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10 International Comparisons of Productivity in Agriculture

Saburo Yamada and Vernon W. Ruttan

10.1 Introduction

The purpose of this paper is to extend the earlier analysis of the sources and direction of agricultural productivity growth over time and of agricultural productivity differences among countries which Yujiro Hayami and Vernon W. Ruttan presented in their book on *Agricultural Development: An International Perspective*.[1] In the Hayami-Ruttan study the induced innovation hypothesis was tested against the historical experience of agricultural productivity growth in Japan and the United States for the period 1880–1960. In this paper it has been possible to include four additional countries—Denmark, France, Germany, and the United Kingdom—in the analysis and to extend the analysis for all six countries to 1970. In the Hayami-Ruttan study the analysis of the sources of productivity differences among countries was based on cross section data centered on 1960. In this paper it has also been possible to analyze the sources of productivity differences among countries using data centered on 1970, and to compare the results with the earlier analysis.

The extensions of the time series analysis to four additional countries and of the time series and cross-section analysis to 1970 adds importantly to our understanding of the interrelationships among changes in relative factor prices, technical change, productivity growth, and agricultural development. The initial test of the induced innovation hypothesis was based on the historical experience of agricultural productivity growth in two countries—the United States and Japan—with extreme differences in relative factor endowments and factor prices. The addition

1. Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971).

of the four European countries permits a test of the induced innovation hypothesis against the experience of countries characterized by less extreme differences in relative factor endowments and prices.

The addition of time series and cross section data for 1970 permits an extension of the analysis to include a period characterized by rapid productivity growth in a number of developed and developing countries. In the developed countries of western Europe and Japan completion of the process of agricultural mechanization led to rapid increases in output per worker during the 1960–70 decade. In several developing countries the new seed-fertilizer or "green revolution" technology, combined with continued decline in fertilizer prices, permitted rapid growth of land productivity during the latter half of the decade.

Both the theoretical foundations on which productivity accounting rests and the precision of productivity measurement have been subject to continuous debate. The debates have focused primarily on problems of index number construction, the proper accounting for depreciation, and the incorporation of inputs not adequately measured in conventional national accounting systems. Even while the elaboration of the theory and method of productivity and growth accounting has been going forward, the several "partial" and "total" productivity measures available have been providing new insights into the process of economic growth. They have also served as useful instruments in development planning and policy.

The comparisons presented in this paper are based primarily on partial productivity measures—output per worker and output per hectare. Our attempts to "account" for differences in productivity over time and among countries also focus on these partial productivity ratios. Total productivity estimates are available for the agricultural sector for a number of developed and developing countries.[2] However, it has been

2. For a survey of international productivity comparisons see Irving B. Kravis, "A Survey of International Comparisons of Productivity," *Economic Journal* 86 (March 1976):1–44. See also the literature survey by Willis Peterson and Yujiro Hayami, "Technical Change in Agriculture," in Lee R. Martin, ed., *A Survey of Agricultural Economics Literature*, vol. 1 (Minneapolis: University of Minnesota Press, 1977), pp. 498–540.

In the United States partial and total productivity indexes for the agricultural sector are published annually by the U.S. Department of Agriculture. For the most recent data see *Changes in Farm Production and Efficiency: 1974* (Washington: U.S. Department of Agriculture, Statistical Bulletin No. 233, August 1975). Data for earlier years are available in R. A. Loomis and G. T. Barton, *Productivity of Agriculture, United States, 1870–1958* (Washington: U.S. Department of Agriculture, Technical Bulletin No. 1238, 1961). We do not know of any other national or international agency which publishes annual output, input, and partial and total productivity data for the agricultural sector.

