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Agglomeration Economies, Mechanization, and Changes in Product Quality: An inquiry into the post-war development of the Sake brewery clusters in Japan, 1980-2020*

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Abstract

While agglomeration economies contribute to the performance of clustered firms, their changing roles are rarely analyzed. This study explores how technology choices and changing nature of agglomeration economies affected firm performance in the Japanese sake (rice wine) brewing industry from 1980 to 2020. Using plant-level data, we find that agglomeration benefits arose from the sale of sake from small unknown firms to large established firms when production was labor-intensive, but its role diminished as scale economies emerged with mechanization. As demand for high-quality sake increased, collective internalization of information spillover benefits appears to become a major source of agglomeration economies.

Keywords: Agglomeration, Technology Choice, Product Quality, Innovation, Collective Action
JEL classification: L66, N65, O14, R11

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1. Introduction

The vital role of industrial clusters in industrial development has been increasingly recognized through an accumulation of empirical studies. Alfred Marshall (1920) was the first economist to identify the three advantages of industrial clusters, called Marshallian agglomeration economies: (1) information spillover, (2) specialization and division of labor among firms, and (3) the development of a skilled labor market. Empirical studies reveal that the development of many manufacturing industries in Japan, Europe, and China is assisted by the development of industrial clusters (Piore and Sabel 1984; Sabel and Zeitlin 1999; Ruan and Zhang 2009; Hashino and Otsuka 2016). In developing countries in Asia and Africa, clusters consisting of small firms have emerged, where the imitation of pioneering firms by new entrants has driven the formation of industrial clusters (Huang and Bocchi 2008; Sonobe and Otsuka 2006, 2011, 2014). Thus, agglomeration economies undoubtedly confer advantages to clustered firms to achieve high performance, thereby fostering industrial development.

Despite this widely shared recognition, much less is known about how the role of agglomeration economies changes over time. Indeed, a large number of the existing studies have found high performance of firms in industrial clusters based on short-term or cross-sectional observations. Yet, industrial clusters tend to undergo significant transformation during long-term economic development. For instance, in Taiwan's machine tool industry, the flexible division of labor within industrial clusters has become increasingly important as product quality improves (Amsden 1992; Hobday 1995; Sonobe et al. 2003). In the case of weaving clusters in pre-war Japan, labor-saving power looms were rapidly introduced as wages increased, enabling firms to enjoy scale economies and reshape the division of labor (Hashino and Otsuka 2016; Okazaki 2021). In addition, it has been widely observed that formerly stagnant clusters develop by achieving multifaceted innovations in production, marketing, and firm management, particularly in the product quality improvement phase (Sonobe et al. 2004; Scott 2006; Fleisher et al. 2010). Such innovative changes are often driven by local collective action, which internalizes the external benefits of information spillovers within a cluster (Nadvi 1999; Boschma and Frenken 2011; Hashino and Kurosawa 2013). These examples suggest that the role of agglomeration economies varies during different development phases. To the best of our knowledge, however, this process has seldom been analyzed using firm-level long-term data.

This study explores how technology choices and the changing nature of agglomeration economies affect firm performance based on the long-term development of the Japanese sake (rice wine) brewing industry from 1980 to 2020. The historical experience of the sake brewing industry provides an appropriate context for analyzing these relationships, for several reasons. The sake brewing industry, one of the largest manufacturing sectors in pre-war Japan, formed nationwide industrial clusters and contributed to Japan's industrial development (Shinbo 1962). In the post-war period, however, this industry experienced rapid changes in technology from skilled worker-based production to mechanized production, and in market demand from low- to high-quality sake during the process of miraculous economic development in Japan.

Using unique plant-level data from 1980 to 2020, including information on inputs, outputs, and geographical characteristics, we analyze the determinants of firm performance across different phases. We found that inter-firm transactions in which large established firms purchase sake from small, unknown firms and sold it using their brand names were active within the cluster. Such transactions occurred because the production process was skilled labor intensive and subject to scale diseconomies, even for relatively large firms. After scale economies emerged through mechanization, large firms independently mass-produced low-quality sake, thereby diminishing the role of inter-firm sake transactions. In recent years, as consumer demand for high-quality sake significantly increased, some small firms have successfully improved the quality of sake by adopting skilled labor intensive production methods and collectively internalizing the benefits of information spillovers within the cluster. These findings suggest that the role of agglomeration economies in firm performance changes over the different phases of industrial development.

The remainder of this article is organized as follows. The next section provides a historical overview of the post-war development of the sake brewing industry in Japan, focusing on the differences and changes in production characteristics across major brewing clusters. In Section 3, we present the testable hypotheses. Section 4 describes our data and reports the summary statistics on firm characteristics. Section 5 describes the regression models and explains the empirical results with robustness checks. We conclude by summarizing the major findings and deriving their implications in Section 6.

2. Overview of the sake brewing industry

2.1. Historical development of the sake brewing industry

The sake brewing industry developed as one of the most important industries in pre-war Japan, not only because it was a large manufacturing sector, but also because it was a major source of tax revenue. In the late nineteenth century, sake accounted for 16% of Japan's total industrial production, and its liquor tax was the largest source of tax revenue (Ministry of Finance 1969).

After World War II, rapid economic growth led to a significant increase in the demand for sake in Japan, which particularly increased sake production from the 1950s to the 1970s (Aikawa 2024). Under this production expansion, a unique “subcontracting” system in the sake brewing industry, which was called *oke-torihiki* (meaning transaction by the tub), played an important role. In this transaction, large local firms with established brand names partly relied their production on small firms, which brewed and sold sake to large firms (Morimoto and Yakura 1998). This transaction was beneficial when the sake brewing industry was skilled labor intensive, and thus production was subject to scale diseconomies, even for large firms at that time that had high selling capacity due to their established brands.[2] This type of inter-firm transaction has been observed not only in the sake brewing industry in Japan but also in other industries, particularly in the final consumer goods industry.[3]

After the 1980s, the sake brewing industry experienced significant market changes. Figure 1 depicts the changes in the number of sake brewing plants and the total quantity of sake production in Japan from 1980 to 2020. The number of plants steadily declined during this period, indicating the industry's maturation phase. The production quantity stagnated during the 1980s and the early 1990s before declining sharply. This reflects the increased competition for sake with a growing variety of other alcoholic beverages such as beer, wine, and whiskey (Miyamoto 2010). As we show below, large firms adopted mechanized production processes to pursue the mass production of sake in this period. Small firms that could not afford such expensive machinery became increasingly bankrupt (Aikawa 2024).

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[2] This transaction benefited both large firms and small firms without established brand names, as they could secure sales channels (Oshima 2009).
[3] Examples include the cotton weaving industry in pre-war Japan (Abe 2022), cashmere weaving and shoemaking industries in contemporary China (Wang 2010; Xu and Zhang 2010), and wine industry in Australia and other countries (Rainer et al. 2023).

