to the previous studies (e.g., Bargain(2020) and Bouët et al. (2017)), *Unit* may have a negative impact upon *sake* export.

H3 Seasonal effects may exist.

Although H1 and H2 seem legitimate in light of the previous studies, we may need to elaborate on H3. As we explained in Chapter 2, traditional *sake* brewing methods require sensitive temperature control. Without any modern temperature management equipment, it is impossible to brew *sake* for all seasons, especially during a hot summer. For this reason, most *sake* breweries start brewing in late fall. This timing is also related to the harvest time of rice, the key material for *sake*, which is harvested in fall, too. Moreover, unlike wine, *sake* is a fermented alcoholic beverage. So the longer it is brewed, the more its quality deteriorates, albeit gradually. This nature of *sake* puts pressure on breweries to sell off *sake* brewed during the winter by the next summer. Thus we expect seasonal fluctuations in *sake* export due to supply-side constraints of *sake* brewing.

Table 4.3 shows the estimation results of the panel data regression model in Equation (4.1). In Table 4.3, Intercept (I) and Intercept (II) represent the country-specific intercept (constant term) in the panel data regression model in Equation (4.1) respectively. Slope (I) and Slope (II) represent the country-specific slope of the time trend in Equation (4.1) respectively. Finally, Intercept (II, UNESCO) and Slope (II, UNESCO) represent the country-specific coefficient of the UNESCO registration dummy variable and that of the UNESCO registration time trend respectively.

Table 4.3: Country-Specific Trends (Export Volume)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	0.417	3.388**	2.335	4.473**	3.268
	(1.589)	(1.536)	(1.497)	(1.575)	(1.710)
Intercept (II)	-1.363	1.851	0.976	3.080	1.196
	(2.006)	(1.976)	(1.902)	(2.003)	(2.175)
Intercept (II, UNESCO)	0.194	-0.310**	0.045	0.415	-0.122
	(0.108)	(0.118)	(0.109)	(0.105)	(0.107)
Slope (I)	0.014**	0.004**	0.002**	-0.001**	0.003**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Slope (II)	0.013**	0.005**	0.001	-0.005**	0.004**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Slope (II, UNESCO)	0.014**	0.004**	0.009**	0.012**	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

In Table 4.3, the number without parentheses is the mean of the posterior distribution of each coefficient while the number within parentheses is the standard deviation of the corresponding posterior distribution. The double asterisk indicates that the 95% interval of the posterior distribution of the corresponding coefficient does not include zero. Following the convention, we conclude that the coefficient is "significant" if its 95% interval does not include zero. We follow the same rules for all tables in this chapter.

In Table 4.3, Intercept (I) is significant for Hong Kong and Taiwan while Intercept (II) are not significant for any countries. Intercept (II, UNESCO) is significantly negative for Hong Kong.

Because the export volume in the left-hand side of Equation (4.1) is in the natural logarithm, the slope of the trend can be interpreted as the growth rate of *sake* export to the corresponding country. In Table 4.3, Slope (I) is significant for all five countries; it is significantly positive except for Taiwan and it is highest for China. This result may reflect a steady growth of *sake* export to China during the sample period. Slope (II) shows a similar pattern, though it is not significant for Singapore.

Table 4.4: Impacts of Economic Variables (Export Volume)

	Unit	*CPI*	*NER*
Model I	-0.204**	1.201**	0.443**
	(0.061)	(0.282)	(0.188)
Model II	-0.630**	1.925**	0.024
	(0.062)	(0.344)	(0.230)

Note that Slope (II) is the growth rate of *sake* export before the UNESCO registration of Japanese cuisine in 2013 while the sum of Slope (II) and Slope (II, UNESCO) is the growth rate after the UNESCO registration. Thus Slope (II, UNESCO) indicates a change in the growth rate of *sake* export after the UNESCO registration. It is significantly positive for four countries except for the United States. This result indicates that the UNESCO registration might accelerate the growth of *sake* export to these four countries. It may not be a wonder that the UNESCO registration boosted *sake* export to countries like China and Hong Kong where *sake* export was already thriving. For Singapore and Taiwan, on the other hand, the impact looks dramatic. Before the UNESCO registration, the growth rate of *sake* export to Singapore is virtually zero and, even worse, it is shrinking for Taiwan. According to the estimation results in Table 4.3, the tide was definitely changed. The *sake* export to Singapore seemed to take off after the UNESCO registration. At the same time, the downward trend of the export to Taiwan was clearly reversed. However, non-significant Slope (II, UNESCO) for the United States may need some explanation. We conjecture that Japanese cuisine was already popular in the United States before the UNESCO registration so that it could not contribute so much to acceleration of the growth of *sake* export. Overall, the results in Table 4.3 shows significant heterogeneity in *sake* export among the countries, which is supportive for H1.

Next, we examine the impacts of economics variables upon *sake* export with the estimation results in Table 4.4. For both Model I and Model II, *Unit* and *CPI* are significant and their signs are consistent with the conventional wisdom in economics. AS for *NER*, it is insignificant in Motel II. So we can support H2 completely in Model I, but partially in Model II. It may be argued that the trend shift due to the UNESCO registration con-

Table 4.5: Monthly Seasonal Effects (Export Volume)

	Feb	Mar	Apr	May	Jun	July
Model I	0.162**	0.242**	0.173**	0.054	0.025	-0.010
	(0.058)	(0.058)	(0.056)	(0.058)	(0.059)	(0.058)
Model II	0.152**	0.237**	0.170**	0.063	0.052	0.016
	(0.055)	(0.053)	(0.055)	(0.054)	(0.054)	(0.054)
	Aug	Sep	Oct	Nov	Dec	
Model I	-0.078	0.053	0.166**	0.230**	0.341**	
	(0.057)	(0.057)	(0.056)	(0.058)	(0.058)	
Model II	-0.070	0.062	0.181**	0.236**	0.357**	
	(0.055)	(0.055)	(0.054)	(0.055)	(0.058)	

founded the effect of exchange rate fluctuations because the UNESCO registration and the QQE, which caused a sharp depreciation of the Japanese yen, happened in the same year.

Lastly, we look into the posterior statistics in Table 4.5 to investigate monthly seasonal effects in *sake* export. Note that the base month is January. For both Model I and Model II, it is a significantly positive from October to April. As for the period from October to December, it may be related to the fact that *sake* breweries start brewing in October, which means that they start exporting newly brewed *sake* in this period. As for the period from February to April, it may be related to *sake* contests. Many *sake* breweries regularly participate in contests on the quality of premium *sake*. If they are successful in the contest, it will be a great boon for marketing. So winning the contest is their top priority. However, brewing premium *sake* is labor-intensive and hinders their daily operation of brewing. Since breweries start preparing for the contest in January, their daily operation will be subsequently in slowdown. Only after they finished brewing premium *sake* for the contest, breweries can start to export new *sake* again. As a result, we observe seasonal fluctuations shown in Table 4.5.

In addition to the volume of *sake* export, we estimated panel data regression models of the unit value of *sake* export. Using the unit value of *sake* export as the dependent

Table 4.6: Country-Specific Trends (Export Unit Value)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	-8.353**	-7.886**	-7.400**	-8.310**	-8.200**
	(0.636)	(0.616)	(0.602)	(0.630)	(0.700)
Intercept (II)	-6.07**	-5.510**	-5.105**	-5.807**	-5.961**
	(0.814)	(0.803)	(0.775)	(0.814)	(0.885)
Intercept (II, UNESCO)	-0.068	-0.132**	0.070	0.107**	0.028
	(0.044)	(0.048)	(0.045)	(0.043)	(0.044)
Slope (I)	0.003**	0.005**	0.002**	0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Slope (II)	0.013**	0.005**	0.001	-0.005**	0.004**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Slope (II, UNESCO)	0.005**	0.004**	0.004**	0.006**	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

variable in Model I and Model II, we computed the posterior statistics of the parameters in Equation (4.1). They are shown in Table 4.6, Table 4.7 and Table 4.8.

In Table 4.6, Intercept (I) and Intercept (II) are significantly negative for all countries. As for Intercept (II, UNESCO), it is significant for Hong Kong (significantly negative) and Taiwan (significantly positive).

As for the slope of the trend, China and Hong Kong move in a similar direction. Slope (I), Slope (II) and Slope (II, UNESCO) in Table 4.6 are all significantly positive for China and Hong Kong. This result indicates that the unit value of imported *sake* has been rising for these countries, which is consistent with rapid growth of the Chinese economy in the sample period. The economic growth made the people richer and higher-grade *sake* more affordable for them. It is also notable that the rise in the unit value is accelerated by the UNESCO registration for these countries.

