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FACTOR PRICES AND TECHNICAL CHANGE IN AGRICULTURAL DEVELOPMENT: THE UNITED STATES AND JAPAN 1880-1960

By

Yujiro Hayami and V. W. Ruttan

Department of Agricultural Economics

University of Minnesota
Institute of Agriculture
St. Paul, Minnesota 55108

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Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880-1960*

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The United States and Japan are characterized by extreme differences in factor endowments and in price ratios among factors. Furthermore, these differences have widened over time. In spite of these differences both countries have attained high and sustained rates of growth in agricultural output and productivity. Indeed, the two countries are frequently identified as alternative "agricultural development models". There is considerable discussion regarding the "lessons", "the relevance", or the "transferability" of the Japanese and United States agricultural development experience to presently developing countries.

The purpose of this paper is to explore the hypothesis that a common basis for rapid growth in agricultural output and productivity lies in a remarkable adaptation of agricultural technology to the sharply contrasting factor proportions in the two countries. It is hypothesized that an important aspect of this adaptation was the ability to generate a continuous sequence of induced innovations in agricultural technology biased towards saving the limiting factors. 1/ In Japan these innovations were primarily biological and chemical. In the United States they were primarily mechanical.

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** Yujiro Hayami is Associate Professor, Department of Economics, Tokyo Metropolitan University and Visiting Associate Professor, Department of Agricultural Economics, University of Minnesota. Vernon W. Ruttan is Professor and Head of Department, Department of Agricultural Economics, University of Minnesota. The authors are indebited to W. K. Bryant, Zvi Griliches, J. M. Henderson, D. G. Johnson, A. O. Krueger, R. R. Nelson, Kazushi Ohkawa, W. L. Peterson, Gustav Ranis, T. W. Schultz, A. M. Tang and G. S. Tolley for suggestions and comments.

Only in the last several decades has there been what appears to be the initial stage of convergence in patterns of technological change in the two countries with the United States beginning to experience rapid advances in bio-chemical technology and Japan experiencing a rapid adoption of mechanical technology.

We will first review the trends in factor prices and in several significant factor-product and factor-factor ratios in the United States and Japan for the period 1880-1960. After presenting this background material we will specify a hypothesis precisely. We will then subject the hypothesis to a statistical test.

The data on which it has been necessary to draw in conducting this study is subject to substantial limitations (see appendix). [2] Since much of the data is admittedly crude and comparability of the data for the two countries is less adequate than we would prefer, the analysis must of necessity deal with only the broadest trends in the comparative growth experience of the two countries.

I. Factor Endowments, Prices and Productivity

In this section we attempt to characterize the differences and similarities in agricultural growth patterns in the United States and Japan for 1880-1960. We first point to the extreme differences in factor endowments and factor prices in the two countries. We then compare changes in factor productivity ratios in the two countries. Finally we contrast the different pace of mechanical and bio-chemical innovations in the two countries.

Factor endowments and prices

Japan and the United States are characterized by extreme differences in relative endowments of land and labor (Table 1). In 1880 total agricultural land area per male worker was 36 times as large in the United States as in Japan and arable land area per worker was 10 times as large in the United States as in Japan. The difference has widened over time. By 1960 total agricultural land area per male worker was 97 times and arable land area per male worker was 47 times as large in the United States as in Japan.

The relative prices of land and labor also differed sharply in the two countries. In 1880 in order to buy a hectare of arable land (compare column 10 and column 18 in Table 1) it would have been necessary for a Japanese hired farm worker to work 9 times as many days as a U.S. farm worker. In the United States the price of labor rose relative to the price of land, particularly between 1880 and 1920. In Japan the price of land rose sharply relative to the price of labor, particularly between 1880 and 1900. By 1960 a Japanese farm worker would have to work 30 times as many days as a U.S. farm worker in order to buy a hectare of arable land.

Productivity Growth

In spite of these substantial differences in land area per worker and in the relative prices of land and labor, both the United States and Japan

Table 1. Land-Labor Endowments and Relative Prices in Agriculture: United States and Japan, Selected Years.

		1880	1900	1920	1940	1960
	USA					
(1)	Agricultural land area (Million ha.)	202	319	363	411	435[a]
(2)	Arable land area (Million ha.)	76	129	189	187	181[a]
(3)	Number of male farm workers (Thousand)	7959	9880	10221	8487	3973
(4)	(1)/(3) (ha./worker)	25	32	36	48	109
(5)	(2)/(3) (ha./worker)	10	13	18	22	46
(6)	Value of agricultural land ($/ha.)	47	49	171	78	285[a]
(7)	Value of arable land ($/ha.)	163	129	352	180	711[a]
(8)	Farm wage rate ($/day)	0.90[b]	1.00[c]	3.30	1.60	6.60
(9)	(6) / (8) (days/ha.)	52	49	52	49	43
(10)	(7)/ (8) (days/ha.)	181	129	107	113	108
	JAPAN					
(11)	Agricultural land area (thousand ha.)	5507	6031	6957	7100	7043
(12)	Arable land area (thousand ha.)	4748	5200	5997	6121	6071
(13)	Number of male farm workers (thousand)	7842	7680	7593	6365	6230
(14)	(11)/ (12) (ha./worker)	0.70	0.79	0.92	1.12	1.13
(15)	(11)/ (13) (ha./worker)	0.61	0.68	0.79	0.96	0.97
(16)	Value of arable land (Yen/ha.)	343	917	3882	4709	1415000
(17)	Farm wage rate (Yen/day)	0.22	0.31	1.39	1.90	440
(18)	(16) / (17) (days/ha.)	1559	2958	2793	2478	3216

a. 1959 b. 1879 or 1880 c. 1899

See the sources of data in Appendix II. Agricultural land areas in Japan are estimated by multiplying arable land areas by 1.16 which is the ratio of agricultural land area to arable land area in the 1960 Census of Agriculture.

experienced relatively rapid rates of growth in output per worker throughout the entire 80 year period (Figure 1). For expository purposes it seems useful to partition the growth in output per worker among two components --- land area per worker and land productivity as the following identity:

$$\frac{Y}{L} = \frac{A}{L} \frac{Y}{A}$$

where

Y - output	Y/L - labor productivity
L - labor	A/L - land area per worker
A - land area	Y/A - land productivity

Given the differences in the prices of land and labor in the United States and Japan we would expect that growth of output per worker (Y/L) in the United States would be closely correlated with changes in land area per worker (A/L) and in Japan with changes in land productivity (Y/A).

These expectations are confirmed by the data on land area per male worker and output per hectare plotted on Figure 1. In the United States land area per worker (A/L) rose much more rapidly than in Japan. In Japan land productivity (Y/A) rose much more rapidly than in the United States.

Contrasts in Innovations

In agriculture it appears consistent with the technical conditions of production to consider growth in land area per worker (A/L) and output per hectare (Y/A) as "somewhat independent, at least over a certain range" (Griliches [7; p. 242]). If this view is accepted, the major source of increase in the land area per worker would be mechanical innovations which facilitate the substitution of other sources of power for human labor. Similarly the major source of increase in land productivity would be biological and chemical innovations which permit conversion of a higher

