An Economic Model Analysis of Industries in a Small Rural Village without Capital Stock Data: A Case Study in Tsumagoi Village, Gunma Prefecture

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For promoting the industries in rural mountain villages, analyzing local industries and proposing improvements based on such analysis are crucial. However, in small municipalities, the lack of industrial data, particularly related to capital stock, poses a challenge for economic model analysis. In response to this issue, this study assumed a linear equation with capital stock as the dependent variable and raw material usage as the explanatory variable, using raw material usage as a proxy for capital stock. A model analysis of the manufacturing industry in Tsumagoi Village was conducted using the System-Wide Approach. The results estimated the manufacturing industry of Tsumagoi Village to have a scale elasticity of 1.278 and an H-index of 7.648, indicating that the industry exhibits increasing returns to scale and is capital-intensive.

Keywords: Small rural mountain villages, H-index, Labor/Capital Intensity, System-Wide Approach, Tsumagoi Village

Introduction

In many municipalities across Japan, economic decline driven by aging populations and depopulation has become an increasingly pressing issue, particularly in agricultural and mountainous rural areas. As the number of workers sustaining local industries continues to dwindle, it is essential to conduct econometric analyses to better understand the characteristics of regional industries—such as productivity and labor/capital intensity—and to develop evidence-based policy recommendations for improvement. However, applying econometric methods to analyze the industrial structures of small rural villages presents several challenges. These include not only a scarcity of reliable economic data but also the limitations of conventional production functions—such as the CES model—which impose strong assumptions like constant returns to scale. Such assumptions often fail to capture the variability inherent in rural economies, which could be significantly affected depending on the future decisions of several companies.

Previous studies that have addressed these challenges include Mizuno et al. (2021), who analyzed the manufacturing industry in Teshio Town, Hokkaido, and Honda (2025), who conducted a similar analysis in Sumita Town, Iwate (Table 1). Both studies utilized data from the Economic Conditions Survey (formerly the Census of Manufactures), conducted by Japan's Ministry of Economy, Trade and Industry (METI). In Teshio Town, capital stock data was unavailable, whereas in Sumita Town, although capital stock data existed, it exhibited discontinuities due to changes in the scale of surveyed establishments across different survey years. Each study developed specific methods to address these respective issues.

Table 1: Existing Case Studies of Econometric Analysis on Small-Scale Rural Industries in Japan

Previous Studies	Region (Population)	Industry	Economic Data Status	Capital Stock Data Estimation and Adjustment Methods	Economic Model
Mizuno et al. (2021):	Teshio town, Hokkaido (2,642)	Manufacturing Industry	Capital stock data is completely missing.	Subtracting the total cash wages in the industry from the value-added amount	System-Wide Approach
Honda (2025):	Sumita town, Iwate (4,742)	Manufacturing Industry	Due to differences in the scale of establishments across survey years, て the capital stock data exhibited discontinuities.	Correcting the discontinuity in the capital stock data.	System-Wide Approach