We may put Singapore and Taiwan into another category. In Table 4.6, Slope (I) for Singapore and Taiwan is significantly positive as China and Hong Kong. So the same factor, economic growth, played the same role to make more expensive *sake* affordable for

Table 4.7: Impacts of Economic Variables (Export Unit Value)

	CPI	*NER*
Model I	1.141**	0.398**
	(0.115)	(0.078)
Model II	0.996**	0.039
	(0.139)	(0.094)

the people in these countries. However, if we look into Slope (II) and Slope (II, UNESCO), we get a little different perspective on the unit value of imported *sake* in these countries. Before the UNESCO registration, Slope (II) is not significant for Singapore and it is even significantly negative for Taiwan. Therefore we may conclude that they preferred less expensive *sake* in that period. After the UNESCO registration, on the other hand, Slope (II, UNESCO) is significantly positive for both Singapore and Taiwan and the absolute value of the coefficient is comparable to those of China and Hong Kong. Thus it may imply that the people in Singapore and Taiwan started to accept higher-grade *sake* after the UNESCO registration.

Consumer preference of the United States seems different from the Asian countries. Slope (I) is not significant and the posterior mean is virtually zero for the United States, which means that the unit value of imported *sake* remains unchanged in the sample period. Furthermore, Slope (II) is significantly positive but Slope (II, UNESCO) is significantly negative, which implies that the upward trend in the unit value was reversed after the UNESCO registration. This seemingly confusing result may be explained by the fact that, in the United States, the UNESCO registration has led to an increase in the number of Japanese restaurants, which in turn has led to an increase in the volume of *sake* export, possibly resulting in a decline of the unit value.

In Table 4.7, both *CPI* and *NER* are significantly positive in Model I, but *NER* is not significant in Model II. This result is the same as the volume regression in Table 4.4.

In Table 4.8, the unit value is higher after June. This is probably due to the fact that *sake* breweries are unable to ship more expensive *sake* until June when contests on premium *sake* finish and breweries can start exporting.

Table 4.8: Monthly Seasonal Effects (Export Unit Value)

	Feb	Mar	Apr	May	Jun	July
Model I	-0.018	0005	0.009	0.026	0.091**	0.084**
	(0.024)	(0.024)	(0.025)	(0.025)	(0.024)	(0.024)
Model II	-0.020	0.020	0.006	0.024	0.008**	0.008**
	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
	Aug	Sep	Oct	Nov	Dec	
Model I	0.052**	0.053**	0.067**	0.055**	0.076**	
	(0.024)	(0.025)	(0.024)	(0.024)	(0.024)	
Model II	0.046**	0.047**	0.062**	0.048**	0.070**	
	(0.022)	(0.022)	(0.022)	(0.023)	(0.022)	

4.4 Differences between Traditional *Nada* Region and the Others

So far we have used export data on the *sake* brewing industry as a whole. It is well known that the structure of the *sake* brewing industry is actually quite different in one particular region - *Nada* - from the rest of the country. The *Nada* region have been playing the major role in the Japanese *sake* brewing industry. Akiyama (1994) states that, in the Edo period, *Nada* was a region blessed with good quality rice and water suitable for sake brewing, as well as good maritime transportation. This led to an industrial agglomeration of *sake* breweries in the *Nada* region which has had a significant impact on the *sake* brewing industry even today. The Japanese National Tax Agency reports that almost half of *sake* consumed in the domestic market is brewed by breweries in the *Nada* region. So it is safe to say that large-scale *sake* breweries, which are called major *sake* companies, are almost exclusively concentrated in this region. To examine any differences between *sake* breweries in the *Nada* region and the rest, we first estimated panel data regression models of the volume of *sake* export from the *Nada* region[3]. Data

[3]We substituted y_{it} in Equation (4.1) for the export volume or unit value of *Nada* and *Unit* for the unit value of *Nada*.

Table 4.9: Country-Specific Trends (Export Volume, *Nada* Region)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	-3.412	-0.750	-1.530	-0.564	-1.550
	(2.010)	(1.947)	(1.902)	(1.994)	(2.178)
Intercept (II)	-8.031**	-5.180**	-5.711**	-4.850**	-7.101**
	(2.571)	(2.530)	(2.442)	(2.563)	(2.796)
Intercept (II, UNESCO)	1.065**	-0.387**	0.01	0.684**	0.167
	(0.141)	(0.155)	(0.145)	(0.138)	(0.141)
Slope (I)	0.012**	0.002**	0.001	-0.001	0.005**
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Slope (II)	0.006**	0.004**	-0.002**	-0.006**	0.004**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Slope (II, UNESCO)	0.012**	-0.002	0.011**	0.008**	-0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)

on *sake* exported from Kobe Customs is used as a proxy variable for sake exported from the Nada region because *sake* from *Nada* mostly exported from Kobe[4].

Compared to the results in Table 4.3, we do not see any notable differences among the intercept estimates in Table 4.9, except that Intercept (I) is insignificant and Intercept (II) is significantly negative for all countries. As for the slope of the trend, Slope (I) is no longer significant for Singapore and Taiwan and Slope (II, UNESCO) is not significant for Hong Kong. All in all, the *sake* export from *Nada* follows a trend similar to the whole

[4]represented by Kobe Customs reports

Table 4.10: Impact of Economic Variables (Export Volume, *Nada* Region)

	Unit	*CPI*	*NER*
Model I	-0.540**	1.408**	0.960**
	(0.064)	(0.361)	(0.246)
Model II	-0.940**	2.800**	0.551
	(0.066)	(0.448)	(0.230)

Table 4.11: Monthly Seasonal Effects (Export Volume, *Nada* Region)

	Feb	Mar	Apr	May	Jun	July
Model I	0.172**	0.270**	0.156**	0.141	0.015	-0.020
	(0.076)	(0.077)	(0.076)	(0.078)	(0.077)	(0.076)
Model II	0.612**	0.260**	0.137**	0.156**	0.021	0.034
	(0.070)	(0.070)	(0.070)	(0.071)	(0.071)	(0.070)
	Aug	Sep	Oct	Nov	Dec	
Model I	-0.041	0.021	0.088	0.200**	0.362**	
	(0.067)	(0.076)	(0.075)	(0.076)	(0.075)	
Model II	-0.021	0.033	0.106	0.193**	0.364**	
	(0.069)	(0.070)	(0.070)	(0.071)	(0.070)	

country. Table 4.10 presents the posterior statistics of coefficients of economic variables. They are comparable to the results in Table 4.4. Monthly seasonal effects in Table 4.11 show one month lag to the whole country as shown in Table 4.5. While the seasonal upward movement in export shipments begins in October for the whole country, it starts in November for the *Nada* region. This would be due to the fact that the *Nada* region has older breweries that start brewing later. Milder climate in this region also makes the arrival of winter behind much cooler regions[5]. As a result, breweries in the *Nada* region must delay the starting date of *sake* brewing until the temperature becomes sufficiently low.

Next, we estimated panel data regression models of the unit value of *sake* export from the *Nada* region. The posterior statistics on trends, coefficients of economic variables, and month seasonal effects are shown in Table 4.12, Table 4.13 and Table 4.14 respectively. As for the trend and the impacts of economic variables, we see no clear differences between the *Nada* region and the whole country. As for the monthly seasonal effects, they almost disappear except for June (Model I and II) and August (Model I). This is because *sake* breweries in the *Nada* region tend to prioritize quantity over quality. They do

[5]The *Nada* region is located in a warmer southern part of Japan, while most other *sake* brewing regions are located in a much cooler northern part of Japan.

Table 4.12: Country-Specific Trends (Export Unit Value, *Nada* Region)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	-6.364**	-6.059**	-5.630**	-6.506**	-6.518**
	(0.790)	(0.762)	(0.746)	(0.681)	(0.855)
Intercept (II)	-4.081**	-3.520**	-3.289**	-3.810**	-4.180**
	(1.018)	(1.001)	(0.966)	(1.015)	(1.107)
Intercept (II, UNESCO)	0.370**	-0.013	-0.008	0.224**	0.214**
	(0.053)	(0.059)	(0.054)	(0.053)	(0.054)
Slope (I)	0.002**	0.003**	0.001 **	-0.000	0.002**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Slope (II)	0.013**	0.005**	0.001	-0.005**	0.004**
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)
Slope (II, UNESCO)	0.001	0.001	0.004**	0.008**	-0.002**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

not differentiate their products so much and tend to prioritize the stable supply of their products with fixed prices throughout the year. They also do not place as much emphasis on entering their products in competitions as do small and medium-sized companies, but rather focus on producing inexpensive products with a high degree of productivity.