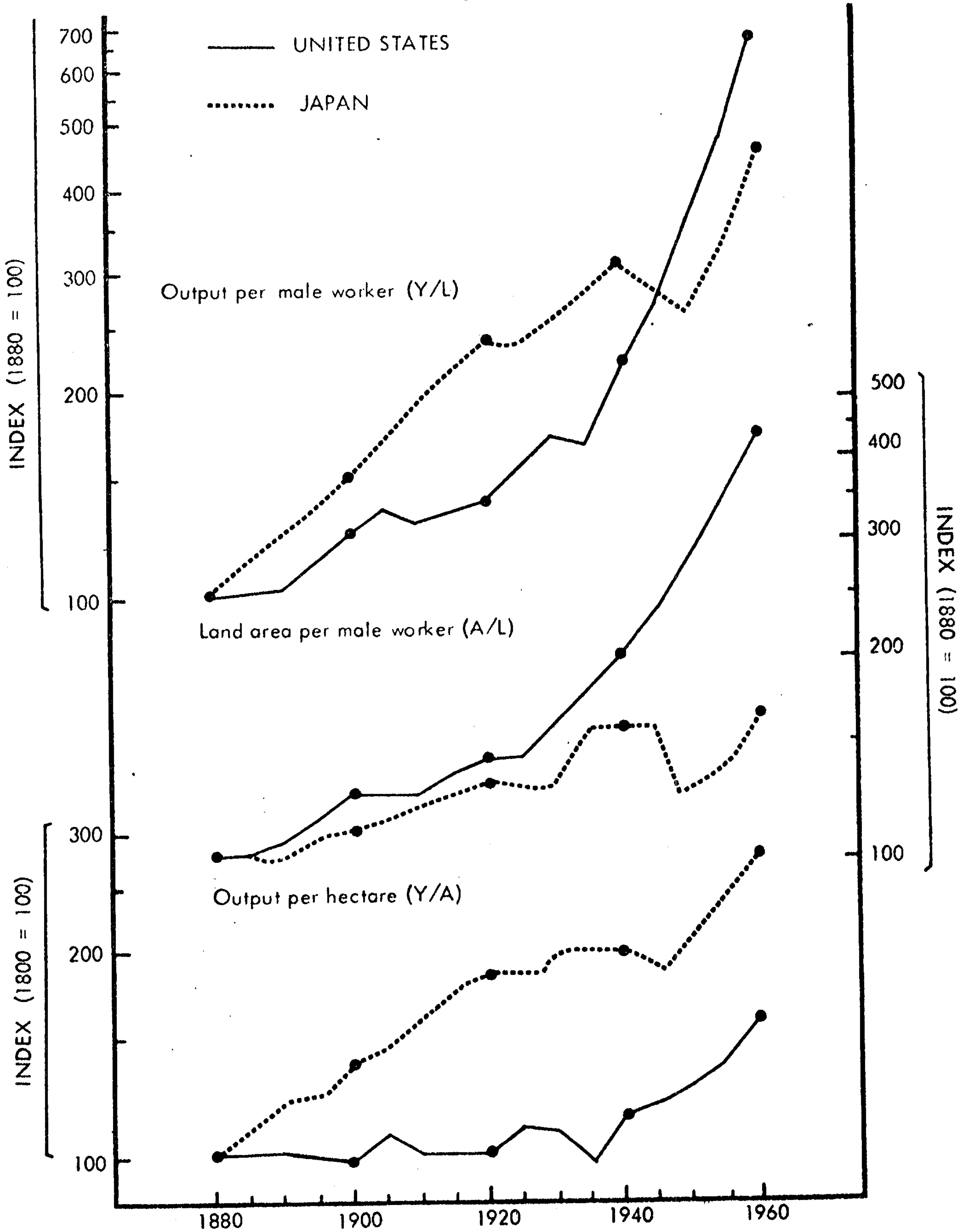


Figure 1. Changes in labor productivity, land-labor ratio and land productivity (1880 = 100), the United States and Japan, 1880-1960.

percentage of the solar energy falling on an area into higher levels of plant and animal production through the increase supply and utilization of plant nutrients.

The association between mechanical and biological innovations and the contrasting growth patterns in land area per worker (A/L) and in the land productivity (Y/A) in the United States and Japan are shown in Figures 2 and 3. In Figure 2 the three indicators of the land-labor ratio (A/L) are compared with the number of work animals (horses, mules and work cattle) and tractor horsepower per worker. [3/] Though there are considerable differences in the three indicators of land area per worker (A/L), when comparing the United States and Japan, their differences are relatively minor and the general pattern is not altered by the choice of indicator. In the United States the number of work animals increased up the 1920's and, then, started to decline. More than compensating the decline in workstock, tractor horsepower increased. Overall, it seems that the non-human power per worker moved more or less in parallel with land area per worker (A/L). These increases in power per worker would represent a convenient index of the adoption of mechanical innovations. For example, the substitution of the self-raking reaper for the hand-rake reaper and, also, the substitution of the binder for the self-raking reaper required more horses per worker. Those innovations also involved the substitution of power for labor, thereby, causing an increase in the land area used per worker in agriculture.

In Japan, corresponding to the slow rate of growth in land area per worker (A/L), the number of work animals increased slowly and the introduction of the tractor started only after the Second World War.

Figure 3 illustrates the contrasting relationship between land productivity (Y/A) and the progress of biological innovations in the

Figure 2. Land-labor ratio and power-labor ratio, the United States and Japan, 1880-1960.

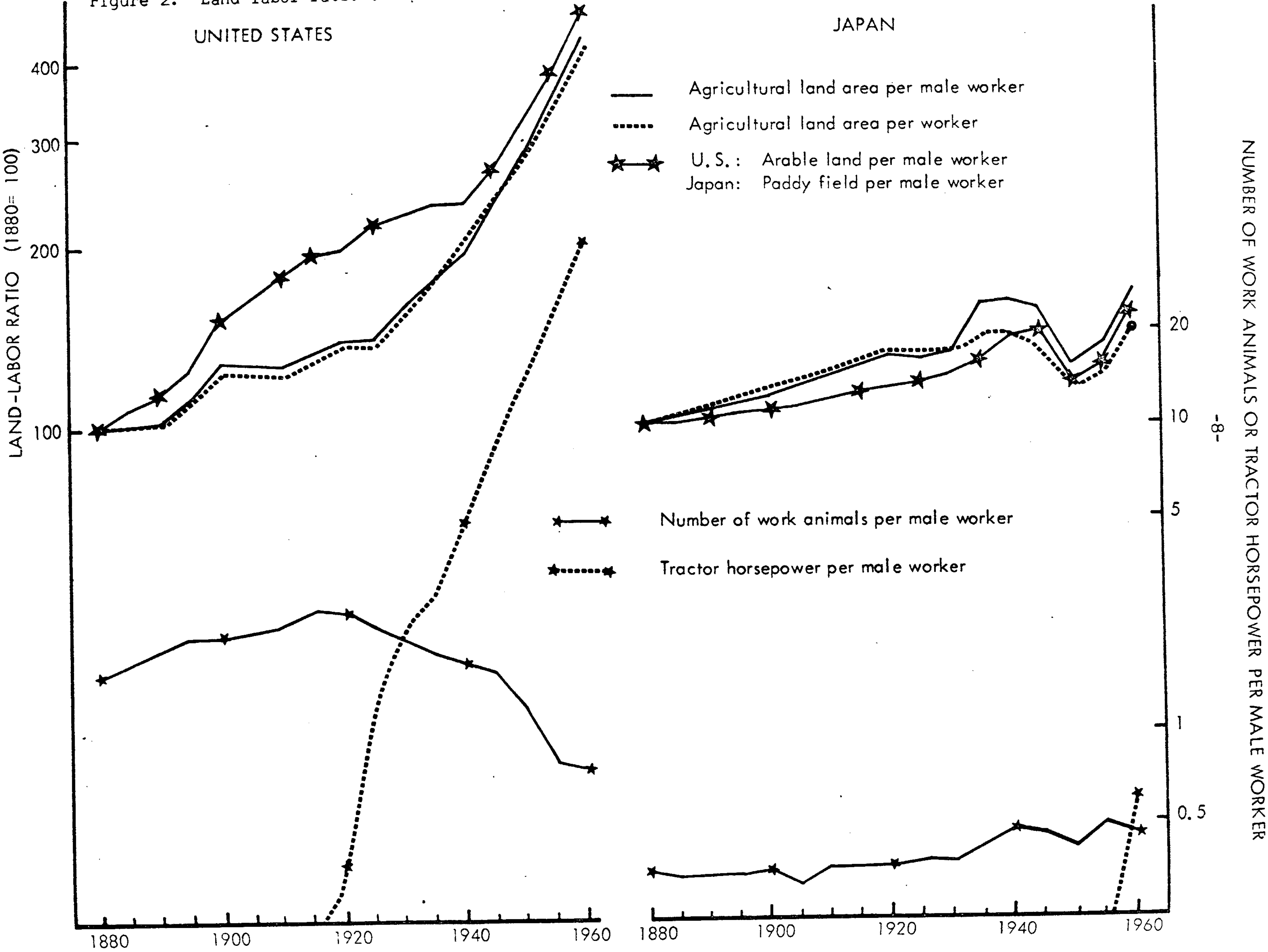
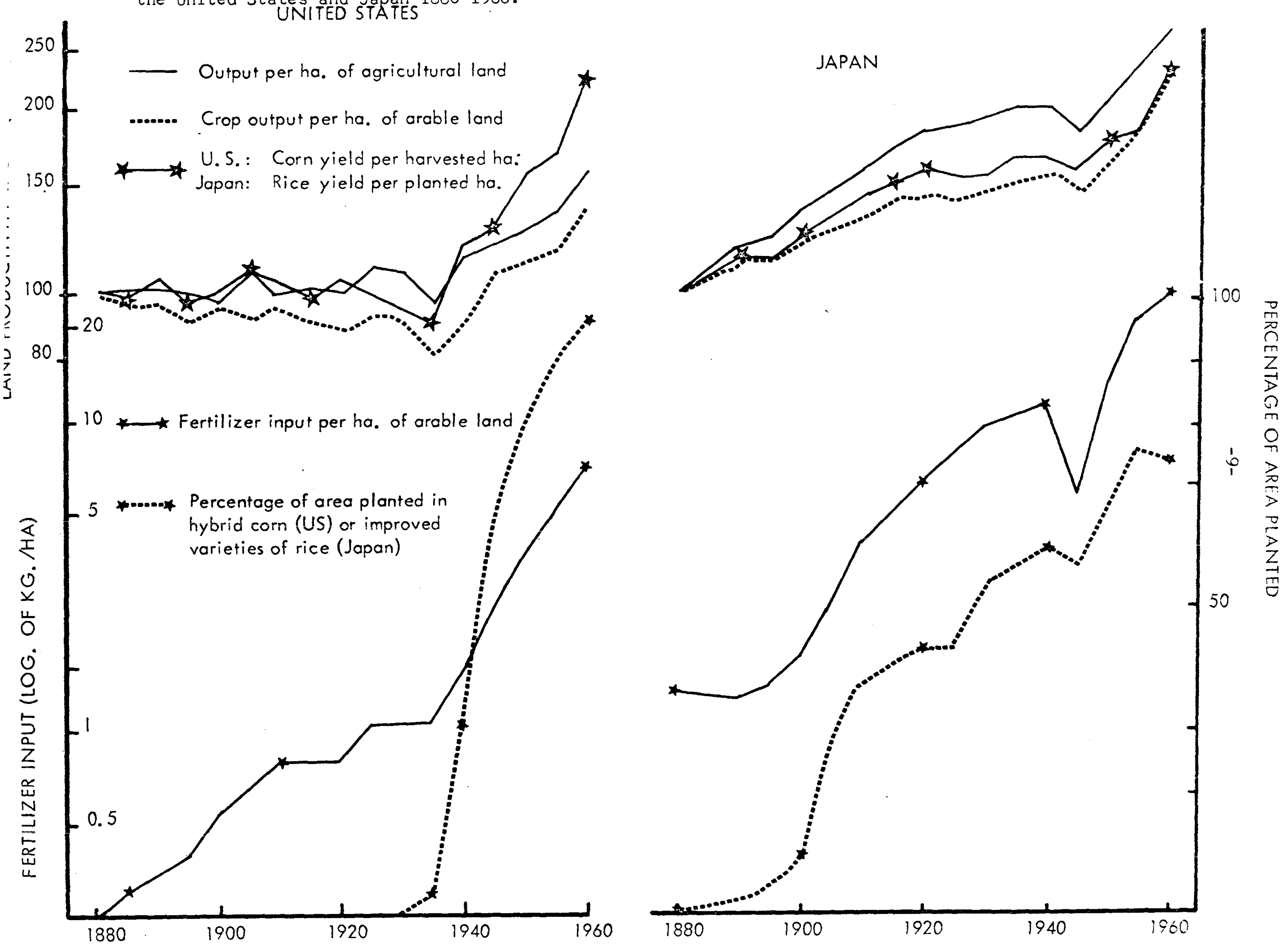


