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Economies of Scale in Raw Milk Production: Evidence from Japanese Farm-level Data

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Abstract: Raw milk production in Japan is subject to various restrictions, including mandating sales to agricultural cooperatives, limits to inter-regional mobility of raw milk, and differentiated prices of raw milk for different dairy products with no say from raw milk farmers. These institutional barriers contribute to inefficiency in production. This paper estimates a translog cost function of raw milk production from individual Japanese dairy farms. Using newly-available farm-level data from 2008 to 2017, we examine the degree of scale economies in raw milk production. Our findings indicate the following: (i) Economies of scale do exist in raw milk production in Japan. The total cost increases only by 0.67% for a 1% increase in production. (ii) Substitutability exists between labor and equipment, suggesting the potential for improving productivity by introducing more mechanization (automation). Simulation analyses, based on the estimated cost function, are conducted to measure the impacts of removing institutional rigidities (multiple prices; regional division of markets) on the profitability of dairy farms by farm scale and region. Results show that removing institutional rigidity tends to increase the profitability of Japanese dairy farms in general, but the magnitude of the effect impact varies across farm scales and regions.

Keywords: Dairy industry; Farm-level analysis; Agricultural policy; Japan

JEL Classification: Q12; Q16; Q18

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1 Introduction

Japan's raw milk production has been declining. This decline is often explained as an inevitable decline in milk consumption. However, raw milk can be used to produce more dairy products. Moreover, drinking milk, if high quality with low costs with skillful marketing, can be exported. A drop in milk consumption can be explained partly by the decreasing population and partly by high costs due to heavy regulation on production and distribution. High production costs make Japanese dairy products internationally uncompetitive and "protection" from imports of dairy products, such as butter, has been maintained.

According to the Statistical Survey on Milk and Dairy Products (*Gyunyu Nyuseihin Tokei Chosa*), raw milk production declined from 8.65 million tons in 1997 to 7.60 tons in 2021, a 12.1% drop in 24 years. During the same period, the number of raw milk-producing cows declined from 1.2 million to 0.8 million. The number of dairy farms decreased from 39.4 thousand to 13.8 thousand, an approximately 65% drop. The number of dairy farms has declined more than the production volume, suggesting that smaller farms in terms of cows have exited. This exit of smaller farms is the first suggestive evidence of scale economies in raw milk production. One region, Hokkaido, the region with the highest raw production in Japan, has more large-scale farms than other regions. If various regulations are preventing farmers from increasing their raw milk production, taking down regulations will make the dairy industry as a whole become more prosperous in Japan.

Raw milk production and distribution in Japan is regulated by the Ministry of Agriculture, Forestry and Fisheries (MAFF). Major regulations are in three categories: First, Japan is divided into ten regions, each of which has only one "designated raw milk producer organization" (the producer organization hereafter), or a regional agricultural cooperatives federation. Shipment of raw milk across the regional boundary is extremely limited unless an importing region requests such sales. Moreover, there is a monopsony distribution channel from dairy farms to wholesalers, and only a monopoly wholesaler in each region can sell milk, with the limited exception of *independent* farms' sales. Second, within each of the ten regions, the producer organization functions as a monopolistic intermediary to collect raw milk from almost all dairy farms in the region and to deliver that to dairy products manufacturing firms, that produce a variety of dairy products, such as drinking milk, butter, cheese, and skimmed milk powder from raw milk. Third, the producer organization negotiates prices of raw milk sold to dairy products manufacturing firms. Still, prices of the same raw milk differ depending on which dairy products the raw milk is used. For example, raw milk for drinking milk commands the highest price, while raw milk for cheese and butter is priced lower. Then, the payment for the raw milk from the producer organization to each dairy farm is based on the average sales prices for different dairy products. This average price is designated as the "pooled price" that the producer organization calculates from the raw milk volume used for each dairy product reported by the dairy processing firms, added to the subsidy from the government. The subsidy is supplied only to the usage of raw milk for dairy processing products other than drinking milk. These regulations combined work toward preserving the inefficient production of raw milk.

Multiple prices exist for one good, raw milk, for different dairy products and regions. If there is surplus raw milk in one region, raw milk can be discarded without compensation, instead of being shipped to other regions to cause price competition. Therefore, depending on the product mixes, the pool price of raw milk may vary from one region to another. In Hokkaido, which hosts many dairy processing firms, there is more production of lower-priced dairy products; therefore, the pooled price is lower. The pooled prices for other regions are higher. Since the shipment of raw milk across the regional boundary is restricted, no arbitrage works. Therefore, Hokkaido farmers suffer from lower pooled prices of raw milk due to their locations. Their lower production costs achieved through scale economies are punished instead of rewarded because of these barriers. Another barrier exists for importing butter and other dairy products under government quantitative control. Imports of these products are allowed only for the Agriculture & Livestock Industries Corporation (ALIC), and all imported butter and other products distributed in Japan pass through ALIC before being wholesaled to dairy manufacturers. If the import volume exceeds the current access volume (137 thousand tons), a high-rate tariff of more than 100% will be added to the imports, virtually restricting the import volume to 137 thousand tons. We do not explicitly consider this issue. Nevertheless, this import restriction is an essential background of this paper since it discourages innovation among Japanese dairy product manufacturers.

These regulations and rigidities are well-known among agricultural economists in Japan. However, how these rigidities affect the efficiency of raw milk production and profitability of dairy farms yet to be rigorously analyzed, mainly due to the availability of microdata. The paper's novelty is to utilize data from large-scale samples of individual dairy farms (the farm-level data). The farm-level data are collected for the "Milk Production Cost Statistics" (the milk production cost statistics hereafter). The statistics for the period 2008–2017 became available to the authors with special permission for academic use.[1] The data are used to estimate a translog cost function of raw milk production. In addition, the study will be carried out to simulate the impact of hypothetical institutional changes. In particular, we examine whether the Japanese dairy industry can improve productivity by promoting mergers of small- and medium-scale farms into large-scale farms, which may be enforced if regulatory barriers such as restrictions on cross-border shipment of raw milk among the ten regions. The scale of dairy farms is smaller in Japan than in other countries, such as Australia and New Zealand, which have strong dairy industries. For example, according to the Dairy Farm Monitor Project (DFMP) of Daily Australia, which conducts a comprehensive survey of the Australian dairy industry, the average number of cows per farm in Victoria, Australia, in 2019–2020 was 415.5.[2] According to a MAFF Survey of Agricultural Management Statistics, the average number of cows per farm in the Japanese dairy industry in 2019 was 58.7, just one-seventh the figure reported for Victoria.

In addition, our analysis uncovers the potential for substitutability among factors of production.

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[1] MAFF provided farm-level data to conduct this study. In this paper, we independently edit the raw information for our research purpose.

[2] Results of the DFMP survey are published on the following website.
(https://www.dairyaustralia.com.au/dairytas/industry-statistics/dairy-farm-monitor-project)

We focus on the substitutability of capital and labor in raw milk production and discuss whether Japanese raw milk production can achieve increased productivity through the promotion of automation. In the dairy industry in Japan, labor shortages and a lack of successors have become acute. Identifying the extent to which labor can be replaced by machines is an important policy issue. According to Yoshimi and Sato (2021), there are significant differences (based on a test of difference in means at a 1% level of significance) among regions in the ratio of farm equipment costs to production costs for Japanese dairy farms: 3.9% in Hokkaido (30,000 yen per milking cow) versus 2.9% in regions other than Hokkaido (26,000 yen per milking cow).[3] The higher equipment costs, which are a result of more capital investment, suggest the employment of labor-saving technology. By examining the differences in productivity between more-mechanized farms and less-mechanized farms, we can infer changes in the industries if and when hypothetical regulatory changes are made and when the external environment changes.

Simulation analyses based on three scenarios will be performed using the parameters estimated by the translog cost function estimation. First, we simulate how much farms' profits would improve if the allocation of factors of production were revised so that all farms could achieve cost minimization. Recall that real-world production may not result from optimized production due to regulatory barriers. Second, we simulate the total cost savings for Japan in a hypothetical case where the entire production could be done at the largest farms only. The simulation analysis corresponds to a scenario that small- and medium-scale farms with relatively low profitability are consolidated (merged) into large farms to take advantage of scale economies. Third, focusing on the regulatory change, we conduct simulations to measure the impact of introducing a uniform national pooled price on farms' profit margins.

The rest of the paper is organized as follows. Section 2 surveys the existing studies in the literature. Section 3 describes the raw milk production cost statistics which form the basis for the panel data, as well as the cost structures for farms. In Section 4, we perform estimates of translog cost

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[3] Yoshimi and Sato (2021) use the same farm-level data as this study to examine the cost structures of Japanese raw milk production.

functions to examine economies of scale and the elasticity of substitution among different cost items. In Section 5, simulation analyses are conducted to derive specific policy recommendations. Section 6 concludes.

2. Literature

Earlier studies of the productivity of the Japanese dairy industry include Kamata (2011) on Hokkaido dairy farms from 1995 to 2003. Sato (2019) examined the productivity of the Japanese dairy farming industry. Fujii and Kondo (2001), using data on Hokkaido dairy farms from 1968 to 1994, found that land rent and purchased feed prices had an important impact on in-house (self-) produced feed production and grassland demand, and that expansion of a farm scale contributed to a decrease in the average cost of raw milk production. However, all these studies used aggregate data published in the Statistical Survey on Farm Management and Economy (*Nogyo Keiei Tokei Chosa*), which does not allow us to examine the heterogeneity among farms' production cost structure. This study is unique and the first in the literature to focus on the heterogeneity of the farms, taking advantage of the newly-available microdata of individual farms.

In other countries, many studies have used farm-level data to examine the productivity of dairy farms. Kompas and Che (2006) examined the efficiency of raw milk production using information from 252 farms in New South Wales and Victoria, Australia, gathered in 1996, 1998, and 2000. They showed that the critical determinants of differences in dairy farm efficiency are the type of dairy shed used and the proportion of irrigated farm area. They also pointed out that dairy production follows constant returns to scale. Neal and Roche (2019) examined the case of New Zealand. They identified the top quartile of observations based on operating return on assets as a proxy for farms achieving their potential to compare with the remaining farms. They found that the greater profitability of the top quartile was associated with greater pasture, greater self-feed crop, and greater production per cow. Notably, greater profitability was not associated with greater use of imported feed.

Other researchers focused more on a policy impact on the efficiency of dairy farms.[4] De Frahan et al. (2011) examine the impact of eliminating production quotas and increased income compensation on farms' production and income using information from 143 farms in the Wallonia region of Belgium for 1996–2006 obtained from the Farm Accountancy Data Network (FADN) database. The FADN database is frequently used in this literature. For instance, Cechura et al. (2021) examined the impact of abolishing milk quotas in the European Union (EU) member states on the productivity and efficiency in European milk production with the same dataset. They revealed that the main driver of an increased trend in total factor productivity is the scale effect while abolishing milk quotas also has a positive impact. Sidhoum et al. (2022) investigated the effects of European agri-environmental schemes on farm-level eco-efficiency using the farm-level data of Germany, France, Italy, and the Netherlands from 2006 to 2011 obtained from the same database. They found a considerable improvement in eco-efficiency for dairy and crop production. As an example of non-EU countries, Kumar et al. (2020) used farm-level data from dairy farmers in India's Bihar state to investigate the impact of the adoption of food safety measures on milk production and profitability of dairy farms. We also aim to contribute to the literature by simulating the impact of several policy changes on Japanese farms' profitability.