For the last empirical analysis in this chapter, we estimated panel data regression models for *sake* export from the other regions in Japan. While we have just analyzed *sake* export by large firms in the *Nada* region, it would be fair to say that it is an analysis of small and medium-sized enterprises (SMEs) in the *sake* brewing industry since large

Table 4.13: Impacts of Economic Variables (Export Unit Value, *Nada* Region)

	CPI	*NER*
Model I	0.643**	0.468**
	(0.143)	(0.095)
Model II	0.728**	-0.131
	(0.177)	(0.115)

Table 4.14: Monthly Seasonal Effects (Export Unit Value, *Nada* Region)

	Feb	Mar	Apr	May	Jun	July
Model I	-0.020	-0.012	-0.004	0.038	0.061**	0.050
	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)
Model II	-0.020	-0.015	-0.001	0.037	0.057**	0.048
	(0.025)	(0.026)	(0.027)	(0.027)	(0.027)	(0.026)
	Aug	Sep	Oct	Nov	Dec	
Model I	0.073**	0.047	0.062	0.015	0.042	
	(0.029)	(0.030)	(0.029)	(0.029)	(0.029)	
Model II	0.070	0.044	0.061	0.012	0.035	
	(0.026)	(0.027)	(0.026)	(0.027)	(0.027)	

firms are concentrated in the *Nada* region. The posterior statistics of trends, coefficients of economic variables and monthly seasonal effects in the volume model are shown in Table 4.15, Table 4.16 and Table 4.17 while the corresponding posterior statistics in the unit value model are shown in Table 4.18, Table 4.19 and Table 4.20.

The results of the volume model in Table 4.15 are comparable to those in Table 4.3, though they show that SMEs are more successful in exporting *sake* to Singapore and Taiwan because the trends of these countries in Table 4.15 are steeper than Table 4.3.

As for economic variables, *NER* is insignificant for both models in Table 4.16. This indicates that the impact of exchange rate fluctuations upon the *sake* export by SMEs was ambiguous in the sample period.

The seasonal effects seem back in Table 4.17. This finding is consistent with our conjecture on why seasonal fluctuations appears in *sake* export. If the monthly seasonal effects in *sake* export are mainly caused by supply-side constraints, they must be more evident for SMEs that lack resources for production and less evident for large firms that have plenty of resources. Thus the difference in seasonal fluctuations between the *Nada* region and the other regions reinforces our conjecture.

As for the unit value model, trends of *sake* export by SMEs are close to those of the whole country. It can be seen that *sake* has become more upscale since the UNESCO

Table 4.15: Country-Specific Trends (Export Volume, Other Area)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	-12.037**	-6.293	-6.310	-5.976	-5.260
	(3.527)	(3.430)	(3.341)	(3.506)	(3.821)
Intercept (II)	-11.177**	-4.771	-4.540	-4.060	-4.183
	(4.707)	(4.647)	(4.470)	(4.704)	(5.115)
Intercept (II, UNESCO)	-1.225**	-0.610**	0.344	0.478	-0.312
	(0.277)	(0.297)	(0.270)	(0.266)	(0.270)
Slope (I)	0.035**	0.019**	0.011 **	0.007**	0.005**
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Slope (II)	0.040**	0.020**	0.082**	0.001	0.007**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Slope (II, UNESCO)	0.010**	0.011**	0.013**	0.017**	-0.006
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)

Table 4.16: Impacts of Economic Variables (Export Volume, Other Area)

	Unit	*CPI*	*NER*
Model I	-2.347**	2.518**	0.481
	(0.103)	(0.642)	(0.442)
Model II	-2.572**	2.771**	-0.003
	(0.110)	(0.830)	(0.563)

Table 4.17: Monthly Seasonal Effects (Export Volume, Other Area)

	Feb	Mar	Apr	May	Jun	July
Model I	0.200	0.271**	0.311**	0.149	0.294**	0.125
	(0.141)	(0.140)	(0.139)	(0.140)	(0.138)	(0.142)
Model II	0.188	0.267**	0.302**	0.143	0.302**	0.138
	(0.134)	(0.132)	(0.136)	(0.135)	(0.136)	(0.135)
	Aug	Sep	Oct	Nov	Dec	
Model I	-0.074	0.227	0.402**	0.404**	0.543**	
	(0.138)	(0.140)	(0.138)	(0.138)	(0.140)	
Model II	-0.078	0.213	0.389**	0.398**	0.546**	
	(0.135)	(0.133)	(0.135)	(0.135)	(0.134)	

registration in all countries except the United States.

It should be noted that *sake* brewed by SMEs is not affected by the exchange rate in terms of volume in Table 4.16, but in terms of unit value in Table 4.19. Exchange rates have a positive impact on both Model I and Model II. This may indicate that there is still room for price hikes and upscaling with regard to products exported by SMEs.

As for the monthly seasonal effects in the unit value model, compared to breweries in the *Nada* region, they tend to export high-end *sake* at different times of the year. March, April, and July have a higher impact than January. This is because, after finishing brewing *sake* for the competition in January, SMEs start entering their *sake* in the various competitions in February. The results of the competitions are often available between March and July, depending on the type of competition. If a product wins an award at this time, it sells at a higher price as an award-winning product, and this activity is likely to have an impact. Unit values will rise again from early fall onwards for the same reasons as the whole country.

Based on findings in this study, it is now clear that there are significant differences in export activities between regions when it comes to *sake* in a nutshell. It can be said that this study showed the heterogeneity between two types of regions in Japan. In regions like *Nada* with a high concentration of large companies and capital, priority is given to

Table 4.18: Country-Specific Trends (Export Unit Value, Other Area)

	China	Hong Kong	Singapore	Taiwan	US
Intercept (I)	-7.910**	-8.046**	-7.294**	-8.352**	-8.107**
	(0.889)	(0.863)	(0.844)	(0.883)	(0.964)
Intercept (II)	-8.691**	-8.890**	-7.995**	-9.077**	-9.181**
	(1.232)	(1.217)	(1.171)	(1.231)	(1.341)
Intercept (II, UNESCO)	-0.045	-0.250**	0.138 **	0.158**	-0.033
	(0.064)	(0.070)	(0.065)	(0.062)	(0.065)
Slope (I)	0.002**	0.006**	0.002**	0.002**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Slope (II)	0.001**	0.006**	0.000	0.001**	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Slope (II, UNESCO)	0.007**	0.002	0.004**	0.003**	-0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

Table 4.19: Impact of Economic Variables (Export Unit Value, Other Area)

	CPI	*NER*
Model I	1.100**	0.484**
	(0.158)	(0.108)
Model II	1.338**	0.445**
	(0.209)	(0.140)

Table 4.20: Monthly Seasonal Effects (Export Unit Value, Other Area)

	Feb	Mar	Apr	May	Jun	July
Model I	-0.023	0.020	0.006	0.022	0.0102**	0.122**
	(0.034)	(0.034)	(0.035)	(0.035)	(0.035)	(0.034)
Model II	-0.024	0.018	0.003	0.022	0.099**	0.120**
	(0.032)	(0.032)	(0.032	(0.032)	(0.033)	(0.032)
	Aug	Sep	Oct	Nov	Dec	
Model I	0.080**	0.037	0.029	0.060	0.075**	
	(0.034)	(0.034)	(0.034)	(0.034)	(0.033)	
Model II	0.075**	0.031	0.023	0.052	0.070**	
	(0.032)	(0.031)	(0.032)	(0.032)	(0.032)	

brewing stable quantities rather than raising prices, whereas in regions dotted with SMEs, brewing high value-added products is required.

4.5 Conclusion

In recent years, *sake* has been actively exported overseas, but there has yet to be an active study of what factors are involved. In this study, we analyzed the unbalanced panel of each country using hierarchical Bayesian modeling. As a result, it was confirmed that the registration of Japanese cuisine as an intangible cultural heritage by UNESCO had a significant impact on *sake* export to some countries. It was also confirmed that both shipment volume and unit price were related to prices in each country. In addition, it was shown that shipment volume and unit price may differ depending on the season. Furthermore, when the data were analyzed separately by company size, it was confirmed that there was little reaction to the unit price in regions with a high concentration of large companies, while in regions with scattered small and medium-sized companies, the unit price was greatly affected by the exchange rate. The *sake* export will continue to grow, and the Japanese government has also made it clear since the preparation of the 2020 budget that it will invest huge subsidies in the *sake* export. We hope that our research will be of some help not only to businesses currently exporting or considering exporting in the future, but also to the governments that support them.

4.6 Appendix: Derivation of conditional posterior distribution of parameters

Conditional posterior distribution of $\boldsymbol{\delta}$

The conditional posterior distribution of $\boldsymbol{\delta}$ is

$$p(\boldsymbol{\delta}|\mathcal{D},\boldsymbol{\theta}_{-\boldsymbol{\delta}}) \propto \exp\left[-\frac{1}{2\sigma_\epsilon^2}\left\{(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})'(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})+(\boldsymbol{\delta}-\boldsymbol{\mu})'\boldsymbol{\Sigma}^{-1}(\boldsymbol{\delta}-\boldsymbol{\mu})\right\}\right], \tag{4.1}$$

with likelihood (4.4) and prior distribution (4.6). We apply the square completion formula, then we obtain

$$\begin{aligned}
&\sigma_\epsilon^{-2}(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})'(\boldsymbol{y}-\boldsymbol{Z}\boldsymbol{\delta})+(\boldsymbol{\delta}-\boldsymbol{\mu})'\boldsymbol{\Sigma}^{-1}(\boldsymbol{\delta}-\boldsymbol{\mu})\\
&=\boldsymbol{\delta}'\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)\boldsymbol{\delta}-2\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)'\boldsymbol{\delta}+\text{Constant}\\
&=\left(\boldsymbol{\delta}-\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)\\
&\quad\times\left(\boldsymbol{\delta}-\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)+\text{Constant}^{6}.
\end{aligned}$$

The conditional posterior distribution of Equation (4.1) is

$$\begin{aligned}
&p(\boldsymbol{\delta}|\mathcal{D},\boldsymbol{\theta}_{-\boldsymbol{\delta}})\\
&\propto\exp\Bigg[-\frac{1}{2}\left(\boldsymbol{\delta}-\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)\\
&\qquad\times\left(\boldsymbol{\delta}-\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{Z}+\boldsymbol{\Sigma}^{-1}\right)^{-1}\left(\sigma_\epsilon^{-2}\boldsymbol{Z}'\boldsymbol{y}+\boldsymbol{\Sigma}^{-1}\boldsymbol{\mu}\right)\right)\Bigg].
\end{aligned}\tag{4.2}$$

This is equivalent to the probability density function of the distribution in Equation (4.12).