Figure 1 shows that sake production began to decline during the mid-1990s. This trend coincides with the change in consumer preference for high-quality sake, spurred by the introduction of the premium sake qualification system by the central government in 1993, which established rigorous quality standards. Prior to this reform, the quality of sake was ambiguous, relying on subjective measures, such as the color and flavor of sake (Morimoto and Yakura 1998). Based on the new qualification system, the quality of the raw material rice used and the amount of shaving it became the critical determinants of high-quality sake, called premium sake (National Tax Agency 2024). Since the rice used for brewing high-quality sake, known as sake rice, is produced by more specialized and labor-intensive methods than ordinary rice, it is notably expensive (Hyogo Sake Rice Research Group 2010).[4] Concomitantly, consumer preferences gradually shifted from low- to high-quality sake.

Meanwhile, the increasing demand for high-quality sake significantly influences firm survival patterns. Table 1 presents the changes in the number of firms by firm size in selected years from 1981 to 2017. Large firms are defined as

[4] Sake rice is characterized by its large grain size. To brew high-quality sake, grains of raw-material rice must be shaved significantly, and thus ordinary rice is easily cracked because of its smaller grain size compared to sake rice (Hyogo Sake Rice Research Group 2010).

those with initial capital exceeding 300 million yen or employing more than 300 workers, whereas small and medium-sized firms are defined as those that do not meet either of these criteria.[5] It seems clear that the sake brewing industry is comprised of a small number of large established firms and a large number of small unknown firms. During the 1980s and the early 1990s, the number of non-corporate, small and medium-sized firms decreased. While the exact number of large firms is unknown, their numbers appear to have remained stable (National Tax Agency 1980 - 2020). This stability indicates that the decline in the number of firms during this period is largely attributable to the exit of small and medium-sized firms. Since the late 1990s, however, the number of large firms has declined sharply, suggesting that large firms cannot survive by simply pursuing mass production.

Although the trend of declining sake production has persisted, there was a notable shift in consumer demand in the 2010s in favor of high-quality sake. Indeed, the market share of premium sake expanded significantly from approximately 10% in the 1990s to nearly 50% in the 2010s (National Tax

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[5] Based on the Small and Medium-Sized Enterprise (SME) Basic Act in Japan, firms in the manufacturing sector are classified as SMEs if they do not meet either of these criteria. In this study, since over 99% of the sake brewing firms consists of micro-enterprises, we classify firms meeting even one of these criteria as large firms.

Agency 2024), suggesting the decisive importance of quality improvement in sake production under changing market demand conditions. The slow decline in the number of firms, especially after the late 2000s (see Figure 1 and Table 1), indicates that firms that successfully improved sake quality were likely to survive. As we explain later, only small firms that use skilled labor intensive production methods can improve sake quality. Large firms continued to produce low-quality sake and decreased their market share, suggesting that a transformation of the sake market occurred during this period.

2.2. The location of sake brewing clusters in Japan

Sake brewing plants are located throughout the country and clustered in specific areas within their respective prefectures. Figure 2 shows the average number of sake brewing plants in each prefecture. This was calculated by taking the average number of sake brewing plants in each prefecture from 1980 to 2020, with dark-colored areas representing prefectures where the plants are highly concentrated. Hyogo, Kyoto, and Niigata prefectures have the densest agglomerations of sake brewing firms. These prefectures contain famous sake brewing clusters such as *Nada* in Hyogo prefecture and *Fushimi* in Kyoto prefecture.[6] These three prefectures consistently accounted for approximately 50% of sake production in Japan between 1980 and 2020 (Ministry of Economy, Trade, and Industry of Japan 2020).

Sake brewing clusters developed in these three prefectures, partly because of their geographical advantages. In addition to maritime access for shipment, cold climates in mountain valleys and the availability of essential resources such as high-quality sake rice and clean spring water are crucial for ensuring high-quality sake. Furthermore, and most importantly, a skilled labor market has developed in these three prefectures. The production of high-quality sake requires skilled sake brewers (called *Toji*) who are technically responsible for sake brewing. Historically, farmers began sake brewing as a side business during the slack winter months. As these three prefectures are covered by heavy snow in winter, many farmers engage in sake brewing, leading to the development of a skilled labor market since the pre-war period (Yunoki 1965).

2.3. Mechanization and declining role of inter-firm transactions

[6] In Niigata prefecture, many small sake brewing firms are uniformly located rather than concentrated in specific areas.

Table 2 presents a comparison of sake brewing firms' characteristics for the top three prefectures and the average for other prefectures in the selected years from 1984 to 2020. According to this table, the Hyogo and Kyoto prefectures are characterized by large sales shares and average sales per plant since the 1980s. In 1984, the average sales per plant in Hyogo was 3,393.9 kiloliters, which was significantly higher than the 2,304.7 kiloliters in Kyoto, and both far exceeded Niigata's 510.3 kiloliters and average in other prefectures. Such significant disparities in average sales per plant persisted throughout the subsequent periods.

The dominance of large-scale clusters in Hyogo and Kyoto prefectures in the early period is attributed to the importance of inter-firm sake transactions in sales expansion. The last column in Table 2 shows that both the Hyogo and Kyoto prefectures had a large average purchase quantity per plant, particularly in the early 1980s. In 1984, the average purchase quantity of the breweries located in Hyogo prefecture was 847.7 kiloliters, and 773.5 kiloliters in Kyoto prefecture, far exceeding the other prefectures. In the 1980s, the optimum scale of production was not large, even for large firms, because of limited mechanization of production processes, whereas the optimum scale of sales was large because of established brand names. Thus, large firms prefer to purchase sake from small firms for their sales.

In this transaction, geographical proximity played a crucial role in reducing transaction costs, such as the monitoring costs of contract enforcement and the transportation costs of raw sake. In fact, famous large firms in Hyogo prefecture stated that they used non-mechanized production processes, and thus it was efficient to purchase sake rather than expand its own production (Hakutsuru Sake Brewing Company 1977; Nishinomiya Sake Brewing Company 1989). Furthermore, large firms regularly visit small local firms to check whether the quantity and quality of raw sake meet their quality requirements (Editorial Office of the Journal of the Brewing Society of Japan 1971). Similar to other case studies of the post-war development of the manufacturing industry in Japan (Asanuma 1989; Kawasaki and McMillan 1987; Yamamura et al. 2005), it seems clear that industrial clusters are important in facilitating inter-firm transactions among the firms.

Subsequently, the large market share of Hyogo and Kyoto prefectures was maintained by the significant progress of mechanization in production processes. Owing to the rapid growth in wage rates in the 1980s, labor-saving technologies became important for sake brewing firms to increase their profits, which led to the adoption of labor-saving machinery (Sakurai 1981).[7] In addition, large-scale firms jointly developed these machines. For example, workers at large-scale firms in the *Nada* cluster in Hyogo prefecture actively share information on mass production technologies (Morimoto and Yakura 1998). This case demonstrates the existence of technological spillovers within a cluster. Because such machinery is expensive, only large firms have introduced mechanized brewing methods, enabling the mass production of sake with high labor productivity. As the optimum scale of production increases, large firms expand their production, leading to a decline in inter-firm transactions in the subsequent period (see Table 2). This suggests that the agglomeration benefit arising from inter-firm transactions is diminished by the mechanization of production processes.