3. Data

3.1 Overview of the farm-level data and construction of a panel data

This paper presents analyses of panel data composed of farm-level milk production cost statistics. These statistics are compiled as part of the Agricultural Management Survey and Livestock Production Cost Statistics conducted by the Statistics Department of MAFF. They are a core metric generated by the Statistics Law for analyzing dairy farming in Japan. Article 13 and Article 61, Item 1

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[4] Many studies examined a policy impact on the dairy industry without using farm-level data. For example, Lips and Rieder (2005) conducted a country-level analysis of the impact of the abolition of raw milk quota in the EU. Klootwijk et al. (2016) simulated the impact of a new manure policy in the Netherlands on farm structure, including profitability and the distribution of inputs. They also focus on the policy impact on environmental variables such as nitrogen, phosphate surpluses, and greenhouse gas emissions.

of the Statistics Law in Japan stipulate penalties for survey targets who refuse to report or report falsely. The survey targets farms who keep at least one milking cow and sell raw milk. The data are determined based on a stratified sample survey. The purpose of the milk production cost statistics is to understand the production status and cost breakdown of each farm, the financial conditions of agriculture workers, and others. Each farm responds to a survey questionnaire that includes information on the volumes and values of their main products, usually raw milk, by-products, and the cost of each expense item to produce by-products. Other survey items include labor hours by operation and age of workers, volumes and values of feed and other commodities, land area, buildings, and the number of vehicles and farm equipment owned, among others. These milk production cost statistics are the only available farm-level statistics on dairy farms in Japan, and their reliability is high. We first construct an annual unbalanced panel dataset based on the milk production cost statistics data from 2008 to 2017. The number of farms which have been sampled at least once (for more than one year) during the sample period of the farm-level data in question is 389 in Hokkaido and 441 in other regions. Table 1 shows the number of farms per year of sampling as well as the number of farms which have been sampled for two consecutive years and the rate of farm replacement each year. The number of farms sampled in all sample periods is 213, representing about a quarter of the farms in the sample.[5] Table 2 shows the mean, median, and standard deviation of the number of cows and raw milk yield kept by the designated group for the entire sample period.[6] Because of the design of the statistical survey in question, Hokkaido accounts for about half of the total sample. The average number of cows and average raw milk yield are both about 1.7 times higher in Hokkaido than in other regions.

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[5] The review of sample farms is generally conducted two years after the census revision, which is done every five years. The census was revised in 2010 and 2015, resulting in a higher replacement rate of sample farms in 2012 and 2017. For other years, there were basically no changes to the sample farms, but some farms were replaced because of business closures or other reasons.

[6] Okinawa Dairy Cooperatives is the only applicable prefectural body in Okinawa Prefecture. Therefore, if the tabulation results for the designated organization in question alone are posted, the possibility remains that individual sample farms could be identified due to the small sample size. Accordingly, Table 2 lists the results for this designated organization as a single group, the Kyushu Seinyuhanren.

3.2 Overview of Cost Structures

We use seven cost items that account for 85.9% of total production costs (not excluding by-product value) in the milk production cost statistics: self-produced feed, purchased feed, labor (family labor and hired labor), equipment (vehicles and farm equipment), buildings, land rent (land rent paid plus imputed rent for owned land), and cow depreciation.[7] The other items which make up the total production costs include production management, seeding, bedding, heat and power, other materials, veterinary fees and medicines, rent and fees, property taxes and public charges, interest paid, and interest on equity capital. However, because these other cost items account for only a small percentage of total costs, and because calculating unit costs for the purpose of estimating cost functions is difficult, they are dropped from the subsequent analysis and estimation.

Panel (a) of Table 3 shows the average cost, pooled price, and actual production cost breakdown (average values for the entire sample period; average cost and pooled price are per 100 kg of raw milk) for the entire country (all samples), by herd scale (small farm group, medium farm group, large farm group), and by Hokkaido and other regions (i.e., "excluding Hokkaido").[8] The pooled price for Hokkaido is distinctively lower than in other regions, suggesting that raw milk in Hokkaido is used more for producing daily products other than drinking milk than in the rest of Japan. In this study, farms less than the first quartile are considered small farms, farms above the first less than the third quartiles are considered medium farms, and farms above the third quartile are considered large farms, based on the number of cows kept for the full year. Specifically, small farms are those with less than

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[7] By-product values are excluded from the overall production costs in the milk production cost statistics, but individual cost items include the costs invested in the production of by-products. Therefore, if we use the total cost of production as stated, we find a sample in which the total cost of the seven items used in this study exceeds the total cost of production. To avoid this difficulty, the denominator used here is not the total input production cost as it is, but the total input production cost excluding by-product value.

[8] The most recent agriculture and forestry census conducted within the sample period of this study (2008–2017) is the 2015 one, and the sample extraction for the 2017 individual data is based on this 2015 agriculture and forestry census. Figure A1 in the Appendix compares the 2017 sample of our panel data with the distribution of the number of cows kept in the 2015 Census of Agriculture and Forestry based on a full survey, for Japan, Hokkaido, and in other regions. The figure shows that the distribution of the number of cows in the milk production cost statistics and the census is generally similar, although there are some deviations depending on the number of cows. Furthermore, Figure A2 presents the distribution of the cost of major production inputs (per 100 tons of raw milk) by Hokkaido and other regions. The figure shows that the cost distribution differs across Hokkaido and other regions. Due to this, we show the empirical results separately for Hokkaido and other regions.

29.7 cows, medium-scale farms are those with between 29.7 and 68.7 cows, and large farms are those with more than 68.7 cows. The average cost per 100 kg of raw milk across all farms is 7,251.1 yen. Those costs for small, medium, and large farms were 9,048.8 yen, 6,924.5 yen, and 6,111.6 yen, respectively, indicating that average costs were the lowest for large-scale farms. From these costs, it can be inferred that larger farms produce raw milk at lower costs. While the average cost in regions other than Hokkaido is 8,292.6 yen, the cost in Hokkaido is 6,552.8 yen, which is 1,739.8 yen lower. One of the reasons for this is that there are more large-scale in Hokkaido than in the other regions. The average number of cows in Hokkaido is 64.1 compared to 35.7 in the other regions. Pooled prices for raw milk are lower in Hokkaido than in the other regions. These lower prices reflect the fact that Hokkaido produces more raw milk destined for products of relatively low purchase prices. In contrast, the other regions produce more raw milk intended for drinking, with a higher purchase price.

Panel (a) of Table 3 also shows the share of each cost item. Purchased feed is the item with the largest share regardless of farm scale or region. However, the share of purchased feed is also larger for smaller farms. A more striking difference is observed between Hokkaido and other regions. The average purchased feed cost is 42.2% of total costs in the other regions compared to 27.7% in Hokkaido. On the other hand, the share of self-produced feed costs was 7.8% in other regions but was significantly higher in Hokkaido, at 18.3%. Therefore, in Hokkaido, farms can use a large amount of self-produced feed, while in other regions farm operations are highly dependent on purchased feed. The expense item with the second largest share in all categories is labor, with 27% of the total sample. The share of labor costs is smaller for larger farms. In other words, the larger the farms are, the less labor-dependent they are. Conversely, larger farms have higher equipment and building costs. Thus, they produce more capital-intensively than small farms. The share of cow depreciation costs is greater for larger farms that have a higher number of cows.

4. Estimating Economies of Scale and Elasticities of Substitution between Factors

In this section, we estimate translog cost functions (a la Christensen, Jorgenson and Lau, 1973), which allows us to detect both scale economies and cross-price elasticities between inputs.

4.1 Estimation of translog cost functions

Assuming the n factors of production of one product, the translog cost function can be written as follows[9]

$$\begin{aligned}\ln C = \ln k + a\ln q + \frac{1}{2}d(\ln q)^2 + \sum\nolimits_{r=1}^{n} b_r \ln w_r \\ + \frac{1}{2}\sum\nolimits_{r=1}^{n}\sum\nolimits_{s=1}^{n} f_{rs}\ln w_r \ln w_s + \sum\nolimits_{r=1}^{n} g_r \ln q \ln w_r.\end{aligned} \tag{1}$$

In that equation, C is the total cost incurred by the farm to produce the raw milk, q is the amount of raw milk produced, and w_r is the price per unit of the production factor r.[10] For this study, $n = 7$ is used as w_1 for self-produced feed cost (per 100 kg), w_2 for purchased feed cost (per 100 kg), w_3 for labor cost (per hour of family and hired labor), w_4 for equipment cost (per vehicle and piece of farm equipment), w_5 for building cost (per square meter), w_6 for land rent (sum of land rent paid per 1a and imputed rent for owned land) and w_7 for depreciation cost (per cow head).

Table 4 shows the derivation method and descriptive statistics for each "calculated" factor price.[11] Descriptive statistics are calculated by excluding both the lower and upper 1% of the distribution of each factor price because of the presence of outliers. The necessary and sufficient conditions for the cost function are (a) non-diminishing with respect to element prices, (b) first-order homogeneous with respect to element prices, (c) concave with respect to element prices, and (d)

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[9] The by-products of Japanese raw milk producers consist mainly of manure and calves. According to the data in this paper, by-product production value as a percentage of total raw milk production value is 13.4% for the full sample. This paper does not consider farm by-products and focuses only on raw milk production. Ray (1982) presents additional details for estimating a translog cost function assuming multiple products.

[10] The translog cost function is derived by taking the logarithm of both sides of the "true" cost function in general form and performing Taylor's quadratic approximation. Ray (1982) provides more information.

[11] Each factor price is *calculated* by dividing the total amount of each cost item by the quantity of its inputs. The total value of each cost item is then deducted from the by-product value multiplied by the percentage of each cost item within the total cost. Figure A3 in the Appendix shows the distribution of those factor prices.

continuous with respect to element prices.[12] From condition (b), we transform equation (1) using the dairy cow depreciation cost (w_7) as the reference price as follows.[13]

$$\begin{aligned}\ln\frac{C}{w_7} &= \ln k + a\ln q + \frac{1}{2}d(\ln q)^2 + \sum_{r=1}^{n-1} b_r \ln\frac{w_r}{w_7} \\ &+ \frac{1}{2}\sum_{r=1}^{n-1}\sum_{s=1}^{n-1} f_{rs}\ln\frac{w_r}{w_7}\ln\frac{w_s}{w_7} \\ &+ \sum_{r=1}^{n-1} g_r \ln q \ln\frac{w_r}{w_7}.\end{aligned} \tag{2}$$

Also, by organizing equation (2) together with Shepherd's complement, the following cost-sharing equation can be derived as

$$cs_i = \frac{w_i x_i}{C} = b_i + \sum_{s=1}^{n-1} f_{is}\ln\frac{w_s}{w_7} + g_i \ln q, \qquad \text{where } i = 1,\cdots,n-1. \tag{3}$$

Here, x_i represents the input of factor i. Because the sum of the cost shares of all production factors is 1, $\sum_{i=1}^{n} cs_i = 1$ is established. There are six independent cost-sharing equations.

Using the unbalanced panel data described above, we estimate the parameters of the simultaneous equations consisting of equations (2) and (3) using the one-way Seemingly Unrelated Regressions (SUR) system with random effects by Generalized Least Squares (GLS).[14] In the estimation, we impose the symmetry of factor prices $f_{rs} = f_{sr}$ as a constraint with respect to all r and s.[15] For the estimation, we remove the first percentile at both ends of the distribution for all series in order to exclude outliers.[16]

Estimations are conducted by scale (the small, medium, and large farm groups) and by region (Hokkaido and other regions). The reason for dividing the sample by district (Hokkaido and other regions) and by scale (small, medium, and large) for the estimation is that we expect that production

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[12] Ray (1982) explains this point.

