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# THE TECHNICAL EFFICIENCY OF JAPANESE AGRICULTURE, 1878–1940

RICHARD GRABOWSKI
CARL PASURKA

It has been increasingly recognized that agriculture has an important role to play in the development process. As a consequence, increased attention has been paid to the analysis of the agricultural problems of less-developed nations. Scholars have also been interested in the experiences of several nations who have, within the last century, rapidly modernized their agricultural sectors. Within this group, Japan has become the subject of intensive examination. Some economists believe that its historical experiences should be used as a model for policymaking in today's less-developed countries (more will be said concerning this in the next section of this paper.)[1]

Given the importance of Japan in the literature on agricultural development, this paper concentrates its attention on Japanese agriculture during the period 1878 to 1940. Specifically, this paper will determine the extent to which Japanese agriculture was technically efficient during this time period. The issue of technical efficiency is important for several reasons. First, the extent to which farmers in developing nations are efficient has been an issue for debate in development economics for some time.[2] As a result, it will be interesting to see the extent to which Japanese farmers were technically efficient during the early phases of their development. Second, an analysis of technical efficiency may add to our understanding of the growth process in Japan. If significant technical inefficiencies are found one can conclude that rapid agricultural growth does not require technical efficiency.

In measuring the extent of technical efficiency a relatively new method is being used. A production frontier is constructed and inefficiency is measured by the extent to which any given years production occurs within or below the frontier. Not only is the extent of technical inefficiency measured, but it is decomposed into inefficiency stemming from operation at non-constant returns to scale and pure technical inefficiency (operating off the isoquant, wasting resources).

The next section will briefly review the process of agricultural development in Japan for the period 1878 to 1940. In Section II, the methodology which is used to measure technical efficiency is discussed in some detail. Section III will present the empirical result and discuss them. Finally, Section IV will present a brief summary of the paper.

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[1] See, for example, [5] or [6].

[2] See [7].

TABLE I

GROWTH RATES OF TOTAL OUTPUT, INPUT, AND PRODUCTIVITY

| | Period | Output | Input | Productivity |
|---|---|---|---|---|
| (1) | 1880–1900 | 1.6 | 0.4 | 1.2 |
| | 1876–1904 | 1.6 | 0.4 | 1.2 |
| (2) | 1900–1920 | 2.0 | 0.5 | 1.5 |
| | 1904–1918 | 2.5 | 0.6 | 1.9 |
| (3) | 1920–1935 | 0.9 | 0.5 | 0.4 |
| | 1918–1938 | 1.0 | 0.4 | 0.6 |

Source: Adapted from [8, p. 43].

## I

In terms of the growth of output and productivity, Japanese agricultural development from 1878 to 1940 can be divided into three periods. The growth rates for output, input, and productivity for each of these periods is presented in Table I. As can be seen, from 1880 to 1900 output and productivity grew at modestly high and stable rates. From 1900 to 1918 the growth rate accelerated. Finally, from 1918 to 1940 growth rates in the agricultural sector declined rapidly and the sector seemed to stagnate.

The key factor in Japan's ability to rapidly increase agricultural productivity in periods one and two seems to have been rapid technological change [4]. This is supported by the data in Table I which indicate that in these periods a large proportion of the increase in output resulted from productivity increases rather than increased input use. However, not only was the rate of technical innovation important in generating growth, but also the techniques were appropriate to the resource endowments of Japan at that time. Specifically, in Japan land was becoming increasingly scarce relative to other inputs, especially fertilizer. This was reflected in a steady decline in the price of fertilizer relative to the price of arable land. Therefore, the type of technology most appropriate for Japan from an economic point of view would be one which is land saving and fertilizer using [3, p. 340].

Mechanical innovations are thought to be labor saving and land using in nature. They are not likely to lead to significant yield increases. Given the discussion in the previous paragraph, this type of technology would have been inappropriate for application in Japan. Alternatively, biochemical innovations are thought to be land saving in nature and result in significant increases in yield. This type of technology generally involves the development of new yield-increasing seed varieties which are highly responsive to the increased application of chemical fertilizers. This type of technology seems to have been appropriate for application to Japanese agriculture during this time period. In fact, if one examines Tables II and III, it can be seen that generally the productivity increases in Japan during this time period were of a yield-increasing nature. The usage of chemical fertilizers increased

TABLE II

ANNUAL PERCENTAGE RATES OF GROWTH

| Period | Labor | Land | Fixed Capital | Fertilizer |
|---|---|---|---|---|
| 1880–1900 | 0.1 | 0.5 | 0.9 | 1.6 |
| 1900–1920 | −0.6 | 0.7 | 1.3 | 7.7 |
| 1920–1935 | −0.1 | 0.1 | 0.9 | 3.4 |
| 1935–1945 | 0.1 | −0.4 | −1.4 | −4.9 |

Source: Adapted from [9, p. 88].