Conditional posterior distribution of $\mu_{\gamma j}$

The conditional posterior distribution of $\mu_{\gamma j}$ ($j \in \{1,\ldots,K\}$) is

$$\begin{aligned}
p(\mu_{\gamma j}|\mathcal{D},\boldsymbol{\theta}_{-\mu_{\gamma j}}) &\propto \exp\left[-\frac{\sum_{i=1}^N(\gamma_{ij}-\mu_{\gamma j})^2}{2\sigma_{\gamma j}^2}-\frac{(\mu_{\gamma j}-\varphi_\gamma)^2}{2\tau_\gamma^2}\right]\\
&\propto \exp\left[-\frac{1}{2}\left\{\left(\sigma_{\gamma j}^{-2}N+\tau_\gamma^{-2}\right)\mu_{\gamma j}^2-2\left(\sigma_{\gamma j}^{-2}\sum_{i=1}^N\gamma_{ij}+\tau_\gamma^{-2}\varphi_\gamma\right)\mu_{\gamma j}\right\}\right]\\
&\propto \exp\left[-\frac{1}{2}\left(\sigma_{\gamma j}^{-2}N+\tau_\gamma^{-2}\right)\left(\mu_{\gamma j}-\frac{\sigma_{\gamma j}^{-2}\sum_{i=1}^N\gamma_{ij}+\tau_\gamma^{-2}\varphi_\gamma}{\sigma_{\gamma j}^{-2}N+\tau_\gamma^{-2}}\right)^2\right],
\end{aligned}\tag{4.3}$$

from Equations (4.8) and (4.9). This is equivalent to the probability density function of the distribution in Equation (4.13).

Conditional posterior distributions of $\sigma^2_{\gamma j}$ and $\xi_{\gamma j}$

The conditional posterior distribution of $\sigma^2_{\gamma j}$ ($j \in \{1, \dots, K\}$) is

$$\begin{aligned}
&p(\sigma^2_{\gamma j}|\mathcal{D}, \boldsymbol{\theta}_{-\sigma^2_{\gamma j}}, \xi_{\gamma j}) \\
&\propto (\sigma^2_{\gamma j})^{-\frac{N}{2}} \exp\left[-\frac{\sum_{i=1}^N(\gamma_{ij} - \mu_{\gamma j})^2}{2\sigma^2_{\gamma j}}\right] \times (\sigma^2_{\gamma j})^{-\left(\frac{1}{2}+1\right)} \exp\left(-\frac{1}{\xi_{\gamma j}\sigma^2_{\gamma j}}\right) \\
&\propto (\sigma^2_{\gamma j})^{-\left(\frac{N+1}{2}+1\right)} \exp\left[-\frac{\frac{1}{2}\sum_{i=1}^N(\gamma_{ij} - \mu_{\gamma j})^2 + \xi^{-1}_{\gamma j}}{\sigma^2_{\gamma j}}\right],
\end{aligned} \tag{4.4}$$

given the latent variable $\xi_{\gamma j}$ from Equations (4.8) and (4.16). This is equivalent to the probability density function of the distribution of σ^2_γ in Equation (4.14). Whereas, the conditional posterior distribution of $\xi_{\gamma j}$ is obtained as

$$\begin{aligned}
p(\xi_{\gamma j}|\sigma^2_{\gamma j}) &\propto \xi_{\gamma j}^{-\frac{1}{2}}(\sigma^2_{\gamma j})^{-\left(\frac{1}{2}+1\right)} \exp\left(-\frac{1}{\xi_{\gamma j}\sigma^2_{\gamma j}}\right) \times \xi_{\gamma j}^{-\left(\frac{1}{2}+1\right)} \exp\left(-\frac{1}{s^2_\gamma \xi_{\gamma j}}\right) \\
&\propto \xi_{\gamma j}^{-(1+1)} \exp\left(-\frac{\sigma^{-2}_{\gamma j} + s^{-2}_\gamma}{\xi_{\gamma j}}\right).
\end{aligned} \tag{4.5}$$

This is also equivalent to the probability density function of the distribution of $\xi_{\gamma j}$ in Equation (4.14).

Conditional posterior distribution of σ^2_ϵ and ξ_ϵ

The conditional posterior distribution of σ^2_ϵ is

$$\begin{aligned}
&p(\sigma^2_\epsilon|\mathcal{D}, \boldsymbol{\theta}_{-\sigma^2_\epsilon}) \\
&\propto (\sigma^2_\epsilon)^{-\frac{T}{2}} \exp\left(-\frac{\sum_{i=}^N\sum_{t=1}^{T_i} e^2_{it}}{2\sigma^2_\epsilon}\right) \times (\sigma^2_\epsilon)^{-\left(\frac{1}{2}+1\right)} \exp\left(-\frac{1}{\xi_\epsilon\sigma^2_\epsilon}\right) \\
&\propto (\sigma^2_\epsilon)^{-\left(\frac{T+1}{2}+1\right)} \exp\left(-\frac{\frac{1}{2}\sum_{i=1}^N\sum_{t=1}^{T_i} e^2_{it} + \xi^{-1}_\epsilon}{\sigma^2_\epsilon}\right),
\end{aligned} \tag{4.6}$$

from Equations (4.5) and (4.16). This is equivalent to the probability density function of the distribution in Equation (4.15). Whereas, the conditional posterior distribution of ξ_ϵ in Equation (4.15) is derived by replacing $\sigma^2_{\gamma j}$ and s^2_γ by σ^2_ϵ and s^2_ϵ in Equation (4.5) respectively.

Chapter 5

Testing Structural Breaks in the Japanese *Sake* Import in the US Market

5.1 Introduction

Since ancient times, alcoholic beverages have always been present in human life. Wine, beer, or whiskey, for instance, are currently important commodities in our daily lives. It is no different for people living in the US. The market of alcohol beverages in the US have been spreading in these decades. Figure 5.1 shows the historical expenditure on alcohol beverages in the US. In 1994, the total purchase price of alcohol beverages, which combines prices purchased in restaurants and retail stores were about one thousand billion dollars. In 2022, that had increased to 4.5 thousand billion dollars[1]. As evident from Figure 5.1, consumption of imported alcoholic beverages have been the main contributor to this rapid growth of alcoholic beverage consumption. The green area in Figure 5.1 shows the expenditure on imported alcoholic beverages in the US[2]. It grew from 396 billion dollars in 1994 to 2,320 billion dollars in 2022 and became more than six times higher within less than three decades. In mid-1990s, imported alcohol beverage consumption

[1]Datasets are obtained from Bureau of Economic Analysis.

[2]We retrieved the data on alcoholic beverage consumption from the US Census Bureau website. The data is available from 1994.

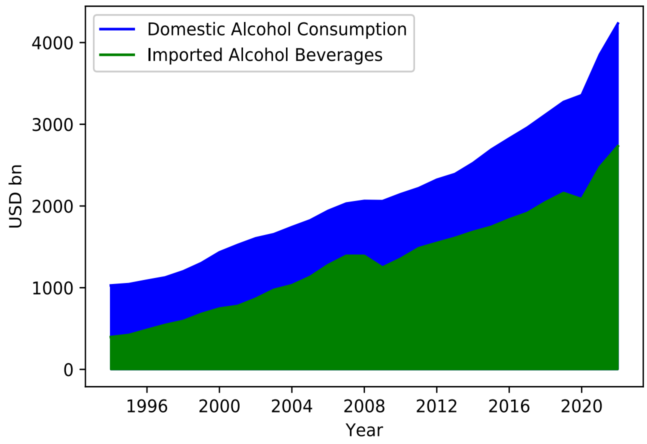

Figure 5.1: Domestic Consumption and Imports of Alcohol Beverages in the US

accounted for about 40% of overall consumption, but since mid-2000s, it has consistently exceeded 60%. These facts indicate that the increase in imported alcoholic beverages has contributed significantly to the growth of alcoholic beverage consumption in the US. Therefore, analyzing the determinants of imported alcoholic beverages in the US is crucial in predicting the future demand for alcohol beverages. While a variety of alcoholic beverages are imported to the US, this study focuses on one type of alcoholic beverage: *sake*, the Japanese rice wine.