2.4. Changing demand for sake quality

[7] Mechanization in sake brewing includes processes such as rice polishing, fermentation control, and temperature management (Aikawa 2024), though information about the types of machinery introduced at each plant is unavailable.

Mass production of sake using labor-saving technology was chosen at the expense of quality. Figure 3 shows the changes in the real price per kiloliter of sake among the prefectures, which is a proxy for sake quality. According to this figure, Hyogo and Kyoto produced sake at higher prices than other prefectures in the early 1980s; however, this price gap diminished and was eventually surpassed by other prefectures. Originally, Hyogo and Kyoto prefectures produced high-quality sake, benefiting from geographical advantages and the availability of skilled labor (Yunoki 1965). Since consumer demand for low-quality sake increased during this period, the role of skilled sake brewers diminished.[8] Although large firms have attempted to incorporate production techniques and the experience of skilled labor into the mechanized production process, they have not been successful. Thus, large firms employed fewer, less expensive unskilled workers who can operate machinery (Morimoto and Yakura 1998; Ozeki Company 2014).

[8] Furthermore, since high-quality sake rice is hard to handle by machinery, large firms began to use cheap sake rice as a raw material for brewing. According to our interviews with representatives of the Nada Sake Brewers' Association on October 21, 2021, many large firms in *Nada* in Hyogo prefecture used cheap raw-material rice and adopted labor-saving technologies to reduce production costs in this period.

Since the 1990s, however, consumer demand has gradually shifted from low- to high-quality sake. As shown in Figure 3, the sake price in Niigata and other prefectures gradually increased, whereas prices in Hyogo and Kyoto stagnated during the same period. This emerging price difference among prefectures can be attributed to differences in production techniques. According to Shinoda (1981), brewing high-quality sake requires traditional, skilled labor intensive production methods. As seen in other traditional industries, small firms that rely on skilled labor intensive traditional technologies have a comparative advantage in producing high-quality products (Hashino and Otsuka 2016).

An important question is how small sake brewing firms improve sake quality. The private benefit for an entrepreneur who succeeds in quality improvement is lower than the social benefit owing to imitation by other firms within the cluster. Thus, private incentives for innovation tend to be weak in clusters (Sonobe and Otsuka 2014). To overcome this market failure, local sake producers in small-scale clusters organized collective actions aimed at internalizing the external benefits of information spillover. For instance, the Niigata Sake Brewers' Association organized technical exchange meetings and offered member firms training to improve brewing techniques.[9] In addition, they collectively established educational institutions to train skilled sake brewers (Niigata Sake Brewers' Association 2003). Efforts to improve the quality of sake through local collective action have also been observed in small-scale clusters in prefectures such as Akita, Saitama, and Shiga (Kimura 2015; Ono 2019).[10] In short, institutions that support multifaceted innovation play a crucial role in quality improvement, as seen in recent empirical studies focusing on the development of other industrial clusters (Nadvi 1999; Boschma and Frenken 2011; Hashino and Kurosawa 2013).

In the 2010s, consumer preferences for high-quality sake mainly produced by small firms, continued to increase. Figure 3 shows that real sake prices increased not only in small-scale clusters (see Niigata and other prefectures) but also in large-scale clusters, reflecting their attempt to improve quality. In fact, many large firms in Hyogo and Kyoto prefectures shifted their

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[9] These attempts to enhance cluster competitiveness through collective actions in education, research, and marketing also exist the wine industry (Cusmano et al. 2010; Anderson 2011; Giuliani et al. 2011).

[10] In large-scale clusters like *Nada* in Hyogo prefecture, firms attempted to collectively improve sake quality since the 1990s, without much success (Hyogo Sake Rice Research Group 2010). This may have been due to the large scale of each brewer, which fostered a strong competitive relationship in terms of market share. Unlike smaller-scale clusters, where firms had limited market shares, large firms had less incentive to cooperate as they are market rivals.

strategy to producing high-quality sake by establishing regional brands through collective efforts after the 2010s (Akashi 2017).

As collective quality improvement progresses, product differentiation within clusters has intensified in recent years. Small firms began to produce sake of slightly different qualities from other local firms to emphasize their uniqueness. For example, some firms have begun cultivating sake rice themselves to produce higher-quality sake than that of other firms. Others have succeeded in producing high-quality sake at a lower cost through technological innovations in quality control systems (Yamagiwa et al. 2023).

Note that Hyogo and other prefectures experienced a rapid decline in sake prices in 2020, whereas Kyoto and Niigata prefectures slightly increased their sake prices (Figure 3). This was because the Covid-19 pandemic significantly decreased sake sales in Japan (Goto 2023). Kyoto and Niigata, which increasingly produced high-quality sake in recent years, seem less affected by this pandemic. In contrast, Hyogo prefecture, where low-quality sake is still produced, and many other prefectures with only a few breweries producing established brand name sake, appeared to have discounted the price of their sake to sustain sales value.

3. Testable hypothesis

From an overview of the development of the sake brewing industry, it is clear that technology choice plays an important role in firm performance. The shift from labor-intensive to labor-saving technology, which was likely induced by a rapid increase in the wage rate, was critically important in production expansion until the 1990s. However, the importance of labor-saving technology for mass production decreased after the 2000s, when skilled labor intensive production for high-quality sake became increasingly important. These observations suggest the following hypothesis with the capital-labor ratio is a proxy for mechanization.

Hypothesis 1: The effect of the capital-labor ratio on the real value of production decreases over time because skilled labor intensive production for high-quality sake became more important.

When the production process was largely skilled labor intensive in the 1980s, large firms did not expand their sales without sake purchasing from small local firms because of scale diseconomies in production. Based on

Marshall's (1920) seminal argument,[11] industrial clusters play an important role in inter-firm transactions by reducing transaction costs between large purchasing firms and small subcontracted local firms. After the introduction of the mechanized production method, however, large firms reduced their purchases. This is because the scale economies arise from mechanization; thus, the optimum scale of production has increased. Indeed, the theory of efficient scale of firms formulated by Romer (1990a, 1990b) argues that results of R&D, such as large mechanization of production processes, will increase the minimum efficient size of the plant. We summarize these arguments in the following hypothesis.

Hypothesis 2: When sake production is skilled labor intensive, the size of agglomeration is positively associated with sake purchase. This relationship subsequently disappears as scale economies in production arise.