TABLE III

ANNUAL PERCENTAGE RATES OF GROWTH

| Period | Output per Worker | Output per Hectare | Land Area per Worker |
|---|---|---|---|
| 1880–1900 | 1.5 | 1.1 | 0.4 |
| 1900–1920 | 2.6 | 1.3 | 1.3 |
| 1920–1935 | 1.0 | 0.8 | 0.2 |
| 1935–1945 | −2.0 | −1.5 | −0.5 |

Source: Adapted from [9, p. 92].

very rapidly, excluding the period 1935 to 1945. The implication is that the rapid technical innovation in Japanese agriculture was biochemical, not mechanical, in nature and thus appropriate to the relative factor supplies existing in Japan.

What were the sources of such rapid technological innovation? According to Hayami, Yamada, and other scholars of early Japanese development, there was a substantial backlog of technical knowledge that existed in the late 1800s. This was the result of the fact that during the 300 years of the Tokugawa period preceding the Meiji Restoration (1868) farmers were subject to the constraints of feudalistic society. Farmers were bound to their land and were not generally allowed to leave their village. They were not free to choose either their cultivation techniques or the specific crops to be grown. In other words, Japan was divided into feudal estates and there was a restricted flow of people and ideas between these estates. Under these conditions, the diffusion of new seed varieties and techniques from one region to another was severely limited [3, p. 156].

With the Meiji Restoration, the feudalistic barriers between nations were broken down and farmers were free to choose what they would plant and the techniques used. Nationwide communication was promoted and land ownership rights were clarified. In addition, the government created an institutional network which actively developed and promoted the application of new seeds. In 1877, the government established what is today known as the College of Agriculture, University of Tokyo. An itinerant instructor system was established in 1885 in which instructors, veteran farmers as well as individuals trained at the College of Agriculture, traveled throughout the country holding agricultural extension meetings [3, pp. 155–56].

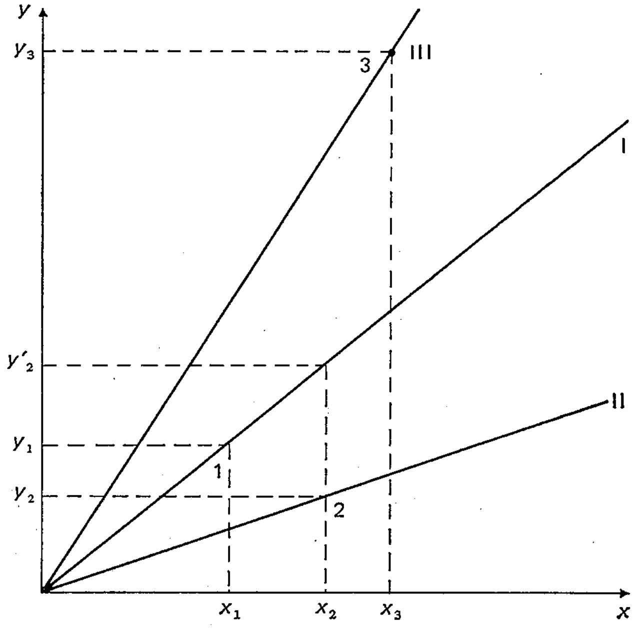
The Experiment Farm for Staple Cereals and Vegetables was established in 1886 and the National Agricultural Experiment Station, with six branches, was established in 1893. The initial research that was conducted was at the applied end of the spectrum. The techniques and seed varieties of specific regions generally needed to be modified in order to be successfully transferred to other localities. These experiments and research were essential in providing the basis for the rapid diffusion of new technology [3, p. 157].

The rapid agricultural growth was, however, not rapid enough to keep up with the growth in the demand for food. Beginning in the mid-1890s Japan was forced to import food. Initially these food imports were moderate in nature and were kept moderate by the rapid technical progress made by agriculture. However, the growth in the domestic demand for such food staples as rice continued to outstrip the ability of Japan's agricultural sector to supply domestic demand as the exhaustion of the technology backlog began to occur. As a result, serious rice shortages occurred which culminated in the rice riots of 1918. The reaction of the government was to drastically increase rice imports from Japan's overseas colonies, Taiwan and Korea. Through squeezing income by taxes and monopoly sales, on the one hand, and investing in irrigation and agricultural research, on the other, Japan was successful in obtaining large-scale rice imports from these colonies. The importation of colonial rice brought down the price of rice to Japanese consumers. However, this also dramatically reduced the income of Japanese farmers and sharply dampened their production incentives [8]. On top of this, the world depression of the 1930s hit Japan resulting in a serious agricultural crisis.