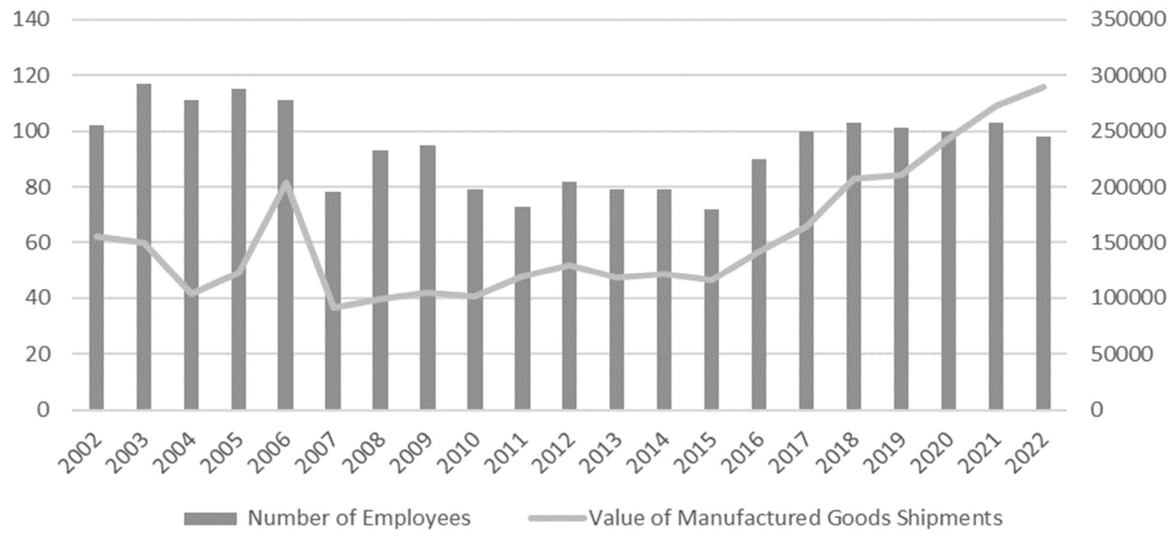
Specifically, Mizuno et al. (2021) addressed the absence of capital stock data for the manufacturing industry in Teshio Town by estimating capital stock as the difference between total value-added and total cash wages. They then applied a generalized residual method based on the System-Wide Approach developed by Theil (1980a, 1980b), which does not assume constant returns to scale, to estimate total factor productivity (TFP) growth rates. In contrast, Honda (2025) corrected for discontinuities in the capital stock data in Sumita Town and estimated marginal factor shares using the same System-Wide Approach in order to examine the capital-labor intensity of the manufacturing industry.

This study examines Tsumagoi Village in Gunma Prefecture, Japan, where industrial data is available solely for the manufacturing industry. In this dataset, capital stock information is missing for the majority of survey years, with the exception of 2005. In such cases, following the approach of Mizuno et al. (2021), capital stock can be approximated from the relation between total cash wages and total value-added. However, this method is based on the assumption of constant returns to scale. When applying an economic framework such as the System-Wide Approach, which does not rely on this assumption, it is more appropriate to employ an alternative method that aligns with the model's theoretical flexibility. Accordingly, this study aims to develop a novel method for estimating capital stock that does not assume constant returns to scale and to conduct an empirical economic analysis of the manufacturing industry in Tsumagoi Village.

2. Overview of the Manufacturing Industry in Tsumagoi Village

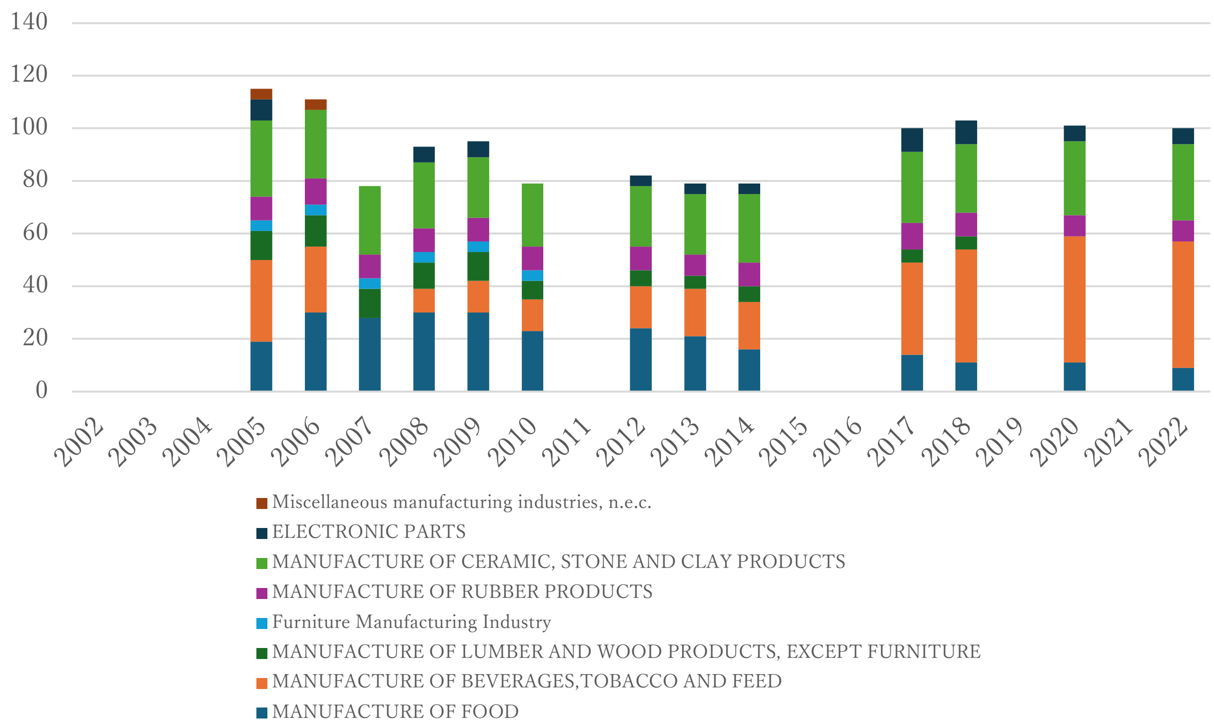
As shown in Figure 1, the number of employees in the manufacturing industry fof Tsumagoi Village has remained between approximately 70 and 120 people from 2002 to 2022. Considering that the total number of employees across all industries in Tsumagoi Village was 2,644 in 2021, the manufacturing industry cannot be considered a major industry in terms of employment. However, sales (value of manufactured shipments, etc.) have shown an upward trend since around 2015. Comparing sales figures from 2015 (1.16 billion yen) to those from 2022 (2.89 billion yen), we see an expansion of approximately 2.5 times.