Originally, large firms in the Hyogo and Kyoto prefectures produced high-quality sake until the 1980s, benefiting from the developed skilled labor market and geographical advantages for brewing high-quality sake. After the 1990s,

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[11] Marshall, however, considered vertical division of labor among firms, rather than "horizontal" division of labor among firms producing a final consumer good.

however, they began concentrating on mass-produced, cheap sake, thereby diminishing the role of the skilled labor market. Meanwhile, small firms in Niigata and other prefectures that have a comparative advantage in skilled labor intensive production produce small quantities of high-quality, expensive sake. Thus, we propose the following hypothesis.

Hypothesis 3: Firm size is positively associated with sake price in the early period and negatively associated in the later period.

Support for this hypothesis would suggest that technological progress for quality improvement can be labor intensive, which has rarely been discussed in past studies.

Based on the discussion thus far, it seems that the product qualities of firms within a cluster tend to be similar owing to information spillovers and imitation. In large clusters, many firms produce mass-produced sake using labor-saving production methods, whereas in smaller clusters, firms pursue the production of high-quality sake using labor-intensive production methods. In addition, in recent years, small firms have tended to improve sake quality by collectively internalizing the external benefits of information spillover within the cluster. This conjecture aligns with the argument of Rigby and

Essletzbichler (2006), who suggest that similar production methods tend to be adopted within the same industrial cluster, while different production methods are employed across different clusters. As product quality collectively improves, firms within the same cluster begin to differentiate the quality of their sake. This suggests that the product prices within the same cluster have gradually diverged in recent years. Therefore, it seems reasonable to hypothesize the following.

Hypothesis 4: Because of information spillover and local collective action, firms in the same cluster had nearly uniform product prices in the early period. As quality improvement progressed, product prices within the same cluster diverged over time.

4. Data

We use plant-level data collected by the Ministry of Economy, Trade, and Industry of Japan from 1980 to 2020. The data is sourced from the Census of Manufacture, an annual survey that provides a comprehensive coverage of manufacturing plants across Japan.[12] Attrition in the dataset primarily reflected business closures or mergers, whereas newly established plants are added to preserve the representativeness of the survey. The census captures detailed information on inputs, outputs, and transaction status, and offers valuable information on the production characteristics of sake brewing plants.

Table 3 presents the descriptive statistics of sake brewing plants and geographical characteristics for three periods: (1) 1980–1992, (2) 1993–2009, and (3) 2010–2020. The number of observations declines significantly across the periods, reflecting a rapid decrease in the number of firms, as illustrated in Figure 1. The average real price per kiloliter of sake shows an upward trend, rising from 52.75 yen in the first period to 90.32 yen in the final period. This demonstrated the increasing importance of high-quality products. The mean purchase value, which is the proxy for the quantity of inter-firm transactions, increases across periods, rising from 189.72 thousand yen to 715.03 thousand yen. Nonetheless, this trend is partly due to a decline in the number of firms rather than an increase in the total quantity of purchased sake. Supporting this

[12] The survey conducted in 2012 and 2016 was jointly carried out with the Ministry of Internal Affairs and Communications as the Economic Census for Business Activity.

conjecture, the maximum purchase value declined across periods, indicating that the quantity of purchased sake has decreased, even among large surviving firms.

5. Regression analysis

5.1. Model specification

To test Hypotheses 1–4, we specified the following regression function:

$$Y_{impt} = \alpha_0 + \alpha_1 KLratio_{impt} + \alpha_2 Labor_{impt} + \alpha_3 Agglomeration_{mpt-1} + \gamma_p + \varepsilon_t + u_{impt}, \quad (1)$$

where *i* refers to the plant; *m* and *p* refer to the municipality and prefecture, respectively; and *t* refers to the year. The dependent variable Y includes the production value per worker, price of sake, value-added per worker (only available after the 2000s), and sake purchases. The regressors include the capital-labor ratio, amount of labor (a proxy for firm size), and agglomeration variables. To identify the key aspects of agglomeration, we decompose the agglomeration variables into the following three components: (1) number of firms in the same municipality, (2) average number of workers in sake brewing firms within the same municipality, and (3) average price of sake in the same municipality. We lag all indicators of agglomeration by one period to avoid the possibility of reverse causality from firm-level performance to agglomeration. Since firm names cannot be identified, firm fixed effects cannot be included. Instead, we include prefecture and year fixed effects to account for unobserved heterogeneity across prefectures and time. All dependent and independent variables are log transformed.

We estimate the above equation separately for three periods: (1) the period before the introduction of the premium sake qualification system from 1980 to 1992, (2) the early period after the introduction of this system from 1993 to 2009, and (3) the period of rapid demand increase in high-quality sake from 2010 to 2020. As a robustness check, we estimate an alternative segmentation of the periods.

5.2. Results

Table 4 presents the estimation results. Columns (1)–(3) indicate the determinants of production per worker. The coefficients of the capital-labor ratio are consistently significant but decrease over time, which supports our first hypothesis that skilled labor intensive technology for producing high-quality sake has become more important.[13] It is also evident that the coefficient of labor is positively significant across all periods, indicating the consistent existence of scale economies in production. To consider the input value, which is not considered in production per worker, we also present the determinants of value-added per worker after the 2000s in Columns (7) and (8). The results show that the coefficients of the capital-labor ratio decrease over time, which demonstrates the robustness of our first hypothesis.

Columns (4)–(6) in Table 4 present the determinants of the sake price. The coefficient of labor, which is a proxy for firm size, has changed over time. Initially, firm size was positively associated with price, indicating that large firms produced high-quality sake by using skilled labor intensive production methods. This effect weakened in the second period and has a negative correlation with the price in the final period, supporting our third hypothesis. These findings indicate that small firms have successfully improved sake quality in response to the rising consumer demand.[14] The average sake price in

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[13] Although the capital-labor ratio could be potentially endogenous, as long as the extent of estimation bias does not change over time, one can assume that a significant change in the relationship with the dependent variable signals a major change in the production method.

[14] Although the fixed effects model separates the effects of time- and prefecture-invariant unobservable factors and alleviates omitted variable bias, the endogeneity problem in firm size is not fully addressed. To address this concern, we use an instrumental variable (IV) approach where we instrument firm size by the total number of workers in other firms

the same municipality was positively correlated with the price of the own-produced sake throughout all periods, supporting our fourth hypothesis on information spillover and collective action. Initially, the coefficient is not significantly different from unity, suggesting that information spillovers and collective action facilitate the production of similar quality sake among clustered firms. As the coefficient decreases over time, it can be assumed that the product quality within the cluster has differentiated in recent years. Note that the coefficients of the number of firms in a municipality on the sake price are consistently negative and increase over time. This finding seems to indicate that large-scale clusters increasingly shifted toward the production of lower-quality sake.