An incomplete list of published total productivity studies for developed countries includes the following: I. F. Furniss, "Agricultural Productivity in Canada:

possible to mine a richer lode of development experience by focusing our efforts on partial productivity ratios. The significance of the partial productivity measures for development theory and policy is enhanced by interpreting this experience within the framework of the induced innovation hypothesis.[3]

In agriculture it has appeared consistent with the technical conditions of production to consider growth in land area per worker and output per worker as "somewhat independent, at least over a certain range."[4,5] Increases in output per worker can be achieved through advances in technology which enable the land area cultivated per worker to rise. This is typically achieved by substitution of more efficient sources of

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Two Decades of Gains," *Canadian Farm Economics* 5 (1970): 16–27; R. Young; "Productivity Growth in Australian Rural Industries," *Quarterly Review of Agricultural Economics* 27 (1973): 185–205; J. C. Toutain, *Le Produit de l'agriculture française, 1700 à 1958*. (Paris: L'Institut de Science Economique Appliquée, 1961); Saburo Yamada, "Changes in Conventional and Nonconventional Inputs in Japanese Agriculture since 1880," *Food Research Institute Studies*, 7 (1967): 372–413; Y. Hayami et al., *A Century of Agricultural Growth in Japan* (Minneapolis: University of Minnesota Press, 1975; Tokyo: University of Tokyo Press, 1975).

There are also several total productivity studies for less developed countries. See, for example, the studies of Taiwan (by Lee and Chen), Korea (by Ban), and the Philippines (by Chrisostomo and Barker) in Yujiro Hayami, Vernon W. Ruttan, and Herman Southworth, eds., *Agricultural Growth in Japan, Taiwan, Korea and the Philippines* (Honolulu: The University Press of Hawaii, 1979); for India by Tara Shukla, *Capital Formation in Indian Agriculture* (Bombay: Vora, 1965) and by Robert E. Evenson and Dayanatha Jha, "The Contribution of the Agricultural Research System to Agricultural Production in India," *Indian Journal of Agricultural Economics*, 27 (October–December 1973): 212–30; see also the cross section analysis for Asian countries by Saburo Yamada, *A Comparative Analysis of Asian Agricultural Productivities and Growth Patterns* (Tokyo: Asian Productivity Organization, 1975).

3. The induced innovation framework and the role of induced innovation in the process of agricultural development is elaborated in Hayami and Ruttan, *Agricultural Development*; Hans P. Binswanger and Vernon W. Ruttan, eds., *Induced Innovation: Technology, Institutions and Development* (Baltimore: The Johns Hopkins University Press, 1978). For a critical review of the theory of induced innovation see Hans P. Binswanger, "A Microeconomic Approach to Induced Innovation," *Economic Journal* 84 (December 1974): 940–58.

4. Zvi Griliches, "Agriculture: Productivity and Technology," *International Encyclopedia of the Social Sciences*, vol. 1 (New York: Macmillan and Free Press, 1968), pp. 241–45.

5. The two partial productivity measures are linked through the ratio of land area per worker. Thus:

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

where Y = output, L = labor, A = land area, and Y/L = labor productivity, A/L = land area per worker, and Y/A = land productivity.

power (animal, mechanical, electrical) and more equipment per worker. For expositional purposes it is useful to refer to those technologies which substitute for labor as *mechanical technology*. Increases in output per worker can also be achieved through increases in land productivity, if the rate of increase in output per hectare exceeds the rate of change in the number of workers per unit of land area. It is useful to refer to those technologies which increase output per hectare as *biological technology*.

In the Hayami-Ruttan induced innovation model the process of technical change can be described in terms of a series of shifts of and along innovation possibility curves.[6] In figure 10.1 (left), for example, I^*_0 represents the land/labor isoquant of the metaproduction function (MPF) in time zero. It is the envelope of less elastic isoquants such as I_0 corresponding, for example, to different types of harvesting machinery. I^*_1 is the innovation possibility curve (IPC) of time period one. A certain technology represented by I_0—a reaper, for example—is invented when a price ratio, *BB*, prevails for some time. When this price ratio changes from *BB* to *CC*, another technology represented by I_1—for example the combine—is invented. Similar inducements in the livestock sector might be represented by the invention of a succession of more highly automated animal-feeding systems.

The new technology represented by I_1 which permits an expansion in land area per worker is generally associated with higher animal or mechanical power inputs per worker. This implies a complementary relationship between land and power, which may be illustrated by the line (A,M). It is hypothesized that mechanical innovation involves the substitution of land and power for labor in response to a change in the wage rate relative to land and machinery prices.

6. We no longer use the term "metaproduction function" to describe innovation possibility curves as in the empirical work of Hayami and Ruttan (*Agricultural Development*). We now define the metaproduction function (MPF) as the envelope of the production points for the most efficient countries. It describes a technological frontier which countries now lying inside it can achieve by appropriate borrowing, adaptive research activities, and investment in human capital, extension, and rural infrastructure.