Figure 1. Trends in the Employment and the Value of Manufactured Shipments in Tsumagoi Village's Manufacturing Industry



Source: Author's compilation based on the Economic Census for Business Frame and the Economic Conditions Survey conducted by the Ministry of Internal Affairs and Communications (MIC) and Communications and the Ministry of Economy, Trade and Industry (METI).

Figure 2. Composition of the Manufacturing industry in Tsumagoi Village (by Number of Employees)



Source: Author's compilation based on the Economic Census for Business Frame and the Economic Conditions Survey.

Note: Data for the years 2002, 2003, 2004, 2015, 2016, 2019, and 2021 are missing.

Figure 2 presents the annual composition of the manufacturing industry in Tsumagoi Village, based on the number of employees. In the early 2000s, the industry was primarily composed of ceramic, stone, and clay product manufacturing—including concrete production and the quarrying of volcanic stones and sand from Mount Asama—as well as food manufacturing. In recent years, however, the beverage and feed manufacturing industry has expanded significantly. By 2022, the manufacturing industry in Tsumagoi had come to be dominated by beverage and feed manufacturing and ceramic, stone, and clay product manufacturing. A mineral water manufacturing company was established in the village in 2008 and has since made multiple investments to expand its production facilities. It is presumed that the growth of this mineral water manufacturer has been a key driver behind both the increasing share of the beverage and feed manufacturing industry and the overall growth in manufacturing sales in the village.

3. Estimation Framework and Empirical Model

3.1 Estimation of Capital Stock

Traditionally, the Perpetual Inventory Method (PIM) has been used to estimate capital stock (OECD, 2009). However, this method relies heavily on assumptions about the initial capital stock and depreciation rates, making it difficult to apply in rural industries where investment data is often unavailable. These limitations present significant practical challenges. As a result, alternative statistical approaches—such as using other production-related variables as proxies for initial capital stock (Martin, 2002; Gilhooly, 2009) or estimating capital stock from related economic indicators—have been gaining increasing attention in recent years (Chen, 2018; Mizuno et al., 2021).