Table 5 shows the determinants of sake purchase. The first three columns present the results of ordinary least squares (OLS) estimation. The dependent variable is unity if the firm purchases sake from other firms and zero otherwise. The coefficient for the number of firms within the same municipality is positively associated with sake purchases in the first period, but became

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within the same municipality. This approach helps mitigate potential bias by leveraging the variation in local labor markets that is exogenous to individual firm decisions. The unreported results are consistent with those in Tables 4 and 5.

insignificant in subsequent periods. These results are consistent with our second hypothesis, suggesting that geographical proximity among firms promotes sake purchase when the production method is labor-intensive. It is worth pointing out that the coefficient of labor was positive and significant in all periods, indicating that large firms continued purchasing sake regardless of changes in production methods. Additionally, the results show that the average number of workers in an agglomeration is positively associated with sake purchases, which supports our discussion that sake purchases are more active in agglomerations where large-scale firms are located. To provide robust evidence, we conduct the same regression using a probit model, the results of which are presented in Columns (4) to (6). These results are consistent with those in Columns (1) to (3). The number of firms within the same municipality is statistically significant only in the first period, whereas the coefficient of labor remains consistently positive and significant across all periods.

5.3. Robustness check

The results in Table 4 include prefectures with a small number of firms, where the role of agglomeration is likely to be negligible. To address this concern, we restrict the sample to the top three sake brewing prefectures, Hyogo, Kyoto, and Niigata, where firms are more agglomerated than in the other prefectures. The estimated results are listed in Table 6. The magnitudes of the coefficients and their significance are consistent with those in the full-sample analysis presented in Table 4. Notably, from Columns (1) to (3), the coefficients of the capital-labor ratio remain larger than those in the full-sample analysis, even in the later phases. This suggests that labor-saving production methods continue to play an important role in sake production in the top three prefectures. In addition, a strong negative relationship between the average municipal price and production is evident in Columns (2) and (3). This finding indicates that, in the top three prefectures, there is a clear distinction between municipalities focusing on the mass production of low-quality sake, and those producing limited quantities of high-quality sake.

Another concern in our estimation is that municipalities with only one firm were included in the full-sample analysis, making it impossible to assess the effects of agglomeration. To understand the relationship between agglomeration and firm performance, we restrict the sample to municipalities with at least two firms and conduct the same estimation. The estimation results in Table 7 are generally consistent with those in Table 4, indicating the robustness of our results. Another point worth mentioning is that the relationship between the average municipal price and production per worker was not statistically significant in the last period, while the direction of the relationship remained consistent with the full-sample analysis. This is likely because municipalities with only one firm that produced high-quality sake in small quantities were excluded from the sample.

The remaining concern is that the period segmentation in our analysis may be arbitrary. To address this concern, we examined whether our findings remained robust during alternative periods. Table 8 presents the estimation results for the different periods of segmentation. First, we conduct a full-sample analysis by aggregating data from all years. The estimation results shown in Columns (1) to (3) are consistent with our discussion thus far. Regarding the price of sake, a positive and significant coefficient of labor suggests that large firms primarily pursued the production of high-quality sake for most periods from 1980 to 2020.

Second, we examine the performance of clustered firms by aggregating all the years after the introduction of the premium sake qualification system in

1993. Columns (4) and (5) present the estimation results. According to column (5), a negative relationship between price and firm size is not observed, suggesting that small firms did not immediately succeed in producing premium sake following the policy change.

Third, we split the sample into early (1980–1999) and later (2000–2020) periods to compare the differences in the magnitude of the coefficients. This is because the central government may have endogenously determined the timing of the 1993 policy change. The results in Columns (6) to (9) qualitatively show that our previous findings remain robust. Moreover, the effect of firm size on real sake prices is negative and significant after 2000. This indicates that small firms attempt to improve sake quality, whereas large firms pursue the production of inexpensive, low-quality sake.

Finally, we consider the potential effects of the COVID-19 pandemic on the sake brewing industry. Because the first state of emergency in Japan was declared in April 2020, we exclude this year from our sample to examine whether the observed trends are affected by the pandemic. The results shown in Columns (10) to (12) align with our previous findings. Therefore, the changing determinants of clustered firm performance were primarily driven by changes in the structure of the sake brewing industry rather than by temporary pandemic effects.

6. Conclusion

While many studies have attempted to assess the role of agglomeration economies on firm performance based on short-term observations, few explored how and why this role changes during the long-term process of industrial development. This study investigates how technology choice and the changing nature of agglomeration economies affect firm performance, based on the historical experience of the Japanese sake (rice wine) brewing industry from 1980 to 2020. Using unique plant-level data from the sake brewing industry, we find that the role of agglomeration economies in firm performance changes over the different phases of industrial development. When production was largely skilled labor intensive, agglomeration played an important role in stimulating inter-firm transactions of sake between large established firms and small unknown firms. After the 1980s, the technology choice of the labor-saving production method enabled large firms to produce mass-produced, low-quality sake. As the optimum scale of production increased through mechanization, large firms expanded their production, leading to a decline in inter-firm transactions. In recent decades, the increasing consumer demand for high-quality sake has led to the rise of small firms that use skilled labor intensive production methods. Such quality improvement was achieved through collective action within the cluster, such as quality checks and technical exchanges by local associations which attempt to collectively internalize the external benefits of information spillovers.

One crucial finding of this study is that the horizontal division of labor in production and sales plays a significant role in the development of industrial clusters. Marshall (1920) assumes a vertical division of labor among firms rather than a horizontal division of labor among firms that produce final consumer goods. In the manufacturing industries envisaged by Marshall, inter-firm transactions primarily occur in business-to-business transactions, where purchasing firms have knowledge of product quality. In contrast, for consumer goods, transactions are business-to-consumer, and general consumers often lack sufficient knowledge to assess product quality. This finding highlights the importance of marketing systems and branding in conveying product quality to consumers. A major future issue is to explore where and to what extent such a division of labor exists and how important it is in cluster development.

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Table 1. Changes in the number of sake brewing firms by size, 1981 - 2017

	1981	1991	1999	2005	2011	2017
Large firms	-	-	26	16	14	12
Small and Medium firms (Corporate)	-	-	1,854	1,613	1,451	1,326
Small and Medium firms (Non-Corporate)	236	182	135	108	84	67

Notes: Authors' calculation based on the data provided by the National Tax Agency. Large firms are those with initial capital exceeding 300 million yen or employing more than 300 workers, whereas small- and medium-sized firms are defined as those that do not meet either of these criteria. Small- and medium-sized firms are divided into corporate firms (legal entities) and non-corporate firms (individual proprietorships). The numbers of large, small, and medium-sized corporate firms before 1999 were unavailable.
Sources: Seishu Seizo-gyo no Gaikyo (1981 – 2017).