Figure 3: Land productivity, fertilizer input per ha. and progress in the improvements of plant varieties, the United States and Japan 1880-1960.



United States and Japan. Here, again, three indicators of land productivity (Y/A) are shown in order to check whether any different conclusion is implied by the different choices of data. The percentage of total corn area planted to hybrid corn, and of total rice area planted to improved varieties are treated as proxy variables representing an index of biological innovation in the United States and Japan respectively.

Though the evidences from these two crops is certainly not conclusive (the percentages are poor proxies even for corn and rice improvements), from a comparison of the corn and rice adoption ratios with the trends in fertilizer inputs, it seems fairly safe to say that in Japan the significant yield-increasing innovations date from the 1880's, while in the United States they began only in the 1930's. The yield-increasing varieties are almost invariably associated with high levels of plant nutrient utilization. Biological innovations of the yield-increasing type involve the creation of crop varieties which can respond to higher levels of fertilization. The parallel increases in fertilizer input per hectare and in the percentage of area planted in improved rice varieties in Japan indicate that the significant biological innovations started in Japan as early as the 1880's. In the United States the introduction of hybrid corn (and other high yielding crop varieties) is closely associated with the growth of fertilizer consumption. A major factor in the development, introduction and adoption of hybrid corn and other new crop varieties, was greater responsiveness to the higher analysis commercial fertilizers which were becoming available at continuously lower real prices. 4/

In connection with the complementarity between fertilizer input and the development of yield-increasing varieties, it's suggestive that Japan's level of fertilizer input per hectare in the 1880's was almost identical to the

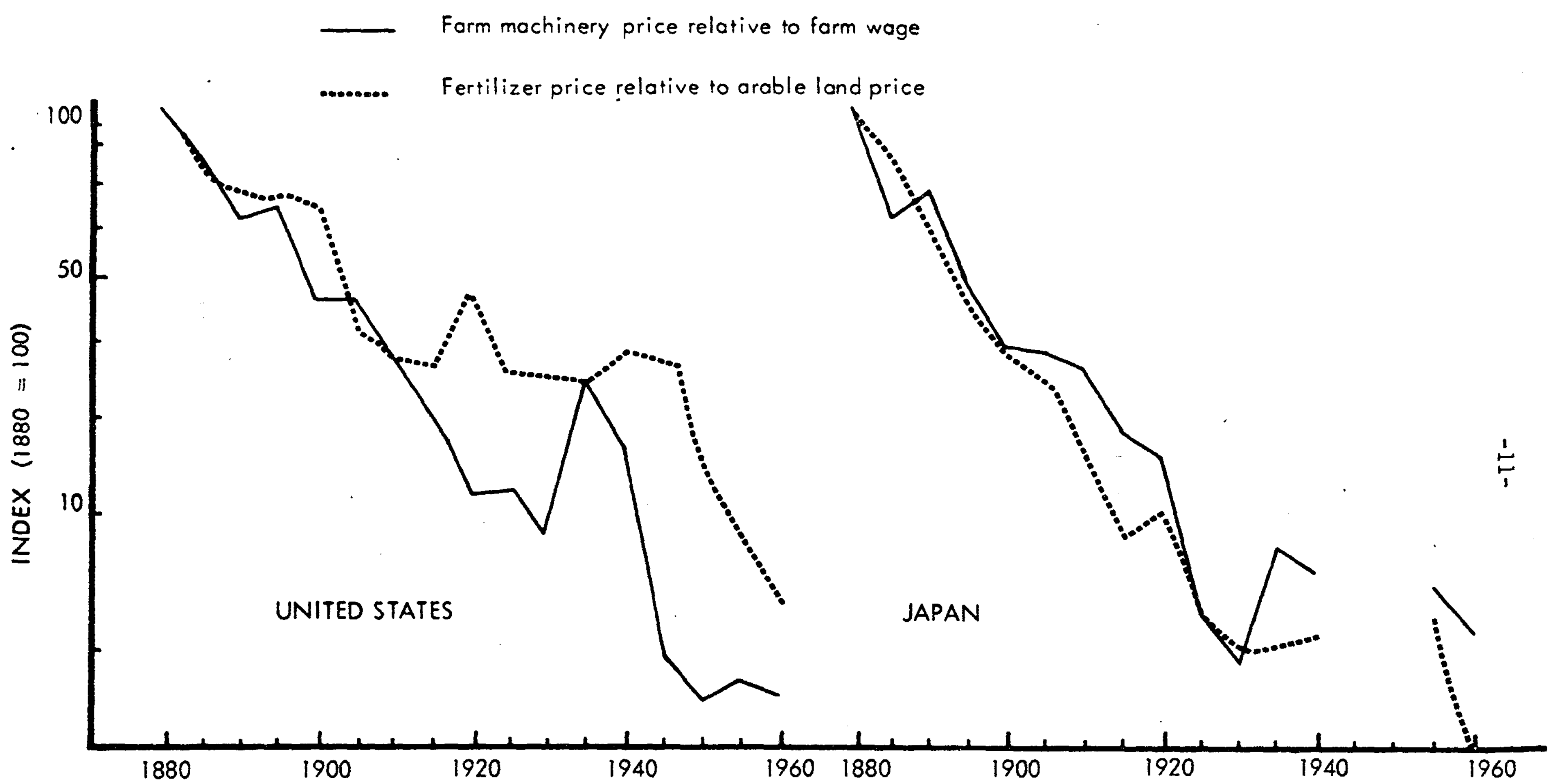


Figure 4. Farm machinery price relative to farm wage and fertilizer price relative to arable land price, (1880 = 100) the United States and Japan, 1880 - 1960. Prices are the averages of the five years preceding the year shown.

level of the United States in the 1930's. Furthermore, these dates represent the beginning of periods in which significant advances in biological innovations accompanied by rapid growth in fertilizer consumption were initiated in both countries.

Increases in power per worker and in fertilizer input per hectare were accompanied by dramatic declines in (a) the price of machinery (a proxy for the price of power and machinery) relative to the wage rate and (b) the price of fertilizer relative to the price of land (Figure 4). These trends in factor price ratios, along with the trend in the price of land relative to labor (Table 1), are consistent with the hypothesis that the differential development of mechanical and bio-chemcial innovations in the United States and Japan represented a process of dyamic factor substitution in response to the changes in relative factor prices.