The innovation possibility curve (IPC), on the other hand, can be regarded as the envelope of neoclassical production functions which might be invented. Each number of the set of innovation possibility curves corresponds to a given budget, and the larger the budget, the closer the IPC lies to the origin of the isoquant map. The IPC corresponding to an unlimited research budget is the "scientific frontier." It is unlikely that applied research will ever be carried to that frontier, however, due to diminishing returns to research. The scientific frontier shifts with advances in the basic sciences and this shift carries with it a shift in the whole set of IPCs, but not of the MPF. However, shifts in the IPCs make shifts of the MPF easier or less costly to achieve.

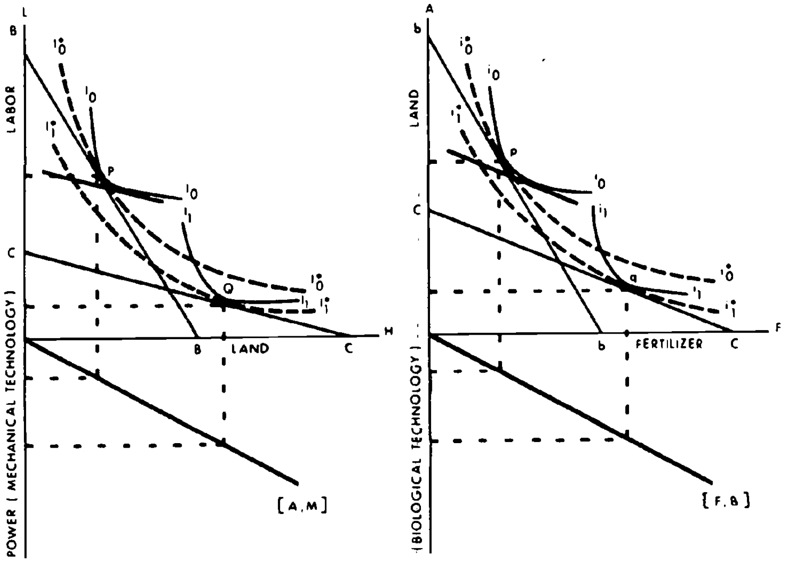


Fig. 10.1 Factor prices and induced technical change. Adopted from Hayami and Ruttan, *Agricultural Development*, p. 126.

The process of advance in biological technology is also illustrated in figure 1 (right panel), where i^*_0 represents the land fertilizer isoquant of the metaproduction function. The metaproduction function is the envelope of less elastic isoquants such as i_0 which correspond, for example, to crop varieties characterized by different levels of fertilizer responsiveness. A decline in the price of fertilizer is regarded as inducing a response by plant breeders to develop more fertilizer-responsive crop varieties, which might be described by the isoquant i_1 along the IPC i^*_1, and by farmers to adopt the new varieties as they become available.

The complementary relationship between biological technologies and fertilizer use, represented by (F,B), also extends to the protective chemicals (insecticides, herbicides) and the institutional innovations associated with the marketing and delivery of chemical inputs and services. Similarly, in livestock production a decline in the price of concentrated feedstuffs (oilcake, fish meal, urea) has induced animal nutritionists and breeders to direct their efforts to the development of feedstuffs which incorporate a higher percentage of the lower cost proteins and to select and breed for lines which have a more rapid rate of gain when fed the new rations. Complementarity between breeding and nutrition also extends to related biological and chemical technologies in the area of animal health.

10.2 Resource Endowments and Productivity Growth in Six Developed Countries

Data showing differences among countries and changes over time in output and in factor productivity, endowments, and prices for the agricultural sectors of Japan, Germany, Denmark, France, the United Kingdom, and the United States for 1880–1970 are shown in tables 10.1 and 10.2 and in figures 10.2 and 10.3. The more detailed data on which the tables and figures rest are presented in an appendix to this chapter.