In this study, we propose a method for estimating missing capital stock using the cost of raw materials. Capital stock refers to the machinery and facilities utilized in production. For instance, in the food manufacturing industry, capital stock includes machinery for cooking and packaging. Workers operate this machinery to process raw materials—such as meat, fish, and vegetables—into finished food products. In such manufacturing environments, the amount of capital stock (e.g., cooking and packaging machinery) is typically determined by the quantity of raw materials to be processed, which reflects the desired level of output. In other words, the quantity (or cost) of raw materials used (M) is determined based on the available capital stock (K). Following this logic, we assume a linear relationship between M and K, as depicted in Equation (1).

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$$K_t = aM_t \tag{1}$$

K_t：Capital stock in year t

M_t：Cost of raw materials used (etc.) in year t

a ：Constant

As mentioned earlier, capital stock data for the manufacturing industry in Tsumagoi Village is missing, except for the year 2005. However, capital stock data are available for the manufacturing industries in Sumita Town and for the entire Gunma Prefecture, where Tsumagoi Village is located. To examine the validity of Equation (1), we conduct a two-stage least squares (2SLS) regression analysis using data from the manufacturing industries in Sumita Town (1990–2015) and Gunma Prefecture (2002–2022). As an instrumental variable, we use regional diesel fuel prices, which are a significant cost factor in both the transportation and processing stages of manufacturing. Diesel prices are assumed to strongly influence raw material costs, but to have no direct causal relationship with capital stock. The results of the 2SLS estimation on these data are represented by Equations (1)’ and (1)”. (The data used in this study are provided in the appendix.)

$$K_t = 0.2802M_t \qquad (1)'$$

R^2: 0.9392、t-value of a: 19.6497

$$K_t = 0.3876M_t \qquad (1)''$$

R^2: 0.9857、t-value of a: 37.1084

The estimation results indicate that Equation (1) can be statistically significantly estimated for both the manufacturing industries in Sumita Town and Gunma Prefecture. Therefore, it is reasonable to assume that Equation (1) holds for the manufacturing industry in Tsumagoi Village as well. Using the available data from 2005 for Tsumagoi Village’s K_t and M_t, the constant *a* is calculated to be 1.772, which leads to the derivation of Equation (1)’”.

$$K_t = 1.772M_t \qquad (1)'''$$

By substituting the M_t for each year into Equation (1)’”, the capital stock K_t for each year can be estimated. Based on these estimated capital stock values, an economic model analysis of the manufacturing industry in Tsumagoi Village can be conducted based on the System-Wide Approach.

3.2 Specification of the Economic Model based on the System-Wide Approach

This study employs the following factor demand equation (Equation 2), which is based on the System-Wide Approach.

$$f_K \mathrm{dln} q_K = \gamma\theta_K \,\mathrm{dlnY} + \pi_{KK}\mathrm{dln}p_K + \pi_{KL}\mathrm{dln}p_L$$

$$f_L \mathrm{dln} q_L = \gamma\theta_L \,\mathrm{dlnY} + \pi_{LK}\mathrm{dln}p_K + \pi_{LL}\mathrm{dln}p_L \qquad (2)$$

q_K：Capital stock (estimated based on equation (1)’”)
q_L：Labor
Y：Output
p_K：Price of capital stock (real capital service price)
p_L：Price of labor (wage)
θ_K：Marginal share (ratio of the increase in capital cost to the increase in output)
θ_L：Marginal share (ratio of the increase in labor cost to the increase in output)
γ：Inverse of the elasticity of scale
π_{KK}、π_{KL}、π_{LK}、π_{LL}：Slutsky coefficients
f_K：Share of Capital Cost（$q_K p_K$） in total Cost
f_L：Share of Labor Cost（$q_K p_K$） in total Cost

Because of the symmetry condition $\pi_{KK}+\pi_{KL}=0$、$\pi_{LK}+\pi_{LL}=0$、$\pi_{KL}=\pi_{LK}$B, equation (2) can be rewritten as follows.

$$f_K \mathrm{dln}q_K = \gamma\theta_K\ \mathrm{dlnY} + \pi_{KK}(\mathrm{dln}p_K - \mathrm{dln}p_L)$$
$$f_L \mathrm{dln}q_L = \gamma\theta_L\ \mathrm{dlnY} + \pi_{LL}(\mathrm{dln}p_L - \mathrm{dln}p_K) \qquad (2)'$$

Due to the parameter constraints, estimating the coefficients in one of the equations in (2)' automatically determines those in the other.

