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RESOURCE ENDOWMENTS AND TECHNOLOGICAL CHANGE IN AGRICULTURE: U.S. AND JAPANESE EXPERIENCES IN INTERNATIONAL PERSPECTIVE

By

Yujiro Hayami

Department of Agricultural Economics

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

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The United States and Japan, despite enormous differences in resource endowments, have attained high rates of growth in agricultural output and productivity. The patterns of growth in productivity and resource use in the two countries are as contrasting as their resource endowments. This study searches for the common thread in the success of the U.S. and Japanese agricultural growth experience. To approach this problem we try to evaluate the U.S. and Japanese experiences in a cross-country perspective. The influences of original resources endowments on technological progress can best be inferred from cross-country observations characterized by wide variations in factor proportions and factor-product ratios.

The plan of this paper is as follows: First, the growth records of U.S. and Japanese agriculture for 1880-1960 are summarized in order to provide perspective on the differences and similarities of U.S. and Japanese agricultural development. Second, it is hypothesized, drawing on the 38 cross-country observations, that different patterns of agricultural productivity growth have emerged as the results of adaptation of agriculture to new economic opportunities with different constraints of land and labor. Third, this hypothesis is tested by comparing the U.S. and Japanese groth experiences with cross-country observations. Data used in this study are explained in the appendix.

I. Productivity Growth in U.S. and Japanese Agriculture

The growth records of U.S. and Japanese agriculture for the period 1880-1960 are summarized in Table 1. During those eighty years agricultural output increased at the annual compound rate of 1.5 per cent in the U.S. and 1.6 per cent in Japan; output per worker increased at 2.4 per cent in the U.S. and 1.9 per cent in Japan; total factor productivity increased at 0.7 per cent in the U.S. and 1.0 per cent in Japan.[1]

A remarkable feature is that such high overall growth rates of equal magnitudes were attained under extremely different factor proportions. In Japan arable land area per male worker was less than 1 hectare and it increased by only 60 per cent during the eighty years, while in the U.S. it increased more than fourfold from 10 hectares in 1880 to 46 hectares in 1960. In Japan the supply of land has been inelastic and its marginal cost high since the beginning of modern economic growth. Growth in labor productivity was primarily brought about by increases in output per unit of land area in Japan. In the U.S. labor productivity growth was primarily the result of increase in land area per worker at least until 1940.

There were also sharp contrasts in the use of inputs other than land and labor and, also, in the pattern of technological change. In the U.S. it was primarily the progress of large scale mechanization which made it possible to increase the area operated per worker. In Japan it was primarily the progress of bio-chemical technology represented by seed improvements with larger application of fertilizer which permitted rapid growth in agricultural output in spite of the severe constraint of land endowment. Although U.S. agriculture has experienced significant bio-chemical innovations since the

Table 1a. Changes in output, inputs, productivity and factor proportions in U.S. and Japanese agriculture, 1880-1960: indices (1880=100) in selected years.

	1880	1900	1920	1940	1960
United States					
Output (net of seeds and feed)	100	155	180	232	340
Total inputs	100	138	172	181	190
Total productivity (output/total inputs)	100	112	105	128	179
Number of male workers	100	124	128	107	50
Output per male worker	100	125	141	217	680
Agricultural land area	100	157	180	203	215
Arable land area	100	170	249	246	238
Output per ha. of agricultural land	100	99	100	114	158
Output per ha. of arable land	100	91	72	94	143
Agricultural land area per male worker	100	127	141	190	430
Arable land area per male worker	100	137	195	230	476
Japan					
Output (net of seeds and feed)	100	149	232	264	358
Total input	100	105	119	127	156
Total productivity	100	142	195	208	229
Number of male workers	100	98	97	81	79
Output per male worker	100	152	239	326	453
Arable land area	100	110	126	129	128
Output per ha. of arable land	100	135	184	205	280
Arable land area per male worker	100	112	130	159	162

Flow variables such as output and total inputs are five years average centering years shown. Stock variables such as land and labor are measured in years shown.
Sources of data are explained in Appendix.

Table 1b. Changes in output, inputs, productivity and factor proportions in U.S. and Japanese agriculture, 1880-1960: annual compound rates of change.

	1880 to 1900	1900 to 1920	1920 to 1940	1940 to 1960	1880 to 1960
United States					
Output (net of seeds and feed)	2.2	0.8	1.3	1.9	1.5
Total inputs	1.6	1.1	0.3	0.2	0.8
Total productivity (output/total input)	0.6	-0.3	1.0	1.7	0.7
Number of male workers	1.1	0.2	-0.9	-3.9	-0.9
Output per male worker	1.1	0.6	2.2	5.8	2.4
Agricultural land area	2.3	0.7	0.6	0.3	1.0
Arable land area	2.7	1.9	-0.1	-0.2	1.1
Output per ha. of agricultural land	-0.1	0.1	0.7	1.6	0.5
Output per ha. of arable land	-0.5	-1.1	1.4	2.1	0.4
Agricultural land area per male worker	1.2	0.5	1.5	4.2	1.9
Arable land area per male worker	1.6	1.7	0.8	3.7	2.0
Japan					
Output (net of seeds and feed)	2.1	2.2	0.7	1.5	1.6
Total input	0.2	0.6	0.3	1.0	0.6
Total productivity (output/total input)	1.9	1.6	0.4	0.5	1.0
Number of male workers	-0.1	0	-0.9	-0.1	-0.3
Output per male worker	2.2	2.2	1.6	1.6	1.9
Arable land area	0.5	0.7	0.1	0	0.3
Output per ha. of arable land	1.6	1.5	0.6	-1.5	1.3
Arable land area per male worker	0.6	0.7	1.0	0.1	0.6

1930's and farm mechanization has been progressing in an accelerating pace since the 1950's in Japan, the overall contrast is conspicuous.

Is there any common thread in the agricultural growth of the two countries? This must be the question confronting those who compare the growth records of U.S. and Japanese agriculture.

II. Cross-Country Comparison and the Hypothesis on Agricultural Productivity Growth

In this section we will try to deduce a hypothesis from a cross-country comparison of factor productivity ratios and factor input mixes, which may shed light on the question raised in the previous section.