In 1880 agricultural land per male worker ranged from 0.66 hectares in Japan to 25.4 hectares in the United States. Variations in the price of land and labor varied inversely with resource endowments. In the United States 181 days of labor, at hired farm labor wage rates, were required to earn enough to purchase one hectare of arable farm land.[7] In Japan it required 1,874 days. Land was approximately half as expensive relative to labor in Germany and the United Kingdom as in Japan and was even less expensive in France and Denmark.

Variations in output per hectare among countries were inversely related to land per worker and positively related to the price of land per hectare. Output per hectare was approximately 0.5 wheat units in the United States, 1.1–1.3 wheat units in the four European countries, and 2.9 wheat units in Japan. Variations in output per hectare were sufficient to only partially offset the variations in land per worker. Output per male worker varied directly with land area per worker, ranging from 1.9 wheat units in Japan to 16.2 in the United Kingdom and 13.0 in the United States.

Limitations in resource endowments were apparently not a major constraint on growth of agricultural output over the period 1880–1970, even in countries with the most limited land resource endowments. The most rapid growth was experienced by Denmark, where output grew from an index of 100 in 1880 to 459 in 1970, and the slowest by the United Kingdom, where output rose from an index of 100 to 236 during the same period. Japan, Germany, and the United States experienced roughly comparable rates of growth in output.

7. Definitions of agricultural land are not strictly comparable among countries and over time, but generally include all land in farms, including cropland used for crops, pasture, and fallow plus permanent pasture.

Arable land generally includes only cropland used for crops, pasture, and fallow. Over time land may be added to the arable land class as a result of investment in clearing, drainage, terracing, irrigation, and fencing. In 1880 such investments in land development were much more intensive in Japan, Germany, Denmark, France and the United Kingdom than in the United States. In general it is useful to think of agricultural land as a factor created by investment rather than as an "original" factor of production. Data on agricultural land area are more generally available than for arable land area. Data on land prices are more generally available for arable land.

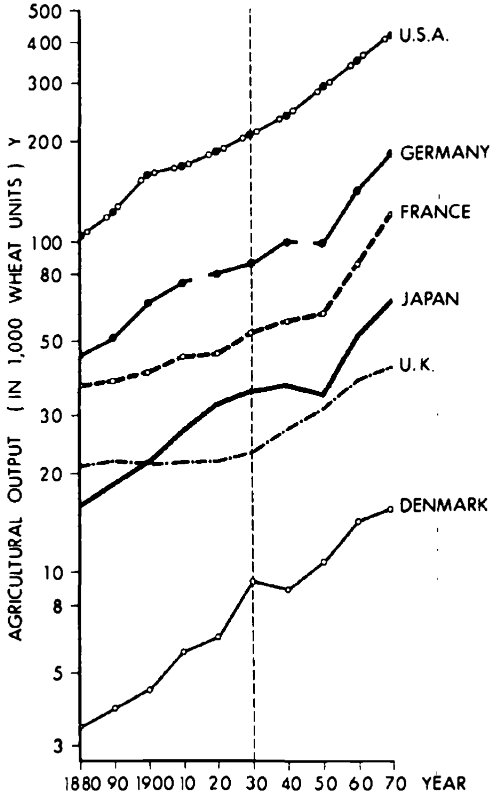


Fig. 10.2 (diagonals are land/labor ratios). Source: Appendix A. Agricultural output in six countries (in logs), 1880–1970.

In Japan agricultural output grew at 1.6% per year during 1880–1930 and at approximately the same rate during 1930–70. During the earlier period growth in output per hectare accounted for approximately 70% of the growth in total output and over two-thirds of the growth in output per worker. After 1930 growth in output per hectare rose more rapidly than total output. Increases in land area per worker became a more important source of growth in output per worker than output per hectare, particularly after 1960.[8]

In Germany agricultural output grew at approximately 1.3% per year during 1880–1930 and at 1.93% per year between 1930 and 1970. Growth in output per hectare accounted for the entire increase in output

8. For a detailed analysis of the sources of agricultural productivity growth in Japan see Yujiro Hayami et al., *A Century of Agricultural Growth*.