[13] See Kumbhakar (1996) and Weill (2013).

[14] SUR estimation is used in cases in which the error terms in the simultaneous equations may be correlated with each other (inter-equations correlation). Also, in panel data estimation, there may be correlations (intra-individual correlations) in the error terms because of unique effects. Chapter 6 of Baltagi (2021) shows that feasible SUR-GLS estimators are asymptotically consistent and efficient when the simultaneous equations are estimated through SUR using panel data.

[15] If the production technology is homothetic, then $g_r = 0$ would be imposed as a constraint for all r. However, this constraint is not required in this study.

[16] Since this study uses farm-level data, the issue of outliers, such as for reasons of misdescription, is expected to be more significant than in studies using aggregate data. Factor prices and production volumes are divided by their respective sample averages for use in the estimation. See Croissant and Millo (2019) for a description of this procedure.

technology differs by district and by scale. Table 5 shows that a and b_r are positive at the 1% significant level in all estimations irrespective of the scale and region. Thus, we can confirm that the necessary and sufficient conditions for the use of the translog cost function: "(a) non-diminishing with respect to factor prices" and monotonicity with respect to output, are satisfied. Wald tests for the full sample and all subsamples by scale and region reject $g_r = 0$, indicating that the related production function is not homothetic. Also, $d = 0$, and $f_{rs} = 0$ are rejected, suggesting that the cost function does not exhibit the Cobb–Douglas form.

4.2 Economies of scale and elasticity of substitution between factors

Economies of scale is generally defined as the incremental value of costs being less than z times when production output is z times greater. To verify this condition, we define the economies of scale indicator called SAL as follows.[17]

$$SAL = \frac{\partial \ln C}{\partial \ln q} - 1 = \left(a + d \ln y + \sum\nolimits_{r=1}^{n} g_r \ln w_r\right) - 1. \tag{4}$$

SAL can be calculated using the estimated parameters, the observed production, and factor prices for each farm. The condition under which economies of scale operate is that SAL takes a negative value, as shown below.

$$SAL < 0. \tag{5}$$

Figure 1 shows the distribution of SAL for Hokkaido farms and other regions. Observe that SAL is below zero for all sample farms. Table 6 also shows SAL for national data, and disaggregated by scale region. The results suggest that the average value of SAL is below zero regardless of scales and regions, suggesting that economies of scale generally exist for Japanese raw milk producers, irrespective of the farm scale or geographic region. Figure 1 also shows that SAL tends to be closer to

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[17] Because this paper focuses on a single product (raw milk), the distinction between so-called Partial Scale Economies and Overall Scale Economies is inapplicable.

zero for farms with larger numbers of livestock, suggesting that there is more room for small-scale farms to improve their profit margins by increasing the number of cows than large-scale farms.

In the translog cost function, the self-price elasticity e_{ii} and cross-price elasticity e_{ij} of demand for factor i concerning factor j are obtained, respectively, as follows.[18]

$$e_{ii} = \frac{\partial x_i}{\partial w_i}\frac{w_i}{x_i} = \sigma_{ii}\widehat{cs}_i, \quad e_{ij} = \frac{\partial x_i}{\partial w_j}\frac{w_j}{x_i} = \sigma_{ij}\widehat{cs}_j. \tag{6}$$

Here, the hat symbol represents the estimated value of each parameter. In addition, σ_{ii} and σ_{ij} represent the Allen–Uzawa estimates of the partial elasticity of substitution, which are given as

$$\sigma_{ii} = \frac{\hat{f}_{ii} + \widehat{cs}_i^2 - \widehat{cs}_i}{\widehat{cs}_i^2}, \qquad \sigma_{ij} = \frac{\hat{f}_{ij} + \widehat{cs}_i\widehat{cs}_j}{\widehat{cs}_i\widehat{cs}_j}. \tag{7}$$

Table 6 lists the own-price and cross-price elasticities for each production factor obtained from equation (6). Three interesting results of the analysis are obtained. First, focus on e_{43} shown in the table. In Japan as a whole, a 1% increase in labor prices will result in a 0.28% increase in the demand for equipment, suggesting that a certain degree of substitutability between labor and equipment exists, and that mechanization can increase scales of production without necessarily requiring additional labor input. The cross-price elasticity is smaller for larger farms, 0.22%, compared to small farms, 0.33%. A slightly smaller elasticity is obtained for Hokkaido, 0.27% in Hokkaido, compared to other regions, 0.30%. Second, focusing on e_{12}, a 1% increase in the price of purchased feed would result in a 0.33% increase in the demand for self-supplied feed in Japanese farms. For this cross-price elasticity, the difference between Hokkaido and other regions is substantial: 0.28% for Hokkaido and 0.42% for the rest of Japan. In Hokkaido, which has a vast land area, the use of self-supplied feed has traditionally been high. Therefore, changes in purchased feed prices may have a small effect on the demand for self-supplied feed. Third, focus on e_{62}. A 1% increase in purchased feed prices results in a 0.33% increase in demand for land for Japanese farms, suggesting a need for more land to produce self-produced feed as demand for it increases in line with the rising price of purchased feed. Again, the difference between

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[18] Ray (1982) presents a detailed derivation of price elasticity.

Hokkaido and other regions is remarkably pronounced, with 0.27% in Hokkaido compared to 0.41% in the rest of the country.

Conversely, cross-price elasticities among equipment, buildings, and land are estimated to be low. For example, a 1% increase in equipment prices has a smaller effect on the demand for building costs (0.05%, see e_{54} of the "All" column) and on the demand for land (0.05%, see e_{64} of the "All" column). Therefore, the substitutability between these factors of production is smaller than for pairs such as labor and equipment or self-produced feed and purchased feed.

5. Simulation Analysis

In this section, we use the results of the translog cost function estimation in the preceding section to perform three simulation analyses. First, we examine how much farms' profits would improve in the case that the allocation of (some) factors of production were modified so that the farms were able to achieve cost minimization. Second, we will examine how much hypothetical mergers of small- and medium-scale farms into larger-scale farms would reduce production costs and increase profit margins. Third, we will examine the impacts of introducing a uniform national integrated pooled price integrated for raw milk, combined with or without the elimination of subsidies for milk for processing on farms' profitability.

5.1 Revision of production factor allocation and farm profits

In this section, we compare the actual profits observed in the data to those that would result if the allocations of the seven major items were revised to achieve cost minimization. The observed profit $\Pi_{i,t}$ of the farm i in period t is defined as follows.

$$\Pi_{i,t} = p_{i,t}q_{i,t} - C_{i,t}(\boldsymbol{w_{i,t}}, q_{i,t}) \tag{8}$$

where $p_{i,t}$ and $q_{i,t}$ respectively stand for the observed pooled price and output of farm i in period t,

$\boldsymbol{w}_{i,t}$ is the observed cost vector of each production factor, and $C_{i,t}(\boldsymbol{w}_{i,t}, q_{i,t})$ is the total cost.[19] Also, given the observed output, the profit realized under an allocation of factors of production that minimizes the costs estimated in the previous section is calculated as follows.

$$\Pi_{i,t}^{*} = p_{i,t}q_{i,t} - C_{i,t}^{*}(\boldsymbol{w}_{i,t,r}, \boldsymbol{w}_{i,t,k}, q_{i,t}). \tag{9}$$

To be comparable with the realized profit of each farm, the total cost $C_{i,t}^{*}$ is calculated here by using the actual value ($\boldsymbol{w}_{i,t,k}$) as it is, except for the cost vector $\boldsymbol{w}_{i,t,r}$ of the production factors (7 main items) that is estimated to minimize costs. In other words, $C_{i,t}^{*}(\boldsymbol{w}_{i,t,r}, \boldsymbol{w}_{i,t,k}, q_{i,t})$ represents the total cost of partial cost minimization for the seven major items only. That is, $\Pi_{i,t}^{*}$ represents the profit calculated based on the partially cost-minimized total costs.

Figure 2 displays the distribution of observed and estimated partial cost-minimized profits, and panel (b) of Table 3 reports each cost-minimized share. Panels (a) and (b) of Table 7 show their respective descriptive statistics. First, the average actual profit margin by scale shows higher returns for large farms, followed by medium and small farms, in that order. The profit margins of small farms are negative, indicating that business conditions are tough for them.[20] The average actual profits in other regions are larger than in Hokkaido. One reason might be that the pooled price in Hokkaido is lower than that in the other regions, while Hokkaido farms have better cost efficiency. On the other hand, the coefficient of variation, defined as the ratio of the standard deviation to the mean, is 8.51 for Hokkaido and 5.20 for other regions. This indicates that the variance of actual profits is greater in Hokkaido than in the other regions.

Next, the profit calculated based on the partially cost-minimized total cost of production according to equation (9) (profit from optimizing the allocation of factors under a given production

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[19] The observed pooled price is reported based on the following definition. Firstly, various expenses are subtracted from the milk payments from dairy manufacturers plus subsidies. Those expenses include the costs incurred for collecting and delivering milk, sales commissions, and other shipping and selling costs. This amount is then divided by 100 kilograms of raw milk production (milk fat content 3.5% equivalent), which constitutes the observed pooled price.

[20] Total costs include the wage costs of family labor as well as external labor. The wage cost of family labor is an imputed calculation and is different in nature from other cost items. One reason that many small farms are able to continue to operate despite negative profit margins might be that the primary cost bearers are family members.

volume and price) shows an improvement in the mean and median values compared to the profit observed across all groups. As shown in Panel (b) of Table 7, the improvement in total profit was largest for medium-scale farms, with 48% for large farms, 153% for medium-scale farms, and 25% for small farms, by scale.[21] By region, the profit improvement effect of the revision of input allocation would be greatest in Hokkaido, at 199% compared to 74% in other regions. In other words, Hokkaido farms and medium-scale farms are expected to benefit the most from cost minimization.

Table 8 reports the number and share of deficit-running farms by scale and region in each simulation scenario. Row i of panel (a) of the table shows the number of farms that show losses (deficits) in the actual data. Row i of panel (b) shows the number of deficit-running farms in a counterfactual case in which production is conducted with the cost-minimized combination of production inputs. First, the percentage of deficit-running farms would become lower in the counterfactual cases. The degree of reduction is highest among medium farms, followed by large-scale farms and small farms. Among small farms, the actual ratio of the deficit-running farms is highest: 74%. Although cost minimization is taken into account, the ratio of loss-making farms remains almost the same for small farms, while it decreases by about 3-4% for medium and large farms. Looking at the result by region, the percentage of loss-making farms in Hokkaido was slightly higher than in other regions, at 53.1%, based on actual profits. However, in a counterfactual case of cost minimization, the percentage of loss-making farms will be lower in Hokkaido, at 47.3%, than in other regions, because the rate of improvement would be greater in Hokkaido than elsewhere in Japan.

Rows ii of panels (a) and (b) display the number of farms that have been in the sample for more than four years and have reported a deficit in profit over the same period in actual and counterfactual cost-minimizing cases, respectively.[22] First, by scale, the percentage of loss-making farms in actual data is highest for small farms, followed by medium, and large farms, in that order. In the

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[21] Where the profit improvement rate is defined as (cost-minimized profit – actual profit)/actual profit.