4. Results

4.1 Estimation of the Factor Demand Equation

For the data of the manufacturing industries in Tsumagoi Village from 2003 to 2020, the maximum likelihood estimation (MLE) of the equation above (Equation 2') was performed, and the results are presented in Table 2. Due to concerns about endogeneity, two-stage least squares (2SLS) would typically be the preferred method of estimation. However, an appropriate instrumental variable could not be identified. Therefore, as an alternative approach, we used MLE, which accommodates structural constraints in the model, to estimate the parameters.

Table 2. Regression Results of the Demand Function (2003-2020)

	Coef.	Std. Err.	z	P>|z|	95% cof. interval	
$\gamma\theta_K$	0.3484	0.0688	5.07	0.0000	0.2136	0.4833
π_{KK}	0.0600	0.1127	0.53	0.594	-0.1608	0.2809

Note: The estimate for π_{KK} was not statistically significant (z = -0.53, p =0.594), but it has been retained in the model for theoretical reasons.

Here, the elasticity of scale, γ can be obtained by estimating Equation (3), which was derived by Theil (1980b), using MLE. The results are presented in Table 3.

$$\mathrm{dlnQ} = \gamma \mathrm{dlnY} \qquad (3)$$

Q: Divisia Quantity Index $(f_K \mathrm{dln}q_K + f_L \mathrm{dln}q_L)$

Table 3. Estimation results of the inverse of the elasticity of scale (2003-2020)

	Coef.	Std. Err.	z	P>|z|	95% cof. interval	
γ	0.5412	0.1013	5.34	0.0000	0.3426	0.7398

Furthermore, based on the results in Tables 2 and 3, along with the parameter constraint $\theta_K + \theta_L = 1$, the results presented in Table 4 are derived.

Table 4. Estimation Results of Each Parameter (2003-2020)

$1/\gamma$	θ_K	θ_L
1.8478	0.6438	0.3562

The elasticity of scale, 1/γ, as shown in Table 5, can be interpreted as follows: if it is less than 1, it indicates increasing returns to scale; if it equals 1, it indicates constant returns to scale; and if it is greater than 1, it indicates decreasing returns to scale. For the manufacturing industry in Tsumagoi Village, the elasticity of scale is greater than 1, indicating that the manufacturing industry experienced increasing returns to scale between 2003 and 2020.

When considering that the estimated elasticity of scale based on the System-Wide Approach for the manufacturing industry in Teshio Town is 1.0630 (almost constant returns to scale, Mizuno et al., 2021) and for Sumita Town is 4.1798 (indicating highly increasing returns to scale, Honda, 2025), it suggests that the elasticity of scale in the manufacturing industires of rural agricultural villages exhibits significant diversity.

Table 5. Interpretation of the Elasticity of Scale

$1/\gamma<1$	Decreasing returns to scale
$1/\gamma=1$	Constant returns to scale
$1/\gamma>1$	Increasing returns to scale

4.2 Estimation of the H-Index

We further examined the contribution of each production factor to production in the manufacturing industry of Tsumagoi Village. Specifically, we looked at the marginal share of capital, θ_K, which represents the proportion of capital costs that increase when production output rises, and the marginal share of labor, θ_L, which represents the proportion of labor costs that increase when production output increases. We then calculated the H-index, developed by Honda (2024), as the ratio θ_K/θ_L. As shown in Figure 3, when the H-index is greater than 1, the industry is considered capital-intensive; when it is less than 1, it is considered labor-intensive. Table 6 presents the estimation results of the H-index for the manufacturing industry in Tsumagoi Village. With an H-index exceeding 1, this indicates that the manufacturing industry in Tsumagoi Village is capital-intensive.

