# 日本の農業の全要素生産性ラチェット効果の分析

# Analysis of the Ratchet Effecton Total Factor Productivity in Japanese Agriculture

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## 1. Introduction

### 1.1 Objective

In November 2016, an agriculture subcommittee of Japan's Liberal Democratic Party drew up a plan for agricultural reform. The reform calls for agricultural exports to reach one trillion yen by 2019. Expanding exports alone will set off international trade friction. Therefore, if exports are to grow, then imports need to be expanded as well. However, certain groups of farmers were strongly opposed to this reform proposal; however, this is because the farmers do not realize that the superb technology they possess can be a valuable tool in competing with other countries' agricultural products.

This paper aims to convey to the Japanese farmers and citizens the great potential for Japanese agricultural products in overseas markets and to raise awareness that if the market is deregulated, Japanese agriculture can remain competitive, even in global markets. We believe that to enhance the quality of produce and the national living standard for both Japan and other countries, each country should liberalize its agricultural market and create friendly competition under free trade among them. For Japanese agriculture, we assume a production function of $n$th-order homogeneity. The theoretical objective of this paper is to verify whether the technological progress of the ratchet effect (i.e., to prevent decline by advancing technological progress during the decline period) is operating on Japanese agriculture by applying the theory of the ratchet effect of total factor productivity of total factor productivity, which we have developed. In this paper, we develop this theory based on the idea that even if agriculture is in decline, the elasticity of scale of agriculture $n$ is at a high level (i.e., increased investment will dramatically increase productivity); therefore, such a decline will counteract

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in a way wherein the vitality of the decline will enhance productivity and, thus, technological progress. This study verifies that this ratchet effect indeed is operating on Japanese agriculture.

Our hope is that by proposing this study to the government, we can inform Japanese farmers about the strength of Japanese agriculture that results from the ratchet effect so that they will feel confident about liberalizing Japanese agricultural products markets in other countries. To promote this move, we will also be proposing deregulation to the government.

This is a study that desires Japan to not just engage in exporting large amounts of produce, but also to engage in importing large amounts of produce; in this way, the Japanese agricultural products market will initiate globalization and contribute toward the global economy.

### 1.2 Prior research

Mizuno (1985) developed formulas for calculating total factor productivity, which is the basis of our theory of the ratchet effect on total factor productivity. This is a generalized residual theory for measuring total factor productivity. Prior studies have addressed the theory of total factor productivity and measured the total factor productivity of Japanese agriculture.

Caves et al. (1982) and Färe et al. (1994) meticulously applied the Malmquist Index, a productivity index that can measure total factor productivity using elasticity of scale instead of linear homogeneity as a variable, to economic theory. In addition, as indicated by Sakuragawa (1995), the measurement theory dealing with residuals has come into general use as in Equation (1) below[1].

Fu (1993) calculated the total factor productivity of agriculture for the period 1960–1990 for 10 regions: nine agricultural districts in Hokkaido, Tohoku, Hokuriku, Kanto/Tosan, Tokai, Kinki, Chugoku, Shikoku, and Kyushu, plus the average for all prefectures except Hokkaido. These pioneering works were followed by many other studies on total factor productivity in Japanese agriculture. Although Fox (2005) determined the degree of harvest regarding the scale in consideration of the total factor productivity, he made a separation between the contribution toward total factor productivity and the rate of technological progress. In this paper, we viewed the total factor productivity itself as technological progress and viewed technological progress and degree of harvest regarding the scale as inseparable factors; thus, we developed a theory where the rate of technological progress is influenced by the degree of harvest regarding the scale.