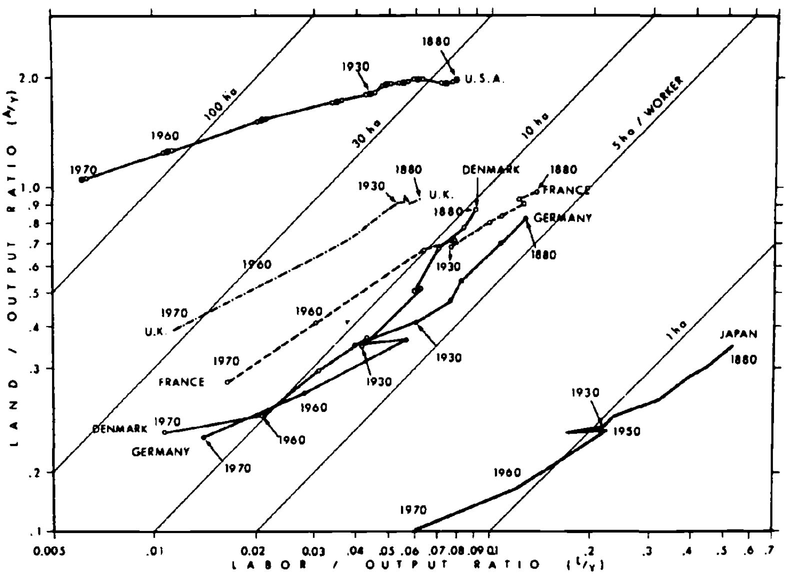


Fig. 10.3 Input-output ratios for six countries (in logs), 1880–1970

between 1880–1970. Between 1880 and 1930 output per hectare also accounted for most of the increase in output per worker. After 1930 declining employment in agriculture permitted a significant contribution to output per worker from increases in land area per worker.[9]

Among the six countries the rate of growth of both total agricultural output and output per hectare between 1880 and 1930 was highest in Denmark. It was also the only country which experienced a decline in land area per worker. Output per hectare rose more rapidly than output per worker, but slightly less rapidly than total output. Denmark was also the only country in which output per hectare rose less rapidly during 1930–70 than during 1880–1930. Output per worker continued to rise relatively rapidly, however, as a result of a reduction in the number of workers employed in agriculture.[10]

9. For an extensive review of the literature on agricultural growth in Germany see Adolf Weber, "Productivity of German Agriculture: 1850 to 1970" (Saint Paul: University of Minnesota Department of Agricultural and Applied Economics, Staff Paper 73–1, August 1973).

10. For a very useful review of Danish agricultural policies over the 1870–1970 period see Karen J. Friedman, "Danish Agricultural Policy, 1870–1970: The Flowering and Decline of a Liberal Policy," *Food Research Institute Studies* 13 (1974): 225–38. During the early part of the period, Denmark was shifting rapidly from a crop-based agriculture to a more intensive crop-livestock system.

Table 10.1 **Agricultural Output, Factor Productivity, Factor Endowments, and Factor Price Ratios in Six Countries, 1880–1970**

	Year	Japan	Germany	Denmark	France	United Kingdom	United States
Agricultural output index (Y)	1880	100	100	100	100	100	100
	1930	223	192	279	146	111	204
	1960	334	316	422	235	185	340
	1970	428	412	459	334	236	403
Agricultural output per male worker in wheat units (Y/L)	1880	1.89	7.9	10.6	7.4	16.2	13.0
	1930	4.60	16.0	24.1	13.2	20.1	22.5
	1960	8.41	35.4	47.5	33.4	45.3	88.8
	1970	15.77	65.4	94.4	59.9	87.6	157.4
Agricultural output per hectare of agricultural land in wheat units (Y/A)	1880	2.86	1.25	1.19	1.06	1.10	0.513
	1930	5.06	2.47	2.95	1.50	1.18	0.555
	1960	7.44	4.01	4.65	2.48	1.94	0.811
	1970	10.03	5.40	5.27	3.70	2.61	0.981
Agricultural land per male worker in hectares (A/L)	1880	0.659	6.34	8.91	6.96	14.7	25.4
	1930	0.908	6.46	8.18	8.80	17.0	40.5
	1960	1.131	8.83	10.21	13.44	23.3	109.5
	1970	1.573	12.20	17.92	16.19	33.5	160.5
Days of labor to buy one hectare of arable land (P_A/P_L)	1880	1,874	967	382	780	995	181
	1930	2,920	589	228	262	189	115
	1960	2,954	378	166	166	211	108
	1970	1,315	244	177	212	203	108

NOTES

One wheat unit is equivalent to one ton of wheat. The method of constructing output measures in terms of wheat units is described in Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971), pp. 308–25.