II. The Induced Innovation Hypothesis

In this section we outline in greater detail the manner in which differences in factor price movements in Japan and the United States have influenced the process of technical change and the choice of inputs in the two countries. The argument is developed that the contrasting patterns of productivity growth and factor use in U.S. and Japanese agriculture can best be understood in terms of a process of dynamic adjustment to changing relative factor prices --- dynamic in the sense that production isoquants change in response to the changes in relative factor prices.[5]

A decline in the prices of land and machinery relative to wages encouraged the substitution of land and power for labor in the United States. This substitution generally involved mechanical innovations. With fixed technology represented by a certain type of machinery there is little possibility of factor substitution. For example, an optimum factor combination with the hand-rake reaper (such as the McCormick or Hussey) was more or less determined as two workers, one reaper, four horses (two horses for original models), assuming two shifts of horses and 140 acres of wheat. Only when a new technology, in the form of the self-rake reaper was introduced was it possible for the farmer to change this proportion to one worker, one reaper, four horses and 140 acres. [6] Although we do not deny the possibility of substitution within a limited range (e.g., through change from two shifts to three shifts of horses), such enormous changes in factor proportions as observed in Figure 2 could hardly occur with fixed technology.

Dramatic increases in land area and power per worker of the magnitude that occurred in the United States indicate a response to mechanical innovations which raise the marginal rate of substitution in favor of both land and power for labor.[7/] This is a continual process. The introduction of the tractor, which can be considered as the single most important mechanical innovation in agriculture, greatly raised the marginal rate of substitution of power for labor by making it much easier to command more power per worker. Substitution of higher powered tractors for low powered tractors has a similar effect.

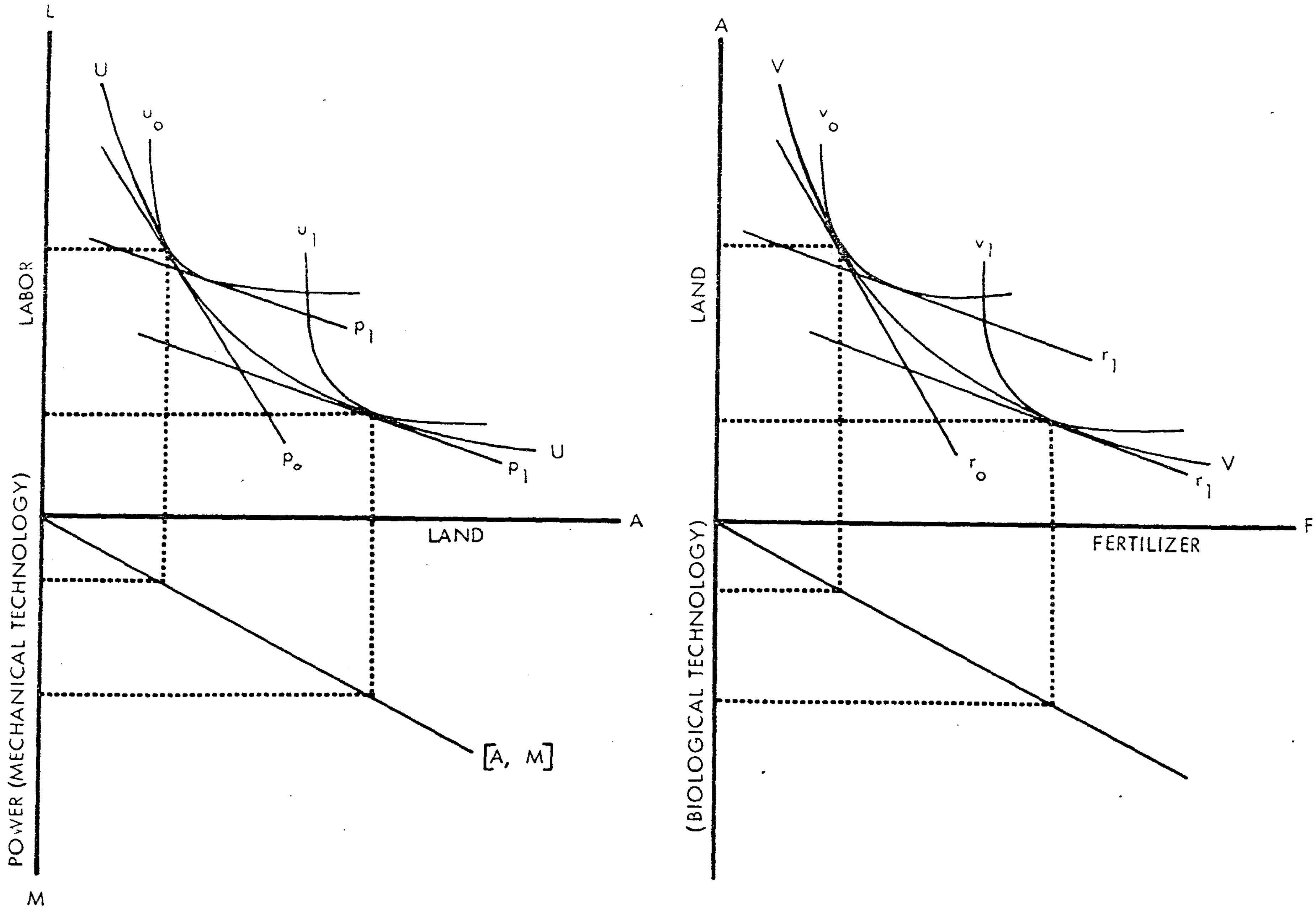
In Japan, the supply of land was inelastic and the price of land rose relative to wages. It was not, therefore, profitable to substitute land and power for labor. Instead, the opportunity arising from the declining price of fertilizer relative to the price of land was exploited through bio-chemical innovations. Seed improvements were directed to the selection of more fertilizer responsive varieties. Traditional varieties have equal or higher yields than improved varieties at the lower level of fertilization, but do not respond to higher application of fertilizer. With fixed biological technology represented by a certain variety of seed, the elasticity of substitution of fertilizer for land was low. And such enormous changes in fertilizer input per hectare as observed in Japan since 1880 and in the United States since the 1930's reflect not only the effect of decline in the price of fertilizer but the development of more fertilizer responsive crop varieties to take advantage of the decline in the real price of fertilizer.

In Japan where expectations have been formed from past trends that not only would wages rise but fertilizer prices fall drastically relative to land price, the motivation of farmers and experiment station workers to develop the biological innovations of high yielding - fertilizer responsive crop varieties has been very strong. It is suggestive that in the United States the biological innovations represented by hybrid corn began about 10 years after the rate of increase in arable land area per worker decelerated (around 1920), and that biological innovations and fertilizer application were accelerated after acreage restrictions were imposed by the government. It seems that the changes in the land supply conditions coupled with a dramatic decline in fertilizer price induced a more rapid rate of biological innovation in the United States after the 1930's. It may be that when the increase in fertilizer input per hectare resulting from this relative price decline exceeded the amount of natural fertility depleted from the soil, demand for biological innovations became a pressing need, which, coupled with the change in the supply condition of arable land, brought about the dramatic bio-chemical innovations in the United States since the 1930's.

Our basic hypothesis is that such adjustments in factor proportions in response to changes in relative factor prices represent movements along the iso-product surface of a "meta-production function" or "potential production function". 1/ This is illustrated in Figure 5. U in Figure 5a represents the land-labor isoquant of the meta-production function which is the envelope of less elastic isoquants such as u_o and u_1 corresponding to different types of machinery or technology. A certain technology represented by u_o (e.g., reaper) is created when a price ratio, p_o, prevails a certain length of time. When the price ratio changes from p_o to p_1, another technology represented by u_1 (e.g., combine)is induced in the long-run, which gives the minimum cost of production for p_o.

The new technology represented by u_1, which enables enlargement of the area operated per worker, generally corresponds to higher intensity of power per worker. This implies the complementary relationship between land and power, which may be drawn as a line representing a certain combination of land and power [A , M]. In this simplified presentation, mechanical

Figure 5


L
U
u_o
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LABOR
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U
A
LAND
POWER (MECHANICAL TECHNOLOGY)
[A, M]
M
A
V
v_o
v_1
LAND
r_1
r_o
V
r_1
F
FERTILIZER
(BIOLOGICAL TECHNOLOGY)

