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Causality between Capital Investment and Productivity in Japanese Agriculture, 1957-97

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This study examines the causality between total factor productivity (TFP) and capital investment in Japanese agriculture for the period 1957-97. We employ the Granger causality test to determine the causality between the two variables. This study also investigates movements in total output, total input and TFP for average farms of four size classes for the same period. We employ the aggregation technique to estimate total output and total input and use a large pooled cross-section and time series data set. It has been found that both TFP and capital investment had a fairly high growth rate from the mid 1950s to the early 1970s, and thereafter it started declining. The result of this study shows that there is a significant and positive bi-directional Granger-causal relationship between TFP and capital investment in Japanese agriculture over the long term.

Key words : Japanese agriculture, total factor productivity, capital investment, Granger causality.

1. Introduction

Japanese agriculture experienced a rapid growth in productivity from the mid 1950s to the early 1970s. The annual average growth rate was 1.52% for the period 1957-71. Concurrently, capital investment[1)] in Japanese agriculture also grew at a rapid rate during the same period. The growth rate of capital investment was 5.56% between 1957-71. This indicates that 'learning-by-doing' and 'technological spillover' may have been at work during this period in Japanese agriculture.

However, over the past two decades the productivity grew at a relatively lower rate compared to the earlier period.[2)] Between 1972-84 and 1985-97, the annual average growth rate of productivity was 0.18% and 0.12%, respectively. We have also noticed that the growth rate of capital investment per year continuously decreased during the same period.[3)] The growth rate was 2.79% during the 1972-84 period and it became negative (−0.38%) in the 1985-97 period. The reason for the decreasing trends in productivity growth rates and capital investment during this period might be because of technological regression, decrease in demand for agricultural commodities, and increase in costs of machinery inputs and farm buildings and structures.

Thus, it is interesting to note that both capital investment and productivity in Japanese agriculture had fairly high growth rates until the 1970s and then afterwards they started decreasing till the end of the period under study. Why have both capital investment and productivity growth rates been increasing and decreasing simultaneously? What has been the connection between capital investment and productivity in Japanese agriculture during the periods of rapid and slow

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growth ? Do they cause each other and if so, then in which direction ?

Therefore, it is of great interest to test for the causality between productivity and capital investment. Accordingly, the objective of this study is to investigate the causal relationship between total factor productivity (TFP) and capital investment in Japanese agriculture for the 1957-97 period and to find out the direction of causality.

We have found that a substantial number of studies on postwar Japanese agricultural productivity have been carried out by Yamada [19, 20], Yamada and Hayami [21], Yamada and Ruttan [22], Kuroda [7, 8, 9], Van Der Meer and Yamada [18], and Ito [4], to name only a few. Their works were focused on measuring and decomposition of TFP, linking the growth of TFP to the theory of production, biased technological change, and factor demand in postwar Japanese agriculture et cetera. However, we have found that there have been few attempts to establish a relationship between TFP and the variables that explain TFP growth in Japanese agriculture.

Like many papers of the past this paper also measures TFP ; however, it differs in a few aspects. It has used a large sample size after the postwar and used pooled data. This paper used the multilateral index proposed by Caves, Christensen, and Diewert [1][4] to measure the total output, total input, and TFP indexes. This paper measures aggregated output index (consisting of five outputs)[5] and aggregated input index (consisting of five inputs)[6] for measuring TFP index.

There have been several studies on the causality concept in international agricultural economics, which include test of the export-led growth hypothesis, the induced innovation hypothesis, price dynamics, market integration, and linkages between the macro economy and agriculture. However, there are very few studies on this issue on Japanese agriculture.

Oniki [13] used the time series-based econometric analysis on Japanese rice production to provide evidence supporting the technological change process of learning-by-doing and technological spillover. The learning-by-doing effect was confirmed by cointegration between the capital and the total factor productivity and the technological spillover effect was confirmed by the Granger [3] causality tests for the TFP of large scale producers and that of small scale producers.

It has been found that most of the earlier studies on causality used time series data. Recently, there have been a few studies on foreign direct investment and trade, effect of public infrastructure on productivity, and between agricultural R & D and productivity, which have used panel data to test for causality.