Definitions of agricultural land are not strictly comparable among countries and over time, but generally include all land in farms, including crop land used for crops, pasture, and fallow plus permanent pasture.

In Denmark the land price includes the value of agricultural land and buildings.

SOURCE: Data are from Appendix A.

Table 10.2 **Annual Rates of Change in Agricultural Output, Factor Productivity, and Factor Endowments in Six Countries, 1880–1970**

	Japan	Germany	Denmark	France	United Kingdom	United States
1880–1970						
Agricultural output (Y)	1.63	1.59	1.71	1.35	0.96	1.56
Output per worker (Y/L)	2.39	2.48	2.46	2.35	1.89	2.81
Output per hectare (Y/A)	1.40	1.64	1.67	1.40	0.96	0.72
Land per worker (A/L)	0.97	0.73	0.78	0.94	0.92	2.07
1880–1930						
Agricultural output (Y)	1.62	1.31	2.07	0.76	0.21	1.44
Output per worker ((Y/L)	1.79	1.42	1.66	1.16	0.43	1.10
Output per hectare (Y/A)	1.15	1.37	1.83	0.70	0.14	0.16
Land per worker (A/L)	0.64	0.04	−0.17	0.47	0.29	0.94
1930–70						
Agricultural output (Y)	1.64	1.93	1.25	2.09	1.91	1.72
Output per worker (Y/L)	3.13	3.81	3.47	3.85	3.74	4.98
Output per hectare (Y/A)	1.73	1.97	1.44	2.28	2.00	1.43
Land per worker (A/L)	1.38	1.60	1.98	1.54	1.71	3.50
1930–60						
Agricultural output (Y)	1.36	1.67	1.39	1.60	1.72	1.72
Output per worker (Y/L)	2.03	2.68	2.29	3.14	2.75	4.68
Output per hectare (Y/A)	1.29	1.63	1.53	1.69	1.67	1.27
Land per worker (A/L)	0.73	1.05	0.74	1.42	1.06	3.37

Table 10.2 (cont.)

	Japan	Germany	Denmark	France	United Kingdom	United States
1960–70						
Agricultural output (Y)	2.51	2.69	0.84	3.58	2.45	1.71
Output per worker (Y/L)	6.49	6.35	7.11	6.02	6.82	5.89
Output per hectare (Y/A)	3.03	3.02	1.26	4.08	3.01	1.92
Land per worker (A/L)	3.35	3.29	5.79	1.88	3.69	3.90

NOTES:

One wheat unit is equivalent to one ton of wheat. The method of constructing output measures in terms of wheat units is described in Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971), pp. 308–25.

Definitions of agricultural land are not strictly comparable among countries and over time, but generally include all land in farms, including crop land used for crops, pasture, and fallow plus permanent pasture.

In Denmark the land price includes the value of agricultural land and buildings.

SOURCE: Data are from Appendix A.

France experienced the most dramatic transition of any of the six countries between 1880–1930 and 1930–70. During the earlier period French agriculture was essentially static. Output grew at less than 0.8% per year and output per hectare at 0.7% per year.[11] Both output and productivity growth accelerated after World War II. Between 1960 and 1970 France achieved a 3.6% annual rate of growth in agricultural output (the highest among the six countries).

The United Kingdom experienced the slowest rate of growth of agricultural output and of output per worker among the six countries during 1880–1930. The rate of growth of agricultural output rose from 0.2% per year in 1880–1930 to 1.9% per year in 1930–70. Output per worker rose from 0.4 to 3.7% per year and output per hectare from 0.1 to 2.0% per year. By the 1960s the United Kingdom was beginning to make a relatively successful transition from the earlier period of stagnation to higher modern growth rates in output and productivity. The United Kingdom has, however, been somewhat less successful than France in making the transition to modern growth rates in the agricultural sector.[12]

The United States has been on a quite different growth path than the other five countries throughout the period 1880–1970. The rate of growth in total output lagged relative to Denmark and Japan in 1880–1930 and relative to Germany and France in 1930–70. Output per worker grew less rapidly than any of the other countries except Great Britain during 1880–1930, but more rapidly than any of the other countries during 1930–70. Output per hectare lagged relative to all other countries except Great Britain in 1880–1930 and relative to all countries other than Denmark during 1930–70. The distinguishing feature of U.S. agricultural development has been the primary reliance on growth in land area per worker as a source of growth in output per worker over the entire period 1880–1970.