A similar crisis occurred in England after the repeal of the Corn Laws in 1846. This resulted in an inflow of cheap grains which led many farmers to leave agriculture and move into the industrial sector. The British agricultural sector also moved away from grain production and toward a more extensive system of livestock agriculture. This transformation process could not occur in Japan because its agricultural sector was rigidly locked into a sophisticated labor-intensive system of crop production, which was highly dependent on irrigation and fertilizers. There was not an adequate basis in either agricultural research or the industrial infrastructure to make the rapid change to livestock agriculture. The demand for labor in the industrial sector also slackened after 1920 and this indicates that there were few alternatives available for Japanese farmers. This contraction occurred due to a decline in the world demand for the products of Japanese industry, a contraction in domestic demand due to deflationary domestic policy, and the adoption of an industrial rationalization policy. This latter policy placed a great emphasis on efforts to save labor through the use of capital-intensive methods in industry [3, pp. 227–28].

In summary, from 1878 to 1900 Japanese agriculture grew at a modestly high rate as a result of the diffusion of best practice techniques and inputs throughout Japan. These represented a technological backlog resulting from the constraints of feudalism. When these constraints were eliminated, the new knowledge diffused throughout Japan. The exhaustion of the backlog led to increasing shortages of

Fig. 1.



basic food staples, rice. The Japanese government dealt with this by importing large quantities of rice from Taiwan and Korea which caused an agricultural crisis in Japan.

## II

This section[3] specifies the model utilized in this study to measure the extent of inefficiency. This approach allows us to decompose technical inefficiency into scale inefficiency (i.e., not producing at constant returns to scale) and pure technical inefficiency (operating off the isoquant). It is also possible to disaggregate the source of inefficiency even further so as to include congestion of inputs (i.e., producing on the backward bending portion of the isoquant). However, for the purposes of this study, input congestion is not measured.

In the discussion of the methodology which follows, it will be assumed that there are $m$ inputs, denoted by $x=(x_1, x_2, \ldots, x_m) \in R_+^m$, a single output, $y$, and $n$ observations (years) of $x$ and $y$. A linear programming technique is used to construct a number of production frontiers which encompass the observations on $x$ and $y$.

The first type of best practice frontier which is constructed restricts returns to scale to be constant. The construction of such a frontier is illustrated in Figure 1

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[3] Much of the discussion here is based on [1] and [2].

with $x$ on the horizontal axis and $y$ on the vertical axis. Movements to the right along the horizontal axis represent equiproportional increase in all inputs. One, two, and three represent observations on $y$ and $x$ for years one, two and three.

The best practice frontier is constructed by using only data for the current year and all previous years.[4] So, for example, at time period one there is only one observation and thus the best practice frontier (I) passes through one (1) and the observation must be efficient. At time period two we construct the frontier using the data for periods one and two. In this case, the best practice frontier will not pass through two (2), but through one (1). Thus observation two is technical inefficient and one can determine what could have been produced in time two using $x_2$ inputs, if technical efficiency exists, by moving up the frontier to $y'_2$. The ratio of potential output, $y'_2$, to actual $y_2$ is defined as $\theta_1$ and $\theta_1$ is always greater than one when technical inefficiency exists. For observation three, the best practice frontier is III. In this case, observation three is efficient, i.e., $\theta_1 = 1$. This is the overall measure of inefficiency.

The linear programming (LP) problem that is used to construct the frontiers and calculate overall technical efficiency, $\theta_1$, is:

$$
\begin{aligned}
&\text{Maximize } \theta_1\\
&\text{subject to}\\
&\qquad K_1z_1 + K_2z_2 + \ldots + K_nz_n \leqq K_n,\\
&\qquad N_1z_1 + N_2z_2 + \ldots + N_nz_n \leqq N_n,\\
&\qquad L_1z_1 + L_2z_2 + \ldots + L_nz_n \leqq L_n,\\
&\qquad C_1z_1 + C_2z_2 + \ldots + C_nz_n \leqq C_n,\\
&\qquad y_1z_1 + y_2z_2 + \ldots + y_nz_n - y_n\theta_n \geqq 0.
\end{aligned}
\tag{1}
$$

The first four constraints are input constraints. In this paper four inputs are used: $K$ is capital, $N$ is labor, $L$ is land, and $C$ is current inputs (fertilizers, pesticides, etc.). The constraint for capital is discussed in detail in order to give the reader an economic interpretation of the constraint. The left-hand side of the constraint constitutes the theoretical efficient observation against which the current years observation, $K_n$, is to be compared ($K_1$ through $K_{n-1}$ represent all previous years observations on $K$). This constraint states that the theoretically efficient observation will use an amount of capital that is less than or equal to the amount utilized by the $n$th years observation to produce the output of the $n$th year.