Schimmelpfennig [16] extends Granger's test to handle panel data in a linear model. Schimmelpfennig and Thirtle [17] presented a restricted versus unrestricted model to test Granger causality between TFP and R & D expenditures for the ten European Countries (EC) and the USA. This study follows the Schimmelpfennig and Thirtle's [17] model to test causality between TFP and capital investment in Japanese agriculture.

This paper differs from past research in several ways. It is the first paper to use causality testing between TFP and the variables that explain TFP, i. e., capital investment, in Japanese agriculture for aggregated output. In the way of causality testing, we will derive a capital and TFP index.

While deriving the capital index, we will use two models to check the behavior of land (does it play a fixed input role or not ?). This paper attempts to test the existence of a long-run relationship between TFP and capital and the direction of the relationship between them.

The rest of this paper is arranged as follows. Section two presents the analytical framework. Section three describes the sources and definitions of the variables and the data used in this study. Section four contains the empirical results and analysis. Finally, conclusions are drawn in section five.

2. Analytical Framework

The analysis presented in this study is basically divided into two major parts. The first part will deal with the measurement of productivity in Japanese agriculture. While measuring productivity, it will investigate the movements in total output, total input, and total factor productivity (TFP) for average farms of four size classes, 0.5-1.0 (I), 1.0-

1.5 (II), 1.5-2.0 (III), and 2.0 hectares or larger (IV) for the 1957-97 period. The second part will investigate the direction of causality between the capital investment and productivity.

In order to draw an overall perspective on the Japanese agricultural sector, total output, total input, and TFP indexes are computed for the total average farm of the four size classes by using the shares of the number of farm households as weights.

The multilateral CCD method was used to estimate the indexes of total output, total input, and total factor productivity for the four size classes.

To test the null hypothesis that 'x does not cause y', we regress y against lagged values of y and lagged values of x (unrestricted model) and then regress y only against lagged values of y (restricted model). The Lagrange multiplier (LM) test can then be used to determine whether the lagged values of x contribute significantly to the explanatory power of the first regression. If they do, we can reject the null hypothesis and conclude that the data are consistent with x causing y. The null hypothesis that 'y does not cause x' is then tested in the same manner.

Unrestricted model :

$$y_{it} = \mu_i + \sum_{j=1}^{m} y_{it-j}\,\alpha_j + \sum_{j=1}^{m} x_{it-j}\,\beta_j + u_{it} \quad (1)$$

Restricted model :

$$y_{it} = \mu_i + \sum_{j=1}^{m} y_{it-j}\,\alpha_j + u_{it} \quad (2)$$

For this study, in the above equations (1) and (2), y and x represent TFP and capital, respectively, j $(=1,\ldots,m)$ is the number of lags chosen, i indexes the size classes, so the u_i's are size class specific fixed effects, t is the number of years of observations and each u_{it} satisfies the classical zero conditional mean, no serial correlation, and homoscedasticity assumptions. The assumption made here is that the coefficients α_j and β_j are the same across the size classes in the sample.

It is possible to test different numbers of lags of TFP and capital together in the panel data model, but there is no final prediction error criterion, so we use the common assumption that the lags of x and y should be the same.

The estimation problem for this model is that fixed effects panel data specifications with lagged dependent variables yield inconsistent results. However, once the fixed effects are removed by the standard technique of first differencing, the pooled data model becomes consistent. Then the model is,[7]

$$\Delta y_t = \sum_{j=1}^{m} \Delta y_{t-j}\,\alpha_j + \sum_{j=1}^{m} \Delta x_{t-j}\,\beta_j + u_t \quad (3)$$

Since we will be testing causality between TFP and capital, the equation can thus be rewritten as :

$$\Delta TFP_t = \sum_{j=1}^{m} \Delta TFP_{t-j}\,\alpha_j + \sum_{j=1}^{m} \Delta K_{t-j}\,\beta_j + u_t \quad (4)$$

$$\Delta K_t = \sum_{j=1}^{m} \Delta K_{t-j}\,\delta_j + \sum_{j=1}^{m} \Delta TFP_{t-j}\,\theta_j + v_t \quad (5)$$

For there to be unidirectional causality from capital to TFP, the estimated coefficient on lagged capital (K) in equation (4) should be significantly different from zero as a group ($\Sigma\,\beta_j \neq 0$) and the set of estimated coefficients on lagged TFP in the equation (5) should not be significantly different from zero ($\Sigma\,\theta_j \neq 0$).