The periods for which data are presented in tables 10.1 and 10.2, 1880–1930 and 1930–70, are not ideal for all countries. Some of the distortions involved in selecting a common date such as 1930 for "epochal" comparisons can be visualized from figure 10.2 in which the data are plotted by decades (five-year averages centered each decade). For some countries, particularly Germany, France and Japan, growth accelerated after a long period of relative stagnation that did not end

11. This apparently represented a decline in the rate of growth of output from approximately 1.1% per year during the preceding 60 years. William H. Newell, "The Agricultural Revolution in Nineteenth Century France," *The Journal of Economic History* 33 (December 1973): 710.

12. See William W. Wade, "Institutional Determinants of Technical Change and Productivity Growth: Denmark, France and Great Britain, 1870–1965," Ph.D. diss., University of Minnesota, 1973.

until after World War II. Yet selection of 1950 as a comparison base would have also introduced significant distortions.

In figure 10.3 we have brought together the long-term trends in land per unit of output, labor per unit of output, and land area per worker. The diagonal lines represent constant land/labor ratios. Movements of land/output and labor/output ratios toward the lower left-hand corner represent improvements in the two partial productivity ratios resulting from yield-increasing (or biological) and labor-saving (or mechanical) technology (see fig. 10.1). An isoquant drawn through the 1970 input-output points describes what might be regarded as a metaproduction function (MPF). The innovation possibility curve (IPC) which describes the technology that would be feasible, given existing scientific and technical knowledge, would stand farther to the left. Investment in experiment station and industrial capacity is necessary to embody the available technical and scientific knowledge in improved crop varieties, animals, chemicals, and equipment in order to make the productivity ratios described by the 1970 metaproduction function available to farmers in countries whose productivity ratios are to the right of the 1970 metaproduction function.

Several generalizations emerge from the data presented in table 10.1 and in figures 10.2 and 10.3.

First, it is clear that there were enormous differences in factor endowment ratios among the six countries in 1880, and that these differences remain large in 1970. Yet all six countries have experienced a decline in labor intensity, whether measured in terms of labor per unit of output or in terms of land per worker. During the 1880–1970 period, Denmark was the only country that experienced a sustained decline in land per worker, comparable to the decline currently being experienced in many developing countries today.

Second, those countries in which land area per worker was relatively limited in 1880 depended primarily on increases in agricultural output per hectare as a primary source of growth in agricultural output throughout most of the period since 1880. Increases in land area per worker in these countries in recent decades have been associated primarily with declines in the number of agricultural workers rather than an increase in land area.

Third, the countries in which land area per worker has been relatively limited have been able to achieve rates of growth in total output and in output per worker that have been roughly comparable to the rates achieved by countries with more favorable resource endowments. Limitation on land per worker has apparently not represented a critical constraint on capacity for growth in agricultural output.

Fourth, the growth rates of agricultural output, and of output per hectare and output per worker, have risen sharply in most countries since 1930. In some countries these higher growth rates represent the acceleration of trends that were already apparent. In others they represent a sharp transition from earlier experiences. Modern growth rates range in the neighborhood of 2–4% per year in output, over 5% per year in output per worker, and 2–4% per year in output per hectare. This is in contrast to growth rates of output and productivity that were typically less than 2% per year before 1930.

10.3 Factor Prices and Factor Use in Six Developed Countries

In this section the relationships between factor prices and the patterns of factor use associated with growth in output per hectare and in output per worker in the six countries are explored more formally than in the previous section.

10.3.1 Biological Technology

The model of biological technology outlined earlier in this chapter (fig. 10.1) suggests that a decline in the price of fertilizer relative to the price of land can be expected to induce a rise in fertilizer use per hectare as a result of a movement to the right along the short-run production function (i_0). It can also be expected to induce advances in crop technology, such as the development and introduction of more fertilizer-responsive crop varieties, which can be characterized by a new short-run production function to the right of and below i_0, along the innovation possibility curve (IPC) i^*_1, such as i_1. A strong negative relationship is hypothesized between the price of fertilizer relative to land (P_F/P_A) and fertilizer use per hectare (F/A).