In Figure 1 the partial productivity ratios, agricultural output per male worker and output per hectare of agricultural land, are plotted for 38 countries. The slope of the line commecting each country to origin represents the land-labor ratio or area per farm worker for the country. Three distinct productivity scatters or paths can be observed: (a) the path indicated by the group of countries in the new continents, represented by New Zealand, Australia, Canada and the U.S.A., where man-land ratios are particularly favorable, (b) the path indicated by countries in Asia, represented by Taiwan and Japan, where unfavorable man-land ratios prevail, and (c) the path indicated by countries in Europe, represented by the Netherlands and Belgium, in which the condition of original factor endowments is between the other two groups. Each path seems to represent a long-run process of agricultural growth for a given man-land ratio. The endowments of land and labor can be treated as largely exogenous to the agricultural sector.[2/] Given the resource constraints farmers try to increase output and income. In the one extreme case it is land which limits

Key to symbols:

Argentina	Arg.	Greece	Gr.	Philippines	Ph.
Australia	Aus.	India	In.	South Africa	S.A.
Austria	Au.	Ireland	Ir.	Spain	Sp.
Belgium	Be.	Israel	Is.	Surinam	Su.
Brazil	Br.	Italy	It.	Sweden	S.
Canada	Can.	Japan	Ja.	Switzerland	Sw.
Ceylon	Ce.	Mauritius	Ma	Syria	Sy.
Chile	Ch.	Mexico	Me.	Taiwan	Tai.
Columbia	Co.	Netherland	Ne.	Turkey	Tu.
Denmark	De.	New Zealand	N.Z.	U.A.R.	U.A.R.
Finland	Fi.	Norway	No.	U.K.	U.K.
France	Fr.	Paraguay	Pa.	U.S.A.	U.S.A.
Germany(West)	Ge.	Peru	Pe.	Venezuela	Ve.

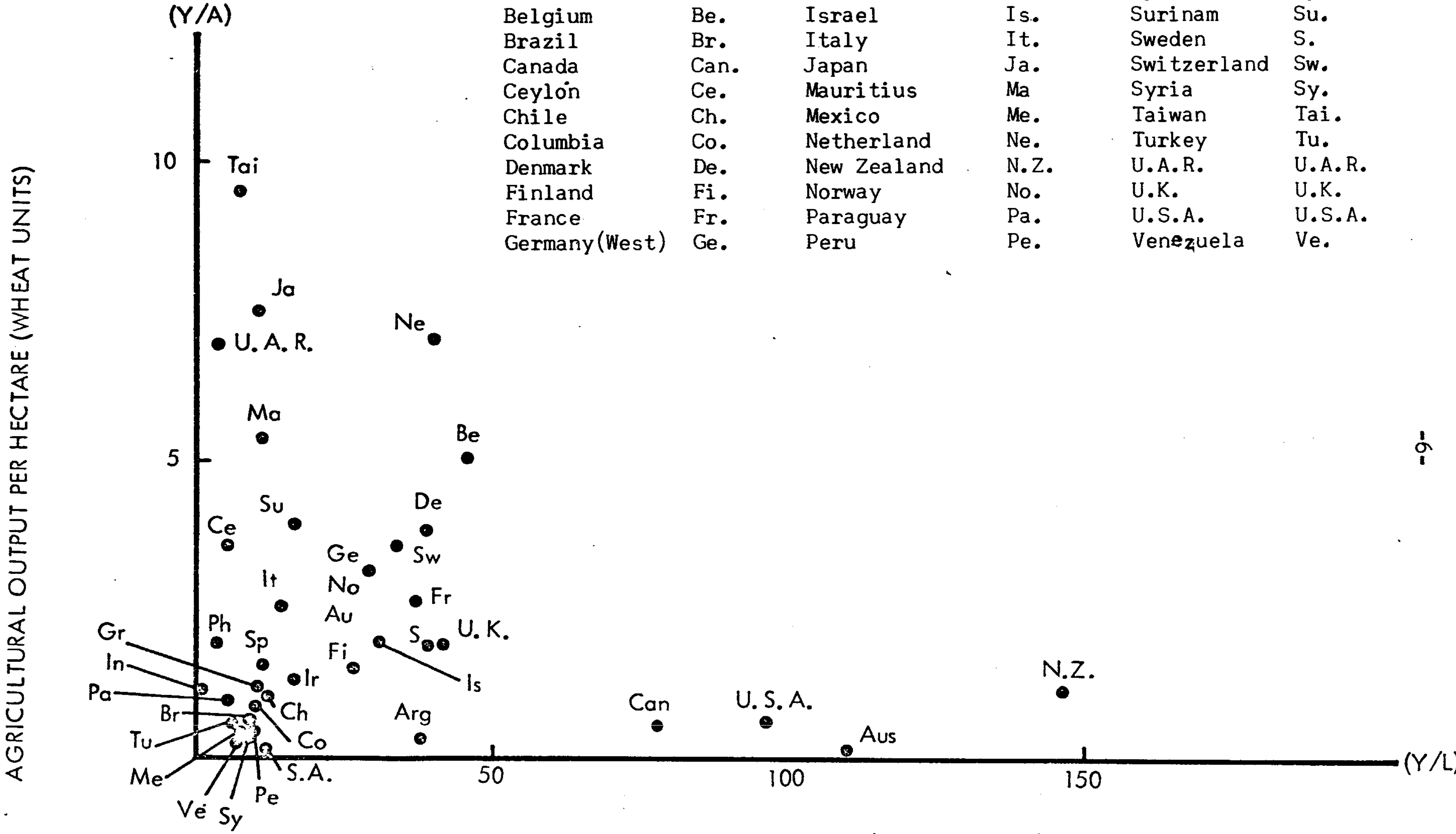


Figure 1. Cross-country comparison of agricultural output per male worker and output per hectare of agricultural land area: Output data are 1957-62 averages, and labor and land data are measured in years closest to 1960. Wheat unit = equivalent to one ton of wheat. Sources of data in Appendix.