Bidirectional causality is suggested when both $\Sigma\,\beta_j \neq 0$ in (4) and $\Sigma\,\theta_j \neq 0$ in (5) and independence when both sets of coefficients are not significantly different from zero.

To test the joint significance of the β_j's, the LM test statistic for the restricted versus the unrestricted model is computed refer to Maddala [12] and Pindyck and Rubinfeld [15]. This statistic has a χ^2 limiting distribution, with degrees of freedom equal to the number of β_j's, which is the number of lags (m).[8]

For the estimation of equations (4) and (5), we need to have two series of indexes : TFP[9] and capital. There will be two models while calculating capital. In model one, capital ($K1$) consists of machinery, other inputs, and land. In model two, capital ($K2$) will consist all the above variables except land. The determination of capital stock will follow the same indexation procedure as aggregate input.

$$\Delta \ln K = \ln\left(\frac{K_t}{K_{t-1}}\right) = \frac{1}{2}\sum_i \left(M_{it} + M_{it-1}\right) \ln\left(\frac{D_{it}}{D_{it-1}}\right) \quad (6)$$

where K represents capital ; $M_i = \frac{G_i D_i}{T}$, the cost share of capital i ; G_i and D_i are respectively the price and quantity of capital i ; T

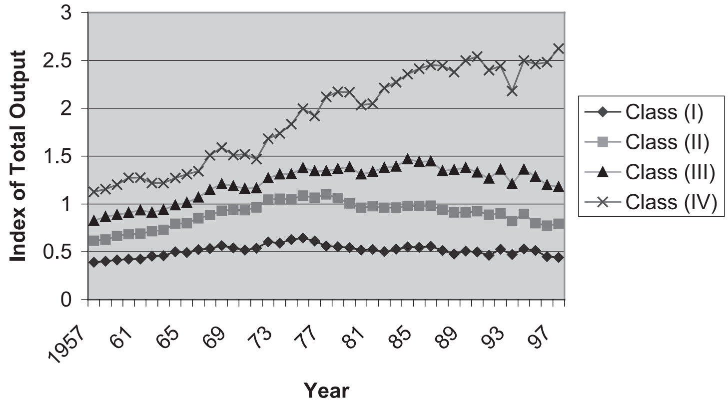

Figure 1. Index of total output (1957-97)

$=\sum_i G_i D_i$ is the total cost ; and t denotes time period. The CCD [1] multilateral index procedure will be used to construct the index of capital.

The sources of data and the variables required for this study are explained in the following section.

3. Data

The data required for the estimation of the model are the total cost, total revenue, the prices and quantities of outputs, the prices and quantities of inputs, revenue shares of outputs, and cost shares of the five factor inputs : labor, machinery, intermediate inputs, land, and other inputs. Eleven different items of output were classified into five categories to construct total output. The base of all indexes was set at 1985 values.

The data has been collected from the 'Survey Report on Farm Household Economy (FHE)' [6] and the 'Survey Report on Prices and Wages in Rural Villages (PWRV)' [5], published annually by the Ministry of Agriculture, Forestry, and Fisheries. In each year of the 1957-97 period, one average farm was taken from each of the four size classes, 0.5-1.0 (I), 1.0-1.5 (II), 1.5-2.0 (III) and 2.0 hectares and larger (IV), from all Japan (excluding Hokkaido prefecture because of the different size classification).[10] Thus the sample size is 41×4=164.

As we mentioned earlier, pooled data is used for this study. To measure the quantity and price indexes of total output and total input, a multilateral index proposed by Caves, Christensen, and Diewert [1] is employed.

By using this data, the results we have found are explained in the next section.

4. Empirical Results and Analysis

This section discusses the results found from productivity measurement and causality testing. The empirical results and interpretations are presented in the following sub-sections.

1) Result of the productivity measurement

The estimates of the indexes of total output, total input, and TFP are presented in graphic form in Figures 1, 2, and 3, respectively. According to Figure 1, total output increased in all the size classes for the 1957-97 period, although the rates of growth are apparently different among the size classes.