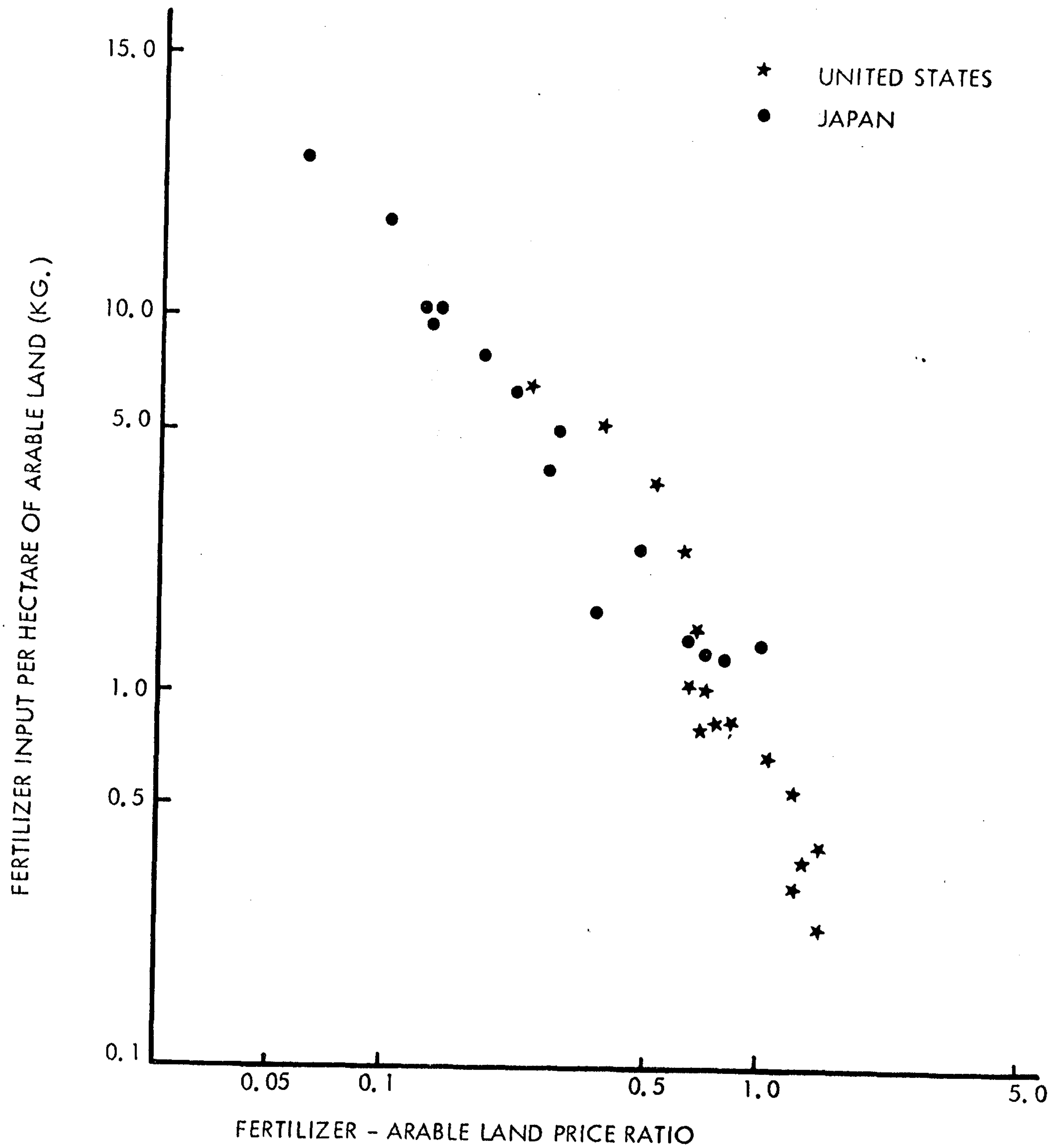
innovation is conceived as the substitution of a combination of land and power [A , M] for labor (L) in response to a change in wage relative to an index of labor and machinery prices, though, of course, in actual practice land and power are substitutable to some extent.

In the same context, the relation between the fertilizer-land price ratio and bio-chemical innovations represented by the development of crop varieties which are more responsive to application of fertilizers is illustrated in Figure 5b. V represents the land-fertilizer isoquant of the meta-production function, which is the envelope of less elastic isoquants such as v_0 and v_1 corresponding to varieties of different fertilizer responsiveness. A decline in the price of fertilizer relative to the price of land from r_0 to r_1 makes it more profitable for farmers to search for crop varieties which are described by isoquants to the right of v_0. They also press public research institutions to develop new varieties.[8/] Through a kind of dialectic process of interaction among farmers and experiment station workers a new variety such as that represented by v_1 will be developed.

Such movements along the meta-production function may be inferred from Figure 6, which plots U.S. and Japanese data on the relation between fertilizer input per hectare of arable land and the fertilizer-land price ratio. Despite the enormous differences in climate and other environmental conditions, the relation between these variables are almost identical in both countries. This suggests the U.S. and Japanese agricultural growth has involved a movement along a common meta-production function.[9/]

All mechanical innovations are not necessarily motivated by labor saving incentives nor are all biological innovations necessarily motivated

Figure 6. Relation between fertilizer input per hectare of arable land and fertilizer - arable land price ratio (= hectares of arable land which can be purchased by one tone of N + P_2O_5+ K_2O contained in commercial fertilizers), the United States and Japan: quinquennial observations for 1880-1960.



by land saving incentives. In Japan horse plowing was propagated as a device to cultivate more deeply so as to increase yield per hectare. The mechanical powered threshing machine was introduced long before the Second World War. This innovation was motivated to divert labor from rice threshing to the preparation for the second crop, which resulted in an increase in the double cropping ratio and the increase in total yield per hectare of land area. In the United States in recent years attempts have been made to develop crop varieties which are more suitable for mechanical harvesting. For example, tomato plants have been developed which yield tomatoes at certain range of height so that they are susceptible for harvesting machinery. This shows mechanical innovations could be land saving and biological innovations could be labor saving depending on the conditions of factor supply and factor price trends. Historically, however, it appears that the dominant factor for saving labor has been the progress of mechanization and the dominant factor for saving land has been the biological innovations.

III. The Statistical Test

A hypothesis developed in the previous section can be summarized as follows: Agricultural growth in the United States and Japan during the period 1880-1960 can best be understood when viewed as a dynamic factor substitution process. Factors have been substituted for each other along a meta-production function in response to long-run trends in relative factor prices. Each point on the meta-production surface is characterized by a technology which can be described in terms of specific sources of power, types of machinery, crop varieties and animal breeds. Movements along this meta-production surface involve innovations. These innovations have been induced, to a significant extent, by the long-term trends in relative factor prices.

As a test of this hypothesis, we have tried to determine the extent to which the variations in factor proportion, as measured by the land-labor, power-labor, and fertilizer-land ratios, can be explained by changes in factor price ratios. This is not, in a rigorous sense, a test of the so-called "induced innovation hypothesis." [10/] In a situation characterized by a fixed technology, however, it seems reasonable to presume that the elasticities of substituion among factors are small, and this permits us to infer that innovations were induced, if the variations in these factor proportions are consistently explained by the changes in price ratios. The historically observed changes in those factor proportions in the United States and Japan are so large that it is hardly conceivable that these changes represent substitution along a given production surface describing a constant technology.

In order to have an adequate specification of the regression form, we have to be able to infer the shape of the underlying meta-production function and the functional form of the relationship between changes in the production function and in factor price ratios. Because of a lack of adequate apriori information, we have simply specified the regression in log-linear form with little claim for theoretical justification. 11/ If we can assume that production function is linear homogeneous, the factor proportions can be expressed in terms of factor price ratios alone and are independent of product prices.

Considering the crudeness of data and the purpose of this analysis, we used quinquennial observations (stock variables measured at every five years' interval and flow variables averaged for five years) instead of annual observations for the regression analysis. 12/ A crude form of adjustment is built into our model, since our data are quinquennial observations and prices are generally measured as the averages of the past five years preceeding the year when the quantities are measured (e.g., the number of workers in 1910 is associated with the 1906-1910 average wage).

The results of regression analyses are summarized in Tables 2 and 3. Table 2a presents the regressions for land-labor and power-labor proportions for the United States. In those regressions we originally included the fertilizer-labor price ratio as well. But, probably due to high intercorrelation between machinery and fertilizer prices, either the coefficients for the fertilizer-labor price ratio were insignificant or resulted in implausible results for the other coefficients. 13/ This variable was dropped in the subsequent analysis.

Table 2a. Regressions of Land-Labor Ratio and Power-Labor Ratio on Relative Factor Prices: United States, 1880-1960 Quinquennial Observations.

Regression Number	Dependent Variables	Coefficients of Price of: Land Relative to Farm Wage	Coefficients of Price of: Machinery Relative to Farm Wage	$\bar{R}^2$	$\bar{S}$	d
	Land-labor ratio:					
(1)	Agricultural land per male worker	-0.451 (0.215)	-0.486 (0.120)	.828	.0844	1.29
(2)	Arable land per male worker	-0.035 (0.180)	-0.708 (0.101)	.882	.0706	1.37
(3)	Agricultural land per worker	-0.492 (0.215)	-0.463 (0.120)	.828	.0789	1.34
(4)	Arable land per worker	-0.077 (0.182)	-0.686 (0.102)	.879	.0713	1.41
	Power-labor ratio:					
(5)	Horsepower per male worker	-1.279 (0.475)	-0.920 (0.266)	.827	.1865	1.33
(6)	Horsepower per worker	-1.321 (0.474)	-0.898 (0.265)	.828	.1863	1.36

Equations are linear in logarithm. Inside of the parentheses are the standard errors of the estimated coefficients.