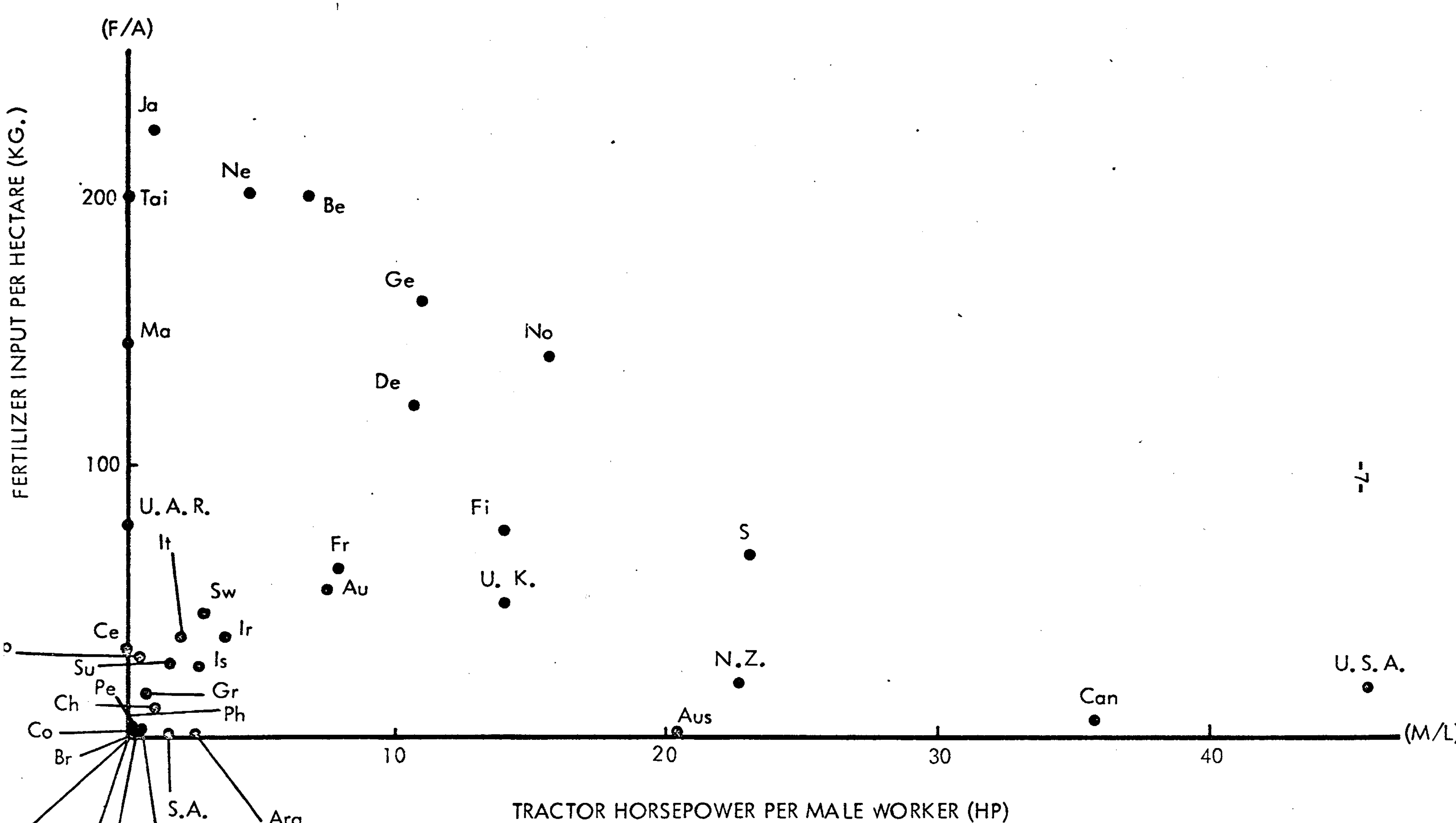


Figure 2. Cross-country comparison of tractor horsepower per male worker and fertilizer input $(N + P_2O_5 + K_2O)$ per hectare of agricultural land: Fertilizer data are 1957-1962 averages, and land, labor and tractor horsepower data are measured in years closest to 1960. Sources of data in Appendix.

the increase in output, and in another it is labor. In order to ease the limitation set either by land or by labor, farmers would try to economize in the use of the limiting factor or to substitute man-made inputs for it, e.g., fertilizer for land and other forms of power for labor. The growth path suggested by the countries in the new continents seems to reflect the process of easing the limitation in the supply of labor, and the one suggested by Asian countries to reflect the process of easing the limitation set by the supply of land.

Such processes may be visualized by comparing Figure 1 with Figure 2. In Figure 2 the factor-factor ratios, fertilizer input ($N + P_2O_5 + K_2O$) per hectare of agricultural land and tractor horsepower per male worker, are plotted. The former is used as an index of the level of input of the factors which substitute for land and the latter is an index of the input of the factors which substitute for labor. It will be seen that the productivity ratios for these respective countries in Figure 1 correspond roughly to their positions of input mix in Figure 2. Despite large differences in climate and other environmental conditions almost 80 per cent of the variations in agricultural productivities of land and labor can be explained by the differences in the levels of inputs which substitute for those original production factors.[3/]

The relations observed in Figures 1 and 2 suggest the hypothesis that growth in agricultural productivity is essentially a process of adaptation of the agricultural sector to new opportunities created by the progress of inter-industry division of labor accompanying industrialization -- the term <u>industrialization</u> as used here does not mean the expansion of manufacturing sector alone, but rather the coordinated growth of manufacturing and service industries including international trade and transport. If we measure the industrialization by the number of male workers in the nonagricultural sector to the total number of male workers, we find the countries located close to the efficiency frontier in Figure 1 are high in this ratio: 0.82 in New Zealand, 0.87 in Australia, 0.91 in the United States, 0.92 in Belgium, 0.88 in Netherlands, and 0.74 in Japan around 1960 when this comparison is made. In contrast this ratio is very low in countries located nearby the origin: 0.41 in Mexico, 0.31 in Colombia, 0.47 in Syria, 0.39 in Turkey, 0.31 in India and Pakistan. The fact that countries such as Australia and New Zealand which are the prime exporters of agricultural products and the importers of industrial commodities are high in this ratio for their high agricultural efficiencies seems to suggest that the industrialization provides a momentum for the growth in agricultural productivity, while a rise in agricultural productivity also promotes industrialization.[4]

Industrialization affects agriculture in many ways. The expansion of the nonagricultural sector, requiring more food and materials, shifts the demand for farm products upwards, stimulating farmers to increase the use of inputs and to adapt new technology in order to meet the increased demand. More crucial are the changes in the supply conditions of agricultural inputs. With the progress of inter-industry division of labor accompanying industrialization increasing returns, as conceived by Allyn Young [30], set in and the costs of such modern agricultural inputs as fertilizer, chemicals, and tractors are reducde. Agricultural growth can be attained through the adaptation of the agricultural sector to the lower prices of such modern chemical and mechanical inputs relative to land, labor and product prices.

Such opportunities do not bring about productivity growth unless they are exploited adequately. A requisite for agricultural productivity growth is the capacity of the agriculture to adapt to a new set of factor and product prices. This adaptation involves not only the movement along a fixed production surface but also the creation of new production surface which is optimum for the new set of prices.

For example, even if fertilizer prices decline relative to the prices of land and farm products, an increase in the application of fertilizer is limited unless new crop varieties are developed which respond better to fertilizer than traditional varieties. Table 2 compares the yield response of indigenous varieties of rice to nitrogen in East Pakistan and of improved varieties in Japan. It shows that the yields of the indigenous varieties are as high as the improved varieties at the low level of fertilization but do not respond to the increase in nitrogen input. In this study they merely increase the output of straw. This relation may be drawn as u_0 and u_1 in Figure 3 which represent the fertilizer response curves of indigenous and improved varieties respectively. For farmers facing u_0, a decline in fertilizer price relative to product price from p_0 to p_1 would not be expected to create much increase in fertilizer application or in yield. The benefit of a decline in the fertilizer price can only be fully exploited if u_1 is made available to farmers through the selection of more responsive varieties.

Conceptually it is possible to draw a curve such as U on Figure 3, which is the envelope of many such response curves, each representing a variety of different degree of fertilizer responsiveness. We may call it an "innovation frontier curve" or a "meta-production function" representing the potential

Table 2. Yield response to nitrogen input by rice varieties.