The last constraint is the output constraint. The left-hand side of the constraint consists of two parts. The component $(y_1z_1 + y_2z_2 + \ldots + y_nz_n)$ represents the level of output of the theoretically efficient observation. This is the maximum output that can be produced by the $n$th observation given its actual levels of inputs. The component $(-y_n\theta_1)$ is the actual level of output of the $n$th observation multiplied by the level of inefficiency, $\theta_1$. If the observation is overall technically efficient, then $\theta_1 = 1$. As a result, the component $(y_1z_1 + y_2z_2 + \ldots + y_nz_n)$ is

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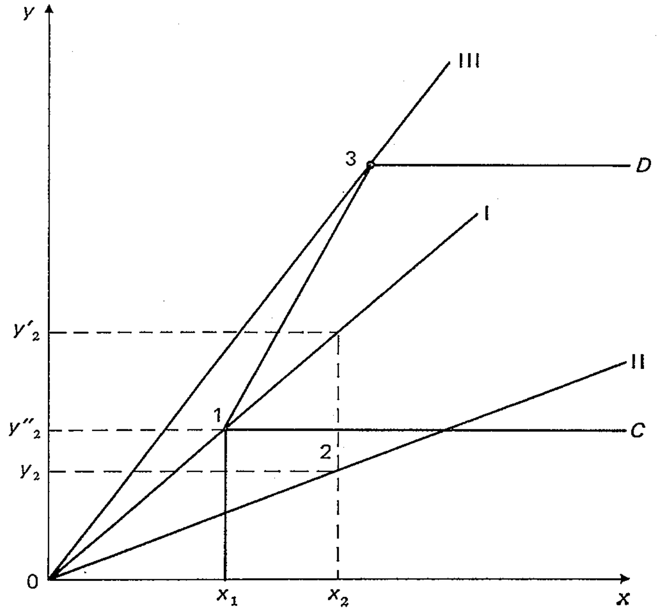
[4] This is done so as not to confuse technological change with technical inefficiency. For a given year, the only relavant years for a given technology are past years and the present year. The current year should not be compared with a future year, because technology available in the future is not available in the current year.

Fig. 2.



exactly offset by $(-y_n\theta_1)$. If the observation is inefficient then $\theta_1>1$. This implies that the output of the theoretically efficient observation is greater than the actual level of output of year $n$.

The overall level of technical efficiency can be disaggregated into two components: scale and pure technical. In order to distinguish between these, two additional frontiers are constructed. The construction of one of these frontiers is illustrated in Figure 2. These best practice frontiers are constructed so as to allow for increasing, constant, and decreasing, returns to scale. They use only the current year and all previous years in the process of constructing the frontiers. With respect to observation one, the variable returns to scale best practice frontier is $x_1 1C$ and the constant returns to scale frontier is I. Thus the first period observation lies on both frontiers, i.e., there is no inefficiency. For the second period observation the best practice variable returns to scale frontier is $x_1 1C$ (the best technology is that represented by year one) and the best practice constant returns to scale frontier is I. If the second observation had been on the variable returns to scale frontier it would have produced $y''_2$ output. The difference between this and the actual output level is pure technical inefficiency. The ratio of potential output (measured relative to the variable returns to scale frontier) relative to actual output is greater than one and this is defined as $\theta_2$. Thus when an observation is purely technically efficient then $\theta_2=1$. Finally, for year three the best practice frontier would be $x_1 13D$. Evaluating year three relative to this frontier indicates that this year is purely technically efficient, i.e., $\theta_2 = 1$.

The linear programming problem used to solve for $\theta_2$ is written as:

$$\begin{aligned} &\text{Maximize } \theta_2 \\ &\text{subject to} \\ &\quad K_1 z_1 + K_2 z_2 + \ldots + K_n z_n \leqq K_n, \\ &\quad N_1 z_1 + N_2 z_2 + \ldots + N_n z_n \leqq N_n, \\ &\quad L_1 z_1 + L_2 z_2 + \ldots + L_n z_n \leqq L_n, \\ &\quad C_1 z_1 + C_2 z_2 + \ldots + C_n z_n \leqq C_n, \\ &\quad y_1 z_1 + y_2 z_2 + \ldots + y_n z_n - y_n \theta_n \geqq 0, \\ &\quad z_1 + z_2 + \ldots + z_n = 1. \end{aligned} \tag{2}$$

The last constraint allows the production frontier to reflect varying returns to scale. A detailed explanation of the effect of this constraint is presented in the Appendix.