## 2. Materials and methods－Economic Model for Measuring Total Factor Productivity and the Ratchet Effect on Total Factor Productivity－

### 2.1 Economic model for measuring total factor productivity

Let us first give the equation for total factor productivity that we used in this paper to estimate the technological progress of Japanese agriculture. We developed a model that uses the generalized residual method to analyze the economy with a $1/\gamma$-th order of homogeneity. This is called the MAIDO-I model[2]. It assigns the unexplainable growth in capital and labor that accompanies growth in production to total factor productivity. This is calculated by deducting the weighted average of the growth rate of capital and labor (the Divisia Quantity Index) from the growth rate of production. In other words, total factor productivity of the generalized residual method in the MAIDO-I model is given in the following equation:

$$\rho = d\ln Y - \frac{1}{\gamma}(f_K d\ln K + f_L d\ln L) \qquad (1)$$

where $\rho$ denotes total factor productivity (increasing rate), $Y$ is production volume, $K$ is the capital stock of agriculture, and $L$ is the number of people engaged in agriculture.

$f_K$ and $f_L$ are proportions of capital and labor, respectively. They denote the proportions of capital and labor costs to total costs:

$$f_K = \frac{rK}{rK + wL} \qquad f_L = \frac{wL}{rK + wL}. \qquad (2)$$

$r$ is the cost of capital, which stands for the interest rate, and $w$ is the cost of labor, which stands for wages.

The ratio $\frac{1}{\gamma}$ that appears in the second item on the right-hand side of Equation (1) denotes elasticity of scale. When this ratio has a value of 1, it has linear homogeneity. Equation (1), therefore, has a $\frac{1}{\gamma}$-order of homogeneity.

### 2.2 The ratchet effect on total factor productivity

Let us now describe the theory of the ratchet effect on total factor productivity. Looking at the second item on the right-hand side of the equation for total factor productivity in Equation (1), we see that it has a negative value and that total factor productivity $\rho$ becomes smaller as the value of $1/\gamma$ increases. This shows that technological progress slows the decline of industry during periods of industrial recession.

This phenomenon stimulates consumption during periods of recession, thus imitating a ratchet effect on consumption that keeps the recession in check. Therefore, we have called this the “total factor productivity ratchet effect theory.” During a recession, this phenomenon will spur technological progress and slow down the recession’s pace if returns to scale are increasing. Although there are several studies on total factor productivity in relation to the degree of harvest regarding the scale after 1985 (e.g., Fox, 2005), no study has actually expanded on this theory to date.

### 2.3 Estimation of the constant elasticity of substitution (CES)-type production function

One way to use the aforementioned MAIDO-I model is to estimate the elasticity of scale by specifically defining the production function[3]. For this, we use a CES production function that has a $\frac{1}{\gamma}$-th order of homogeneity and is expressed as follows:

$$Y = b\,(aK^{-\delta} + (1-a)\,L^{-\delta})^{-\frac{1}{\delta}\times\frac{1}{\gamma}} \qquad (3)$$

The method for calculating this equation is shown in the Appendix A. The data used for the estimates are also listed in the Appendix. The estimation period is 1990-2011.

We formulated Appendix Equation (S-3) to estimate Equation (3). Conducting a regression analysis using the maximum-likelihood method in respect to Equation (S-3) solves for the alternative elasticity of substitution ($\sigma$). This yields $\delta = (1-\sigma)/\sigma$.

$$\ln\frac{L}{K} = 3.5878 + 0.4609\,\ln\left(\frac{r}{w}\right). \qquad (4)$$

**Table 1 Maximum-Likelihood Method Estimation Result of Equation (4)**

| | Coefficient | Std. Dev. | z | P > \|z\| | 95% Conf. Interval | |
|---|---|---|---|---|---|---|
| Constant | 3.5878 | .0189 | 6.63 | 0.000 | .0884 | .1625 |
| $\ln\left(\frac{r}{w}\right)$ | .4609 | .0483 | 9.53 | 0.000 | .3661 | .5557 |

Note: $t$-value of constant term is 17.6892 and $t$-value of coefficient is 9.0865, and they meet the standard. Decision coefficient of two variables is also at a high level (0.8050) .