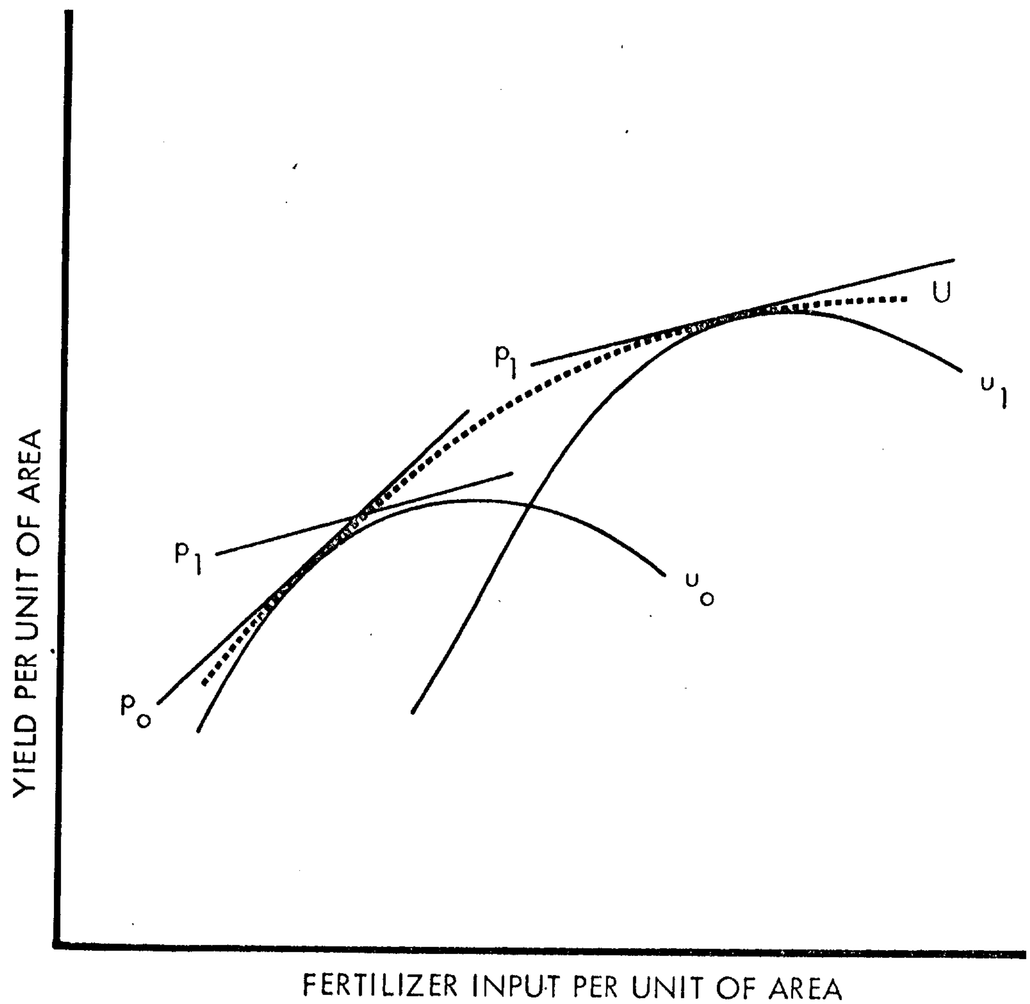
	Yield (lb/acre) at the levels of N				Marginal product of N $\frac{(II - I)}{55}$	
	I		II			
	95 lb./acre		150 lb./acre			
	Paddy	Straw	Paddy	Straw	Paddy	Straw
Habiganj[a]	4785	7948	4372	10478	-7.5	46.0
Batak[a]	5445	9488	5875	11743	7.8	41.0
Kamenoo[b]	5417	5500	6077	7617	12.0	38.5
Norin 1[c]	6352	7205	7700	8225	24.5	18.5
Norin 87[c]	5118	6352	6517	7892	25.4	28.0
Rikuu 232[c]	5802	6902	7425	8553	29.5	30.0

a Indigenous varieties in East Pakistan.

b A variety selected by a veteran farmer, which became prevalent in Japan for 1905-1925.

c Varieties selected through hybridization by agricultural experiment stations in Japan after the nation-wide coordinated experiment system called "Assigned Experiment System" was established in 1926-27.

Source: Institute of Asian Economic Affairs [14; p. 14].


U
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YIELD PER UNIT OF AREA
FERTILIZER INPUT PER UNIT OF AREA

Figure 3

inherent in nature. It is hypothesized that the adaptation of agriculture to new opportunities in the form of lower relative prices of modern inputs involves an adjustment to a new optimum along this meta-production function.5/ In terms of this hypothesis it appears to be equally rational for farmers in Japan and Southeast Asia to plant different varieties at different levels of fertilization corresponding to the different factor-factor and factor-product price relationships.6/

The endowments of the original factors, land and labor appear to have a significant influence upon the location of respective countries along the meta-production function. Where labor is the limiting factor -- limiting in the sense that its supply is inelastic -- the optimum for new opportunities in the form of lower prices of modern inputs is likely the point with the higher land-labor ratio. Movement to this new optimum would involve mechanical innovations embodied in the new forms of power and machinery. On the other hand, where land is the limiting factor, the new optimum is likely the point at which yield per hectare is higher for higher level of fertilizer input. Movement to this point would involve bio-chemical innovations.

It seems possible to explain the vast differences in productivity and input mix in agriculture among countries by the hypothesis of the adaptation of agriculture to the new economic opportunities created by developments in the nonagricultural sector. It must be noted that this adaptation does not occur without cost. The development of a fertilizer responsive variety, which is optimum for a new set of prices, requires investment in research before it can actually be made available to farmers. Public investment in the improvements in water control and other environmental conditions may also be required for the farmers to adapt the newly developed varieties. Farmers seek new inputs and new techniques in order to move along the meta-production function in response to a new set of prices. Only when public research institutions and private farm supply firms perceive this demand of farmers and make the new inputs or methods available to farmers, it is possible to move to the optimum point on the meta-production function. Unless this mechanism of dialectic interaction functions properly, productivity growth in agriculture is not insured.

The positions of the U.S. and Japan in Figures 1 and 2 seems to suggest their success in the adaptation of agriculture to the rising economic opportunities through the dialectic interaction among farmers, public institutions and farm supply firms.