Referring again to Figure 2, if the observation for period two is operating at constant returns to scale (frontier I), the output will be $y'_2$. For observation two, the total output lost as a result of overall technical inefficiency is $y'_2 - y_2$, with $y''_2 - y_2$ due to pure technical inefficiency and $y'_2 - y''_2$ due to scale inefficiency. Alternatively, we could measure scale inefficiency as

$$\theta_3 = \frac{\theta_1}{\theta_2}. \tag{3}$$

If $\theta_3 = 1$, $\theta_1 = \theta_2$, then scale efficiency prevails (as at years one and three). Alternatively, if $\theta_1 > \theta_2$, it follows that $\theta_3 > 1$, scale inefficiency exists (as for year two).

Calculating $\theta_3$ allows us to determine whether a particular observation is operating at constant or non-constant returns to scale. However, it does not allow us to determine whether increasing or decreasing returns to scale prevail. In order to do this, a third type of frontier is calculated. This frontier is constructed so as to impose non-increasing returns to scale.

The third frontier is constructed by solving the following linear programming problem:

$$\begin{aligned} &\text{Maximize } \theta_4 \\ &\text{subject to} \\ &\quad K_1 z_1 + K_2 z_2 + \ldots + K_n z_n \leqq K_n, \\ &\quad N_1 z_1 + N_2 z_2 + \ldots + N_n z_n \leqq N_n, \\ &\quad L_1 z_1 + L_2 z_2 + \ldots + L_n z_n \leqq L_n, \\ &\quad C_1 z_1 + C_2 z_2 + \ldots + C_n z_n \leqq C_n, \\ &\quad y_1 z_1 + y_2 z_2 + \ldots + y_n z_n - y_n \theta_n \geqq 0, \\ &\quad z_1 + z_2 + \ldots + z_n \leqq 1. \end{aligned} \tag{4}$$

The last constraint imposes non-increasing returns to scale on the production frontier. A detailed explanation of this constraint is presented in the Appendix.

The construction of such a frontier is illustrated using Figure 2. With respect to observation one, the best practice non-increasing returns to scale frontier is

01*C*. The ratio of the potential output for observation one, using frontier 01*C*, to actual output is called $\theta_4$ and, as can be seen, is equal to one (i.e., observation one is on frontier 01*C*). Thus $\theta_4 = \theta_1$ and it can be shown that this only occurs when either increasing or constant returns to scale prevail [1] [2]. Since $\theta_3 = 1$, we know that observation one represents constant returns to scale. If $\theta_3 > 1$ and $\theta_4 = \theta_1$, then increasing returns to scale prevail. With respect to observation two, it has already been shown that $\theta_3 > 1$, non-constant returns to scale. Notice that $\theta_4 \neq \theta_1$ for this observation and it can be shown that this always holds when decreasing returns to scale occur [1].

In summary, the measurement of technical inefficiency involves the construction of three types of frontiers. Each years relative technical efficiency is calculated by constructing each of the frontiers using the current year being evaluated and all past years observations. Using these frontiers, one can then determine the extent of overall technical inefficiency, $\theta_1$, and decompose this into scale, $\theta_3$, and pure technical inefficiency, $\theta_2$. In addition, one can determine whether scale inefficiency stems from operating at increasing or decreasing returns to scale.

## III

The method outlined above was applied to Japanese agricultural data for the time period 1878 to 1940.[5] Agricultural output was measured in terms of total production valued in 1934–36 yen. Labor is measured in thousands of workers and arable land in thousands of hectares. Fixed capital and current inputs (fertilizers, pesticides, etc.) are measured in millions of yen at 1934–36 prices.

The results are presented in Table IV and can be divided into four periods. First, from 1878 to 1890 the averages for $\theta_1$, $\theta_2$, and $\theta_3$ are respectively 1.0202, 1.0200, and 1.0002.[6] As can be seen, this was a period of relative technical efficiency, with what little technical inefficiency that occurred being the result of pure technical inefficiency. This represent a period of transition, following the Meiji Restoration during which the government was consolidating its position and during which agriculture had yet to experience fundamental change.

During the second period, 1890–1906, the averages for $\theta_1$, $\theta_2$, and $\theta_3$ were respectively 1.0632, 1.0615, and 1.0016. During this period there was an increase in technical inefficiency compared to the first period. It is necessary to determine whether or not the difference in $\theta_1$ between periods one and two is statistically significant. To do this several simple tests were used, two of which are nonparametric: analysis of variance, the median tests, and the Kruskal-Wallis one way analysis based on ranks. The nonparametric tests do not make the assumption of normality. The analysis of variance compares within and among group (time period) variations of $\theta_1$. The median test compares the $\theta_1$ of the groups (time periods) on the basis of central tendency as defined by the median. The Kruskal-Wallis test compares the distributions of $\theta_1$ for the two groups (time periods).