Table 2. Comparison of sake brewing firm characteristics in the top three prefectures in selected years from 1984 to 2020

	Sales share (%)	Average sales per factory (kl)	Average purchase per factory (kl)
1984			
Hyogo	32.2	3,393.9	847.7
Kyoto	11.1	2,304.7	773.5
Niigata	3.1	510.3	15.8
Average in other prefectures	-	421.9	0.9
2001			
Hyogo	32.8	2,880.1	426.4
Kyoto	13.8	2,290.7	291.6
Niigata	5.9	647.2	20.4
Average in other prefectures	-	298.8	0.6
2017			
Hyogo	32.7	2,353.9	390.0
Kyoto	15.1	1,792.1	76.3
Niigata	7.9	512.0	37.0
Average in other prefectures	-	187.8	0.2
2020			
Hyogo	29.4	1,708.0	-
Kyoto	13.6	1,379.4	-
Niigata	7.2	388.4	-
Average in other prefectures	-	179.5	-

Notes: Authors' calculation based on the data provided by the Ministry of Internal Affairs and Communications and the Ministry of Economy, Trade and Industry. The availability of data on purchase amounts is limited to 1984–2017.
Sources: Kogyo Tokei Chosa–kekka Hokoku (1984 – 2020).

Table 3. Descriptive statistics by period

	1980 - 1992				1993 - 2009				2010 - 2020			
	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max	Mean	Std.dev.	Min	Max
1. Firm Characteristics												
Production per worker (thusand yen)	1,295.19	2,166.46	36.42	224,857.70	1,851.58	1,836.60	66.93	25,660.95	1,961.22	2,440.28	57.69	31,829.29
Price per kl (yen)	52.75	15.87	9.26	193.33	67.20	22.23	9.11	222.63	90.32	31.85	13.20	235.59
Purchase value (thusand yen)	189.72	4,040.48	0.00	165,089.10	241.53	2,257.90	0.00	60,302.98	715.03	3,546.11	0.00	49,589.59
Capital (thousand yen)	11,180.29	36,971.65	1.00	956,443.00	36,335.44	100,439.10	17.00	1,846,617.00	91,314.19	206,615.20	4.00	2,020,935.00
Labor	28.80	45.49	10.00	895.00	35.12	52.25	10.00	839.00	43.78	47.00	10.00	555.00
Capital-labor ratio	284.63	415.04	0.05	13,178.60	760.31	1,128.93	1.38	25,485.09	1,460.88	1,867.82	0.27	34,724.13
2. Agglomeration Characteristics (municipality-level)												
Number of firms	5.19	7.44	1.00	43.00	4.33	5.94	1.00	38.00	4.37	4.22	1.00	19.00
Average number of labor	25.48	22.20	6.00	203.00	28.34	25.47	5.00	265.20	30.94	25.45	4.20	192.00
Average price per kl (yen)	43.87	11.52	10.50	139.23	64.16	16.80	13.04	183.50	88.19	23.05	15.90	228.30
Observations	15,905				8,894				2,219			

Notes: All values are deflated by the consumer price index obtained from the Bank of Japan (2021).

Table 4. Determinants of sake brewing firm performance

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Production per worker			Price			Value added per worker	
	1980-1992	1993-2009	2010-2020	1980-1992	1993-2009	2010-2020	2000-2009	2010-2020
KLratio	0.251***	0.244***	0.120***	-0.024***	-0.011***	0.008	0.177***	0.105***
	(0.006)	(0.007)	(0.017)	(0.003)	(0.004)	(0.008)	(0.022)	(0.016)
Labor	0.291***	0.310***	0.256***	0.143***	0.076***	-0.074***	0.415***	0.230***
	(0.009)	(0.011)	(0.033)	(0.007)	(0.009)	(0.014)	(0.037)	(0.037)
Agglomeration - N of firms	0.017***	-0.004	0.077***	-0.019***	-0.018***	-0.019*	-0.100***	-0.007
	(0.005)	(0.007)	(0.023)	(0.002)	(0.003)	(0.010)	(0.025)	(0.022)
Agglomeration - Average N of workers	0.035***	0.020	0.173***	-0.085***	-0.032***	-0.054***	-0.052	0.108***
	(0.010)	(0.013)	(0.038)	(0.007)	(0.010)	(0.017)	(0.050)	(0.036)
Agglomeration - Average price	0.015	-0.182***	-0.292***	0.819***	0.779***	0.509***	0.217*	0.077
	(0.018)	(0.026)	(0.066)	(0.011)	(0.016)	(0.038)	(0.113)	(0.071)
Constant	4.575***	5.492***	6.235***	0.659***	0.849***	2.565***	3.395***	4.509***
	(0.072)	(0.110)	(0.307)	(0.042)	(0.068)	(0.181)	(0.517)	(0.331)
Pref FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14972	8801	2129	14972	8801	2129	1511	2129
R-squared	0.467	0.449	0.398	0.499	0.462	0.293	0.362	0.258

Notes: Production is calculated as the shipping value of sake minus the purchase value. All dependent and independent variables are log transformed. Robust standard errors in parentheses are clustered at the municipality-year level. ***p<0.01; **p,0.05; *p<0.10.

Table 5. Agglomeration effect on sake purchases

	(1)	(2)	(3)	(4)	(5)	(6)
	Purchase dummy (OLS)			Purchase dummy (Probit)		
	1980-1992	1993-2009	2010-2020	1980-1992	1993-2009	2010-2020
KLratio	-0.002*	0.005**	0.011**	0.013	0.122***	0.069
	(0.001)	(0.002)	(0.005)	(0.037)	(0.035)	(0.055)
Labor	0.052***	0.089***	0.168***	0.558***	0.603***	0.984***
	(0.004)	(0.007)	(0.017)	(0.035)	(0.046)	(0.088)
Agglomeration - N of firms	0.005***	0.005*	0.014	0.161***	0.058	0.014
	(0.001)	(0.003)	(0.010)	(0.049)	(0.042)	(0.058)
Agglomeration - Average N of workers	0.007**	0.015**	-0.021	0.535***	0.490***	-0.004
	(0.003)	(0.008)	(0.016)	(0.054)	(0.068)	(0.117)
Agglomeration - Average price	-0.004	-0.015	-0.095***	-0.237	-0.179	-0.650***
	(0.006)	(0.011)	(0.027)	(0.153)	(0.149)	(0.222)
Constant	-0.137***	-0.248***	-0.034	-5.044***	-6.351***	-1.184
	(0.024)	(0.048)	(0.127)	(0.589)	(0.692)	(1.005)
Pref FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	14972	8801	2129	10602	5876	1684
R-squared	0.100	0.213	0.322	-	-	-

Notes: In the probit models presented in Columns (7) – (9), several samples are dropped because the prefecture fixed effect perfectly predicts the dependent variable, preventing the model from converging. Robust standard errors in parentheses are clustered at the municipality-year level. ***p<0.01; **p,0.05; *p<0.10.