III. U.S. and Japanese Experiences in International Perspective

In this section we evaluate the agricultural growth experiences of the U.S. and Japan in terms of the hypothesis postulated in the previous section.[7] How do the hypothesized explanations of U.S. and Japanese growth paths stand up under a more intensive analysis? The time series paths of agricultural productivity growth in the U.S. and Japan are plotted respectively in Figures 4 and 5 which are, in effect, the enlargements of Figure 1. The numbers in the parentheses indicate the percentage of male workers in nonagricultural occupations in the total number of male workers. The time series path of the U.S. is nearly parallel with the line connecting Mexico, Argentina, Canada, and New Zealand and the path of Japan is parallel with the line connecting India,

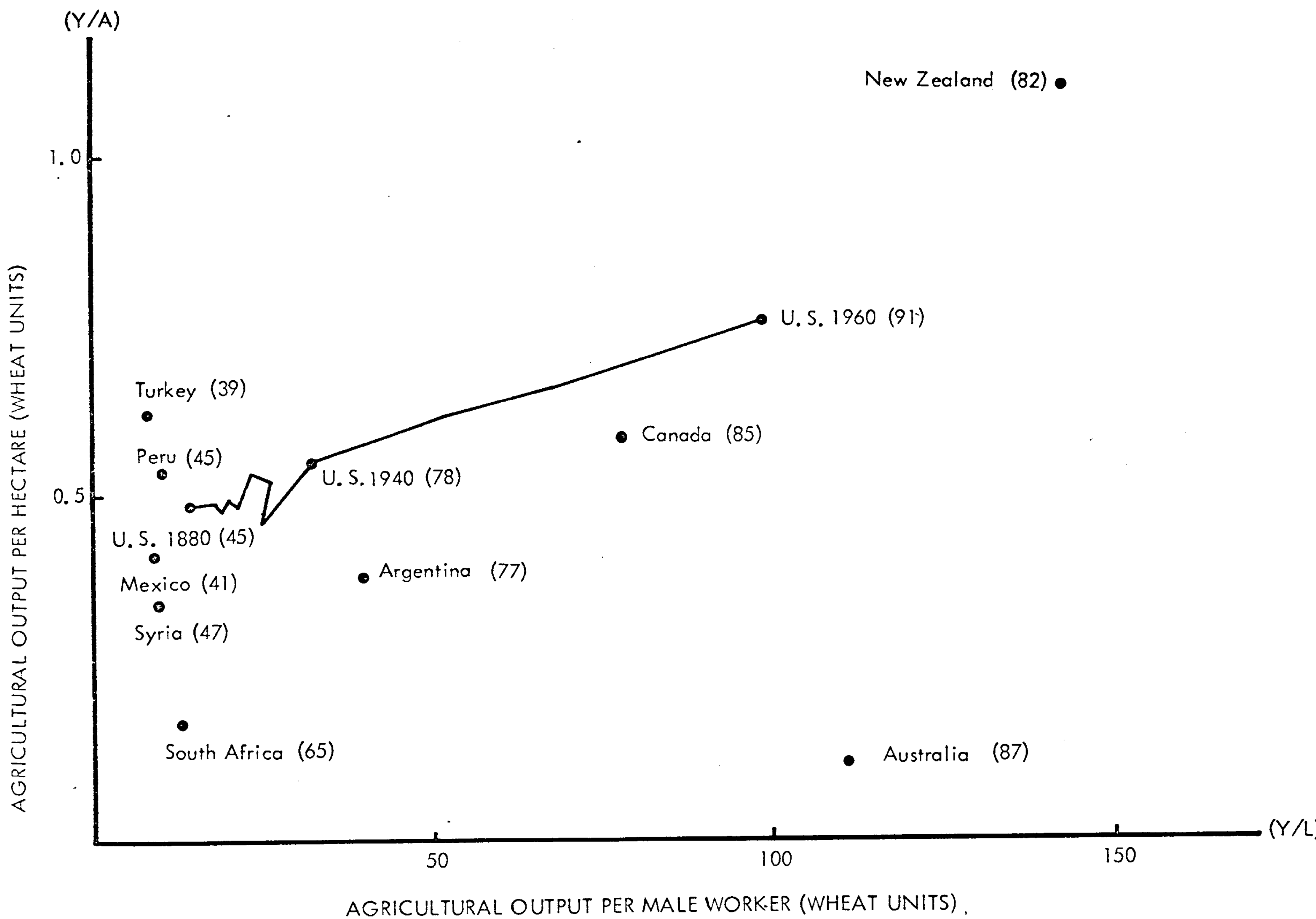

Figure 4. Historical growth path of agricultural productivity in the U.S. for 1880-1960 compared with cross-country observations in 1960: An enlargement of Figure 1.

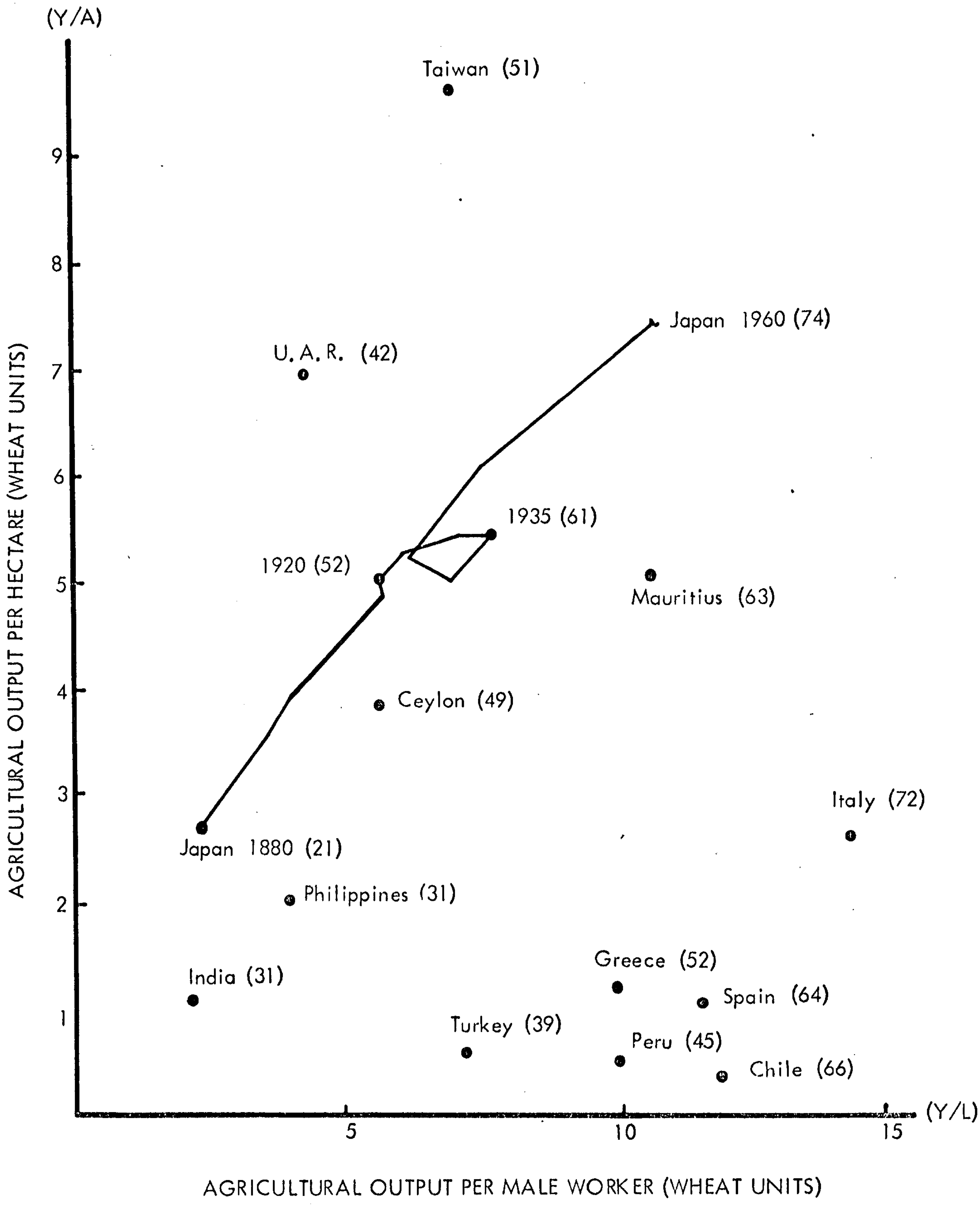

Figure 5. Historical growth path of agricultural productivity in Japan for 1880-1960 compared with cross-country observations in 1960: An enlargement of Figure 1.

the Philippines, Ceylon, and Mauritius.[8/] The historical relationships between the level of industrialization and the level of agricultural productivity both in the U.S. and in Japan are quite similar to the cross-country relationship.