Because the elasticity of substitution $\sigma = 0.4609$,

$$\delta = \frac{1-\sigma}{\sigma} = 1.1693.$$

This fulfills the condition for the CES function, which is $-\delta \leq 1$. Calculating $a$ we get

$$a = 0.0444.$$

Although this value is small, it is not a problem because it changes with the derivation of units for $K$ and $L$. Taking the logarithm of the CES production function in Equation (3) gives us the following:

$$\ln Y = \ln b - \frac{1}{\delta}\times\frac{1}{\gamma}\ln\,(aK^{-\delta} - + (1-a)\,L^{-\delta}), \qquad (5)$$

where $\frac{1}{\gamma}$ stands for elasticity of scale and corresponds to the $n$th order in the $n$th-order homogeneity. Equation (5) solves for $\frac{1}{\gamma}$ after a regression analysis using the maximum-likelihood method, which solves for $\delta$:

$$\ln Y = -7.8165 - 1.1107\,\ln(aK^{-\delta} + (1-a)L^{-\delta})$$

**Table 2　Maximum-Likelihood Method Estimation Result of Equation (5)**

| | Coefficient | Std. Dev. | z | P > \|z\| | 95% Conf. Interval | |
|---|---|---|---|---|---|---|
| Constant | −7.8165 | 3.4105 | −2.29 | 0.022 | −14.5010 | −1.132 |
| $\ln(aK^{-\delta}+(1-a)L^{-\delta})$ | −1.1107 | .1960 | −5.66 | 0.000 | −1.4951 | −.7264 |

Note: $t$-value of constant term is −2.5156 and $t$-value of coefficient is −6.1601, and they meet the standard. Coefficient decision of two variables is also 0.6226, which indicates that it is an equation that holds interpretability.

In the second item on the right-hand side of Equation (5), $\frac{1}{\delta}\times\frac{1}{\gamma}$ = 0.1107. Calculating with this equation, we get $\frac{1}{\gamma}$ = 1.2987 In other words, the elasticity of scale of Japanese agriculture is 1.2987. Thus, Japanese agriculture has increasing returns to scale.[4]

Increasing returns to scale is not necessarily a good thing. Since this inverse 0.7700 (the point of profit maximization) signifies the ratio of revenue against expenditure 1, its value is smaller than 1. In other words, it shows that Japanese agriculture is in the red because the revenue accounts for just less than 80% of expenditure.

This signifies that Japanese agriculture has not yet matured because Japanese farmers are still being helped by agricultural cooperatives and other organizations.

## 3. Results

### 3.1 Results of total factor productivity measurement

The elasticity of scale is 1.2987. Plugging this value into Equation (1) for measuring total factor productivity and substituting the data gives total factor productivity for Japanese agriculture. Figure 1 shows the measurement of total factor productivity at a 1.2987-th order of homogeneity. This is the total factor productivity of Japanese agriculture over about a 20-year period from 1991 through 2011.

The 20-year average is 0.0010, meaning that technological progress amounted to 0.1% per annum. This shows that Japanese agriculture experienced almost no technological progress after the bursting of the asset bubble in 1991.[5]

However, if we look at the data in a time series, we can see differences from period to period. After the bubble economy ended, there was a tendency to minimize the role of agriculture in the Japanese economy and the rate of technological progress was frequently negative. However, agriculture's importance has been re-evaluated recently and the younger generation has started to become more interested in agriculture. The government and citizens' regard for agriculture is expressed in its growth rates of technological progress of 11.1% in 2010 and 5.2% in 2011.

### 3.2 The reality of the total factor productivity ratchet effect

The ratchet effect on total factor productivity occurs when, in a situation of increasing returns to scale, total factor productivity increases even as capital stock or labor declines.