[22] If profit deficits persist for multiple years, even after cost minimization, the company might be forced to exit the market abruptly (bankruptcy or business closure). For this study, although the sample replacement in the census is five years, we used four years as a guideline, given that the number of eligible farms would be greatly reduced if we narrowed the sample to farms selected for more than five years.

counterfactual cost-minimizing case, the ratio of loss-making farms among medium- and large-scale farms is lower, while it remains relatively unchanged or higher for small-scale farms. By region, the ratio of loss-reporting farms is higher in Hokkaido by 11.1% point compared to other regions in actual data. In the counterfactual scenario of cost minimization, the percentage of loss-making farms in Hokkaido would decrease by 10.4% compared to the actual data. However, there is no substantial reduction in the percentage of loss-making farms in regions outside Hokkaido. These simulation results suggest that 50% of farms in Japan are making losses in actual data and that even in the counterfactual scenario of cost minimization through input reallocation for small farms and regions outside Hokkaido, which have a high concentration of small-scale farms, the situation would not be significantly improved.

5.2 Cost savings by merging small and medium farms

As explained in the previous section, profit margins, especially for small farms, do not improve much even in case of implementing cost minimization via reallocation of input. However, the analysis suggests that increasing scale can significantly increase farms' productivity and profitability. In this section, a simulation will be conducted for a counterfactual scenario in which small- and medium-scale farms merge to form a larger farm without changing their total production (and, therefore, their aggregated number of cows). The simulation assumes that small- and medium-scale farms in proximity would merge within each of ten regions. The total production of all small and medium farms in a region is divided by the average production for a large farm to obtain the new number of large farms after the consolidation. We use parameters obtained from estimates for large farms' cost function for post-merger productivity. Next, we examine the effect of consolidation on farms' profit by examining how much the total costs incurred by the hypothetical new large farms are reduced relative to the total costs incurred by the small and medium farms before the merger. For example, in the case of Hokkaido, the total production of 2,005 small-scale and medium-scale farms is approximately 1,014 million kilograms, which is divided by the average production of 919 thousand kilograms of large-scale farms to arrive at the number of new large-scale farms after consolidation at 1,104. In this case, the assumption is that approximately two small to medium-scale farms will be merged to create one new large farm.

Under this assumption, the cost-minimized profit is calculated as follows.

$$\Pi_{i,t}^{sim*} = p_{sim} q_{sim} - C_{i,t}^{*}\left(\boldsymbol{w}_{i,t,r}, \boldsymbol{w}_{sim,k}, q_{sim}\right) \tag{10}$$

where p_{sim} is a value generated from a normal distribution consisting of the mean and standard deviation of the pooled prices experienced by small-scale and medium-scale farms and q_{sim}, holding the total output of small-scale and medium-scale farms being constant.[23] Similarly, for costs $\boldsymbol{w}_{sim,k}$ other than the seven main items, values generated from a normal distribution consisting of the mean and standard deviations for large farms were used.

Table 7 summarizes the simulation results based on equation (10). It compares the number of small- and medium-scale farms, total revenue, total cost, total profit, and coefficient of variation of farms' profit in the simulated post-merger case to the actual data, i.e., pre-merger case.. The number of small- and medium-scale farms in Hokkaido would decrease from 2,005 to 1,104 due to the consolidation. The total revenue slightly differs between pre-merger and post-merger as we used the distribution of pooled prices (not exactly the same pooled price in the pre-merger case) in the post-merger case. Total profit would increase about 7.6-fold because total costs would be reduced by 7% as a result of small- and medium-scale farms improving their cost efficiency after mergers. Similarly, in other regions, the total number of farms would decrease by about two-thirds, from 1,678 to 588, but the total profits would increase about ten times because the total costs would be reduced by 31%.

In practice, mergers of small and medium farms do not usually proceed smoothly because of

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[23] Here, we use the distribution of pooled prices for small and medium farms before consolidation, rather than for large farms. This is done for this study because whether the purchases made are for drinking milk or for raw milk for processing depends mainly on the presence of plants for raw milk processing near the farm’s location. Therefore, we assume here that there is no change in location after the merger and that pooled prices follow the pre-merger pooled price distribution for small- and medium-scale farms.

various institutional and geographical constraints. The simulation results here should be taken to show the maximum benefits. But the results presented here suggest that it is possible to increase profits without changing an overall production volume in Japan. Although the number of farms closing businesses will most likely increase in the future due to the aging of farmers, a smooth transition from small and medium family-run farms to large-scale corporate-run farms will promote an increase in overall profit margins for dairy farming in Japan. Table 9 also shows that the coefficient of variation of total profits would decrease after consolidation in both Hokkaido and other regions. This decrease of the coefficient of variation implies that the profit gaps between farms may narrow as they become larger scale.

5.3 Introduction of the national uniform pooled price

As discussed in the *Introduction*, the purchase prices of raw milk by dairy processing firms vary by dairy products, with higher prices for drinking milk and lower prices for milk intended for products like cheese and butter. As a result, the pooled price for farms in regions other than Hokkaido, which primarily produce milk for drinking, is higher than the pooled price for farms in Hokkaido, which primarily produces milk for processing.[24] A natural question is why Hokkaido farms or its designated producer organization do not "export" raw milk to the rest of Japan, where the pooled price is higher. The cross-regional border movement of milk is likely self-regulated by the ten designated producer organization. There are exports from Hokkaido to other regions at the request of another region although the amount of exports is limited.[25] It seems that they have formed a cartel not to compete. In other words, these product-specific price systems inhibit competition among farms across regions, combined with a restricted cross-border milk movement, reducing consumers' benefits of

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[24] For farms producing milk for processing, the pooled price, including subsidies from designated organizations, is the purchase price of milk.

[25] For example, according to The Daily Dairy News (*Nikkan Rakuno Nyugyo Sokuho*), the share of raw milk exports from Hokkaido to other regions out of the total production of Hokkaido is approximately 11.5 percent in 2021. Kanagawa, Ibaraki, and Kyoto are major importers from Hokkaido in order and those prefectures import 24.4, 13.1 and 13.0 percent, respectively, out of total domestic exports of Hokkaido. Tokyo, the largest economic prefecture, imports limited amount from Hokkaido (1.1 percent) while it mainly imports from other periphery prefectures such as Gunma and Tochigi.

having inexpensive milk. From the producer side, Hokkaido farms on average are, on average, cost-effective because they have achieved a large scale, but their cost advantage is partly offset by being forced to accept lower pooled prices just because more dairy products manufacturing firms that produce butter and cheese exit in Hokkaido compared to other regions. This predicament for Hokkaido farms is caused by market segmentation between regions in this industry.

This section considers a counterfactual case in which product-specific prices for raw milk are eliminated, and a uniform nationwide pooled price is introduced. Regarding national subsidies, we assume two cases: one in which there is no change in the subsidies in this section, and the other in which the subsidies are eliminated in the next section.

First, one can consider a subcase of no change in national subsidies. One can use the observed national average pooled price of 8,413 yen (per 100 kg of raw milk) for p_{sim} in the profit function equation (10).[26] This hypothetical raw milk price is calculated as the sum of the total milk payments made by dairy manufacturers to dairy farms and the total national subsidy for raw milk used in processed products, divided by total raw milk production. Therefore, the simulation is for eliminating product-specific raw milk prices and introducing a one price for raw milk, but maintaining the national subsidy.[27] In addition, the cost is minimized to $C^{*}_{i,t}(\boldsymbol{w}_{i,t,r}, \boldsymbol{w}_{sim,k}, q_{sim})$ for the seven main items.

Panel (c) of Table 7 displays the simulated statistics of the farm profits under the above scenario when a uniform price for raw milk is introduced, regardless of the products or region for which raw milk is used. Panel (b) of the table shows the counterfactual case of cost minimization by adjusting inputs, but no change in raw milk pricing. A comparison of results in panels (b) and (c) allows us to understand the effect of introducing uniform national pooled pricing in addition to cost minimization. First, introducing a uniform national pooled price would improve total profit by an average of 122% and 73% for medium and large farms, respectively. In contrast, small farms would widen their losses

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[26] We also simulate farm profits using both 7,992 yen (95% of 8,413yen) and 8,834 yen (105% of 8,413 yen) other than 8,413 yen. Nevertheless, the results do not change qualitatively.

[27] The subsidy amounts were obtained from the ALIC website. (https://www.alic.go.jp/r-keiei/raku03_000003.html)

by 46% because Hokkaido, where the pooled price is low due to a higher percentage of raw milk being processed for dairy products other than drinking milk, benefits most from introducing a uniform national pooled price. In other regions, where raw milk tends to be more for drinking milk, the actual pooled price for raw milk is higher than in Hokkaido, and because most small-scale farms are located outside of Hokkaido, in a counterfactual case of uniform national pooled price would be averse to them. Hokkaido is expected to see a 183% improvement in profits, while profits in other regions will decrease by 117%. This difference in profits represents a huge contrast. The reason is the same as the comparison by scale.

The coefficients of profit variation are smaller in this counterfactual case than in case (b) for all scales. Introducing the uniform national price of raw milk would reduce the disparity in profits among farms. This reduced disparity holds for Hokkaido but not for other regions. In summary, in a counterfactual case where the total amount of subsidies is kept constant at the current level and a uniform pooled price is introduced nationwide, medium-scale and large-scale farms anywhere and those in Hokkaido would benefit from higher profits, whereas small farms and those in other regions would undergo a reduction in profits.

5.4 Uniform price with elimination of subsidies for raw milk for non-drinking dairy products

Panel (d) of Table 7 shows the simulation results of introducing the uniform price for raw milk but also abolishing the subsidy system simultaneously. This simultaneous introduction of uniform prices and subsidy abolishment might be a more realistic hypothesis because subsidies are meant to partially compensate for lower prices of raw milk destined to non-drinking dairy products. Here, the "pooled price without subsidies" is equal to "the total pooled price received by all farms minus the total amount of subsidies (i.e., only the total amount paid by dairy manufacturers)" divided by "total raw milk production nationwide." This virtual pooled price p_{sim} is 8,090 yen. Again, as in panel (c) of Table 7, we assume that the allocation of costs has been revised so that the farms achieve cost minimization. Accordingly, a comparison of panels (c) and (d) shows the impact of the abolition of the subsidy program. Not surprisingly, eliminating the subsidy program alone would reduce farms' profits, regardless of scale or region. Regions other than Hokkaido would be particularly affected, with a 258% decrease in profit margins. However, the profit reduction impact would be relatively small for Hokkaido and large farms, at around -22%.

The government may judge that an introduction of uniform raw milk price would be accompanied by eliminating subsidies, because the subsidies are intended as partial compensation of the lower prices of raw milk that are used for non-drinking dairy products.[28] A combination of a national uniform raw milk price and the eliminating subsidies is shown in panel (d), in comparison with panel (b). A comparison of (b) and (d) shows that that while small-scale farms and farms in regions other than Hokkaido would still have negative profit margins, large-scale farms in any region and any scale farms in Hokkaido would benefit most. This disparity of benefits is natural since the Hokkaido farms are discriminated against in the pooled price system, being forced to have large proportion of raw milk used for non-drinking dairy products, and being prohibited to export to other regions where the pooled price is higher.