Considering the crudeness of the data this similarity is rather impressive and gives support to the hypothesis that the progress of inter-industry division of labor accompanying industrializations works as a momentum for agricultural productivity growth by providing new opportunities in the form of lower prices of modern inputs. The parallel relationships between the growth path of the U.S. and the scatter of countries in the new continents, and between the path of Japan and the scatter of Asian countries seem to suggest that the direction of agricultural growth along the meta-production function is strongly constrained by the original factor endowments. In Japan land has been the limiting factor and the efforts of farmers, public institutions and agricultural supply firms to exploit new opportunities have brought about significant bio-chemical innovations represented by seed improvements with larger application of fertilizer. In the U.S. where labor has been more limiting, advances in mechanical technology have become the main feature of agricultural development.

Such processes may be illustrated by Figures 6 and 7. Figure 6 contrasts the input of power per worker with the movement in the price of farm machinery relative to the farm wage. In the U.S. the number of work animals increased up to 1920. This reflects the progress of horse mechanization. Such major innovations as the introduction of the self-rake reaper as a substitute for the hand-rake reaper and the introduction of the binder as a substitute for

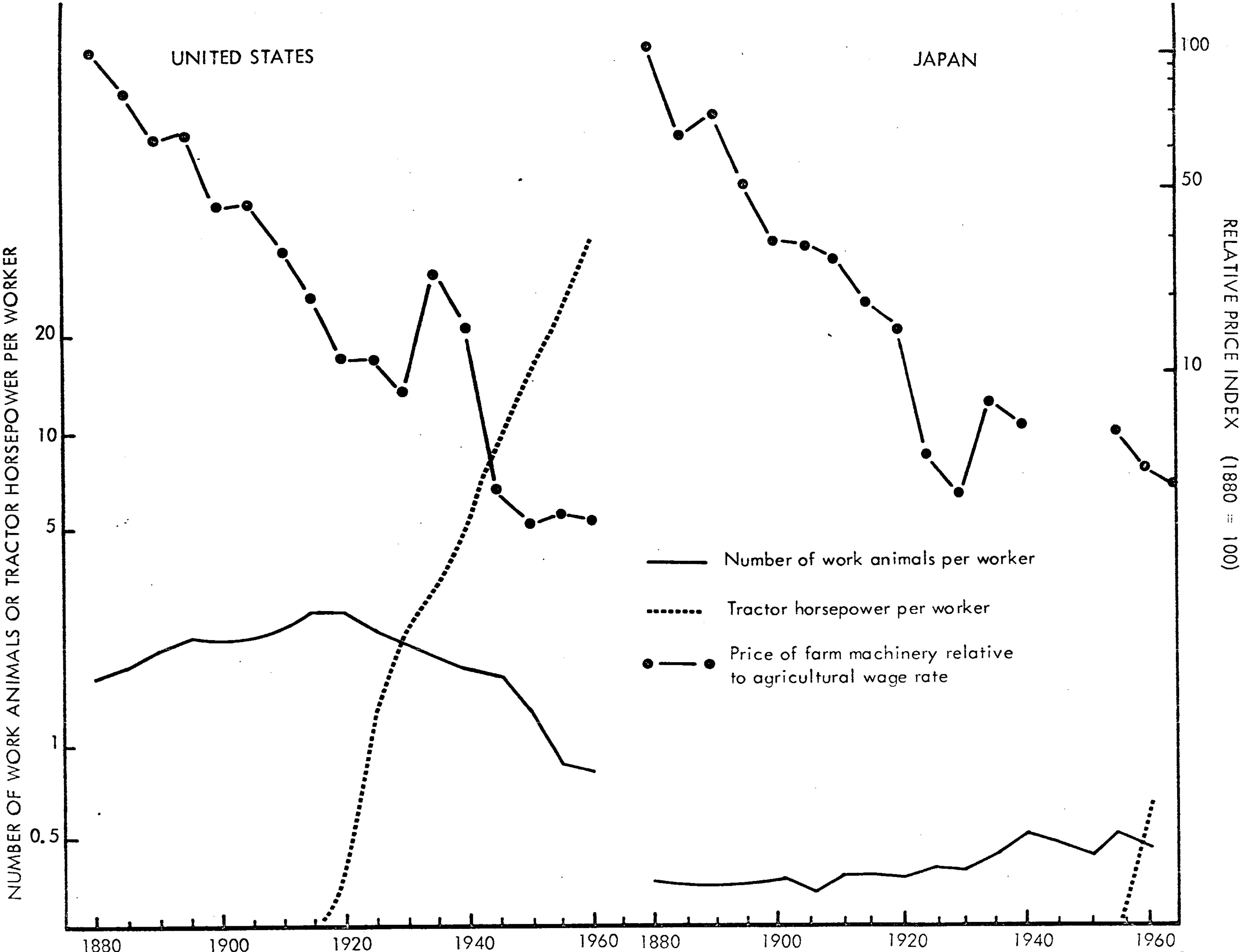

Figure 6. Changes in power per male worker and the price of farm machinery relative to farm wage rate, the U.S. and Japan, 1880–1960.