In the smallest size class (I), total output of average farm declined in the late 1970s, and then it became almost stagnant. Total output of average farm in size class II also started declining in the late 1970s, and continued to decline till the end of this study period. However, total output of size class III continued to increase till 1985, and then started declining. Total output of average farm in the largest scale farm (IV) increased in general throughout the study period and growth of total output of this size class was remarkable compared with those of the other classes.

In Figure 2, we see that the patterns of growth of total input seem to have been different among different size classes. Total input of the largest size class (IV) slightly declined in the early 1960s and immediately af-

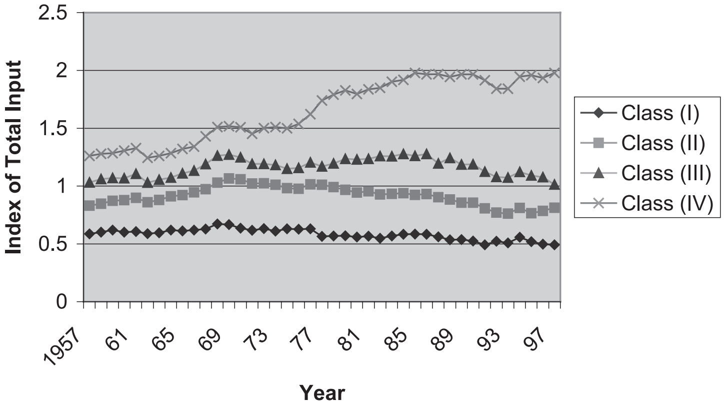

Figure 2. Index of total input (1957-97)

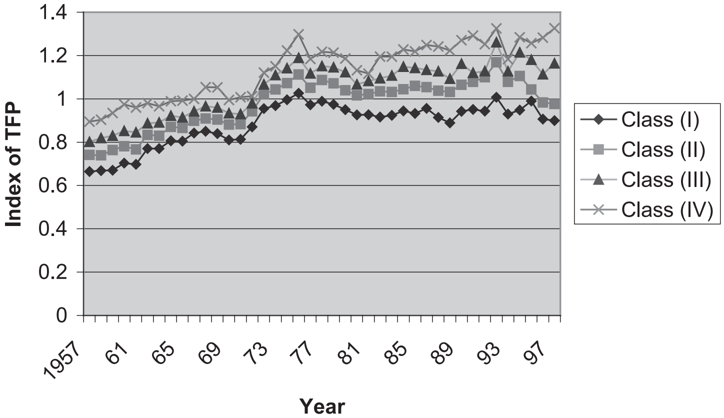

Figure 3. Index of total factor productivity (1957-97)

ter that it started growing and grew continuously throughout the study period. The growth of total input of three size classes (I, II, and III) did not increase as compared to the growth of the size class IV.

Finally, the movement of TFP is given in Figure 3. The graph shows that the patterns of the growth of TFP are almost similar among all the size classes. Until the 1970s, the growth of TFP in smaller size classes grew at a faster rate compared to the larger size classes. From the 1980s, the growth of TFP in all the size classes shows the same pattern.

Table 1 shows the growth rates of total output, total input, and TFP for all the size classes. The annual growth rate of TFP in size class III (0.92%) was greater than those in the other size classes.[11)]

2) Results of causality testing

Capital indexes of all the size classes are given in graphic form in Figures 4 and 5. The growth rates of capital among the different size classes are calculated and given in Tables 3 and 4.

Table 1. Compound growth rates of total output, total input, and TFP (1957-97)

Size class	Total output	Total input	TFP
0.5-1.0(I)	0.2315	−0.5298	0.7613
1.0-1.5(II)	0.5357	−0.3233	0.8590
1.5-2.0(III)	1.0324	0.1171	0.9153
2.0----(IV)	2.2318	1.3308	0.9010
Average	1.0079	0.1486	0.8593

We have divided the study period (1957-97) into three sub-periods in order to understand the decreasing trend in the growth rate of capital among the different size classes. From Table 3 we see that the growth rate of capital is decreasing in all the size classes.