Table 6. H-Index of the Manufacturing Industry in Tsumagoi Village

	H-Index
Manufacturing Industry in Tsumagoi Village between 2003 and 2020	1.8075

Figure 3. Definition of the H-Index

H-Index:

The H-index is the ratio of the marginal share of capital to the marginal share of labor,
H-index = θ_1 / θ_2

- H-index > 1
  An increase in capital contributes more to output growth than an increase in labor.
  ⇒ Capital-intensive

- H-index < 1
  An increase in labor contributes more to output growth than an increase in capital.
  ⇒ Labor-intensive

4.3 Estimation of Total Factor Productivity (TFP) Growth Rate

Using the generalized residual method developed by Mizuno (1985), we calculate the TFP growth rate ρ for the manufacturing industry in Tsumagoi Village. The formula for measuring the TFP growth rate without assuming homogeneity of degree one in the production function is given by Equation (4).

$$\rho = \mathrm{dlnY} - 1/\gamma \mathrm{dlnQ} \tag{4}$$

Figure 4 shows the annual TFP growth rate for the manufacturing industry in Tsumagoi Village, estimated using Equation (4). The TFP growth rate for Tsumagoi Village has been negative in 10 out of the 18 years from 2003 to 2020, and positive in the remaining 8 years, suggesting that TFP has alternated between positive and negative growth. Equation (4) calculates the TFP growth rate as the residual between the weighted average of the differential changes in production factor inputs (i.e., the Divisia quantity index) and the logarithmic change in output. Therefore, the TFP growth rate captures factors—such as technological progress—that contribute to changes in output but cannot be explained solely by changes in the quantities of input factors. As shown in Figures 5 and 6, both the capital-labor ratio and labor productivity in the manufacturing industry of Tsumagoi Village exhibit an upward trend, whereas capital productivity, despite some fluctuations, shows a declining trend. As indicated by the H-index, the manufacturing industry in Tsumagoi Village is capital-intensive, and the lack of improvement in capital productivity could be the reason for the absence of improvement in TFP.

Figure 4. TFP Growth Rate of the Manufacturing Industry in Tsumagoi Village

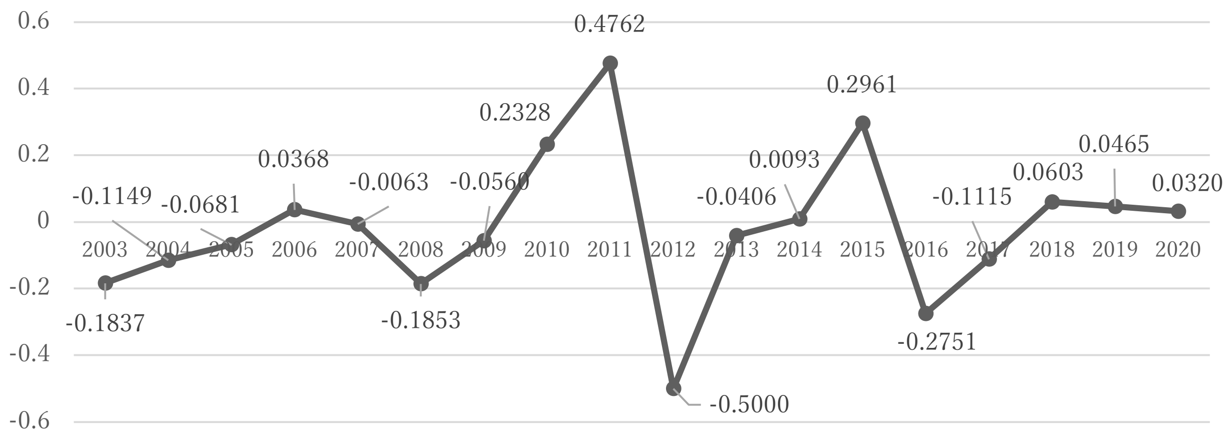
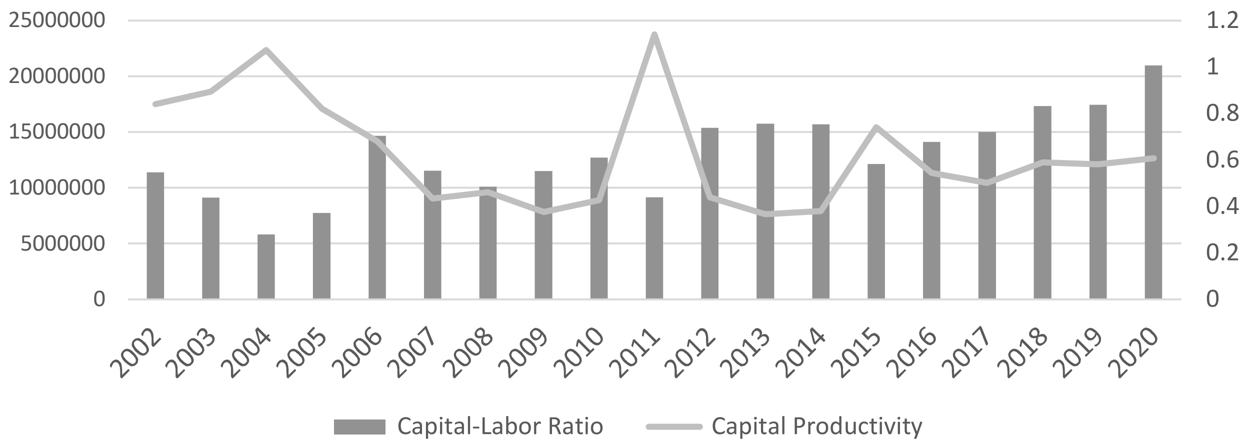