Figure 5.2 shows the historical time series of the total value, the total volume and the unit value (the total value divided by the total volume) of *sake* exported from Japan to the US. The total value of *sake* exported to the US was only 0.65 billion dollars in 1988, but it reached 8.2 billion dollars in 2022. Compared to the total value of imported alcoholic beverages in the US, which increased seven-fold from 1994 to 2022 in Figure 5.1, the total value of imported *sake* increased 13-fold, and the share of *sake* increased from only 0.1% in 1994 to 0.3% by 2022. Although its share in the total alcoholic beverage consumption is still small, it has tripled in three decades. The total volume and the unit value of *sake* export are also on the rise. The total volume has increased from 2,700 KL to 9,000 KL in the 1988–2022 period, and the unit value has increased from $1.7 to $6.5 in the same period. In other words, both total volume and unit value was more than

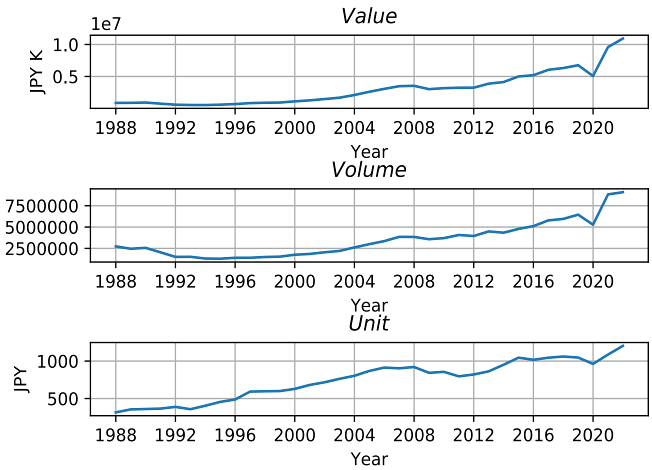

Figure 5.2: *Sake* Export to the US

tripled over the past several decades. The fact that *sake* is growing faster than imported alcoholic beverages as a whole in terms of volume and unit value would make it a more product for breweries and retailers.

We believe that this rapid growth of *sake* export can be studied from two different perspectives. The first is to detect what kinds of factor determines *sake* export to the US. There would be several determinants for *sake* export and they could be investigated with econometric models. To the best of our knowledge, there are no studies that have empirically examined this issue on *sake*. The second is to test possible structural breaks in the time series data. As Figure 5.2 shows, the growth trajectory of *sake* export is not always linear in both value and volume where periods of faster growth and of slight stagnation are mixed. It would be important for us to identify when structural breaks occurred and to examine how the characteristics of *sake* export differ from regine to regime. Since the structural break probably occurred not only once but multiple times, it is necessary to determine the number of break points in a statistically appropriate manner. Therefore, in order to investigate the above two issues at once, we need an econometric framework that allows multiple structural breaks.

Although no studies have ever been conducted on econometric analysis of *sake*, there are several studies on other alcoholic beverages. For example, Bouët.et.al (2017) studied

Cognac and found that income elasticity of demand for Cognac has significant impact on its export. Cardebat and Figuet (2019) argued that appreciation of the euro increased the share of premium wines in French wine export. Bargain (2020) found that income and price effects of French wine exports to China was different by wine-growing regions in France.

Several studies also investigated structural breaks in alcohol beverage merkets. Hart and Alston (2020) showed two breaks in the US alcohol market in 1996 and 2016 by Chow's test. Faye and Le Fur (2019) found there are two periods in the wine prices of Liv-ex Bordeaux Legends 50 Index by Buishand's (1982) tests. Valverde (2004) argues that there was a regime shift by structural break since 1982 in Chilean domestic wine market by Bai and Perron (BP) (1998, 2003) tests.

In our research, we apply BP methods to identify structural breaks in *sake* export to the US since the number and the dates of structural breaks are unknown and we need to determine them statistically. Once tests by BP methods are performed and the number and the dates of structural breaks are obtained, we will proceed to estimate regression models of the volume or unit value of *sake* export to the US for each regime identified with BP methods. Then we can understand how changes in regulations and economic policies, which might caused those breaks, would affect the *sake* brewing industry in general and its export to the US in particular.

The organization of this chapter is as follows. Section 2 briefly explains the current trends in the Japanese *sake* brewing industry and its export to the US. Then Section 3 describes the datasets and the estimation procedure we used in our research. Section 4 presents the hypotheses related to the *sake* export to the US and explains the estimation results of the volume model as well as the unit value model. Section 5 briefly explains regional heterogeneity on *sake* breweries in Japan and examines how regional differences affect *sake* export from the corresponding regions to the US. Finally, Section 6 summarizes the findings of our research and states their implications.

Table 5.1: Tax Rates for *Sake* under the Old *Sake* Tax Law

	Premium	First	Second
Tax per 1KL [4]	410,100	214,200	85,800

5.2 Current Trends in the Japanese *Sake* Brewing Industry and its Export to the US

For the present, unfortunately, overall domestic demand for *sake* has continued to decline. The Japanese National Tax Administration Agency reports an overview of the *sake* beverage industry. It describes that the amount of *sake* consumption peaked (1.77 million kl) in 1973 and since then has decreased. It is currently only 23% (0.41 million kl) compared to its heyday. The percentage of sake consumption in the Japanese alcohol beverage market has also continued to decline, falling from 28% at its high in 1973 to 7% at present. There are many possible reasons for this decline in the *sake* brewing industry, but one reason is that in the 20th century the tax laws on *sake* were not always conducive to the development of the *sake* brewing industry. In the old days, *sake* breweries were taxed at a progressive rate based on the quality of alcoholic beverages they brewed. The quality of *sake* is categorized into three grades: premier, first, and second. Until 1980s, taxes on premier *sake* were about five times higher than on second-grade *sake*. According to Shibata (1980), the old taxation rule was defined as in Table 5.1. In addition, *sake* breweries had to prepare enough capital to be allowed to examine premium *sake* by the National Tax Agency of Japan[3]. For those reasons, only major *sake* breweries with substantial financial power were able to produce premium-grade *sake*, and small breweries were only able to produce *sake* below the first-grade.

From 1980s, Criticism that the tax regime did not reflect the reality of the *sake* brewing industry had been mounting, and the old tax law was phased out beginning in 1992 and completely replaced by the new *Sake* Tax Law in 1993. This legal amendment made it possible for these small breweries to brew and sell premium *sake*[5]. This is

[3]This fact was verified by an interview with a tax office's alcoholic beverage officer in Japan.

[5]The classification system was abolished and new definitions such as *ginjo sake* or *junmai sake*were

because under the new tax regime, *sake* tax is based on the quantity shipped and is no longer dependent on the quality of *sake*. So after 1992, many breweries started to brew premium *sake*. On the other hand, consumer preferences have changed considerably, with a trend toward higher-priced sake. The National Tax Agency reports the brewed volume of such premium *sake* increased from 81,000 kl in 2010 to 98,000 kl in 2020, by about 20% increase. Furthermore, the unit value of *sake* has been on an upward trend since 2012 in Japan. These trends are thought to reflect the growing demand for higher value-added products. Consequently, the *sake* brewing industry is in the process of shifting its business model from mass production of low-priced products to manufacturing small-lot, high-value-added products with higher profit margins. In response to these policy changes and structural changes of the domestic market, *sake* breweries changed their product lineup. They have begun to focus on exporting their products, mainly premium *sake*, to the oversea market including the US.

The US is one of the largest alcoholic beverage markets in the world and has imported a variety of alcoholic beverages including *sake* for many years as shown in Figure 5.1. From the early 20th century now on, *sake* breweries in Japan have exported *sake* to the US. *Sake* export to the US began in 1933 when the US repealed the Eighteenth Amendment that prohibited any alcoholic beverages. Its main target was Japanese immigrants in the US. Although the export was temporarily suspended during World War II, it was already restored in 1948[6].

The export environment has changed dramatically since the 1990s, when the aforementioned legal changes were made. Fujishiro (2019) argues that micro breweries of *sake* started exporting business to the US from mid-1990s. In response to these new entrants, *sake* distributors also developed an aggressive marketing campaign. In 1996, *Jizake Inc.* was founded in the US and Wine of Japan Import, *Inc.* started wholesaling *sake* to restaurants in the US. Combined with aggressive marketing efforts by related companies, the consumption volume and unit value of *sake* in the US rose from the 1990s. In additon, not only large sake breweries but also small and medium-sized breweries began to set up

created in its place.

[6]These records are confirmed by the *Hakushika Shuzo* memorial

offices in the US around mid-2000s[7].