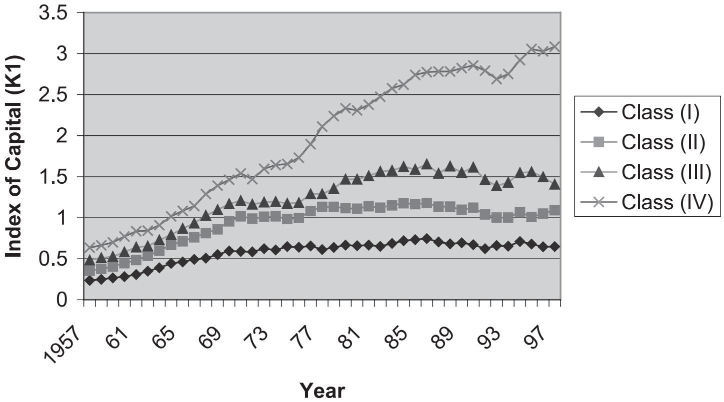

Figure 4. Index of capital ($K1$) in all size classes

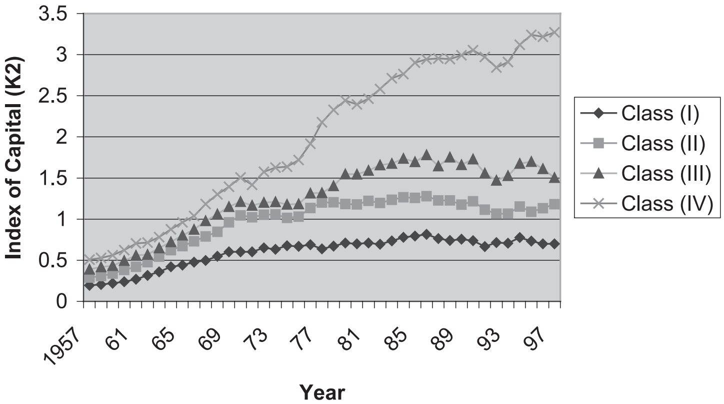

Figure 5. Index of capital ($K2$) in all size classes

During the first sub-period (1957-71), the growth rate of capital was very high among all the size classes. This is mainly because of farm mechanization and increased utilization of fertilizer and agro-chemicals in Japanese agriculture. Thereafter, the growth rate started decreasing and became negative in the third sub-period (1985-97) in all the size classes except size class IV. This is because smaller-scale farms decreased their usage of fertilizer, agro-chemicals, and feed. Table 4 also shows the same result where capital consists of machinery and other inputs.

We have derived TFP index from productivity measurement section. We have used lags of TFP index and lags of capital index to test causality between them.

The test results of the Granger causality between TFP and capital, as well as capital and TFP are presented in Tables 5 and 6.

The first column of Table 5 shows the number of lags chosen for capital in explaining TFP or TFP in explaining capital. The second and third columns report the calculated values of the χ^2_m test statistics for the significance of increasingly longer lags of capital in explaining TFP and the significance of increasing lags of TFP in explaining capital, respectively.

The result shows that with one lag of TFP and one lag of capital, the test statistic of 5.59 suggests that one lag of capital is significant at the 2.5% significance level and that capital is Granger prior to TFP. However, with two lags the calculated value is significant at the 10% level. From three lags onward, capital causes TFP at all the significance levels.

The last column shows that with the third lag, TFP is significant at the 10% level for all the size classes and can be said to be Granger prior to capital.[12] However, from the fourth

Table 2. Compound growth rates of TFP among size classes

Year/Size class	(I)	(II)	(III)	(IV)	Average
1957-1971	2.0232	1.7036	1.3691	0.9891	1.5215
1972-1984	−0.1995	0.1141	0.3200	0.4877	0.1805
1985-1997	0.0324	−0.2795	0.3185	0.3945	0.1164
1957-1997	0.7613	0.8590	0.9152	0.9010	0.8591

Table 3. Compound growth rates of capital (*K*1) among size classes

Year/Size class	(I)	(II)	(III)	(IV)	Average
1957-1971	5.6322	6.1850	5.3655	5.0490	5.5565
1972-1984	1.8227	1.8578	2.9625	4.5006	2.7859
1985-1997	−0.4959	−0.7898	−0.9431	0.7081	−0.3801
1957-1997	1.6373	1.7110	1.9301	3.0825	2.0902

Note : Capital consists of machinery, other inputs and land.