6. Summary and Concluding Remarks

The main results of the paper are presented below. First, economies of scale exist in raw milk production. The total cost increases only 0.67% for a 1% expansion in production for the entire sample. That is, the rate of increase in total cost is smaller compared to the rate of increase in production. This result indicates that the average cost would decrease and that the production efficiency would increase as the scale of each farm expands. Scale economies are observed regardless of the scale of the farm

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[28] One might think that the financial resources made available by abolishing the subsidy system can be used for income compensation to loss-making farms. The actual value of subsidies (sample average) is 24.1 billion yen per year according to the calculation using the data obtained from the ALIC website. The number of farms that run a continuous deficit over four years is estimated to be 7,065 using the share of deficit-running farms calculated in this research (45%) and the total number of dairy farms in Japan obtained from the Census of Agriculture and Forestry (15,700). If a total of 24.1 billion yen in subsidies per year were to be distributed as income compensation to these 7,065 continuously loss-making farms, the per-household income would be 3.41 million yen. As a reference, Japan's average income is 4.41 million yen in 2018.

household or the location, either in Hokkaido or other regions.[29] Second, several interesting results are obtained regarding the elasticities of substitution among factors of production. An estimated cross-price elasticity indicates that a 1% increase in the price of labor will result in a 0.28% increase in the demand for equipment. Therefore, a certain degree of substitutability exists between labor and equipment. The results of this analysis suggest that introducing labor-saving technology (mechanization or automation) may increase profits. Another result is that a 1% increase in the price of purchased feed would result in a 0.33% increase in the demand for self-produced feed. This cross-price elasticity is less pronounced for larger farms. The difference between Hokkaido and other regions was remarkable, the cross-elasticity between the purchased feed and self-produced feed is 0.28% in Hokkaido in contrast to 0.42% in the rest of Japan. This disparity is expected because the use of self-produced feed has already been high in Hokkaido, so changes in purchased feed prices do not have a significant impact on the demand for self-produced feed. The analysis also showed that a 1% increase in purchased feed prices would result in a 0.33% increase in demand for land. This increase can be interpreted as evidence of the demand for more land to produce self-produced feed when the price of purchased feed increases.

The results of the simulation analysis are explained below. First, when the allocation of factors of production is optimized to achieve cost minimization, farms' profits improve regardless of the scale or region. Large farms improved their profit margins by as much as 48%. Even small farms, many of whom are producing milk with deficits in the actual data, could reduce their deficits by as much as 25%. Comparing Hokkaido and other regions, the improvement was 74% in regions other than Hokkaido and 199% in Hokkaido. This difference is attributable to the greater share of large-scale farms in Hokkaido than in other regions. Second, if small-scale and medium-scale farms were consolidated to become larger-scale farms, costs could be reduced by 7% in Hokkaido and 31% in

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[29] Hokkaido is Japan's major production prefecture of dairy products; economies of agglomeration might work more in that prefecture than in other prefectures. Therefore, we show some of our results for Hokkaido and other regions considering the quantitative difference between Hokkaido and other prefectures.

other regions. Third, the introduction of a uniform national raw milk price would improve profits for large- and medium-scale farms while decreasing profits for small-scale farms. This expected effect is attributable to the fact that the pooled price for Hokkaido where less small-scale farms are present is lower than the rest of Japan. In addition, the elimination of the subsidy will reduce farms' profit margins, but introducing a uniform national raw milk price in parallel with the elimination of the subsidy could offset the negative effect of eliminating subsidies in some regions.

The analysis and simulations in the paper are confined to that of a cost function. This limitation is valid when demand for raw milk is held constant. The analysis of farms cost structure when the external conditions and policies change needs to be expanded to a demand analysis if the full implications of policies are explored. Benefits of higher profits in some cases would most likely be distributed to consumers by lowering the (uniform) raw milk prices. Examination of this lowering of prices is anticipated as the next step of research. Also international comparisons of the cost function and regulatory reforms are left as subjects for future research.

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Table 1: Frequency and continuity of sample farm selection

Frequency		Continuity		
Years of sampling	Number of farmers	Period	Number of farmers sampled for two consecutive years	Replacement rate (%)
1 year	111	2008-2009	463	6.5
2 years	66	2009-2010	457	6.0
3 years	67	2010-2011	467	4.5
4 years	102	2011-2012	411	15.4
5 years	73	2012-2013	461	6.1
6 years	58	2013-2014	458	6.5
7 years	34	2014-2015	460	5.2
8 years	31	2015-2016	474	3.9
9 years	75	2016-2017	374	23.7
10 years	213			

Note: The replacement rate is defined as “the percentage of farms sampled in one year which are not sampled in the subsequent year.” For example, the replacement rate in the row for “2008–2009” is calculated as “the percentage of farms sampled in 2008 which were not sampled in 2009.”

Table 2: Farm size by the producer organization

Producer organization in each block	Prefecture	Number of farmers		Number of cows	Raw milk yield (100kg)
Hokuren Federation of Agricultural Cooperatives	Hokkaido	2,428	Mean	66.6	6,222
			Median	58.4	5,228
			S.D.	39.8	4,345
Other organizations	Others	2,428	Mean	39.2	3,667
			Median	30.8	2,825
			S.D.	33.0	3,388
Touhoku Seinyuhanren	Akita, Aomori, Fukushima, Iwate, Miyagi, Yamagata	525	Mean	30.1	2,679
			Median	26.1	2,202
			S.D.	20.6	2,044
Hokuriku Rakuren	Fukui, Ishikawa, Niigata, Toyama	60	Mean	26.5	2,438
			Median	27.7	2,377
			S.D.	11.3	1,103
Kanto Seinyuhanren	Chiba, Gunma, Ibaraki, Kanagawa, Saitama, Shizuoka, Tochigi, Tokyo, Yamanashi	752	Mean	42.9	4,026
			Median	32.7	2,868
			S.D.	42.1	4,378
Toukai Rakuren	Aichi, Gifu, Mie, Nagano	215	Mean	51.0	4,979
			Median	42.2	4,408
			S.D.	38.8	3,811
Kinki Seinyuhanren	Hyogo, Kyoto, Nara, Osaka, Shiga, Wakayama	140	Mean	36.6	3,376
			Median	30.0	2,852
			S.D.	26.5	2,512
Shikoku Seinyuhanren	Ehime, Kagawa, Kochi, Tokushima	85	Mean	28.3	2,635
			Median	27.9	2,616
			S.D.	15.0	1,485
Chugoku Seinyuhanren	Hiroshima, Okayama, Shimane, Tottori, Yamaguchi	182	Mean	38.4	3,710
			Median	29.5	2,842
			S.D.	29.5	3,288
Kyushu Seinyuhanren and Okinawa Dairy Cooperatives	Fukuoka, Kagoshima, Kumamoto, Miyazaki, Nagasaki, Oita, Okinawa, Saga	469	Mean	42.7	4,010
			Median	35.5	3,279
			S.D.	28.4	2,865
All		4,856	Mean	52.9	4,945
			Median	44.1	4,018
			S.D.	39.1	4,100

Note: Descriptive statistics for the entire sample period (2008–2017). The number of farms included in the sample at least once represents the overall number of farms included in the sample. S.D. indicates standard deviation.

Table 3: Breakdown of costs (Actual vs. Cost-minimized)

	All	Small	Medium	Large	Hokkaido	Excluding Hokkaido
(a) Actual value						
Average number of cows	52.7	20.4	46.7	97.1	64.1	35.7
Number of observations	3448	860	1726	864	2064	1384
Milk yield (100kg)	4833.1	1744.5	4197.8	9186.8	5851.7	3314.2
Average cost (yen/100kg)	7251.1	9048.8	6924.5	6111.6	6552.8	8292.6
Pooled price (yen/100kg)	8153.8	8737.7	8068.0	7743.0	7446.9	9207.9
Cost share						
Self-supplied feed	0.141	0.104	0.146	0.168	0.183	0.078
Purchased feed	0.336	0.351	0.327	0.337	0.277	0.422
Equipment	0.044	0.038	0.043	0.050	0.046	0.040
Building	0.024	0.020	0.023	0.030	0.025	0.023
Labor	0.270	0.331	0.273	0.204	0.259	0.287
Land rent	0.037	0.033	0.038	0.038	0.047	0.022
Cow depreciation	0.148	0.123	0.149	0.173	0.163	0.127
(b) Cost-minimized value						
Average cost (yen/100kg)	7240.8	8883.6	6813.8	5957.7	6517.4	8285.5
Marginal cost (yen/100kg)	4790.2	5390.6	3745.4	3396.6	4109.1	5720.7
Lerner index (the degree of monopoly)	0.407	0.372	0.528	0.558	0.444	0.374
Cost share						
Self-supplied feed	0.133	0.093	0.133	0.164	0.173	0.076
Purchased feed	0.339	0.350	0.325	0.311	0.285	0.416
Equipment	0.050	0.043	0.050	0.059	0.054	0.046
Building	0.028	0.026	0.028	0.035	0.029	0.027
Labor	0.260	0.321	0.273	0.208	0.246	0.280
Land rent	0.038	0.037	0.041	0.045	0.048	0.023
Cow depreciation	0.152	0.129	0.151	0.178	0.165	0.133

Note: Average values for the entire sample period (2008–2017).

Table 4: Descriptive statistics of factor prices and their derivation methods

Element	Mean	S.D.	Median	Max.	Min.	Number of observations	Derivation method	Unit
w1: Self-supplied feed	1,454	910	1,214	5,145	330	3,446	Divide the total expenditure for self-supplied feed by the total input quantity (weighted average)	Yen per 100kg
w2: Purchased feed	5,938	960	5,973	8,571	2,814	3,446	Divide the total expenditure for purchased feed by the total input quantity (weighted average)	Yen per 100kg
w3: Labor	1,549	127	1,574	1,323	76	3,446	Divide the sum of family labor and employed labor by the total hours worked by those two types of workers (weighted average)	Yen per hour
w4: Equipment	95,073	81,310	71,443	546,976	23,766	3,446	Divide the sum of car expenses and agricultural equipment cost by the total input quantity of those two items (weighted average)	Yen per unit
w5: Building	522	387	429	2,083	120	3,446	Divide total building cost by the building area (weighted average)	Yen per 1 square meter
w6: Land rent	367	257	282	1,323	76	3,446	Divide the sum of land rent paid and imputed rent for owned land by the total land area (weighted average)	Yen per 1 are
w7: Cow depreciation	91,537	26,386	89,636	201,539	52,836	3,446	Divide the total depreciation cost by the number of cows	Yen per cow

Note: S.D. denotes standard deviation. The table reports the average of the 99th percentile as the maximum (Max.) and the average of the 1st percentile as the minimum (Min.) to ensure the confidentiality of individual farm information.