The second development had stared from 2010s. As Figure 5.2 shows, *sake* export to the US declined after 2008 when a global recession was triggered by the Global Financial Crisis. After the financial crisis was subdued and Mr. Shinzo Abe was inaugurated as the prime minister of Japan again in 2012, the Japanese government induced a sharp depreciation of the Japanese yen through an expansionary monetary policy called the Quantitative and Qualitative Easing (QQE). This once again turned the unit value of *sake* export into an upward trend. In conjunction with these political trends, major changes have occurred in the US food and beverage industry since 2013. Fujishiro (2019) argues that the number of Japanese restaurants in the north America nearly doubled from 2013 to 2015. The reason for this is considered to be the expansion of the Japanese cuisine market due to the registration of Japanese cuisine as a UNESCO Intangible Cultural Heritage in 2013. From these historical records, we suppose there are some structural breaks and factor determinants of *sake* export to the US, for both volume and unit value. In the next section, we will explain the estimation datasets and estimation procedure.

5.3 Datasets and Estimation Procedure

In this study, we obtained monthly records of US-imported *sake* from January 1988 to April 2023. So we have 424 months of historical data. We set the natural logarithm of volume or unit value of *sake* exported to the US as our dependent variable. Following the previous studies, we use the following three variables as explanatory variables:

1. Unit value of imported *sake*[8] (denoted as *Unit*)
2. Real disposable income per capita in the US (denoted as *Income*)
3. Real exchange rate between Japan and the U.S (denoted as *RER*)

We take the natural logarithm of all the above variables.

[7] Typical examples include *Asahi Shuzo* of *Dassai* fame and several breweries in Niigata Prefecture.

[8] The unit value is based on the assumption that the bottle size of *sake* is 720 ml because most breweries export *sake* in 720 ml bottles to the US because their shape resembles a regular wine bottle.

Table 5.2: Descriptive Statistics

Variable	Mean	SD	Max	Min
Volume		179,934	1,078,551	46,968
Unit Value	6.90	2.67	11.35	2.23
Income per Capita	38,305	6,656	61,512	27.576
Real Exchange Rate	0.008	0.002	0.014	0.005

In addition to the previous studies mentioned in the introduction, the following prior studies exist for these economic factors. Fontagné and Hatte (2013) founds that unit value has significant impact on the determinants of high-quality products. As for income, Fogarty (2010) estimated the demand for alcohol by a meta-analysis. He stated that beer belonged to necessity goods and spirits belonged to luxury goods, but it depended on income. Anderson and Wittwer (2001, 2013, 2017, 2018) showed that *RER* had significant role on New World wine-exporting for the US and the European Union between 2007 and 2011 by estimating general equilibrium model.

When we estimate the unit value muodel (e.g., on Bouët (2017)), we treat *Unit* as the dependent variable and drop it from the explanatory variables. From this estimation, we can identify how income and exchange rate affect the unit value of *sake*.

The unit of volume is KL and all other units are in U.S. dollars. We obtained the data on volume and unit value of *sake* from Trade Statistics of Japan and the data on *Income* and *RER* from the website of the Federal Reserve Bank of St.Louis. The descriptive statistics of these variables are shown in Table 5.2.

With these datasets, we constructed a model with multible breaks as Equation (5.1).

$$y_t = \boldsymbol{x}_t'\boldsymbol{\beta} + \boldsymbol{z}_t'\boldsymbol{\delta}_j + u_t, \quad t \in \{T_{j-1}+1, \ldots, T_j\}, \quad j \in \{1, \ldots, m+1\}, \tag{5.1}$$

where y_t is the dependent variable, $\boldsymbol{x}_t$ and $\boldsymbol{z}_t$ are vectors of explanatory variables, $\boldsymbol{\beta}$ and $\boldsymbol{\delta}_j$ are coefficients, u_t is the error term, and we suppose $0 = T_0 < T_1 < \cdots < T_m < T_{m+1} = T$. We treat the break points $T_1, \ldots, T_m$ as unknown positive integers. Then we rewrite

Equation 5.1 as

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{\beta} + \bar{\boldsymbol{Z}}\boldsymbol{\delta} + \boldsymbol{u}, \tag{5.2}$$

where

$$\boldsymbol{y} = \begin{bmatrix} y_1 \\ \vdots \\ y_T \end{bmatrix}, \quad \boldsymbol{X} = \begin{bmatrix} \boldsymbol{x}'_1 \\ \vdots \\ \boldsymbol{x}'_T \end{bmatrix}, \quad \boldsymbol{\delta} = \begin{bmatrix} \boldsymbol{\delta}_1 \\ \vdots \\ \boldsymbol{\delta}_{m+1} \end{bmatrix}, \quad \boldsymbol{u} = \begin{bmatrix} u_1 \\ \vdots \\ u_T \end{bmatrix},$$

and $\bar{\boldsymbol{Z}}$ is a diagonally matrix such that

$$\bar{\boldsymbol{Z}} = \begin{bmatrix} \boldsymbol{Z}_1 & & \\ & \ddots & \\ & & \boldsymbol{Z}_{m+1} \end{bmatrix}, \quad \boldsymbol{Z}_j = \begin{bmatrix} \boldsymbol{z'}_{T_{j-1}+1} \\ \vdots \\ \boldsymbol{z}_{T_j} \end{bmatrix},$$

Next, we compute the optimal partition by solving the recursive problem as follows:

$$\mathrm{SSR}(\{T_m, t\}) = \min_{mh \leq j \leq T-h} \big[\mathrm{SSR}(\{T_{m-1}, j\}) + \mathrm{SSR}(\{j+1, T\})\big]. \tag{5.3}$$

We start the optimization procedure by measuring the optimal one-break partition for all sub-samples. These samples have a possible break ranges from observations h to $T - mh$. Following Bai adn Perron (1998), we solve the optimization problem (5.3) with these three steps:

Dynamic Programming Algorithm for Estimating Structural Break Model

Step 1 We store a set of $T-(m+1)h+1$ optimal one-break partitions along with their related SSR. Each partitions correspond to subsamples which ends at dates from $2h$ to $T=(m-1)h$.

Step 2 Given optimal partitions with two breaks. So those partitions have dates which ranges from $3h$ to $T-(m-2)h$. The method continues sequentially until we obtain a set of $T-(m+1)h+1$ optimal $(m-1)$ breaks partitions with ending dates which has a range from $(m-1)h$ to $T-2h$.

Step 3 In the final step, we find which optimal breaks partition yields an overall minimal SSR when combining with an additional segment. Hence, the method is interpreted as updating $T-(m+1)h+1$ segments sequentially into optimal breaks partitions up to $m-1$. In other words, the third step creates a single optimal m breaks (i.e. $m+1$ segments) partition.

With these steps, we will estimate the number of m breaks (m+1 segments) and estimated parameters.

After we estimate the model, we will test the number of breaks in three steps by UDmax test and sequential supF tests (see Bai and Perron (1998) for details):

1. Compute UDmax statistics to test if there are no breaks.

2. Test 0 break versus m breaks. If the null is rejected, m breaks are supported.

3. Test l breaks versus $l+1$ breaks in $l \leq m$. If the null is rejected, $l+1$ breaks are supported. From these tests, we can identify what number of breaks are supported.

5.4 Hypotheses and Estimation Results

Before estimating structural break models, we need to check stationarity and cointegration. So we conducted Adjusted Dickey-Fuller (ADF) tests with two lags in each variable. We rejected the null hypothesis that the variable has unit roots for $\ln y_t$, $\ln Unit_t$ and $\ln Income$, but not for $\ln RER$. Although BP methods assume the stationarity of re-

Table 5.3: Sequential SupF Test and UDmax Test of *Sake* Export Volume

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	93.51**	54.585**	65.72**	57.84**	56.61**
SupF (m+1|m)		84.32**	11.06	25.04	10.05
UDmax	88.64**				

gressors, Morales and Peruga (2002) argued that they could estimate consistent results with nonstationary regressors. Therefore, we proceed to estimate the models by BP methods.

We have several hypotheses to be tested.

H1 For break periods, there are at least two breaks after 1990s and after 2010s.

H2 For unit values, the sign of the coefficient is negative before 1990s but positive after 1990s.

H3 For income elasticity, the sign of the coefficient is negative before 1990s but positive after 1990s.

H4 For real exchange rates, the sign of the coefficient is positive.

As we mentioned in Section 2, there were two political and commercial changes in the *sake* brewing industry Thus we expect there would be at least two structural breaks in 1990s and 2010s. Before 1990s, unit value and income elasticity would have negative impact on the volume of *sake*. Before the old law was abolished, there were no incentives for *sake* breweries to brew and export premium *sake*. After the abolishment, the consumption volume of premium *sake* might increase. Then the sign of the coefficient on the real exchange rate *RER* would be positive because a higher real exchange rate encourages *sake* export to the US.