Table 4. Compound growth rates of capital (*K*2) among size classes

Year/Size class	(I)	(II)	(III)	(IV)	Average
1957-1971	8.5891	9.1036	7.9764	7.5146	8.2959
1972-1984	2.6044	2.6582	4.0645	5.7830	3.7775
1985-1997	−0.4882	−0.7975	−0.9027	0.6697	−0.3796
1957-1997	2.6476	2.7188	2.9536	4.1659	3.1214

Note : Capital consists of machinery and other inputs.

Table 5. χ^2_m Granger causality test between TFP and capital (*K*1) investment

No. of lags	Capital (*K*1) causes TFP	TFP causes capital (*K*1)
1	5.59**	0.85
2	5.46*	4.58
3	9.58**	6.52*

Note : *, **, denote 10 and 2.5% significance levels, respectively.

Table 6. χ^2_m Granger causality test between TFP and capital (*K*2) investment

No. of lags	Capital (*K*2) causes TFP	TFP causes capital (*K*2)
1	4.99**	0.81
2	5.22*	4.51
3	10.25***	6.73*

Note : *, **, *** denote 10, 5 and 2.5% significance levels, respectively.

lag TFP is Granger prior to capital at all the significance levels.

The above discussion on the causality test between TFP and capital suggests a two-way causality from capital investment to productivity growth. However, Oniki [13] found a one-way causality from capital investment to TFP for Japanese rice production. He used a time series based econometric analysis and single output.

Table 6, where capital consists of all the variables except land, shows the same result as in Table 5. Here, capital causes TFP with one lag length at the 5% significance level and TFP causes capital with three lags at the 10% level.

The reason for showing the same result in Tables 5 and 6, in spite of different capital formulation, might be because land plays the role of a fixed input in Japanese agriculture. Land, like other capital inputs, did not grow in quantity over the years.

In some studies on Japanese agriculture (e.g., Kuroda and Lee [11]), land has been

Table 7. Granger causality test between TFP and capital ($K1$) investment among size classes (TFP causes capital)

No. of lags	Size class I	Size class II	Size class III	Size class IV	All size classes
1	2.83*	3.06*	0.72	1.95	0.85
2	9.75***	9.64***	8.10***	4.18	4.58
3	14.09***	16.69***	6.99*	7.48*	6.52*

Note : *, **, *** denote 10, 5, 2.5% significance levels, respectively.

treated as a fixed input since the land rent[13] during the postwar years was set at a certain low level by the government and therefore not a market price until at least 1975.

Finally, conclusions are drawn in the following section.

5. Conclusion

This paper has measured agricultural productivity and examined the causality between productivity and capital investment in Japanese agriculture for the 1957-97 period. We have found that the rates of growth of total output, total input and TFP are apparently different among the size classes. Table 1 shows that the total average growth rates of total output, total input, and TFP were 1.01, 0.15 and 0.86%, respectively.

In the second part of the study, this paper tested the causal relationship between TFP and capital using data on Japanese agriculture over the period 1957-97. The approach used was for Granger tests of causality between the two variables. This study explored whether productivity increases lead to capital investment or whether capital investment allows greater productivity.

The results of the tests suggest that there has been a significant and positive Granger-causal relationship running from TFP to capital as well as from capital to TFP in Japanese agriculture over the long term. We found capital causes TFP after one lag and TFP causes capital with three lags.[14]

We used two models for capital to test causality with TFP and found a consistent result with both models. This indicates that land plays a fixed input role in Japanese agriculture. Land did not grow in quantity over the years like other forms of capital.

An important policy implication of the result of this study suggests that the government should encourage, in particular, large scale farming in order to increase total output and productivity. Causality test suggests that capital investment has been successful in increasing TFP and capital investment tends to be forthcoming but it takes time for the larger size classes (size classes III and IV). Policy makers would require a very fast response for the short lag relationship from TFP to capital, and therefore, it is suggested that volume of capital investment need to be increased for the larger size classes to increase productivity in Japanese agriculture.

Although Oniki [13] pointed out that unlimited improvement in productivity through capital intensification is not feasible, as capital-based innovation becomes more difficult over time, his study was limited to single output, whereas this study uses aggregated output. Therefore, further study may be needed to identify the exact ratio of capital investment to increasing productivity in the long run. Till then, this study suggests increasing capital investment for the larger size classes to improve productivity.