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[5] The data is drawn from [4].

[6] It must be pointed out that the relationship $\theta_3 = \theta_1/\theta_2$ does not hold for the average results.

## TABLE IV

### Technical Efficiency

| | Year | $\theta_1$ | $\theta_2$ | $\theta_3$ |
|---|---|---|---|---|
| 1 | 1878 | 1 | 1 | 1(c) |
| 2 | 1879 | 1 | 1 | 1(c) |
| 3 | 1880 | 1 | 1 | 1(c) |
| 4 | 1881 | 1.0320 | 1.0316 | 1(c) |
| 5 | 1882 | 1.0028 | 1.0025 | 1.0004(d) |
| 6 | 1883 | 1.0068 | 1.0064 | 1.0004(d) |
| 7 | 1884 | 1.0475 | 1.0461 | 1.0010(d) |
| 8 | 1885 | 1 | 1 | 1(c) |
| 9 | 1886 | 1 | 1 | 1(c) |
| 10 | 1887 | 1 | 1 | 1(c) |
| 11 | 1888 | 1.02896 | 1.02890 | 1(c) |
| 12 | 1889 | 1.1455 | 1.1450 | 1.001(d) |
| 13 | 1890 | 1 | 1 | 1(c) |
| 14 | 1891 | 1.058 | 1.057 | 1.002(d) |
| 15 | 1892 | 1.016 | 1.014 | 1.002(d) |
| 16 | 1893 | 1.069 | 1.068 | 1.001(d) |
| 17 | 1894 | 1 | 1 | 1(c) |
| 18 | 1895 | 1.011 | 1.02 | 1.001(d) |
| 19 | 1896 | 1.104 | 1.098 | 1.006(d) |
| 20 | 1897 | 1.145 | 1.139 | 1.005(d) |
| 21 | 1898 | 1 | 1 | 1(c) |
| 22 | 1899 | 1.1047 | 1.1047 | 1(c) |
| 23 | 1900 | 1.0489 | 1.0489 | 1(c) |
| 24 | 1901 | 1 | 1 | 1(c) |
| 25 | 1902 | 1.18057 | 1.1781 | 1.002(d) |
| 26 | 1903 | 1.101354 | 1.0124 | 1.001(d) |
| 27 | 1904 | 1 | 1 | 1(c) |
| 28 | 1905 | 1.203 | 1.203 | 1(c) |
| 29 | 1906 | 1.0588 | 1.0512 | 1.007(d) |
| 30 | 1907 | 1 | 1 | 1(c) |
| 31 | 1908 | 1 | 1 | 1(c) |
| 32 | 1909 | 1 | 1 | 1(c) |
| 33 | 1910 | 1.0542 | 1.0542 | 1(c) |
| 34 | 1911 | 1 | 1 | 1(c) |
| 35 | 1912 | 1.00073 | 1.00073 | 1(c) |
| 36 | 1913 | 1 | 1 | 1(c) |
| 37 | 1914 | 1 | 1 | 1(c) |
| 38 | 1915 | 1 | 1 | 1(c) |
| 39 | 1916 | 1 | 1 | 1(c) |
| 40 | 1917 | 1.044 | 1.039 | 1.005(d) |
| 41 | 1918 | 1 | 1 | 1(c) |
| 42 | 1919 | 1 | 1 | 1(c) |
| 43 | 1920 | 1 | 1 | 1(c) |
| 44 | 1921 | 1.0874 | 1.0869 | 1.001(d) |
| 45 | 1922 | 1.036 | 1.034 | 1.002(d) |
| 46 | 1923 | 1.06122 | 1.06122 | 1(c) |
| 47 | 1924 | 1.0518 | 1.0518 | 1(c) |
| 48 | 1925 | 1 | 1 | 1(c) |
| 49 | 1926 | 1.046 | 1.046 | 1(c) |

TABLE IV (Continued)

| | Year | $\theta_1$ | $\theta_2$ | $\theta_3$ |
|---|---|---|---|---|
| 50 | 1927 | 1 | 1 | 1(c) |
| 51 | 1928 | 1.014 | 1.0115 | 1.003(d) |
| 52 | 1929 | 1.007 | 1.003 | 1.004(d) |
| 53 | 1930 | 1 | 1 | 1(c) |
| 54 | 1931 | 1.137 | 1.13 | 1.006(d) |
| 55 | 1932 | 1.0812 | 1.0712 | 1.009(d) |
| 56 | 1933 | 1 | 1 | 1(c) |
| 57 | 1934 | 1.18929 | 1.18929 | 1(c) |
| 58 | 1935 | 1.10244 | 1.10244 | 1(c) |
| 59 | 1936 | 1.003 | 1.003 | 1(c) |
| 60 | 1937 | 1 | 1 | 1(c) |
| 61 | 1938 | 1.016 | 1.016 | 1(c) |
| 62 | 1939 | 1 | 1 | 1(c) |
| 63 | 1940 | 1.067 | 1.067 | 1(c) |

Note: c stands for constant, d decreasing, and i increasing returns to scale.