For all tables in this chapter, the number in parentheses is the standard error and the double asterisk ($**$) indicates that it is significant at 5% level. Based on the test resutss in Table 5.3, we identified two breaks in this model. These breaks happened in 1995.10 and 2018.01, which means that H1 is supported and we have three regimes: 1988.01-1995.09,

Table 5.4: Structural Breaks in *Sake* Export Volume

	1988.01-1995.09	1995.10-2017.12	2018.01- 2023.04
Constant	102.26^{**}	-21.78^{**}	25.85^{**}
	(0.32)	(0.14)	(0.22)
Unit	-0.38^{**}	0.20	0.70^{**}
	(0.18)	(0.13)	(0.31)
Income	-8.75^{**}	3.50^{**}	-0.50
	(1.30)	(0.33)	(0.63)
RER	-0.00	0.61^{**}	1.82^{**}
	(0.28)	(0.15)	(0.32)

1995.10-2017.12 and 2018.01-2023.04. Then we estimated regression models of the export volume with three economic variables, *Unit*, *Income* and *RER*, for three regimes. Table 5.4 shows the estimation results of regression models in these regimes.

Let us discuss the estimation results in Table 5.4. In the first regime (1988.01-1995.09), all parameters are significant. The coefficient of *Unit* and *Income* are both significant and have negative sign. In general, if demand for goods falls as its unit price rise, it is considered low-grade goods such as daily necessitiess. In addition, when the income increase and the amount of goods consumption decrease, such goods are regarded as inferior goods. The coefficient of *RER* is insignificant. From these findings, we may conclude that Japanese *sake* was regarded as lower goods by the US consumers under the old Japanese *sake* law. In the second regime (1995.10-2017.12), the coefficient for *Unit* is insignificant but that of *Income* is significant and its sign is positive. The change in the sign for *Income*, from negative to positive, indicates that the status of *sake* among the US consumers was raised from lower-class goods to higher-class goods. In the last regime (2018.01- 2023.04), the coefficient of income is insignificant but that of unit value is positively significant. This finding implies that, after 2010s, it does not depends on income but on unit value, and the increase of unit value has positive effect on the volume of *sake* export, which means that *sake* became luxury good. The aforementioned UNESCO registration of Japanese cuisine and the resulting increase in the number of Japanese

Table 5.5: Sequential SupF Test and UDmax Test of *Sake* Export Unit Value

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	73.76**	45.87**	35.42**	37.06**	36.16**
SupF (m+1|m)		23.98	44.03**	20.04	16.356
UDmax	73.76**				

restaurants are thought to contribute to this increase in volume. Thus both H2 and H3 are supported. Finally, H4 is partially supported by the finding that *RER* has a positive and significant impact on the export volume in the last two regimes.

Next, we estimated regression models of unit value in the same way. We constructed two hypotheses about this model.

H5 There exists at least two breaks in 1990s and 2010s.

H6 The signs of parameter for *Income* are positive in the earlier period but turn in negative in the later period.

Three breaks, 1995.09, 2003.04 and 2013.01, are identified by the SupF test as in Table 5.5. Thus we found an additional break compared to H5. The unit value of *sake* has changed since the mid-1990s, probably for the same reason as the volume. In the mid of 2000s, Some breweries, including *Asahi Shuzo*, which brews *Dassai*, established branches in New York City. The change in 2013 may be due to Japanese political changes and the UNESCO registration. Estimated coefficients in each regime are shown in Table 5.6. All coefficients are significant except for the constant term in the last regiem. It should be noted that the coefficient related to income is positive until 2013 and then it turns negative thereafter. These results imply that the income elasticity of *sake* export have changed. In other words, *sake* was not regarded as luxury goods in the first three regimes so that breweries could afford to raise the unit value even as the income rose. Nowadays, it would be fair to argue that it has become luxury goods so that breweries cannot raise the price even when the income is rising. Finally, we find *RER* has a negative and significant impact on the unit value during all periods.

Table 5.6: Structural Breaks in *Sake* Export Unit Value

	1988.01-1995.08	1995.9-2003.3	2003.4-2012.12	2013.01-2023.04
Constant	-16.13^{**}	-9.17^{**}	-21.34^{**}	1.54
	(5.33)	(1.86)	(3.35)	(1.54)
Income	1.40^{**}	0.71^{**}	1.98^{**}	-0.17^{**}
	(0.53)	(0.15)	(0.30)	(0.10)
RER	-0.50^{**}	-0.58^{**}	-0.35^{**}	-0.35^{**}
	(0.10)	(0.10)	(0.10)	(0.11)

Table 5.7: Descriptive Statistics of Regions

Variable	Mean	SD	Max	Min
$Nada_{volume}$	172,370	111,670	710,286	11,648
$Nada_{unit}$	5.18	2.16	9.72	2.10
$TheOthers_{volume}$	117.541	81,071	398,547	2,142
$TheOthers_{unit}$	9,29	3.07	16.11	2.46

5.5 Differences between Traditional *Nada* Region and the Others

Up to this section, we have treated *sake* as a single good. In fact, there are a wide variety of beverages called *sake* with different tastes and qualities. In particular, the grade of *sake* imported into the US is largely determined by the region where it was brewed. Scale and productivity of brewing differ significantly among *sake* breweries in different parts of Japan. As mentioned in the previous chapter, the *Nada* region is home to a handful number of large enterprises with equipment capable of mass production of *sake*, whereas the rest of the country is home to a large number of small and medium-sized breweries based on low-volume production. This is because the *Nada* region has been the center of the *sake* brewing industry since ancient times.

The export to the US is no exception. Figure 5.3 and Table 5.7 show the time trends

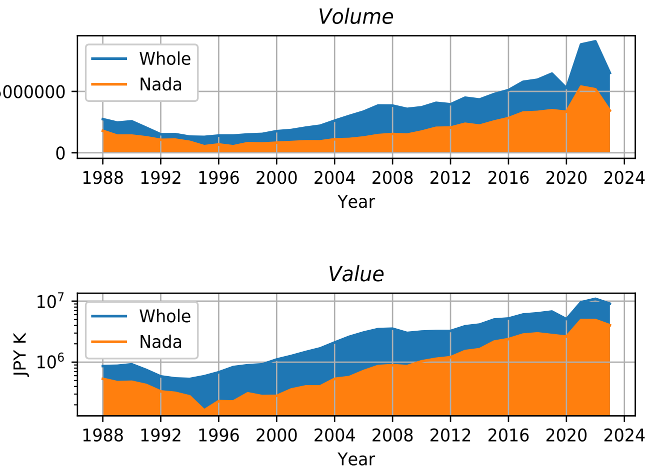

Figure 5.3: Whole Exports and *Nada* Exports to the US

Table 5.8: Sequential SupF Test and UDmax Test of *Sake* Export Volume (*Nada* Region)

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	25.85**	66.74**	70, 48**	56.63**	55.40**
SupF (m+1|m)		28.21**	25.46**	20.16	0
UDmax	88.64**				

Table 5.9: Structural Breaks in *Sake* Export Volume (*Nada* Region)

	1988.01-1995.06	1995.07-2009.02	2009.03- 2016.02	2016.03-2023.04
Constant	138.44**	-4.68	-15.66	15.53**
	(18.39)	(5.68)	(20.57)	(6.85)
Unit	-0.56	-0.15	-1.05	0.12
	(0.42)	(0.16)	(0.37)	(0.30)
Income	−12.21**	2.10**	2.89	3.61
	(1.82)	(0.52)	(1.86)	(0.56)
RER	0.15	1.15**	0.20	1.56**
	(0.34)	(0.27)	(0.31)	(0.35)

and the descriptive statistics of volume and value of *sake* shipments from the *Nada* region[9] and the other regions of Japan to the US. Figure 5.3 and Table 5.7 clearly demonstrate that the prowess of breweries in the *Nada* region dwarf breweries in the other regions in terms of volume and value. These numbers reveal how *sake* breweries in the *Nada* region have been playing a dominant role in *sake* export to the US. Breweries in the *Nada* region are characterized by their capacity that can produce and export low-priced *sake* in large quantities because of the industrial concentration that occurred as a result of business competition at a relatively early stage. Unlike the *Nada* region, in areas dotted with small and medium-sized businesses, breweries are exporting *sake* in small volume but with a reasonable level of added value. As if to vindicate this, the unit value is clearly higher for small and medium-sized enterprises than for breweries in the *Nada* region as shown in Table5.7.

As the next step of this study, we estimated structural break models of *sake* imported from the *Nada* region or the other regions with the same framework. Before estimating regression models for the *Nada* region and the other regions, we conducted the ADF test in the same framework as the model for the whole country and verified both volume and

[9]Most *sake* breweries in the *Nada* region export their *sake* through Kobe Customs. Therefore, this study uses volumes and values of *sake* exported from Kobe Customs as proxy variables.For the other regions, we subtracted the *Kobe* Customs statistics from the overall statistics

Table 5.10: Sequential SupF Test and UDmax Test of *Sake* Export Unit Value (*Nada* Region)

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	21.83	79.92**	82.65**	32.97	32.34
SupF (m+1|m)		12.05	3.30	2.00	0.45
UDmax	21.85				

unit value series are stationary.