1) Capital consists of machinery, other inputs and land. Other inputs include buildings and structures, plants, and animals.
2) Table 2 shows the growth rates of TFP among the different size classes for the three sub-periods.
3) Tables 3 and 4 show the growth rates of capital ($K1$) and capital ($K2$) among the size classes for the three sub-periods. Here capital ($K1$) consists of machinery, other inputs and land. On the other hand capital ($K2$) consists of machinery and other inputs.
4) The CCD method is most relevant for the estimation of the Törnqvist index for a pooled cross-section of a time-series data set. This procedure was used by Kuroda [9, 10, 11] in estimating TFP index.

5) Eleven different items of output were classified into five categories, i. e., rice, vegetables, fruits, livestock and others, to compute the aggregated output index. Other outputs include wheat and barley, grains and beans, various potatoes, industrial crops such as tea, rice stalks and processing of rice stalks, and other crops.
6) Aggregated input consists of five inputs, i. e., machinery, intermediate inputs, other inputs, labor and land.
7) The formulation is given in D. Schimmelpfennig and C. Thirtle [17].
8) Dickey and Fuller [2] unit root was tested for each variable and we have found that all the variables are integrated of order one and therefore, the null hypothesis of a unit root is accepted.
9) We estimated TFP by the CCD [1] multilateral index. The expression of the index is given by :

$$\ln(TFP_t/TFP_{t-1})$$
$$=\sum_j 0.5\times(R_{j,t}+R_{j,t-1})\times\ln(Q_{j,t}/Q_{j,t-1})$$
$$-\sum_j 0.5\times(S_{i,t}+S_{i,t-1})\times\ln(X_{i,t}/X_{i,t-1}),$$

where $R_{j,t}$ and $R_{j,t-1}$ are revenue shares of output j at time t and $t-1$, respectively ; $Q_{j,t}$ and $Q_{j,t-1}$ are quantities of output j at time t and $t-1$, respectively ; $S_{j,t}$ and $S_{j,t-1}$ are the cost shares of input i at time t and $t-1$, respectively ; and $X_{i,t}$ and $X_{i,t-1}$ are the quantities of input i at time t and $t-1$, respectively.
10) The farm production technologies in Hokkaido prefecture are to some extent different from those in other regions in Japan.
11) These estimates are within a reasonable range compared with the other studies for Japanese agriculture. Due to the substantial changes in average farm size of sample farmers in 1992 and 1995, there was a sharp decrease in the TFP index for all the size classes in 1993 and in 1996, except for the size class IV, the three other size classes (I, II and III) had further decreases in TFP measurement.
12) If we look at the causal relationship between TFP and capital among the different size classes, then Table 7 suggests that size classes I and II, which are the representative of smaller size classes, have short lag relationships from TFP to capital. The results show that with one lag TFP is significant at the 10% level in the size classes I and II. However, with two lags size class III is significant at the 2.5% level and with the third lag size class IV is significant at the 10% level.
13) In order to estimate land cost, the land price was first obtained by dividing land rent by the rented land area (1,000 yen per 10 areas). This price was then used to impute the land cost of owned arable land area. Finally, the land cost was defined as the sum of total rent for owned and rented arable land and expenditures on land improvements and water use.
14) The results found in this paper corroborate other studies, such as, Schimmelpfennig and Thirtle [17] and Pardey and Craig [14]. However, they used R & D instead of capital for ten European countries and USA. Moreover, Oniki [13], by using time series based econometric analysis and single output (rice), found unidirectional causality from capital investment to TFP for Japanese rice production.

References

[1] Caves, D. W., L. R. Christensen, and W. E. Diewert. "Multilateral Comparisons of Output, Input, and Productivity Using Superlative Index Numbers," *Economic Journal*, Vol. 92, 1982, pp. 73-86.

[2] Dickey, D. and W. Fuller, "Likelihood Ratio Tests for Autoregressive Time Series with a Unit Root," *Econometrica*, Vol. 49, 1981, pp. 1057-1072.

[3] Granger, C. W. J. "Some Recent Developments in the Concept of Causality," *Journal of Econometrics*, Vol. 39, 1988, pp. 199-211.