Table 6. Determinants of sake brewing firm performance in Hyogo, Kyoto, and Niigata Prefectures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Production per worker			Price			Value added per worker	
	1980-1992	1993-2009	2010-2020	1980-1992	1993-2009	2010-2020	2000-2009	2010-2020
KLratio	0.296***	0.287***	0.201***	-0.040***	0.017	0.047**	0.238***	0.165***
	(0.015)	(0.016)	(0.056)	(0.010)	(0.012)	(0.020)	(0.038)	(0.045)
Labor	0.273***	0.352***	0.352***	0.161***	0.069***	-0.096***	0.486***	0.293***
	(0.015)	(0.018)	(0.055)	(0.015)	(0.018)	(0.021)	(0.050)	(0.065)
Agglomeration - N of firms	0.012	0.009	0.121***	-0.007	-0.027***	-0.02	-0.095**	0.079**
	(0.013)	(0.012)	(0.038)	(0.005)	(0.007)	(0.015)	(0.040)	(0.032)
Agglomeration - Average N of workers	0.127***	-0.015	0.046	-0.097***	0.021	-0.033	-0.005	0.057
	(0.020)	(0.020)	(0.064)	(0.013)	(0.022)	(0.031)	(0.071)	(0.061)
Agglomeration - Average price	-0.074	-0.224***	-0.670***	0.936***	0.836***	0.592***	0.129	-0.316**
	(0.061)	(0.054)	(0.196)	(0.031)	(0.053)	(0.109)	(0.188)	(0.152)
Constant	4.531***	5.506***	7.402***	0.258**	0.252	1.936***	3.072***	5.695***
	(0.249)	(0.232)	(0.935)	(0.114)	(0.210)	(0.531)	(0.908)	(0.731)
Pref FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2655	1735	563	2655	1735	563	431	563
R-squared	0.597	0.509	0.375	0.497	0.445	0.282	0.382	0.258

Notes: Production is calculated as the shipping value of sake minus the purchase value. All dependent and independent variables are log transformed. Robust standard errors in parentheses are clustered at the municipality-year level. ***p<0.01; **p,0.05; *p<0.10.

Table 7. Determinants of sake brewing firm performance: A limited sample of municipalities with at least two firms

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Production per worker			Price			Value added per worker	
	1980-1992	1993-2009	2010-2020	1980-1992	1993-2009	2010-2020	2000-2009	2010-2020
KLratio	0.237***	0.233***	0.143***	-0.029***	-0.017***	0.012	0.148***	0.125***
	(0.007)	(0.010)	(0.030)	(0.004)	(0.006)	(0.014)	(0.030)	(0.028)
Labor	0.312***	0.335***	0.362***	0.153***	0.096***	-0.059***	0.451***	0.295***
	(0.009)	(0.012)	(0.035)	(0.008)	(0.011)	(0.019)	(0.043)	(0.046)
Agglomeration - N of firms	-0.004	-0.013	-0.014	0.000	0.005	0.017	-0.028	-0.037
	(0.008)	(0.013)	(0.038)	(0.003)	(0.005)	(0.016)	(0.041)	(0.039)
Agglomeration - Average N of workers	0.013	-0.034*	-0.049	-0.089***	-0.023	-0.017	0.05	-0.044
	(0.013)	(0.018)	(0.051)	(0.007)	(0.014)	(0.024)	(0.060)	(0.050)
Agglomeration - Average price	0.069**	-0.185***	-0.141	0.956***	0.865***	0.665***	0.134	0.235**
	(0.034)	(0.046)	(0.119)	(0.014)	(0.024)	(0.059)	(0.138)	(0.118)
Constant	4.489***	5.718***	5.984***	0.113**	0.394***	1.604***	3.418***	4.037***
	(0.125)	(0.182)	(0.554)	(0.054)	(0.105)	(0.269)	(0.670)	(0.551)
Pref FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	9432	4641	999	9432	4641	999	705	999
R-squared	0.498	0.492	0.441	0.465	0.399	0.292	0.457	0.319

Notes: Production is calculated as the shipping value of sake minus the purchase value. All dependent and independent variables are log transformed. Robust standard errors in parentheses are clustered at the municipality-year level. ***p<0.01; **p,0.05; *p<0.10.