Data from Appendix II: Number of workers (a), Number of male workers (a), Agricultural land area (a), Arable land area (a), Power in horsepower equivalents = Number of work animals (a) + Tractor horsepower (a), Farm wage (c), Land price (c), Machinery price (c).

Table 2b. Regressions of Land-Labor Ratio and Power-Labor Ratio on Relative Factor Prices: Japan, 1880-1960 Quinquennial Observations.

Regression Number	Dependent Variables	Coefficients of Price of: Land Relative to Farm Wage	Coefficients of Price of: Machinery Relative to Farm Wage	$\bar{R}^2$	$\bar{S}$	d
	Land-Labor Ratio:					
(7)	Arable land per male worker	0.159 (0.110)	-0.219 (0.041)	.751	.0347	1.17
(8)	Arable land per worker	0.230 (0.049)	-0.155 (0.019)	.914	.0156	1.71
	Power-Labor Ratio:					
(9)	Horsepower per male worker	-0.665 (0.261)	-0.299 (0.685)	.262	.2191	0.60
(10)	Horsepower per worker	-0.601 (0.236)	-0.228 (0.620)	.266	.1982	0.61

Equations are linear in logarithms. Inside of the parentheses are the standard errors of the estimated coefficients.

Data from Appendix II: Number of workers (a), Number of male workers (a), Arable land area (a), Power in horsepower equivalents = Number of work animals (a) + tractor horsepower (a), Farm wage (c), Land Price (c), Machinery price (c).

Table 3a. Regressions of Fertilizer Input Per Hectare of Arable Land on Relative Factor Prices: United States, 1880-1960 Quinquennial Observations.

Regression Number	Coefficients of Prices of: Fertilizer Relative to Land	Coefficients of Prices of: Labor Relative to Land	Coefficients of Prices of: Machinery Relative to Land	$\bar{R}^2$	$\bar{S}$	d
(11)	-1.622 (0.200)	1.142 (0.275)	0.014 (0.286)	.950	.1042	2.08
(12)	-1.615 (0.134)	1.138 (0.255)	------	.954	.0968	2.09
(13)	-1.951 (0.166)	------	-------	.895	.1406	.77
(14)	-1.101 (0.184)	1.134 (0.173)	-0.350 (0.214)	.969	.0816	1.38
(15)	-1.357 (0.102)	1.019 (0.168)	-----	.970	.0832	1.15
(16)	-1.707 (0.154)	-----	-----	.884	.1481	.84

Equations are linear in logarithms. Inside of the parentheses are the standard errors of the estimated coefficients.

Data from Appendix II: Fertilizer input (b), Arable land area (a); In case of (11), (12) and (13), Farm wage (a), Land price (a), Machinery Price (c), Fertilizer price (b); In case of (14), (15) and (16), Farm wage (c), Land price (c), Machinery price (c), Fertilizer (c).

Table 3b. Regressions of Fertilizer Input Per Hectare of Arable Land on Relative Factor Prices: Japan, 1880-1960 Quinquennial Observations.

Regression Number	Coefficients of Price of: Fertilizer Relative to Land	Coefficients of Price of: Labor Relative to Land	Coefficients of Price of: Machinery Relative to Land	$\bar{R}^2$	$\bar{S}$	d
(17)	-1.437 (0.238)	0.662 (0.244)	0.236 (0.334)	.973	.0865	2.45
(18)	-1.274 (0.057)	0.729 (0.220)	-----	.974	.0810	2.45
(19)	-1.211 (0.071)	-----	------	.953	.1036	1.52
(20)	-1.248 (0.468)	1.217 (0.762)	-0.103 (0.708)	.878	.1820	1.76
(21)	-1.313 (0.131)	1.145 (0.556)	------	.888	.1670	1.79
(22)	-1.173 (0.126)	------	------	.860	.1794	1.52

Equations are linear in logarithms. Inside of parentheses are the standard errors of the estimated coefficients.

Data from Appendix II: Fertilizer input (b), Arable land area (c); In case of (17), (18), and (19), Farm wage (a), Land price (a), Machinery price (c), Fertilizer price (b); In case of (20), (21) and (22), Farm wage (c), Land price (c), Machinery price (c), Fertilizer price (c).

In Table 2a more than 80 percent of the variation in the land-labor ratio and in the power-labor ratio is explained by the changes in their price ratios. The coefficients are all negative and are significantly different from zero at the standard level of significance except the land price coefficients in Regressions (2) and (4). Such results indicate that in U.S. agriculture the marked increases in land and power per worker over the past 80 years have been closely associated with declines in the prices of land and of power and machinery relative to the farm wage rate. The hypothesis that land and power should be treated as complementary factors is confirmed by the negative coefficients. This seems to indicate that in addition to the complementarity along a fixed production surface, mechanical innovations which raise the marginal rate of substitution of labor for power tend to also raise the marginal rate of substitution of labor for land. Estimates of elasticity of substitution close to one in Regressions (5) and (6) seem to suggest that the observed factor substitution was not restricted to a fixed production surface describing a constant technology. [14/]

The results of the same regressions for Japan (Table 2b) are much inferior in terms of statistical criteria. This is probably because the ranges of observed variation in the land-labor and in the power-labor ratios are too small in Japan to detect any significant relationship between the factor proportions and price ratios. It may also reflect the fact that the mechanical innovations developed in Japan were motivated by a desire to increase yield rather than as a substitute for labor.

The results of the regression analyses of the determinants of fertilizer input per hectare of arable land for the United States are presented in Table 3a. The results indicate that variations in the fertilizer-land price ratio alone explains almost 90 percent of the variation in fertilizers.

It is also shown that the wage-land price ratio is a significant variable, indicating the substitutionary relationship between fertilizer and labor. Over a certain range, fertilizer input can be substituted for human care for plants (e.g., weeding). A more important factor in Japanese history would be the effects of substitution of commercial fertilizer for labor allocated to self-supplied fertilizers.

A comparison of Table 3b with Table 3a indicates a striking similarity in the structure of demand for fertilizer in the United States and Japan. The results in these two tables seem to suggest that, despite enormous differences in climate and initial factor endowments, the agricultural production function, the inducement mechanism of innovations, and the response of farmers to economic opportunities have been essentially the same in the United States and Japan.

The possibility of structural changes in the meta-production function over time, as suggested by some of low Durbin-Watson statistics in Tables 2 and 3, was tested by running regressions separately for 1880-1915 and 1920-1960. The results summarized in Table 4 do not suggest any significant structural change occurred between those two periods. The inference from this test is relatively weak, however, because of the small number of observations involved.

Overall, the results of the statistical analysis are consistent with the hypothesis stated at the beginning of this section.

Table 4. Test for Structural Change of Regression Relations Between 1880-1915 and 1920-1960.

Regression Number	Residual sum of squares			Number of parameters	Sample Size		F - Statistics	
	1880-1915 s_1	1920-1960 s_2	1880-1960 s	p	1880-1915 n_1	1920-1960 n_2	Computed F_c	Theoretical F
(1)	0.00314	0.07898	0.08719	3	8	9	0.23	3.59
(2)	0.00123	0.05539	0.06099	3	8	9	0.28	3.59
(3)	0.00282	0.07788	0.08709	3	8	9	0.29	3.59
(4)	0.00103	0.05443	0.06233	3	8	9	0.45	3.59
(5)	0.00284	0.39095	0.42588	3	8	9	0.30	3.59
(6)	0.00277	0.38936	0.42512	3	8	9	0.31	3.59
(7)	0.00052	0.00865	0.01241	3	8	7	1.06	3.86
(8)	0.00146	0.00046	0.00250	3	8	7	0.93	3.86
(9)	0.00344	0.46381	0.49381	3	8	7	0.17	3.86
(10)	0.00346	0.38035	0.40415	3	8	7	0.16	3.86
(11)	0.01295	0.03399	0.11470	4	8	9	3.25	3.63
(12)	0.01856	0.06597	0.11472	3	8	9	1.31	3.59
(13)	0.07902	0.09521	0.27809	2	8	9	2.43	3.80
(14)	0.00582	0.03278	0.07027	4	8	9	1.35	3.63
(15)	0.01578	0.03771	0.08473	3	8	9	2.14	3.59
(16)	0.02107	0.23481	0.30829	2	8	9	1.33	3.80
(17)	0.01602	0.03085	0.06462	4	8	7	0.66	4.12
(18)	0.01872	0.03859	0.06754	3	8	7	0.54	3.86
(19)	0.05996	0.04582	0.12952	2	8	7	1.01	3.98
(20)	0.11286	0.01408	0.28639	4	8	7	2.20	4.12
(21)	0.11312	0.06828	0.28694	3	8	7	1.75	3.86
(22)	0.12274	0.15434	0.38845	2	8	7	2.21	3.98

$$F_c = \frac{s - s_1 - s_2}{s_1 + s_2} \cdot \frac{n_1 + n_2 - 2p}{p}$$, F : theoretical value at 5 percent level.