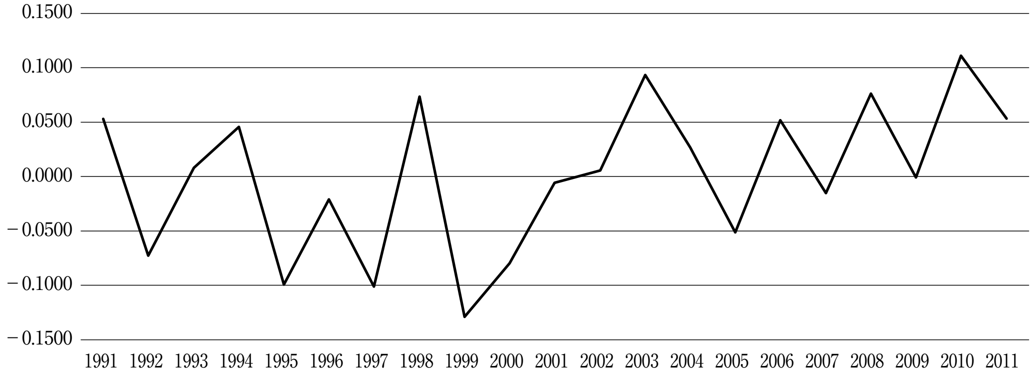


**Figure 1 Total Factor Productivity**

Data on Japanese agriculture show that from 1991 through 2011, capital stock expanded while labor contracted. To find out whether this was due to the ratchet effect, we calculated the Divisia Quantity Index [6] as follows[7]:

$$(\text{Divisia Quantity Index}) = (f_K d\ln K + f_L d\ln L). \qquad (6)$$

The results show that the Divisia Quantity Index has been negative for 20 years; that is, not once in 20 years did it have a positive value. This is because even though capital stock was expanding, labor continued to shrink. Young people did not go to work in agriculture, so the farming profession aged. We can also infer this situation from the trend in the Divisia Quantity Index.

The second item on the right-hand side of Equation (1) has a negative sign and the Division Quantity Index in Figure 2 is also negative, which yields a positive. Even though labor continues to decline, the decline in total factor productivity has ceased. In other words, the ratchet effect has raised the total factor productivity.

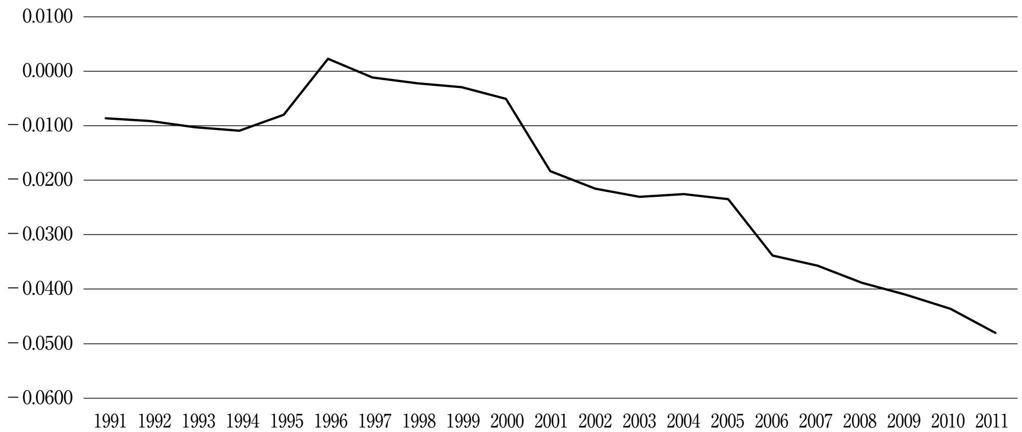


**Figure 2 Divisia Quantity Index**

## 4. Conclusion

Japanese agriculture has been in decline over a long period of time. Nevertheless, technological progress over time has led to more efficient agricultural production.

This analysis investigated the statistical data on agriculture. One objective of this study was to find out whether the ratchet effect functions in Japanese agriculture. We found that the Divisia Quantity Index was negative due to the decline in labor surpassing the growth in capital stock. At the same time, we proved that Japanese agriculture has increasing returns to scale. These factors increased total factor productivity through the ratchet effect. One could say that the ratchet effect on total factor productivity was operating on Japanese agriculture and that agricture was supported by technological progress. Another purpose was to promote free trade by liberalizing the Japanese agriculture market to foreign countries and by informing and instilling confidence among farmers and citizens by telling them about the amazing technological progress that Japanese agriculture have undergone in recent years.

Compared with the negative values of the Divisia Quantity Index shown in Figure 2, the ratchet effect has stopped the reversal of technological progress. Technological progress has improved the quality of agricultural products and raised productivity. We succeeded in conveying the idea that efforts should be made to improve farm management efficiency, not just to prevent imports of agricultural products from overseas.