[4] Ito, J. "Nogyo Kenkyu Toshi no Keizai Bunseki (An Economic Analysis of Investment in Agricultural Research and Extension Activities in Japan)," *Keizai Kenkyu* (*Economic Review*), Vol. 43, 1992, pp. 237-247.

[5] Japan, Ministry of Agriculture, Forestry, and Fisheries. *Noson Bukka Chingin Chosa Hokoku* (*Survey Report on Prices and Wages in Rural Villages*), Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, Tokyo, various issues.

[6] Japan, Ministry of Agriculture, Forestry, and Fisheries. *Noka Keizai Chosa Hokoku* (*Survey Report on Farm Household Economy*), Statistical Bureau of the Ministry of Agriculture, Forestry, and Fisheries, Tokyo, various issues.

[7] Kuroda, Y. "Biased Technological Change and Factor Demand in Postwar Japanese Agriculture, 1958-84," *Agricultural Economics*, Vol. 2, 1988. pp. 101-122.

[8] Kuroda, Y. "Impacts of Economies of Scale and Technological Change on Agricultural Productivity in Japan," *Journal of the Japanese and International Economies*, Vol. 3, 1989, pp. 145-173.

[9] Kuroda, Y. "Research and Extension Expenditures and Productivity in Japanese Agriculture, 1960-1990," *Agricultural Economics*, Vol.

16, 1997, pp. 111-124.

[10] Kuroda, Y. and A. Naziruddin. "Impacts of Set-Aside and R & E Policies on Agricultural Productivity in Japan, 1965-97," *The Japanese Journal of Rural Economics*, Vol. 5, 2003, pp. 12-34.

[11] Kuroda, Y. and Y. Lee. "Output and Input Biases Caused by Public Agricultural Research and Extension in Japan, 1957-97," *Asian Economic Journal*, Vol. 17, No. 2, 2003, pp. 105-128.

[12] Maddala, G. S. *Introduction to Econometrics—Second Edition*. New Jersey: Prentice Hall International, Inc., 1992.

[13] Oniki, S. "Induced Innovation with Endogenous Growth in Agriculture: A Case of Japanese Rice Production," *Japanese Journal of Rural Economics*, Vol. 3, 2001, pp. 15-25.

[14] Pardey, P. G. and B. Craig. "Causal Relationship between Public Sector Agricultural Research Expenditures and Output," *American Journal of Agricultural Economics*, Vol. 71, 1989, pp. 9-19.

[15] Pindyck, R. S. and D. L. Rubinfeld. *Econometric Models and Economic Forecasts—Fourth Edition*. McGraw Hill International Editions, 1998.

[16] Schimmelpfennig, D. E. "An Empirical Investigation of the Capital-Environment Tradeoff," unpublished manuscript, Michigan State University, 1992.

[17] Schimmelpfennig, D. E. and C. Thirtle. "Cointegration and Causality: Exploring the Relationship between Agricultural R & D and Productivity," *Journal of Agricultural Economics*, Vol. 45(2), 1994, pp. 220-231.

[18] Van Der Meer, C. L. J. and S. Yamada. *Japanese Agriculture: A Comparative Economic Analysis*. London: Routledge, 1990.

[19] Yamada, S. "The Secular Trends in Input-Output Relations of Agricultural Production in Japan, 1878-1978," in C. M. Hou and T. S. Yu, eds., *Agricultural Development in China, Japan and Korea*. Taipei: Academia Sinica, 1982.

[20] Yamada, S. *Country Study on Agricultural Productivity Measurement and Analysis, 1945-1980: Japan*. University of Tokyo: Institute of Oriental Culture, 1984.

[21] Yamada, S. and Y. Hayami. "Agricultural growth in Japan, 1880-1970," in Y. Hayami, V. W. Ruttan and H. M. Southworth, eds., *Agricultural Growth in Japan, Taiwan, Korea and the Phillippines*. Honolulu: University Press of Hawaii, 1979.

[22] Yamada, S. and V. W. Ruttan. "International Comparisons of Productivity in Agriculture," in J. W. Kendrick and B. N. Vaccara, eds., *New Development in Productivity Measurement and Analysis*. Chicago: University of Chicago Press, 1980.

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