Table 5.8 and 5.9 show sequential test results and estimation results of the volume model for the *Nada* region. From the results of sequential F tests, we find that $m = 3$ is suitable. The identified regimes are 1988.01-1995.06, 1995.07-2009.02, 2009.03-2016.02 and 2016.03-2023.04. Since the first regime of the *Nada* region is similar to that of the whole country in Table 5.4, the first break point in 1995 has similar implications as the whole country volume model. Until 1995, only *Income* is significant and has a negative sign, which implies that *sake* from the *Nada* region belongs to cheaper goods. After the abolishment of the old tax law mentioned in the previous section, the sign of *Income* changed positively. So it turned into more luxury goods. We observe that the amount of *sake* export sharply declined after 2009. The Japan Sake Brewers Association explains the cause of this as a significant decrease in *sake* export from the *Nada* region due to a series of bankruptcies of distributors handling *sake* just after the Global Financial Crisis in 2008. Thus, there is no significant coefficient in the post-crisis regime, and it can be said that the upward trend that had been continuing since 1995 came to a halt at that time. In the last regime (2016.03-2023.04), the coefficient of *RER* is positive and significant. This confirms that, after overcoming such a steep downturn, *sake* export to the US started growing again in this regime, benefiting from depreciation of the Japanese yen against the US dollar due to the QQE and the UNESCO registration of Japanese cuisine. One result that differs from the overall results here is that the impact of the Global Financial Crisis was not observed in the whole country case, whereas it was observed in the *Nada* region case.

It should be noted here that the coefficient of unit value is consistently insignificant throughout all regimes in the volume model as shown in Table 5.9. As mentioned earlier,

Table 5.11: Sequential SupF Test and UDmax Test of *Sake* Export Volume (Other Regions)

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	31.22**	45.61**	47.30**	47.15**	46.27**
SupF (m+1|m)		29.71**	20.24**	6.10	1.08
UDmax	91.24*∗				

Table 5.12: Structural Breaks in *Sake* Export Volume (Other Regions)

	1988.01-1994.09	1994.10-2003.09	2003.10-2023.04
Constant	12.47	−38.60**	16.64**
	(27.42)	(7.73)	(5.34)
Unit	−0.42**	-0.28	0.29
	(0.21)	(0.34)	(0.20)
Income	-0.09	4.50**	0.03
	(2.66)	(0.64)	(0.43)
RER	0.16	-0.60	1.21**
	(0.43)	(0.43)	(0.23)

sake breweries in the *Nada* region tend to brew *sake* in large quantities while keeping the price as low as possible, which points to the possibility that the unit value has not grown in relation to the increase in shipment volume. To confirm this conjecture, we tested some tests for the unit value of *sake* exported from the *Nada* region. Table 5.10 shows no break points for the unit value model of the *Nada* region, which the null hypothesis is not rejected by UDmax test. In other words, *sake* from the *Nada* region seemed less affected by the aforementioned tax law change, depreciation of the Japanese yen, or the UNESCO registration.

Finally, we estimated regression models for *sake* export from the other regions of Japan. Table 5.11 and 5.12 show some interesting results about the volume model for the other region. From the test results in Table 5.11, we find that $m = 2$ is suitable as the number of structural breaks in the volume model for the other regions. The regimes are 1988.01-1994.09, 1994.10-2003.09 and 2003.10-2003.04. In the first regime, we have

Table 5.13: Sequential SupF Test and UDmax Test of *Sake* Export Unit Value (Other Regions)

	m=1	m=2	m=3	m=4	m=5
SupF (m|0)	98.54**	40.13**	60.75**	66.16**	65.80**
SupF (m+1|m)		17.03	3.20	1.68	0
UDmax	80.91**				

Table 5.14: Structural Breaks in *Sake* Export Unit Value (Other Regions)

	1988.01- 1994.08	1994.09-2023.04
Constant	29.31	-18.94**
	(23.31)	(4.17)
Income	-1.81	3.21 **
	(2.31)	(0.31)
RER	0.11	0.72 **
	(0.47)	(0.21)

estimation results comparable to the whole country and the *Nada* region. Although only the coefficient of *Unit* is significant, its negative sign shows that *sake* was cheaper goods. In the second regime, *Income* changed to have a positive and significant impact upon the export volume, which means that the income elasticity of *sake* had changed. In the last regime, the coefficient of *RER* is significantly positive. A possible explanation for this result is that during this period some breweries started to establish their own branches and produce their brands of *sake* in the US.

. Table 5.13 and 5.14 show the results of structural break tests and the estimation results on the unit value model for the other regions respectively. For the unit value model, we find that $m = 1$ is suitable. The sole structural break occurred in August of 1994. In the second regime, the coefficient of *Income* and *RER* have a positive and significant impact on the export unit value, which implies that *sake* brewed in other regions still has some room for adding more value in the US market.

5.6 Conclusion

Sake, Japanese rice wine, now tremendously increases its consumption in the US. There are various factors behind this trend, including the influence of changes in taxation and the efforts of Japanese and U.S. breweries and distributors to export *sake* to the US.

In this study, we used multiple structural break models to estimate the number of breaks for the volume and unit value of *sake* export. As a result, we found that the abolishment of the old *sake* tax law, the UNESCO registration of Japanese cuisine and the Japanese government's monetary easing policy made a significant impact on structural changes for *sake* export to the US. By analyzing possible determinants of *sake* export, we found that the unit value of *sake* and the income level of the US have significant effects on the *sake* export. Especially, changes in the coefficient of the unit value as well as the income imply that in the sample period *sake* changed from necessary goods to luxury goods in the US market. This conclusion is also supported by the results of the unit value model. In addition, our analysis confirmed heterogeneity among *sake* brewed in different regions.

For further research, we need to classify types of *sake* imported to the US in detail since, as mentioned in Section 2, now Japanese *sake* breweries trying to increase production of luxury *sake*. The datasets we used in this study are only available annually, but not monthly. We hope the Japanese government will publish export volume data by type of *sake* as monthly time series data.

Chapter 6

Conclusion

In this dissertation, we conducted several quantitative analyses of the *sake* industry. Chapter 2 described the history of *sake* and as a result, identified why the *sake* industry is suffering overall today and what brewing techniques it possesses.

In chapter 3, we estimated a hedonic pricing regression model for *sake*. Taste indicators, premium categories, rice breeds, and regional dummies were used as explanatory variables in the hedonic pricing regression model as possible determinants of *sake* prices. In the estimated hedonic pricing regression model, the amount of sugar, which is negatively related to SMV, has a positive impact on the price; thus it can be inferred that Japanese consumers prefer sweeter *sake*. PRR has a negative impact on the price only if the *sake* is categorized as *junmai dai ginjo* (DG) "super premium" *sake*. This may imply that the costly polishing process is justified only for the most luxury category. DG was also found to be priced higher than other less luxury *sake*. Although some flavor indicators seem to influence *sake* prices, rice breeds and producing prefectures appear to have little to do with them. These results do not depend on whether regional dummies and/or rice breed dummies are excluded from the model or not. These results have many implications for us. Breweries and distributors could review their operations from these results, while consumers could gain insight into *sake* pricing.

In chapter 4, we analyzed the unbalanced panel of each country via hierarchical Bayesian modeling. As a result, we confirmed that the registration of Japanese cuisine as an intangible cultural heritage by UNESCO had a significant impact on *sake* export to some countries. It was also confirmed that both shipment volume and unit value were related to prices in each country. In addition, it was shown that shipment volume and unit value may differ depending on the season. Furthermore, when the data were analyzed separately by company size which depend on its region, it was confirmed that there was little reaction to the unit value in regions with a high concentration of large companies, while in regions with scattered small and medium-sized companies, the unit value was greatly affected by the exchange rate. So we identified heterogeneity between *sake* breweries.

In chapter 5, we used multiple structural break models to estimate the number of breaks for the volume and unit value of *sake* export to the US. As a result, we found that there were three main events that made a significant impacts on structural changes for *sake* export to the US: the abolishment of the old *sake* tax law, the UNESCO registration of Japanese cuisine and the Japanese government's monetary easing policy. By analyzing possible determinants of *sake* export, we found that the unit value of *sake* and the income level of the US have significant effects on the *sake* export. Especially, changes in the coefficient of the unit value as well as the income imply that in the sample period *sake* changed from necessary goods to luxury goods in the US market. This conclusion is also supported by the results of the unit value model. In addition, our analysis confirmed heterogeneity among *sake* brewed in different regions.

We do not think the harshness of the industry will improve so easily in the future. However, as this dissertation has shown, some potential exists for brewing and marketing high-quality, high-value-added products and for exporting them.

In summary, the recommendations for the *sake* industry derived from this dissertation are as follows

1. When brewing and selling high value-added products, pricing should take into account the rank and taste of the *sake*

2. Identify export trends by country and promote exports to areas where trends appear to be high

3. Exports are easily influenced by national policies and international events, so be

sensitive to these developments, and identify what regions the *sake* brewery belongs to.

Finally, we hope that this dissertation will lead to the development of the sake industry.

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