This paper is characterized by the theory that recessions induce technological progress, which is contrary to the conventional wisdom that technological progress is spurred by growth. The study showed that Japanese agriculture truly fits this characterization. This theory is also useful for non-agriculture sectors. For example, these findings suggest what needs to be done to achieve economic recovery after a large-scale disaster. We are also advancing a study where this ratchet effect is working to help the recovery process of regional economies disrupted by the Great East Japan Earthquake in 2011. In short, this theory also can be deemed as a theory for disaster recovery.

The issue is what should be done to further increase total factor productivity. Unfortunately, the total factor productivity ratchet effect theory discussed here is merely a theory on how to stem the decline of capital and labor during periods of industrial recession. Raising total factor productivity requires appropriate economic policies. We need to devise ways to increase production and ensure sufficient labor for such production as this would induce technological progress. There are many industries in Japan that have high scales of elasticity that are behind in structural reform. If it is decided to follow the theory behind this paper, then the government must promote policies such as providing subsidies to create technological progress during periods of decline in order to seize these as opportunities. A specific proposal for such a policy will be the topic for the next paper.

## Notes

1. This is shown in Equation (18) on page 177 of Sakuragawa (2005).
2. This equation appears in Mizuno (1985), where it is called the "generalized residual method." Previous equations calculating total factor productivity applied linear homogeneity to the production function overall, but this theory made it possible to measure total factor productivity even in the absence of linear homogeneity.
3. The MAIDO-I model analysis in Mizuno (2016) used a method that estimates a CES production function.
4. Under increasing return to scale, industrial monopoly progresses. However, in the case of agriculture, the production structure is fixed and monopoly does not proceed because the land area is limited and the working population is also limited.
5. Total factor productivity is almost regarded as the technological progress rate, but 100% of them are not the technological progress rates. Regard total factor productivity as a measure of technological progress.
6. The Divisia Quantity Index is a weighted average rate of growth. Mizuno (1991) explains this in detail.
7. The sum of the factors' shares is 1.

$$f_K + f_L = 1$$

8. This calculation method is the same used by Mizuno (2016), cited in note 3.

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**Appendix**

**Appendix A**

Methodology for Estimating the CES Production Function[8]

If a company can optimize themselves, then the ratio of labor and capital, the ratio of capital cost and labor cost, and $\sigma$ are given as follows:

$$\frac{L}{K} = \left(\frac{1-a}{a}\right)^{\sigma}\left(\frac{r}{w}\right)^{\sigma}, \tag{S-1}$$

$$\sigma = \frac{1}{1+\delta}. \tag{S-2}$$

This equation must be estimated in order to estimate the CES production function. Taking the natural logarithm on both sides, we get the following:

$$\ln\frac{L}{K} = \sigma\ln\left(\frac{1-a}{a}\right) + \sigma\ln\left(\frac{\mathrm{r}}{w}\right). \tag{S-3}$$

Estimating the parameters of this equation gives us the values of all parameters except $\gamma$ in the CES production function.

**Appendix B**

Data

The types of data and their sources are as follow:

Amount of Agricultural Output

Ministry of Agriculture, Forestry and Fisheries statistics on farm income, in hundred million yen

Capital Stock of Agriculture

Hitotsubashi University Japan Industrial Productivity (JIP) Database (adjusted to 2010 prices), in million yen

Agricultural Commodity Price Index by Classification

Statistical surveys on commodity prices in agriculture, base year 2010

Number of People Employed in Agriculture

Agriculture Census

Calculated using the same value over a five-year period, as the census is conducted only once every five years

Wage Index, 2010 = 100

Monthly Labor Surveys

Japanese Government Bond (JGB) Yields

For 1981-1985: yields on nine-year paper

For 1986 and thereafter: yields on ten-year paper

Ministry of Finance website data on JGB interest rates

Adjusted to real interest rates using the agricultural commodity price index by classification

Farm Production Income (in hundred million yen)

Ministry of Agriculture, Forestry and Fisheries statistics on farm production income

Adjusted to real numbers using the agricultural commodity price index by classification