Table 5: Estimation results of translog cost functions

	ALL		Small		Medium		Large		Hokkaido		Excl. Hokkaido	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
ln *k*	17.293	0.011 ***	16.522	0.027 ***	17.152	0.015 ***	17.798	0.019 ***	17.382	0.013 ***	17.057	0.017 ***
a	0.667	0.011 ***	0.597	0.022 ***	0.566	0.020 ***	0.599	0.024 ***	0.659	0.015 ***	0.696	0.016 ***
d	0.043	0.011 ***	0.011	0.030	0.237	0.048 ***	0.420	0.060 ***	0.123	0.018 ***	0.057	0.016 ***
b1	0.133	0.003 ***	0.093	0.006 ***	0.133	0.004 ***	0.164	0.005 ***	0.173	0.003 ***	0.076	0.004 ***
b2	0.339	0.005 ***	0.350	0.012 ***	0.325	0.007 ***	0.311	0.009 ***	0.285	0.004 ***	0.416	0.007 ***
b3	0.260	0.003 ***	0.321	0.009 ***	0.273	0.005 ***	0.208	0.005 ***	0.246	0.004 ***	0.280	0.006 ***
b4	0.050	0.001 ***	0.043	0.002 ***	0.050	0.001 ***	0.059	0.002 ***	0.054	0.001 ***	0.046	0.002 ***
b5	0.028	0.001 ***	0.026	0.002 ***	0.028	0.001 ***	0.035	0.002 ***	0.029	0.001 ***	0.027	0.001 ***
b6	0.038	0.001 ***	0.037	0.004 ***	0.041	0.002 ***	0.045	0.002 ***	0.048	0.001 ***	0.023	0.002 ***
f11	0.029	0.001 ***	0.024	0.002 ***	0.030	0.002 ***	0.034	0.003 ***	0.038	0.002 ***	0.019	0.002 ***
f22	0.071	0.003 ***	0.105	0.008 ***	0.058	0.004 ***	0.068	0.005 ***	0.045	0.003 ***	0.125	0.006 ***
f33	0.115	0.003 ***	0.131	0.008 ***	0.119	0.005 ***	0.089	0.006 ***	0.114	0.005 ***	0.133	0.006 ***
f44	0.036	0.000 ***	0.032	0.001 ***	0.037	0.000 ***	0.040	0.001 ***	0.038	0.000 ***	0.033	0.001 ***
f55	0.017	0.000 ***	0.015	0.000 ***	0.016	0.000 ***	0.023	0.000 ***	0.017	0.000 ***	0.017	0.000 ***
f66	0.018	0.000 ***	0.020	0.001 ***	0.016	0.001 ***	0.023	0.001 ***	0.030	0.001 ***	0.013	0.000 ***

Note: ***, **, and ** denote that the null hypothesis of a *t*-test (coefficient of zero) is rejected at the 1%, 5%, and 10% significance levels, respectively. S.D. indicates standard deviation.

Table 5: Estimation results of translog cost functions (continued)

	ALL		Small		Medium		Large		Hokkaido		Excl. Hokkaido	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
f12	0.008	0.001 ***	0.000	0.003	0.012	0.002 ***	0.013	0.003 ***	0.009	0.002 ***	0.004	0.002
f13	-0.017	0.001 ***	-0.013	0.002 ***	-0.023	0.002 ***	-0.011	0.002 ***	-0.020	0.001 ***	-0.013	0.002 ***
f14	-0.004	0.000 ***	-0.002	0.001 ***	-0.003	0.000 ***	-0.008	0.001 ***	-0.005	0.000 ***	-0.001	0.001
f15	-0.003	0.000 ***	-0.001	0.001 *	-0.003	0.000 ***	-0.005	0.001 ***	-0.004	0.000 ***	-0.001	0.000 **
f16	-0.003	0.000 ***	-0.002	0.001 ***	-0.003	0.000 ***	-0.005	0.001 ***	-0.005	0.000 ***	-0.001	0.000 ***
f23	-0.024	0.003 ***	-0.045	0.007 ***	-0.018	0.004 ***	-0.019	0.004 ***	-0.008	0.003 **	-0.056	0.005 ***
f24	-0.012	0.001 ***	-0.012	0.002 ***	-0.012	0.001 ***	-0.010	0.001 ***	-0.010	0.001 ***	-0.014	0.001 ***
f25	-0.008	0.001 ***	-0.009	0.001 ***	-0.007	0.001 ***	-0.007	0.001 ***	-0.006	0.001 ***	-0.011	0.001 ***
f26	-0.002	0.001 ***	-0.007	0.001 ***	0.000	0.001	-0.003	0.001 ***	-0.001	0.001	-0.006	0.001 ***
f34	-0.012	0.001 ***	-0.012	0.002 ***	-0.013	0.001 ***	-0.009	0.001 ***	-0.012	0.001 ***	-0.012	0.001 ***
f35	-0.004	0.001 ***	-0.003	0.001 **	-0.005	0.001 ***	-0.006	0.001 ***	-0.005	0.001 ***	-0.003	0.001 ***
f36	-0.006	0.001 ***	-0.004	0.002 **	-0.005	0.001 ***	-0.005	0.002 ***	-0.013	0.001 ***	-0.003	0.001 **
f45	0.000	0.000 **	0.000	0.000 **	0.000	0.000	-0.001	0.000 ***	0.000	0.000	-0.001	0.000 *
f46	-0.002	0.000 ***	-0.002	0.000 ***	-0.002	0.000 ***	-0.002	0.000 ***	-0.002	0.000 ***	-0.001	0.000 ***
f56	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000 **	0.000	0.000	0.000	0.000
g1	0.010	0.002 ***	0.002	0.005	0.008	0.005	0.009	0.007	0.014	0.003 ***	-0.007	0.003 **
g2	0.071	0.003 ***	0.057	0.007 ***	0.087	0.007 ***	0.089	0.009 ***	0.086	0.004 ***	0.073	0.005 ***
g3	-0.048	0.003 ***	-0.023	0.005 ***	-0.058	0.005 ***	-0.046	0.005 ***	-0.060	0.004 ***	-0.033	0.004 ***
g4	-0.022	0.001 ***	-0.021	0.002 ***	-0.016	0.002 ***	-0.027	0.003 ***	-0.021	0.001 ***	-0.022	0.001 ***
g5	-0.005	0.001 ***	-0.014	0.001 ***	-0.001	0.001	-0.005	0.002 ***	-0.001	0.001	-0.010	0.001 ***
g6	-0.014	0.001 ***	-0.013	0.001 ***	-0.014	0.001 ***	-0.014	0.002 ***	-0.021	0.001 ***	-0.011	0.001 ***

Note: ***, **, and ** denote that the null hypothesis of a *t*-test (coefficient of zero) is rejected at the 1%, 5%, and 10% significance levels, respectively. S.D. indicates standard deviation.

Table 6: Economies of scale and price elasticity

	All	Small	Medium	Large	Hokkaido	Excluding Hokkaido
Average number of cows	52.7	20.4	46.7	97.0	64.1	35.7
Number of observations	3448	860	1726	862	2064	1384
SAL	-0.335	-0.394	-0.441	-0.416	-0.356	-0.305
Own-price elasticity						
e11	-0.643	-0.629	-0.636	-0.622	-0.604	-0.662
e22	-0.451	-0.346	-0.495	-0.471	-0.555	-0.280
e33	-0.299	-0.271	-0.292	-0.368	-0.287	-0.249
e44	0.212	-0.049	-0.427	-0.131	0.153	0.781
e55	-0.131	-0.676	4.770	-0.123	0.029	-3.061
e66	-7.604	-0.364	-0.495	-0.406	-0.289	-1.099
Cross-price elasticity						
e12	0.334	0.352	0.333	0.316	0.278	0.417
e13	0.270	0.317	0.271	0.213	0.258	0.282
e14	0.045	0.039	0.045	0.054	0.048	0.042
e15	0.025	0.023	0.024	0.033	0.026	0.025
e16	0.039	0.035	0.039	0.044	0.049	0.023
e21	0.132	0.090	0.135	0.167	0.172	0.076
e23	0.275	0.319	0.281	0.213	0.264	0.286
e24	0.045	0.039	0.045	0.055	0.048	0.042
e25	0.025	0.023	0.024	0.033	0.026	0.025
e26	0.039	0.035	0.039	0.044	0.049	0.023
e31	0.125	0.086	0.124	0.160	0.165	0.071
e32	0.321	0.337	0.318	0.304	0.272	0.392
e34	0.045	0.039	0.045	0.055	0.048	0.042
e35	0.025	0.023	0.024	0.033	0.026	0.025
e36	0.039	0.035	0.039	0.044	0.049	0.023
e41	0.129	0.090	0.131	0.162	0.170	0.074
e42	0.327	0.351	0.323	0.308	0.274	0.408
e43	0.281	0.333	0.285	0.216	0.266	0.298
e45	0.025	0.023	0.024	0.033	0.026	0.025
e46	0.039	0.035	0.039	0.044	0.049	0.023
e51	0.129	0.090	0.131	0.162	0.170	0.074
e52	0.328	0.352	0.323	0.308	0.274	0.408
e53	0.281	0.334	0.286	0.216	0.267	0.298
e54	0.045	0.040	0.045	0.055	0.048	0.042
e56	0.039	0.036	0.039	0.044	0.049	0.023
e61	0.129	0.090	0.131	0.162	0.170	0.074
e62	0.328	0.352	0.323	0.308	0.274	0.408
e63	0.281	0.334	0.286	0.216	0.266	0.298
e64	0.045	0.039	0.045	0.055	0.048	0.042
e65	0.025	0.023	0.024	0.033	0.026	0.025

Note: The definition of elasticity is as given in equation (6). Here, the reference price in the cost function estimation as follows: element 1, self-supplied feed costs; element 2, purchased feed costs; element 3, labor costs; element 4, equipment costs; element 5, building costs; and element 6, land rent, and dairy cow depreciation costs.

Table 7: Comparison of farm profit margins

		By size			By region	
	All	Small	Medium	Large	Hokkaido	Excluding Hokkaido
(a) Actual value (Baseline)						
Mean	1,149	-1,830	514	5,391	985	1,393
S.D.	7,943	3,239	6,059	11,869	8,381	7,237
Coefficient of variation	6.91	-1.77	11.79	2.20	8.51	5.20
Median	-305	-1,760	-8	3,258	-497	-95
Max.		6,912	20,589	50,108	33,483	43,401
Min.		-10,421	-13,059	-20,648	-17,822	-11,099
Total profit (million yen)	3,960	-1,574	887	4,647	2,033	1,927
(b) Cost-minimized estimates: the current system						
Mean	2,514	-1,377	1,302	7,961	2,943	2,426
S.D.	9,933	2,824	6,004	14,488	9,930	9,531
Coefficient of variation	3.95	-2.05	4.61	1.82	3.37	4.95
Median	-128	-1,799	648	5,750	493	28
Max.		7,849	20,187	80,745	47,772	65,125
Min.		-7,287	-9,753	-15,217	-10,236	-7,409
Total profit (million yen)	8,670	-1,184	2,247	6,862	6,074	3,357
Profit improvement rate						
compared to (a)	119%	25%	153%	48%	199%	74%
(c) Cost-minimized estimates: uniform pooled price with subsidies						
Mean	4,602	-2,017	2,886	13,780	8,337	-416
S.D.	10,630	1,901	5,451	13,038	11,772	6,562
Coefficient of variation	2.31	-0.94	1.89	0.95	1.41	-15.77
Median	1,632	-2,224	2,610	11,767	5,767	-2,193
Max.		3,983	18,114	60,028	58,754	43,727
Min.		-6,163	-9,093	-13,662	-7,188	-9,290
Total profit (million yen)	15,869	-1,734	4,981	11,878	17,207	-576
Profit improvement rate						
compared to (a)	301%	-10%	461%	156%	746%	-130%
compared to (b)	83%	-46%	122%	73%	183%	-117%
(d) Cost-minimized estimates: uniform pooled price without subsidies						
Mean	3,039	-2,581	1,528	10,808	6,444	-1,489
S.D.	9,664	1,790	5,102	12,191	10,746	5,961
Coefficient of variation	3.18	-0.69	3.34	1.13	1.67	-4.00
Median	302	-2,712	1,290	8,957	4,117	-2,876
Max.		3,080	15,760	53,953	53,127	39,388
Min.		-6,720	-10,149	-16,112	-7,787	-10,700
Total profit (million yen)	10,478	-2,220	2,638	9,316	13,300	-2,060
Profit improvement rate						
compared to (a)	165%	-41%	197%	100%	554%	-207%
compared to (b)	21%	-87%	17%	36%	119%	-161%
compared to (c)	-34%	-28%	-47%	-22%	-23%	-258%

Note: Total profits are shown in units of one billion yen. Other items are shown in units of one thousand yen. S.D. denotes standard deviation. The table reports the average of the 99th percentile as the maximum (Max.) and the average of the 1st percentile as the minimum (Min.) to ensure the confidentiality of individual farm information.