Table 8. Determinants of sake brewing firm performance in different periods

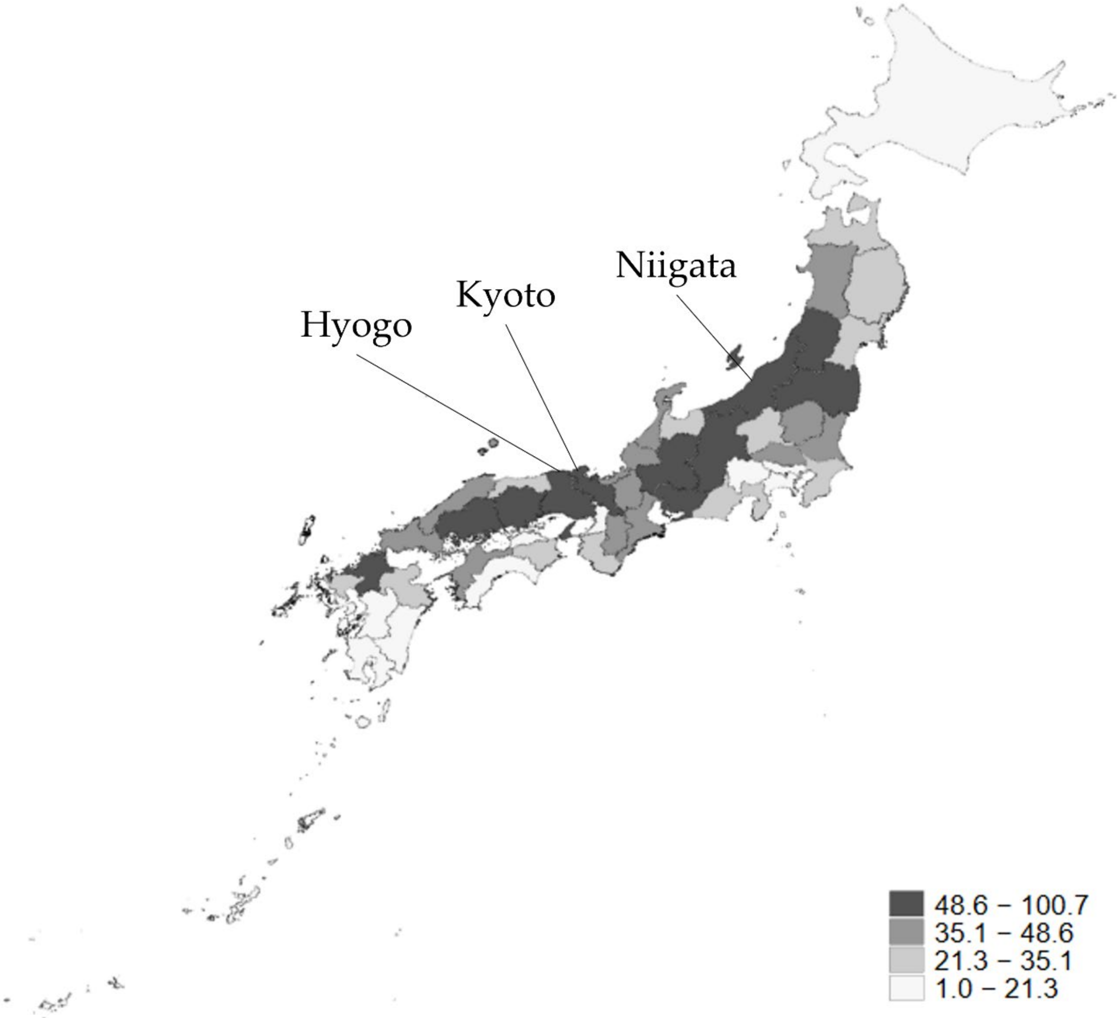
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	Full sample			After Premium Sake Qualification System in 1993		Before and After 2000				Excluding Covid-19 Effect in 2020		
	Production per worker	Price	Value added per worker	Production per worker	Price	Production per worker		Price		Production per worker	Price	Value added per worker
	1980-2020		2000-2020	1993-2020		1980-1999	2000-2020	1980-1999	2000-2020	2010-2019		
KLratio	0.234***	-0.017***	0.120***	0.214***	-0.010***	0.249***	0.156***	-0.020***	0.001	0.146***	0.006	0.125***
	(0.005)	(0.002)	(0.013)	(0.008)	(0.003)	(0.005)	(0.014)	(0.002)	(0.006)	(0.019)	(0.009)	(0.019)
Labor	0.296***	0.104***	0.310***	0.301***	0.050***	0.293***	0.300***	0.135***	-0.081***	0.251***	-0.083***	0.230***
	(0.007)	(0.006)	(0.027)	(0.011)	(0.009)	(0.007)	(0.023)	(0.006)	(0.011)	(0.039)	(0.015)	(0.043)
Agglomeration - N of firms	0.015***	-0.019***	-0.035**	0.012	-0.017***	0.011**	0.044***	-0.018***	-0.019**	0.069***	-0.023**	-0.026
	(0.004)	(0.002)	(0.017)	(0.007)	(0.003)	(0.004)	(0.016)	(0.002)	(0.008)	(0.026)	(0.011)	(0.024)
Agglomeration - Average N of workers	0.043***	-0.060***	0.051*	0.050***	-0.029***	0.034***	0.088***	-0.080***	0.013	0.148***	-0.043**	0.082**
	(0.008)	(0.005)	(0.029)	(0.013)	(0.009)	(0.008)	(0.027)	(0.005)	(0.018)	(0.045)	(0.019)	(0.041)
Agglomeration - Average price	-0.084***	0.785***	0.136**	-0.220***	0.736***	-0.035**	-0.356***	0.812***	0.609***	-0.378***	0.544***	0.023
	(0.015)	(0.009)	(0.064)	(0.024)	(0.015)	(0.015)	(0.048)	(0.009)	(0.028)	(0.072)	(0.042)	(0.083)
Constant	5.023***	0.824***	4.083***	5.726***	1.106***	4.811***	6.438***	0.694***	1.950***	6.546***	2.413***	4.735***
	(0.062)	(0.036)	(0.299)	(0.107)	(0.066)	(0.061)	(0.227)	(0.037)	(0.150)	(0.342)	(0.203)	(0.387)
Pref FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	25903	25903	3642	10931	10931	22237	3666	22237	3666	1721	1721	1721
R-squared	0.469	0.605	0.273	0.417	0.475	0.474	0.435	0.567	0.352	0.410	0.308	0.261

Notes: Production is calculated as the shipping value of sake minus the purchase value. All dependent and independent variables are log transformed. Robust standard errors in parentheses are clustered at the municipality-year level. ***p<0.01; **p,0.05; *p<0.10.

Figure 1. Changes in the number of sake brewing plants and sake production quantity in Japan, 1980 – 2020

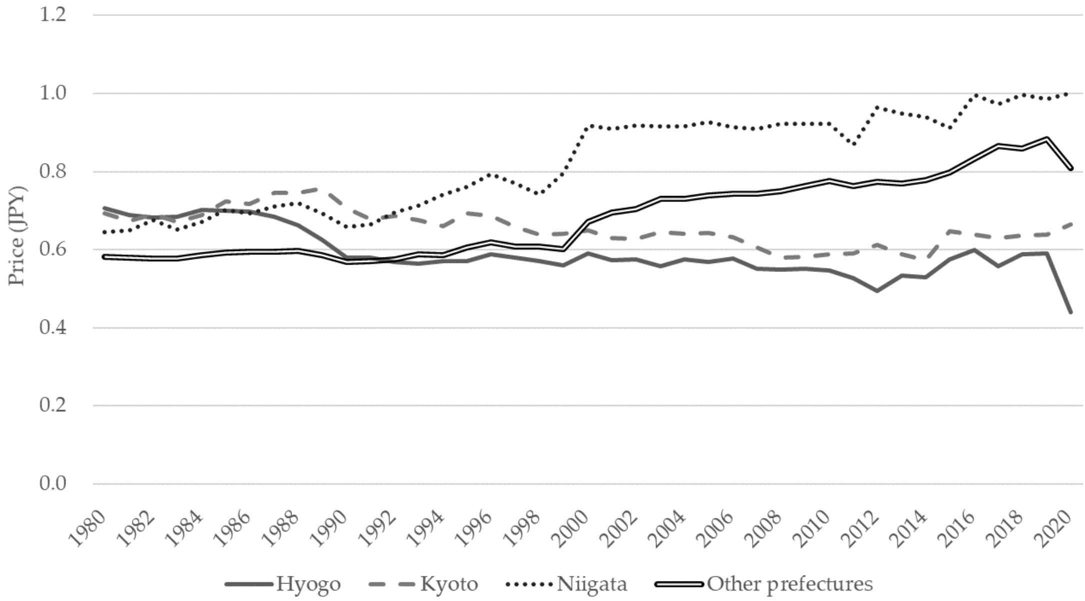
Notes: Production is measured by the quantity of sake bottled and shipped, including purchased sake from other firms.
Sources: Kokuzeicho Tokeinenpo (1980 – 2020).

Figure 2. The average number of sake brewing plants by prefecture, 1980-2020



Notes: Authors' calculation based on the data provided by the Ministry of Internal Affairs and Communications and the Ministry of Economy, Trade and Industry. This was calculated by taking the average number of sake brewing plants in each prefecture from 1980 to 2020.
Sources: Kogyo Tokei Chosa–kekka Hokoku (1980-2020).

Figure 3. Changes in the real price of sake per kiloliter from 1980 to 2020, by prefecture



Notes: Price is deflated by the consumer price index obtained from the Bank of Japan (1980 – 2020).

Sources: Kokuzeicho Tokeinenpo (1980 – 2020).