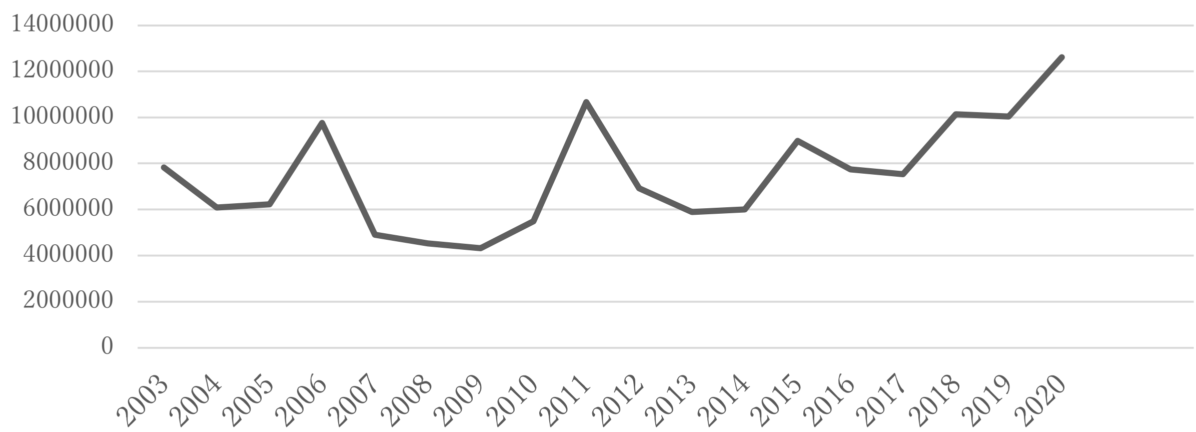
Figure 5. Trends in Capital-Labor Ratio and Capital Productivity of the Manufacturing Industry in Tsumagoi Village



Note: Capital-Labor Ratio (First Axis): Calculated by dividing real capital stock (estimated value based on equation (1)) by the number of employees.

Capital Productivity (Second Axis): Calculated by dividing total value-added (real value-added amount) by real capital stock (estimated value based on equation (1)).

Figure 6. Trends in Labor Productivity of the Manufacturing Industry in Tsumagoi Village



Note: Calculated by dividing total value-added by the number of employees.

5. Concluding Remarks

In this study, to analyze industries in rural agricultural villages where capital stock data is largely missing, we proposed a novel method using a linear equation (Equation 1) and estimated capital stock as a proxy variable derived from cost of raw material used. Using this, we analyzed the manufacturing industry in Tsumagoi Village by calculating the elasticity of scale, the H-index and the TFP growth rate. The results indicate that Tsumagoi Village's manufacturing industry is capital-intensive and exhibits increasing returns to scale. This suggests that the industrial structure of Tsumagoi's manufacturing sector is such that production can be more readily scaled up through capital investment rather than increased labor input, while TFP growth appears to be stagnating.