IV. Conclusion

The results of this study indicate that the enormous changes in factor proportions which have occurred in the process of agricultural growth in the United States and Japan are explainable in terms of changes in factor price ratios. In spite of strong reservations regarding the data and the methodology, when we relate the results of the statistical analysis to historical knowledge of the progress in agricultural technology, we conclude that such changes in input mixes represent a process of dynamic factor substitution accompanying changes in the production surface induced by the changes in relative factor prices.

This conclusion, if warranted, represents a key to the understanding of the success of agricultural growth in the two countries. The basis for the contrasting patterns of factor price changes are the differences in factor supply conditions. In the United States land supply to agriculture has been more elastic than labor supply. In Japan land supply has been equally or less elastic than labor supply. With the increased demand for farm products in the course of economic development, the price of the less elastic factor tends to rise relative to the prices of the more elastic factors. Given the differences in supply elasticities, agricultural growth in both countries accompanied contrasting changes in land-labor price ratios. Prices of agricultural inputs such as fertilizer and machinery supplied by the nonfarm sector tended to decline relative to the prices of land and labor. Such trends induced farmers, public research institutions and private agricultural supply firms to search for new production possibilities that would offset the effects of the relative price changes. Mechanical innovations of a labor-saving type were, thus, induced in the United States and biological innovations of a yield-increasing type were induced in Japan. After the 1930's the decline in fertilizer price was so dramatic that innovation in U.S. agriculture shifted from a predominant emphasis on mechanical technology to the development of new biological innovations, in the form of crop varieties that were highly responsive to the lower cost fertilizer.

Rapid growth in agriculture in both countries could not have occurred without such dynamic factor substitution. If factor substitution had been limited to substitution along a fixed production surface, agricultural growth would have been severely limited by the inelastic supply. Development of a continuous stream of new technology which altered the production surface to conform to long term trends in factor prices was the key to the success in agricultural growth in the United States and Japan.

Such inducement of technological change was not attained without cost. The United States and Japan are among the few countries which have made a substantial national effort in agricultural research and extension for the past 100 years. The history of agricultural research and extension in the United States is relatively well known. 15/ Japan's efforts to develop agricultural techniques were no less significant than in the United States.16/ Starting with the trial importation of Western farming techniques in the 1970's, the itinerant agricultural instructor system started as early as 1885, and the National Agricultural Experiment Station was established in 1893 only five years after the Hatch Experiment Station Act was enacted. Farmers, also, responded vigorously to exploit the opportunities opened by the Meiji Reforms by organizing Nodankai (Agricultural Discussion Societies) or Hinshukokankai (Societies for Exchanging Seeds).17/

The important point in the context of this paper is that such efforts were directed appropriately in terms of factor supply conditions. It is suggestive that in the 1870's the Japanese government tried to develop a mechanized agriculture of the Anglo-American type by importing machinery and implements from the United States and inviting British agronomists at the newly established Komaba Agricultural School. This trial represented one of general efforts to borrow technology from the Western World at the outset of modern economic growth. But, unlike the case in industry, this trail was entirely unsuccessful in agriculture (except in Hokkaido). The government quickly realized the failure and re-oriented its effort to the development of a bio-chemical technology by replacing British agronomists with German soil scientists and hiring veteran farmers as itinerant instructors during the 1880's. Thereafter the main current of agricultural research has been to develop veteran farmers' techniques (with the primary motivation to raise the yield per hectare) on the scientific basis of German agricultural chemistry. 18/

For both the United States and Japan vigorous growth in the industries which supplied machinery and fertilizers at continously declining relative prices is an indispensable element for agricultural growth. Equally important was the efforts in research and extension to best exploit the opportunities created by industrial development. Without the creation of fertilizer responsive crop varieties the benefit from the lower fertilizer price is limited. The success in agricultural growth in both United States and Japan seems to lie in the capacity of their farmers, research institutions and farm supply industries to exploit new opportunities according to the information transmitted through relative price changes.

Agriculture in the United States and Japan under entirely different initial factor endowments and factor supply conditions attained rapid growth. There is little reason that presently developing countries cannot attain the same success if they exploit the opportunities given to them. Their patterns of growth would likely be different from the United States or Japan as their factor supply conditions are different from those two countries. Efforts must be directed to create a unique pattern of growth for each developing country. An important element in this effort appears to be a system which accurately reflects the economic implications of factor endowments to both producers, public institutions and private industry.

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Footnotes

1/ This problem of induced bias in innovations represents a frontier of development economics. Hypotheses have been postulated on historical observations (e.g., Habakkuk [10]) and significant theorems deducted (e.g., Fellner [3] [4], Kennedy [16] and Samuelson [24]). Yet, little work has been done to subject those theorems to quantitative tests. Even in Schmookler's major contribution [25] to the quantitative economic analysis of innovations, the aspect of factor saving bias was not treated.

2/ The reliability of agricultural production statistics in Meiji Japan has been strongly questioned, particularly by Nakamura [18]. For reactions to the Nakamura's criticisms see Hayami [11], Hayami and Yamada [13] and Rosovsky [22].

3/ When it is difficult to choose a single data series to adequately represent a single variable it is reasonable to try several alternatives and to accept the results as conclusive only if the several results are consistent with each other.

4/ The parallelism does not hold, however, for the period before the 1930's. Initially increases in fertilizer input was not accompanied by increases in yield per hectare in the U.S. This contradiction was apparently due to the use of commercial fertilizer primarily to offset declining yields due to depletion of soil fertility. Prior to 1930 use of commercial fertilizer was concentrated in the South, in the production of cotton and tobacco, crops which were classified as soil depleting. The increase in commercial fertilizer input per hectare and the stagnant or even declining land productivity (Y/A) between 1880 and 1935 is consistent with the inference that the supply of plant nutrients from all sources (including both natural and commerical sources) was stagnant or even declining during this period.

5/ Our concept is similar to Fellner's "weak but general proposition" that the anticipated rise in the price of a factor relative to other factor prices induce firms to develop and adopt innovations which save that factor [3] [4].

6/ See Rogin [21] for an excellent historical description.

7/ This is consistent with the emphasis on the importance of the effect of mechanical innovations on the substitution between new and old machineries in terms of relative price changes as analyzed by David [1]. In fact the decline in the price of new machines (relative to old machines) in efficiency terms represents a measure of the contribution of the farm machinery industry to technical changes in agriculture.

8/ See Schultz [26] for greater details.

9/ Griliches has shown, using a distributed lag model, that increase in fertilizer input by United States farmers can be explained solely in terms of decline in fertilizer price [6]. The relation he estimated can be identified as the movement along the meta-production function. The decline in the prices of fertilizer to farmers is a reflection of technical change in the fertilizer industry [23].

10/ A direct test of the induced innovation hypothesis would involve a test for non-neutral change in the production surface. A possible approach is suggested by David and Klundert [2].

11/ Derivation of factor demand functions from a multi-factor production function with different elasticities of substitution (as attempted by Griliches [8] [9]) seems to suggest a possibility for improving the present specification. Our regressions are similar to Griliches' but our factor prices do not measure the costs of factor services other than fertilizer. See footnote 12.

12/ See Appendix for the nature of data. The power and power prices series present the most serious limitations. Instead of resorting to existing estimates of power and machinery (Tostlebe [27] and USDA [28]) which seem to seriously underestimate the growth in power and machinery inputs in efficiency terms because they do not consider quality change, we constructed a series on farm power by aggregating the number of work animals and tractor horsepower in terms of the estimated power they would generate. One horse is assumed equivalent to 1 HP. (see Jones [15; p. 8] and Hunt [14; p. 23]). This assumption was consistent with a statistical test made to examine the adequacy of this conversion factor. The results of the test are available in mimeographed form. All we have for the price of power is the conventional price index of farm machinery and even this does not exist in Japan before the Second World War. We have adjusted the conventional price index in the United States for quality changes based on Fettig's work (Appendix II). The results obtained from such data should of course be taken with the greatest of reservations. Ideally it would have been desirable to prepare data treating factor prices as the costs of factors services, i.e., wage for labor, rent for land, and rental for power and machinery. We could not obtain this kind of data for land and machinery. Our analysis is based on the assumption that changes in the prices of land and machinery in stock terms are an adequate reflection of changes in the costs of their services.

13/ Some of the coefficients of own prices turned positive, e.g., the coefficients of land price relative to wage in Regressions (1) and (2). An exponential time trend was also included. The results were totally implausible due to multicolinearity (the simple cprrelation between time and the machinery price relative to wage was as high as 0.95).