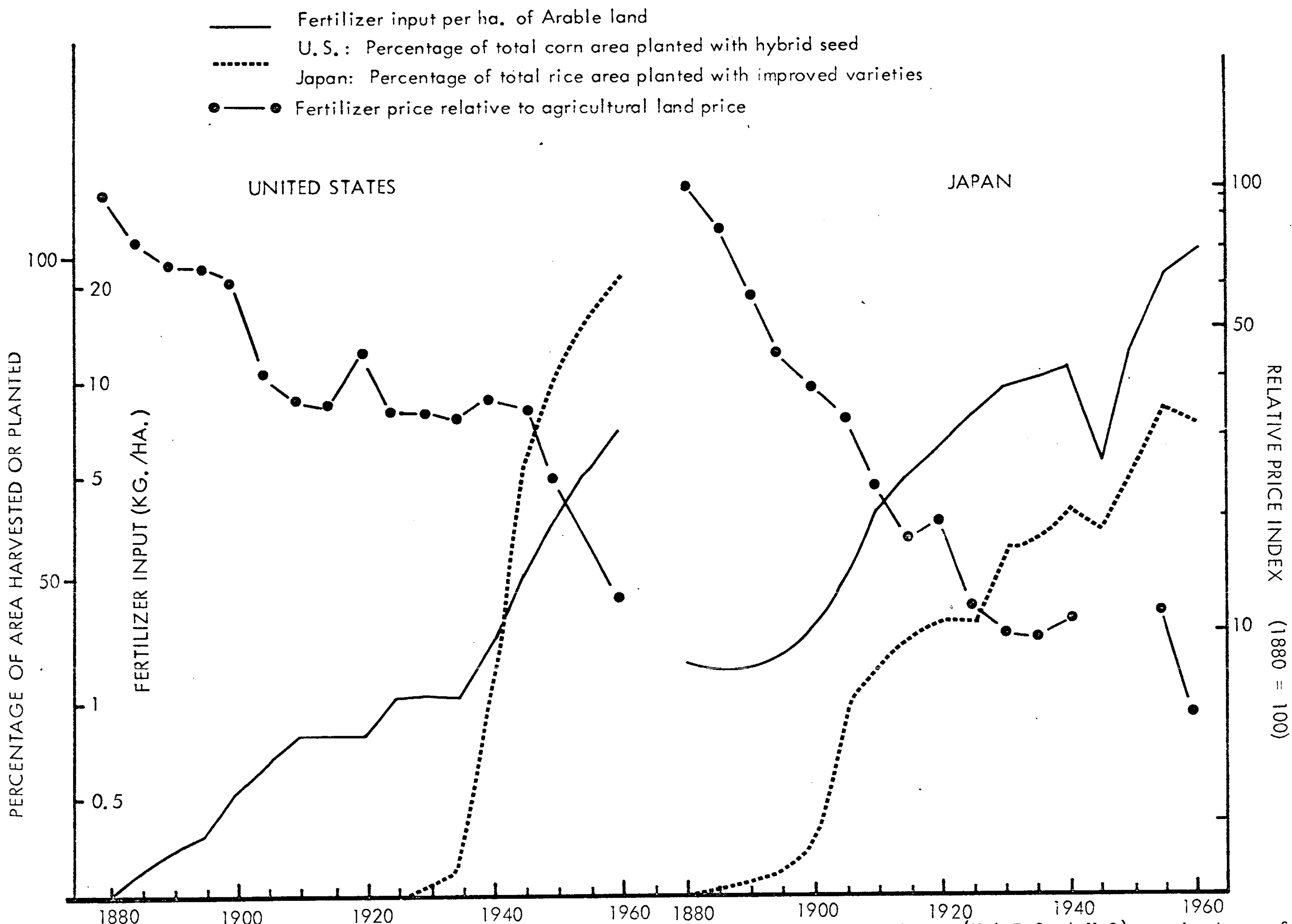

Figure 7. Progress in the improvements in plant varieties and changes in fertilizer input ($N + P_2O_5 + K_2O$) per hectare of arable land area and in the price of fertilizer relative to the price of agricultural land, the U. S. and Japan,

the self-rake reaper required a larger number of horses per worker. After 1920 the number of horses per worker started to decline, but tractor horsepower more than compensated for this decline. The use of tractor was itself a major mechanical innovation in agriculture and the increase in tractor horsepower per worker represented a process of continuous mechanical innovation as it was accompanied by improvements in the transmission system, attachments, etc. Overall the increase in power per worker seems fairly well explained by the decline in the price of machinery relative to the wage rate, given the relatively large and elastic supply of land in the U.S. In Japan, even though the relative price of farm machinery declined, power per worker did not increase significantly due to the strong constraint of the land-labor ratio. Mechanization was limited by farm scale.

Figure 7 contrasts the progress of seed improvements and the increase in fertilizer application with the changes in fertilizer price relative to the price of land. In Japan, corresponding to the rapid decline in fertilizer price, the percentage in the area planted to improved varieties of rice in the total area planted in rice -- by far the most important single crop in Japan -- has increased rapidly from the beginning of the period concerned, accompanying the parallel rise in fertilizer input per hectare of arable land area. This clearly reflects the movement along the isoquant of the meta-production function which describes the continuous improvements in crop varieties.

The fertilizer input per hectare increased also in the U.S. corresponding to the decline in the relative price of fertilizer. However, it was only in the 1930's that the U.S. level of fertilizer input per hectare reached the Japanese level of the 1880's. It is suggestive to note that the significant biological innovations, of which representative is hybrid corn, started at this level of fertilizer input. Before the 1930's fertilizers were primarily used for cotton and tobacco, crops which are characterized of depleting soil. The depletion of natural fertility was also significant in the newly cultivated Great Plains. It seems likely that the level of supply of plant nutrients per unit of cropland after deducting the depletion of natural fertility, would have remained roughly constant or even declined. This is consistent with the stagnation in land productivity before the 1930's. In such situation there would not have been much incentive operating to select fertilizer responsive varieties in order to overcome the decreasing return to fertilizer application. This would have been especially true when output and income per farmer could be raised by expanding the area per worker. It is hypothesized that the balance sheet of total plant nutrient supply market a secular surplus in the 1930's, which called for the selection of fertilizer responsive varieties resulting in the explosive innovations of hybrid corn. This hypothesis is not based on strong evidence, but it is at least unlikely that hybrid corn could diffuse so rapidly unless fertilizers were available at profitable prices.

As was stressed previously, innovations induced by relative price changes in order to adjust along the meta-production function involve substantial cost. The U.S. efforts in agricultural research and extension are well known.[9/] In Japan the national efforts to develop agriculture began with the Meiji Restoration which initiated the period of modern economic growth in Japan.[10/] Beginning with the direct importation of Western crops and machineries in the 1870's (which mostly turned out failures), Japan succeeded by the beginning of this century in building a rather unique system of technology called Meiji Noho (Meiji Agricultural Technology), which is essentially the reformulation of indigenous techniques practiced by veteran farmers on the basis of German agricultural chemistry and soil science. Farmers, especially those who belonged to the Gono class (landlords who cultivated part of the land they owned themselves), actively participated in the development of this technology.[11/] Most of the improved rice varieties available before the 1920's were the varieties selected by farmers themselves. Experiment stations made comparative yield tests and adaptive research in order to propagate the varieties selected by veteran farmers.[12/] Such techniques as the selection of rice seeds in salt water and the oblong-shaped nursery bed were selected from the farmers' practices through the tests of modern science. They were tailored by scientists and were propagated over the nation. Farm supply firms also perceived and attempted to meet the demand of farmers. Long before the chemical fertilizer industry developed, the cost of plant nutrient in commercial fertilizers had declined. This was based on the efforts of fertilizer supply firms to exploit the opportunities created by the inter-industry division of labor accompanying industrialization. The costs of herring meals from Hokkaido and soybean cakes from Manchuria were greatly reduced due to the improvements in transportation, storage and marketing efficiencies.[13/]

It appears that the dialectic interaction among farmers, public institutions and private farm supply firms functioned properly both in Japan and in the U.S. and brought about success in agricultural growth of different patterns.