The manufacturing industry in Tsumagoi Village is primarily composed of beverage and feed manufacturing (mainly mineral water production) and ceramic and stone product manufacturing. These sectors demand efficient production systems characterized by automation and large-scale equipment and machinery. Consequently, sustained capital investment has been essential for their development. Concurrently, the village has undergone a notable population decline. Between 2000 and 2020, the working-age population decreased by approximately 17%, from 6,084 to 5,068 (Tsumagoi Village 2024). In response to this labor shortage, capital investment has become increasingly vital for maintaining productivity. This growing dependence on machinery and equipment has naturally led to a capital-intensive industrial structure. Importantly, this tendency is not only practical but also economically rational: the H-index analysis confirms that capital investment in these industries is justified in terms of investment efficiency.

Moreover, the finding of increasing returns to scale—where productivity rises with larger production scales—supports the argument that Tsumagoi's manufacturing industry should focus on expanding its production through additional capital investment. Regional development policies could play a key role in this expansion by fostering collaboration among local manufacturers. By working together to scale up production, companies could reduce costs and enhance their competitiveness. In the beverage and feed manufacturing sector, a single mineral water producer plays a dominant role. In contrast, the ceramic and stone manufacturing sector consists of several smaller businesses producing ready-mix concrete, asphalt, and aggregates. For these smaller companies, forming an industrial cluster—by sharing production facilities and collaborating to expand sales networks—could be a highly effective growth strategy.

This study contributes to regional economics by making it possible to estimate the elasticity of scale, the H-index, and TFP growth rates for industries where capital stock data is largely missing. The proposed method for estimating capital stock is expected to be applicable to other regions with similar data gaps, thus expanding the scope of empirical economic analysis in areas with limited data availability.

However, several challenges remain. For instance, when capital stock data is entirely absent, estimating it using Equation (1) becomes problematic. A specific issue encountered in Tsumagoi Village's manufacturing industry is the observation of unusual values for the capital-labor ratio and TFP growth rate in 2011–2012. This anomaly may have been caused by a reduction in raw material usage, likely in anticipation of decreased demand following the 2011 Great East Japan Earthquake, which could have led to an underestimation of capital stock using Equation (1). To improve capital stock estimation, further research is necessary. Potential approaches include utilizing investment data (if available) to estimate annual capital stock, applying dynamic models such as Bayesian estimation with Kalman filters, or employing machine learning techniques like Random Forests or Gradient Boosting for non-linear estimation. Given that industrial data availability varies across regions and industries, the most suitable method for data supplementation should be determined on a case-by-case basis.

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7. Appendix - Data Used for the Analysis

Analysis Period: 2003-2020

	Data Item	Resource	Method of Deflation
①	Number of establishments	Economic Conditions Survey and Census of Manufactures（METI）	
②	Total cash wages		Convert it into real data using（⑦）
③	Cost of raw materials used, etc.		Convert it into real data using（⑧）
④	Value of Manufactured Shipments, etc.		Convert it into real data using（⑧）
⑤	Total value-added		Convert it into real data using（⑧）
⑥	Fixed assets		
⑦	Consumer Price Index (2015 base)	Statistics Bureau of Japan (SBJ), Ministry of Internal Affairs and Communications	
⑧	Corporate Goods Price Index (CPI), Major Categories / Industrial Products (2015 base)	Bank of Japan	
⑨	Private Non-Residential Investment Deflator (2015 base)	National Accounts, Cabinet Office, Government of Japan	
⑩	Nominal Capital Services Price	Using the JIP Database 2023 (RIETI), sectoral nominal capital costs are calculated by dividing them by the corresponding real capital stock.	Convert it into real data using（⑨）
⑪	Service Station Retail Price (Diesel Fuel)	Survey of Petroleum Product Prices(ANRE)	Convert it into real data using（⑧）