14/ Bio-chemical innovations represented by improvements in crop varieties characterized by greater response to fertilizer tend to be land saving and labor using. For example, traditional rice varieties in Southeast Asia are equally or more productive than improved varieties under low levels of nutrition and poor cultural practices. The yield potential of the improved varieties is achieved only when high levels of fertilization are combined with high levels of crop husbandry and water management. On this score, the introduction of high yielding varieties enhances the substitution of fertilizer and labor for land. On the other hand, commercial fertilizers have significant labor saving effects as they substitute for self-supplied fertilizers. In Japan the production of such self-supplied fertilizers as manure, green manure, compost and night soil has traditionally occupied a significant portion of farmers' work hours. With the increased supply of commercial fertilizers, farmers could divert their labor to the improvements in cultural practices in such forms as better seed bed preparation and weed control.

15/ See Moseman [17] and USDA [29].

16/ See Ogura [19]. Those who know Japanese are advised to consult Nihon Nogyo Huttatsushi (History of Japan's Agricultural Development), 10 Volumes.

17/ This process is described in Hayami and Yamada [12].

18/ Adjustments of production techniques to factor price ratios are not confined to agriculture. In the early phase of Japan's modern economic growth we see a continuous sequence of modifications of "borrowed techniques" to conform to the factor price ratios which were different from those in Western countries. See Ranis [20].

Appendix I. Quality Adjustments in the Farm Machinery Price Index

Quality adjustment factors for the farm machinery price index (USDA index of prices paid) were calculated for 1915-1960 on the basis of L. P. Fettig [5]. The adjustment factors we calculated are originally for tractor prices but not for the prices of farm machinery in general. The basic assumption we have to make in order to use those factors for farm machinery prices is that the quality improvement in all farm machinery can be represented by or is parallel with quality improvement in wheel type tractors.

The basic approach used by Fettig to construct the quality adjusted index of farm tractors for 1950-1962 is (a) to estimate the regression of tractor price on the two quality variables (average horsepower per tractor and a dummy variable for the diesel engine) on cross-section data and (b) to discount the price changes due to the changes in these quality variables from the actual changes in tractor prices by the estimated regression equations.

Our quality adjustment factors for 1955-1960 are based on the ratios of changes in Fettig's quality adjusted index to changes in the USDA index. The ratios calculated are 0.99 from 1950 to 1955 and 0.94 from 1950 to 1960. For 1915-1950 we calculated the adjustment factors using Fettig's linear regression equation on 1950 cross sections. Since the numbers of diesel-powered tractors are negligible before 1950, and data is unavailable, we dropped the diesel dummy from the equation.

The equation we used is

$$Y_t = 176.02 + 43.81\ X_t$$

where X_t and Y_t are the average horsepower per tractor and the estimate of tractor price (1950 U.S. dollars) for the corresponding horsepower in

Year t. Y_t divided by Y_{1915} can be interpreted as the degree of tractor quality improvement from 1915 to Year t. We made the inverse of (Y_t / Y_{1915}) the quality adjustment factor (k_t) as follows:

Year	X_t (H_pS)	Y_t (dollars)	k_t ($1008/Y_t$)
1915	19	1008	1.00
1920	20	1052	0.96
1925	22	1140	0.88
1930	24	1227	0.82
1935	25	1271	0.79
1940	27	1359	0.74
1945	27	1359	0.74
1950	27	1359	0.74
1955			0.73
1960			0.70

k's for 1955 and 1960 are calculated by multiplying k for 1950 the ratios of Fettig's index to the USDA index (0.99 and 0.94) as explained previously.

Data for average horsepower per tractor are calculated from the USDA, Farm Cost Situation 36, Nov. 1965, for 1940-1960 and, Demand for Farm Tractors in the United States, Ag. Econ. Report No. 103, 1966, for 1925-1935. For 1915-1920, the average horsepower is extrapolated from the 1925 value by the quinquennial growth rate of 7 percent (average rate for 1925 to 1940).

Appendix II Basic Statistical Series

More detailed description of the data is available in mimeographed form. Here we will briefly summarize the basic characters of the statistical series used in the analysis. All data are quinquennial. Series marked as (a) are measured in single years at every five years' interval starting at 1880. Series marked (b) and (c) are five year averages centering on those quinquennial years and ending in these quinquennial years respectively.

U.S. Data

Agricultural output (b): gross output net of seed and feeds, Changes in Production and Efficiency, 1964, USDA, Stat. Bull. 233.

Crop production index (b): Crop production index, (USDA Stat. Bull. 233) extrapolated by 1910-14 constant price aggregate of nine major crops.

Number of male workers (a) and number of workers (a): Economically active population adjusted by D. L. Kaplan and M. D. Kasey, Occupational Trends in the United States 1900-1950, U.S. Bureau of Census Working Report 5, 1958, linked with the number of gainful workers adjusted by A. M. Edwards, Comparative Occupational Statistics for the United States, 1870-1940, U.S. Department of Commerce, 1943.

Arable land area (a): Cropland in the Census of Agriculture with minor modifications.

Agricultural land area (a): Land in farm in the Census of Agriculture with minor modifications.

Number of work animals (a): Oxen, horses and mules, of all ages. Horses and mules from A Century of Agriculture in Charts and Tables, USDA, Ag. Handbook 318, 1966. Oxen from W. M. Hurst and L. M. Church, Power and Machinery in Agriculture, USDA Misc. Pub. 157, 1933.

Tractor horsepower (a): Farm Cost Situation 36, 1965, and Demand for Farm Tractors in the United States, USDA, Ag. Econ. Report 103, 1966.

Fertilizer input (b): ($N + P_2O_5 + K_2O$) series in USDA Stat. Bull 233 linked with Series 160 of U.S. Dept. of Commerce, Historical Statistics of the United States, 1961, (henceforth abbreviated as Hist. Stat.)

Corn yield per harvested ha. (b): USDA Ag. Handbook 318.

Percentage of corn area planted in hybrid seed (b): USDA, Agricultural Statistics 1963.

Farm wage (a): Farm wage per day without board, series K80 of Hist. Stat.

Farm wage index (c): Composite index of farm wage rates, series K76 of Hist. Stat.

Arable land price (a): Total value of farm real estate, series K4 of Hist. Stat. divided by arable land area.

Land price index (c): index of average value of farm real estate per acre of land in farm, series K5 linked with K7 of Hist. Stat.

Farm machinery price index (c): Quality adjusted index of farm machinery prices (Appendix I) extrapolated by the BLS and Warren-Pearson wholesale price index of metal and metal products, series E7 and E20 of Hist. Stat.

Fertilizer price (b) - (c): Current farm expense for fertilizer, USDA, Farm Income Situation 207, 1967, per ton of ($N + P_2O_5 + K_2O$), linked with the index of fertilizer prices at Connecticut market compiled by E. E. Vail, Retail Prices of Fertilizer Materials and Mixed Fertilizers, N. Y. Ag. Exp. Stat. Bull. 545, 1932.

Japan's Data

Most Japanese data are taken from Vol. 9 of Kazushi Ohkawa, et. al., ed., Long-Term of Economic Statistics of Japan since 1968, Tokyo, 1966, (abbreviated as LTES 9) supplemented by Vol. 3 and Vol. 8 of the LTES series.

Agricultural output (b): Gross output net of agricultural intermediate goods. The index of gross agricultural production (Series 10 of Table 35, LTES 9) multiplied by one minus the ratio of agricultural intermediate goods to agricultural production calculated from 1934-36 aggregates.

Crop output (b): Series 10 of Table 4, LTES 9.

Number of male workers (a) and number of workers (a): Gainful workers, Series 1 and 3 of Table 33. LTES 9.

Paddy field area (a) and Arable land area (a): Series 13 and 14 of Table 32, LTES 9.

Number of work animals (a): horses and draft cattle of all ages, Table 7, LTES 3.

Tractor horsepower (a): Estimated from the number of garden tractors or cultivators, Table 9, LTES 3, by assuming the average horsepower is 5.

Fertilizer input (b): $N + P_2O_5 + K_2O$, Series 1 of Table 20-22, LTES 9.

Rice yield per planted ha. (b): In terms of brown rice. Data from Ministry of Agriculture and Forestry, Norinsho Ruinen Tokei-hyo, 1955. Yields before 1890 are adjusted as in LTES 9, pg. 37.

Percentage of rice area planted in improved varieties (a): Estimated in Hayami and Yamada [12].

Farm wage (a): Wage of male daily contract workers. Series 24 of Table 25, LTES 9.

Farm wage index (c): Index of male daily contract workers' wages. Series 24 of Table 25 of LTES 9.

Arable land price (a): Weighted average of the price of paddy field and upland fields. Series 9-10 of Table 34, LTES 9.

Land Price index (c): Simple average of paddy field price index and upland field price index. Series 9-10 of Table 34, LTES 9.

Machinery price index (c): Index of farm machinery prices (paid by farmers) from Bank of Japan, Hundred - Year Statistics of the Japanese Economy, 1966, linked with the index of machinery prices, Series 21 of Table 8, LTES 8.

Fertilizer price (b)-(c): Current farm expense for fertilizer, Series 1 of Table 19, LTES 9, per ton of $(N + P_2O_5 + K_2O)$.