TABLE V

STATISTICAL TESTS: PERIODS ONE AND TWO

| | |
|---|---|
| Analysis of variance ($F$) | 5.32 |
| (Prob>$F$) | (0.029) |
| Median test ($Z$) | −1.67 |
| (Prob>$\|Z\|$) | (0.095) |
| Kruskal-Wallis test ($X^2$) | 5.08 |
| (Prob>$X^2$) | (0.024) |

The test results are presented in Table V. All of the statistical tests indicate that $\theta_1$ is different for the two time periods.

Much of the increase in overall technical inefficiency from period one to two was the result of an increase in pure technical inefficiency. This coincides with the establishment of a variety of programs, discussed previously, aimed at breaking down feudal barriers and diffusing best practice techniques of agricultural production. As a result, traditional methods of production were called into question and the activities of farmers were in a state of flux. One would expect that in such turbulent times inefficiency would appear as new techniques had not yet totally displaced old, and confusion concerning appropriate techniques develops, etc.

The third period ran from 1906 to 1920. During this time the averages for $\theta_1$, $\theta_2$, and $\theta_3$ were respectively 1.0070, 1.0067, and 1.0003. This represents a reduction in technical inefficiency. In order to determine whether $\theta_1$ for periods two and three is statistically different, the same tests as applied above were used and the results are presented in Table VI. As can be seen, all of the tests indicate that $\theta_1$ is different for time periods two and three.

During the third period what technical inefficiency that does occur is mostly

TABLE VI

STATISTICAL TESTS: PERIODS TWO AND THREE

| | |
|---|---|
| Analysis of variance ($F$) | 11.41 |
| (Prob>$F$) | (0.002) |
| Median test ($Z$) | −2.87 |
| (Prob>$\|Z\|$) | (0.004) |
| Kruskal-Wallis test ($X^2$) | 10.51 |
| (Prob>$X^2$) | (0.001) |

TABLE VII

STATISTICAL TESTS: PERIODS THREE AND FOUR

| | |
|---|---|
| Analysis of variance ($F$) | 6.54 |
| (Prob>$F$) | (0.015) |
| Median test ($Z$) | −2.75 |
| (Prob>$\|Z\|$) | (0.006) |
| Kruskal-Wallis test ($X^2$) | 8.29 |
| (Prob>$X^2$) | (0.004) |

purely technical in nature. This is the period during which the indigenous technological potential of the Meiji period was exhausted. The diffusion of new technologies reached their limits and farmers were thus able to "catch-up" in the sense of using best practice agricultural techniques.

During the fourth period, 1920 to 1940 there is again an increase in the extent of technical inefficiency. The averages for $\theta_1$, $\theta_2$, and $\theta_3$ were respectively 1.0449, 1.0436, and 1.0012. In order to determine whether $\theta_1$ for periods three and four is statistically different, the same three tests applied above are used. The results are presented in Table VII. As can be seen, all of the tests indicate that $\theta_1$ is different for time periods three and four.

Again, the main source of inefficiency stemmed from pure technical inefficiency. This was a time of technological stagnation in which food shortages developed. As the reader will remember, this led the Japanese to import large quantities of staple foods. Given the fact that there were few alternative employment opportunities in industry, labor and other factor inputs remained in agriculture while domestic production declined. This appears as technical inefficiency in our analysis.

Looking at the time period overall, one finds that the averages for $\theta_1$, $\theta_2$, and $\theta_3$ were respectively 1.0361, 1.0351, and 1.0009. As can be seen, these seem to be relatively low. Although Japan experienced periods of technical inefficiency, overall Japanese agriculture seemed to be relatively efficient. This tends to support the idea that indeed peasant farmers are rational, in the sense that they seek to attain technical efficiency. Finally, it should be noted that one of the periods of inefficiency seems to be related to the rate of technical innovation. Technical inefficiency seems in some circumstances to be the result of rapid technological innovation. A complete understanding of the Japanese growth experience would thus seem to involve an in-depth analysis of the process of technical innovation.