IV. Conclusion

The agricultural growth experiences of the U.S. and Japan in reference to cross-country observations were explained by the hypothesis of the adaptation of the agricultural sector to the opportunities arising from the progress of the inter-industry division of labor accompanying industrialization. This adaptation involves innovations produced through a dialectic interaction of farmers, public institutions and private farm supply firms to exploit the opportunities available. The common thread in the success of U.S. and Japanese agriculture may be identified as the proper functioning of such interaction mechanism.

It must be stressed that, unless there exists a system under which this mechanism works properly, industrialization would not contribute much to agricultural growth. The efforts for industrialization and economic development neglecting the establishment of such a system would eventually be hampered by lagging agriculture sector. Experiences in Argentina and Soviet Union may be cited as such examples.

More research must be directed to the investigation of the causes of the success and failure in establishing a proper system of such interaction in the course of agricultural growth and economic development.

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Notes

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1/ Reliability of the official statistics of agricultural production in Meiji Japan was serious questioned by Nakamura [16]. See debates on this problem in my two earlier pepers [7] [12], and Nakamura [17]. Though the author recognizes Nakamura's important contribution, he can not accept Nakamura's proposition.

2/ This, of course, is not exactly true. Especially labor may be better treated as a variable determined simultaneously through an inter-industry demand and supply system. Here we treat labor as approximately exogenous to agriculture in the sense that it is primarily the nonagriculture sector which determines its share of existing labor force and that the residual is employed in agriculture sector.

3/ By regressing fertilizer input per hectare (F/A) and tractor horsepower per male worker (M/L) on output per hectare (Y/A) and output per male worker (Y/L) respectively, from the cross-country sample as drawn in Figures 1 and 2, we obtain

$$\log\left(\frac{Y}{A}\right) = 1.015 + \underset{(0.048)}{0.472}\log\left(\frac{F}{A}\right),\quad \bar{R}^2 = 0.723$$

$$\log\left(\frac{Y}{L}\right) = 1.205 + \underset{(0.027)}{0.390}\log\left(\frac{M}{L}\right),\quad \bar{R}^2 = 0.851$$

4/ Statistical analysis of this relationship on cross-country data was made in [6].

5/ Using a distributed lag model Griliches explained the increase in fertilizer input solely by the relative decline in fertilizer price [4]. It could be identified that the demand schedule he estimated corresponds to this meta-production function. Unless biological innovations represented by hybrid corn had occurred, the fertilizer input would not have increased as much as it actually did.

6/ Schultz indicated the enormous gap existing in the price of fertilizer relative to product price between developed and less developed countries [20; pp. 48-50].

7/ A more rigorous analysis is given in [10].

8/ A line which connects India, U.A.R. and Taiwan seems to suggest the existence of another path of agricultural growth characterized by the growth in land productivity with development of irrigation.

9/ See [27].

10/ See more details in [18].

11/ See this process in [11].

12/ Ad hoc nature of veteran farmers' techniques were overcome by scientific tests and their location specific characters are remedied by adaptive research.

13/ See this process in [5].

Appendix

U.S. Time-Series Data

Indices of output and total inputs are taken from [23]. Number of male workers are 1900-1960: economically active population in population census adjusted by Kaplan and Kasey [15]; 1880-1890: the number of gainful workers adjusted by Edwards [1]. Land areas are the agriculture census data taken from [22] with minor adjustments. Arable land is identified as cropland including land in fallow and cultivated pasture, and agricultural land is identified as land in farm in census definitions excluding roads and farmstead. Number of work animals includes oxen, horses and mules of all ages -- data taken from [13] [21]. Tractor horsepower are taken from [3] [24] with extrapolation for 1910-1920. Data of fertilizer input in plant nutrient ($N + P_2O_5 + K_2O$) terms are taken from [23] for 1910-1960, and before 1910 Series K160 of [28] are sliced to the USDA series at 1910-1914. Percentages of total corn area planted with hybrid seeds are from [22]. Agricultural wage index is Series K76 of [28] with interpolations. Land price is the index of average value of farm real estate per acre, Series 7 linked to Series 5 of [28]. The farm machinery price index is USDA index of prices paid by farmers adjusted for quality change by extrapolating the method used by Fettig [2]. The machinery price index before 1910 is the BLS wholesale price index of metal and metal product spliced to the USDA index. Fertilizer price is the unit plant nutrient value obtained by dividing current farm expense for fertilizer by quantity of plant nutrients consumed [24] [25]. Before 1910 the fertilizer price index calculated from price data at Connecticut market in [29] is spliced to the unit value series.

Japan's Time-Series Data

Unless otherwise noted, the time-series data of Japan are taken from Volumes 3,8, and 9 of Long-Term Economic Statistics of Japan [19]. Index of agricultural output net of seeds and feeds is constructed from the linked index of agricultural production and the ratio of agricultural intermediate inputs to gross agricultural output in 1934-36 constant prices. The linked index is used as the index of total inputs. Number of male workers is gainfully occupied population in agriculture. Arable land areas are of 1956 sample remeasurement basis. Work animals include horses and draft cattle of all ages. Tractor horsepower is estimated from the number of tractors assuming the average horsepower is 5. Fertilizer is in plant nutrient terms. Percentages of total rice area planted with improved varieties are interpolated from the estimates in [11]. Agricultural wage index is of male daily contract workers'. Land price index is the simple average of paddy field price index. The index of farm machinery price is of prices paid by farmers for 1950-1960, and before 1950, is the index of general machinery price sliced to the farm machinery index. Fertilizer price is the unit value of plant nutrients obtained by dividing current farm expense for fertilizer by total quantity of plant nutrients consumed.

Cross-Country Data

All data are taken from [8] and English summary may be seen in [9]. 1957-62 averages of agricultural output net of seeds and feed in wheat equivalents are the aggregates of all commodities in FAO's Production Yearbook after deducting seeds and feeds given in Food Balance Sheets. Three aggregations are made each corresponding to a set of wheat relative prices either in India or in

Japan or in the U.S. Final composite series of output used in this analysis are the geometrical averages of those three series. U.S. and Japanese time-series data are spliced to corresponding observations in the cross-country sample at 1957-1962, when they are compared with cross-country observations in Figures 3 and 4 in the text. Land, labor and tractor horsepower are measured at 1960 or years nearest 1960, and fertilizer is the average for 1957-1962. Land is FAO's agricultural land area including permanent pasture and meadows. The number of male workers is on ILO's economically active population. Tractor horsepower data are the estimates by OECD for OECD countries and are estimated for other countries from the number of tractors assuming average horsepower per tractor is 30 and average horsepower per garden tractor is 5. Fertilizer is measured in terms of principal plant nutrients. Percentages of male workers in nonagricultural occupations are calculated for ILO data of industrial distribution of economically active population.