Table 8: Numbers and shares of deficit-running farms

		By size			By region	
	All	Small	Medium	Large	Hokkaido	Excluding Hokkaido
(a) Based on actual profits						
i. Deficit farmers / All farmers [based on the total number over the whole sample period]	1801/3448	636/860	865/1726	300/862	1095/2064	706/1384
	52%	74.0%	50.1%	34.8%	53.1%	51.0%
ii. Farmers with a deficit for more than four years / Farmers sampled for more than four years	229/420	73/97	107/211	31/103	148/251	81/169
	55%	75.3%	50.7%	30.1%	59.0%	47.9%
(b) Based on cost-minimized profits under the current system						
i. Deficit farmers / All farmers [based on the total number over the whole sample period]	1758/3448	633/860	798/1726	269/862	976/2064	689/1384
	51.0%	73.6%	46.2%	31.2%	47.3%	49.8%
ii. Farmers with a deficit for more than four years / Farmers sampled for more than four years	211/420	74/97	93/211	29/103	122/251	77/169
	50%	76.3%	44.1%	28.2%	48.6%	45.6%
(c) Based on cost-minimized profits with uniform pooled price with subsidy						
i. Deficit farmers / All farmers [based on the total number over the whole sample period]	1471/3448	729/860	577/1726	89/862	504/2064	968/1384
	43%	84.8%	33.4%	10.3%	24.4%	69.9%
ii. Farmers with a deficit for more than four years / Farmers sampled for more than four years	171/420	81/97	65/211	6/103	58/251	111/169
	41%	83.5%	30.8%	5.8%	23.1%	65.7%
(d) Based on cost-minimized profits with uniform pooled price and zero subsidy						
i. Deficit farmers / All farmers [based on the total number over the whole sample period]	1670/3448	788/860	709/1726	140/862	615/2064	1063/1384
	48%	91.6%	41.1%	16.2%	29.8%	76.8%
ii. Farmers with a deficit for more than four years / Farmers sampled for more than four years	190/420	87/97	80/211	12/103	67/251	127/169
	45%	89.7%	37.9%	11.7%	26.7%	75.1%

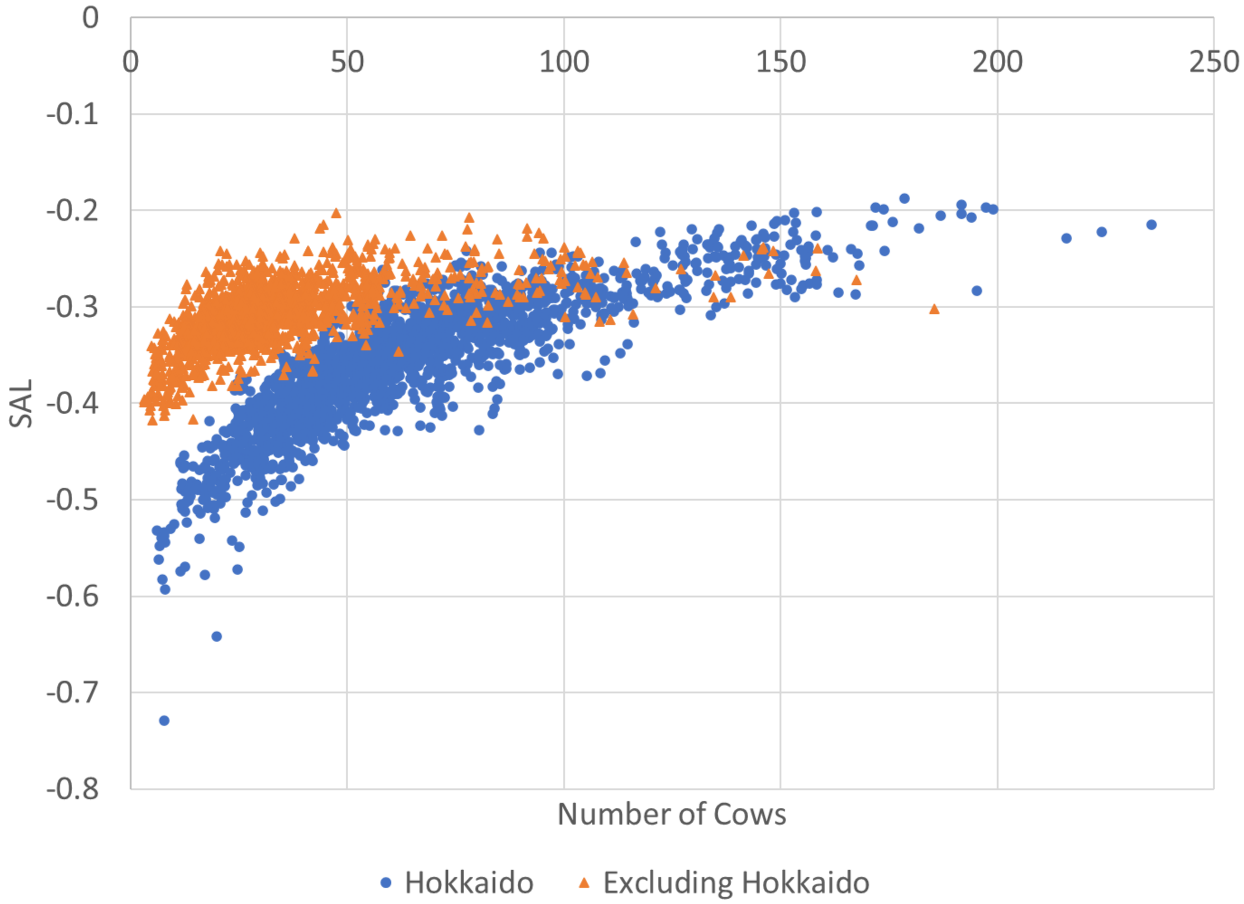
Note: Row i of each panel shows the number and share of farms that show losses (deficits) in the actual data (panel a) or simulations (panels b, c, and d) for the entire sample. Row ii shows those numbers and shares focusing on farmers that are sampled for more than four years.

Table 9: Consolidation effects on small-scale and medium-scale farms

	Hokkaido		Excluding Hokkaido	
	Pre-merger	Post-merger	Pre-merger	Post-merger
Number of small and medium-scale farmers	2,005	1,104	1,678	588
Total revenue	76,055	75,879	49,976	52,244
Total cost	75,292	70,070	48,152	33,363
Total profit	763	5,809	1,824	18,881
Coefficient of variation of the each farmer profit	19.2	2.5	5.7	0.6
Rate of profit improvement		661%		935%
Rate of cost reduction		-7%		-31%

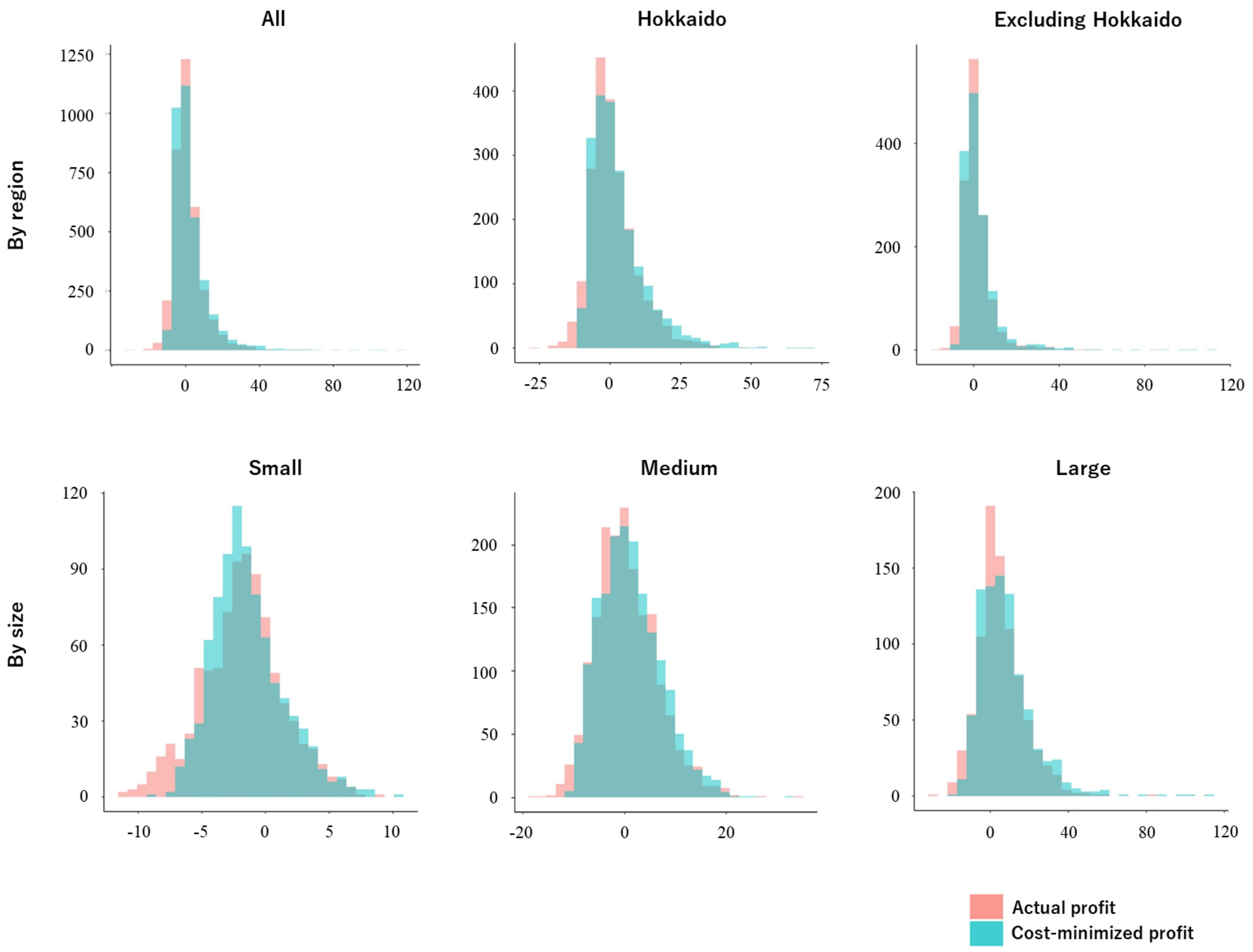
Note: Total revenue, total profit, and total cost are shown in units of one million yen.