## IV

In summary, several different production frontiers were constructed using Japanese data on output and inputs for the period 1878 to 1940. From comparing the actual observation of output and inputs for each year to those various frontiers it was possible to measure the extent of technical inefficiency and to decompose this into technical inefficiency resulting from operation at an inappropriate scale and pure technical inefficiency resulting from operation off the isoquant.

The results indicate that there are four distinct subperiods. First, from 1878 to 1890 Japanese agriculture appears to be relatively efficient. After 1890, as new technology diffused throughout the agricultural sector, technical inefficiency increased. From 1906 to 1920 as Japanese farmers adjusted to the new technology the extent of technical inefficiency fell. Finally, Japan was forced to import large amounts of food, domestic production of food staples fell. Since there were few alternative employment opportunities, technical inefficiency again rises from 1920 to 1940.

One future topic for research readily suggests itself. It would seem possible to use the frontier approach to determine the relative roles technological change, increased input usage, and improvements in technical efficiency played in accounting for the increase in output in Japanese agriculture. It would then be possible to determine which factor was most important in accounting for Japanese growth.

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## APPENDIX

In the method outlined above the role of the $z$s in the linear programming problems are probably the most difficult aspect to clearly understand. This appendix will attempt to clarify this matter.

Intuitively, the $z$s are the weights to be attached to each observation. In constructing the constant returns to scale frontier in year one, Figure 1, it is obvious that $z_1 = 1$ at $x_1$ because there is only one year. For levels of inputs less than $x_1$, $z_1 < 1$. For input levels greater than $x_1$, $z_1 > 1$. Thus increases (decreases) in inputs will lead to proportional increases (decreases) in output along ray I. Thus observation one is efficient. With year two, we now have two observations. Constructing a frontier based on year two's technology at $x_2$ would imply that $z_1 = 0$ and $z_2 = 1$. For input levels less than or greater than $x_2$, $z_2 < 1$ and $z_2 > 1$, respectively. Proportional increases (decreases) in inputs result in proportional increases (decreases) in output along ray II. As can be seen, if we are maximizing output for year two, this technology is inferior. Thus the frontier used to measure year two's technical inefficiency is based on year one's technology. Thus in Figure 1 if $x_2$ is twice $x_1$, then $z_1 = 2$ and $y'_2$ would be twice as high as $y_1$. As a result, the extent of year two's inefficiency is measured in terms of $y''_2 - y_2$ lost output.

In order to allow for varying returns to scale, the restriction that $\Sigma\, z_i = 1$ must be imposed. The impact of this restriction can be seen by examining Figure 2. Again, in the first year there is only one observation and thus it must be efficient. Since $\Sigma\, z_i = 1$, then $z_1$ must equal one. Input levels less than $A$ must give zero output since $z_1 = 1$. $y''_2$ output cannot be produced with less than $x_1$ inputs, i.e., we cannot move proportionately down ray I. For input levels to the right of $A$ output levels must also remain at $y''_2$ since, again, $z_1 = 1$, i.e., we cannot move proportionately up ray I. Thus the frontier would be $x_1 1C$. In Figure 2, year two's observation lies within year one's frontier. It follows that year one is the superior technology and will be used to evaluate year two's pure technical efficiency. Thus this frontier will allow the production of $y''_2$ output with $x_2$ inputs and the loss of output from pure technical inefficiency will be $y''_2 - y_2$. Finally, it is obvious that the frontier, $x_1 1C$, exhibits varying returns to scale.

With year three, there are now three observations from which to construct the frontier. At $x_1$, $z_1 = 1$, $z_2 = 0$, and $z_3 = 0$. Output is zero to the left of $x_1$ and $y''_2$ at $x_1$. Comparing observations two and three, it is obvious that three represents a superior technology (i.e., ray III lies above I and II). For input levels between observations one and three, the technology is represented by a linear combination of the technologies for observations one and three, i.e., the weights ($z$s) attached to observations one and three will each be less than one and sum to one (the weight for observation two is zero). The line segment 13 in Figure 2 represents this linear combination of technologies. For input levels given by observation three and to the right, $z_1 = 0$, $z_2 = 0$, and $z_3 = 1$. In this case, the frontier is $x_1 13D$ and observation three is purely technically efficient.

The final frontier constructed allows for only non-increasing returns to scale. This is constructed only if the restriction that $\Sigma z_i \leqq 1$ is imposed. Thus for year one at $x_1$, $z_1 = 1$. For input levels less than $x_1$, $z_1 < 1$, i.e., we would move proportionately down ray I. For input levels greater than $x_1$, $z_1 = 1$ and output can be no higher than $y''_2$. The frontier constructed is $01C$ and this frontier exhibits non-increasing returns to scale.