Figure 1: Distribution of SAL, an indicator of economies of scale



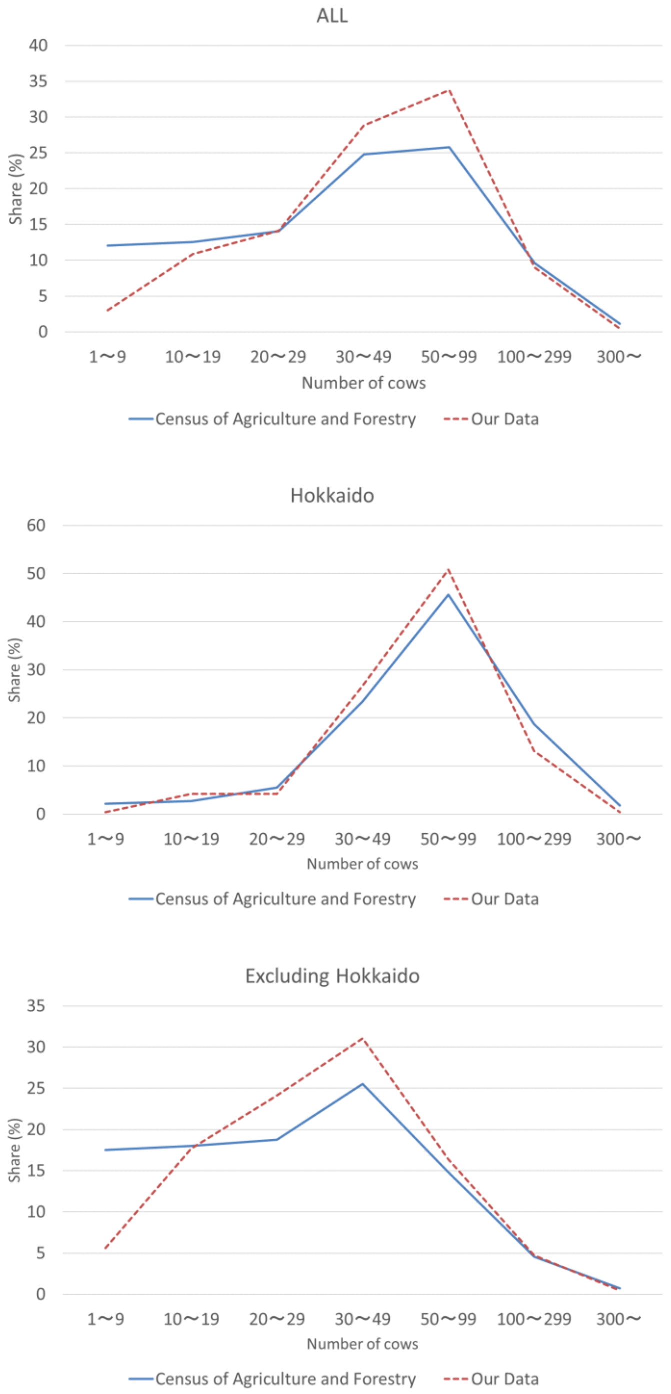
Source: Prepared by the author based on farm-level data. The vertical axis shows SAL. The horizontal axis shows the number of cows.

Figure 2: Profit distribution after cost minimization



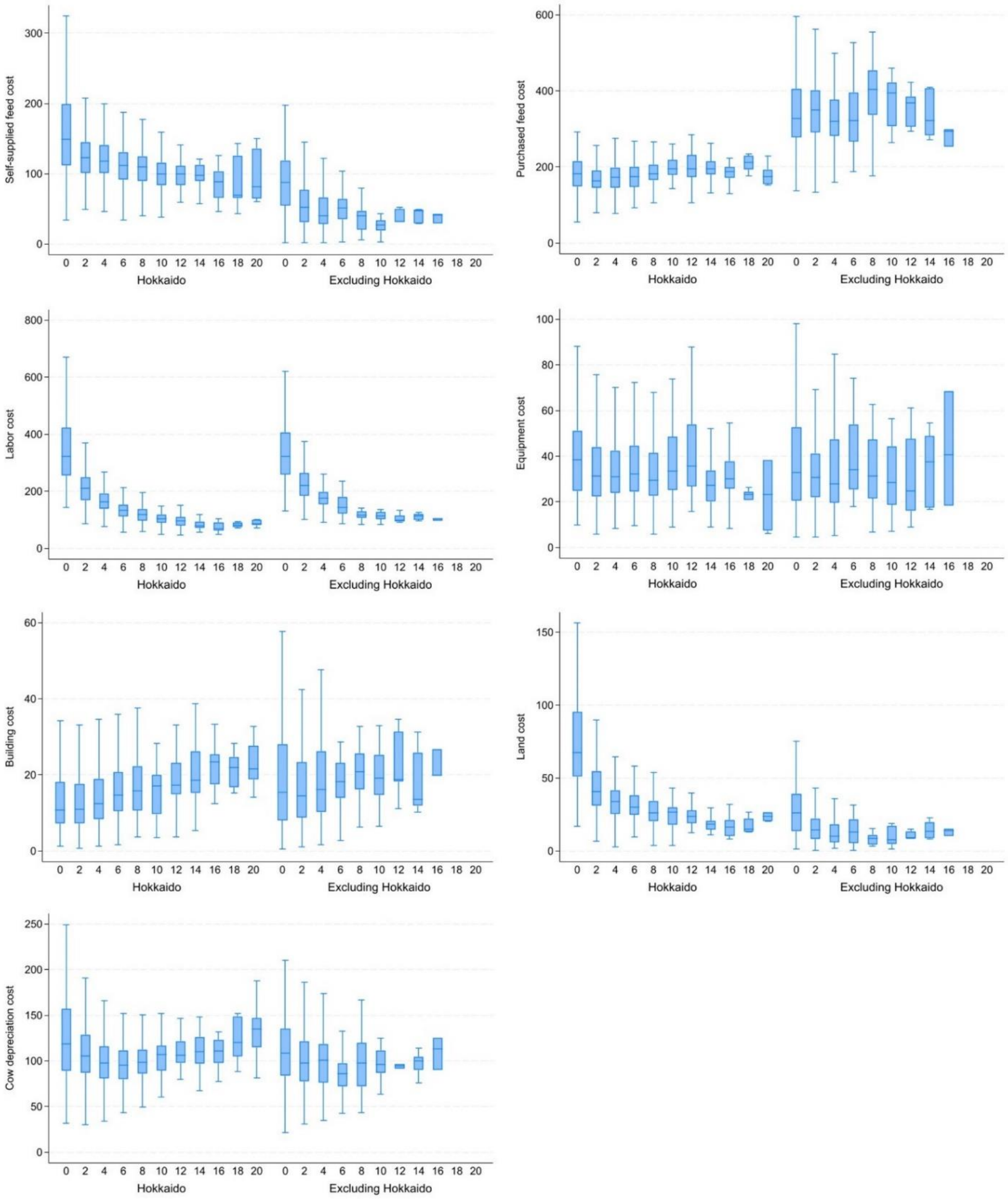
Note: The vertical axis and horizontal axis present the numbers of farms and the profits (million yen), respectively.

Figure A1: Comparison of the Census of Agriculture and Forestry and our data



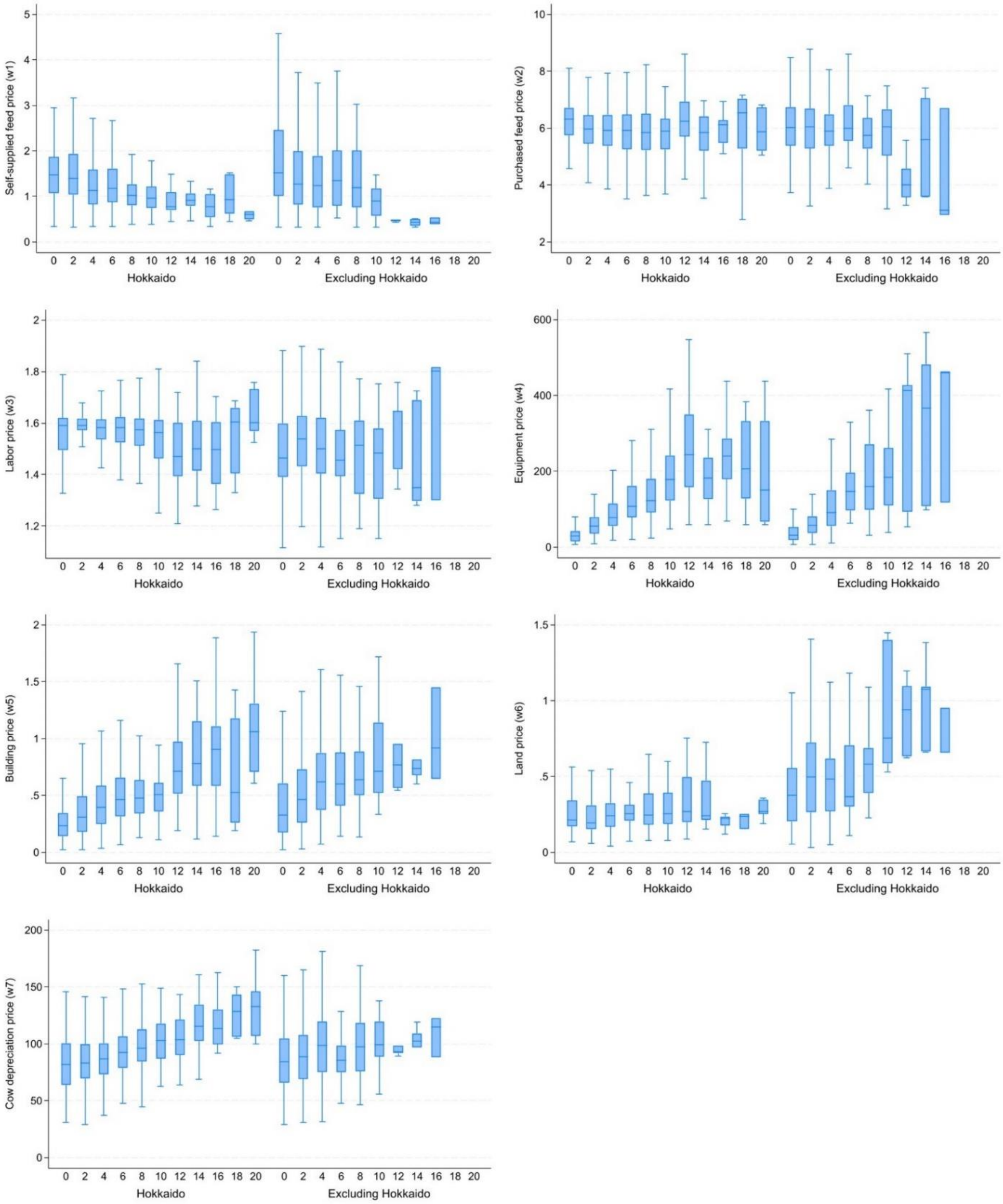
Note: The 2015 Census of Agriculture and Forestry sample is being compared to the 2017 sample of the milk production cost statistics.

Figure A2: The distribution of the cost of inputs per 100 tons of raw milk



Note: The vertical axis represents the cost per 100 tons of raw milk production, measured in units of 10,000 yen. The horizontal axis indicates the range of raw milk production in units of 100 tons. In each box plot, the box's upper end signifies the 75th percentile, the lower end represents the 25th percentile, and the central line denotes the median. The upper (lower) end of the whisker is the largest (smallest) observation that is less (more) than or equal to the 75th (25th) percentile plus (minus) 1.5 times the interquartile range. To ensure the confidentiality of individual data, samples that fall outside the upper and lower ends of the whiskers are not displayed.

Figure A3: Factor price distributions



Note: The vertical axis represents the price of each input, measured in units of 1,000 yen. The horizontal axis indicates the range of raw milk production in units of 100 tons. In each box plot, the box's upper end signifies the 75th percentile, the lower end represents the 25th percentile, and the central line denotes the median. The upper (lower) end of the whisker is the largest (smallest) observation that is less (more) than or equal to the 75th (25th) percentile plus (minus) 1.5 times the interquartile range. To ensure the confidentiality of individual data, samples that fall outside the upper and lower ends of the whiskers are not displayed.

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