Changes in the price of labor relative to the price of land are also expected to have an impact on the level of fertilizer use per hectare. As the price of labor rises relative to the price of the land, farmers can be expected to attempt to reduce labor input per unit of land by substituting fertilizer and other chemical inputs such as herbicides and insecticides for more labor-intensive husbandry practices. A decline in the price of fertilizer can also be expected to result in the substitution of chemical fertilizers produced by the industrial sector for farm-produced fertilizers such as animal manures and green manures. Thus a positive relationship is hypothesized between the price of labor relative to land (P_F/P_A) and fertilizer use per hectare (F/A).

The strong negative relationship between the fertilizer/land price ratio and fertilizer use per hectare for all six countries is confirmed in table 10.3. Given the enormous difference in the cultural and physical environments in which farmers operate and crops are produced among the six countries, and the great differences in the level of technology and social organization over time in each country, the similarity in the response coefficients in table 10.3 is truly remarkable. The implication is not only that farmers have responded in a roughly comparable manner to similar factor/price ratios, but that farmers have been able to respond in a similar manner as a result of comparable shifts in the short-run production function. This implies a similar institutional response in making more fertilizer-responsive crop varieties available to farmers by research institutions in the several countries.

A positive relationship between the price of labor relative to land and fertilizer use per hectare hypothesized above is also confirmed in table 10.3. The relationship appears to have emerged later in France and Germany than in the other four countries.

It seems reasonable to hypothesize that the model outlined in figure 10.1 has an analogy in the livestock as well as in the crop sector. In some respects concentrate feeds, particularly the protein meals such as soybean, copra, and cottonseed meal, occupy a role in livestock production similar to fertilizer in crop production. As the price of concentrate feeds has declined over time they have been increasingly substituted for forages, hay, and other roughages. The availability of lower cost concentrates has led to the development of husbandry practices and to the selection and breeding of animals to achieve earlier maturity and more rapid rates of weight gain per day and per feed unit. In countries with limited land resources such as Western European countries and Japan concentrates are usually imported, thus reinforcing their role as land substitutes.

The relationship between the price of concentrates relative to land hypothesized above is confirmed by the data presented in table 10.4. Although the estimated relationships are not entirely comparable among countries, it is clear that the rise in the use of concentrate feeds per hectare in Germany, Denmark, and the United Kingdom has been closely associated with a continuing decline in the price of concentrates relative to land. It also seems clear that as the price of labor has risen relative to the price of land in the three Western European countries, farmers have substituted imported concentrates for labor-intensive systems of livestock feed production at home.

10.3.2 Mechanical Technology

The model of mechanical technology outlined earlier suggests that the use of land per worker rises as the price of land declines relative to the price of labor. In constructing the model it was assumed that over the long run increases in the area cultivated per worker were dependent on increased use of machinery and power per worker. Thus technical changes leading to a decline in the price of machinery relative to labor would also contribute to expansion of the area cultivated per worker. Drawing on the model, a negative relationship is hypothesized between

Table 10.3 **Relationships between Fertilizer Use per Hectare and Relative Factor Prices in Six Countries**

Country and Period		Coefficient of Prices of: Fertilizer Relative to Land (P_F/P_A)	Coefficient of Prices of: Labor Relative to Land (P_L/P_A)	Coefficient of Determination (R^2)	Standard Error of Estimate (S)	Degrees of Freedom
Japan[a]	(1880–1960)	−1.274* (0.057)	0.729* (0.220)	0.974	0.0810	14
Germany[b]	(1880–1913)	−1.806* (0.009)	0.083 (0.515)	0.943	0.289	13
	(1950–68)	−0.377* (0.098)	0.799* (0.093)	0.954	0.100	15
Denmark[c]	(1910–65)	−1.120* (0.348)	0.958* (0.430)	0.87	0.310	9
France[d]	(1870–1965)	−0.950* (0.332)	−1.375*I (0.362)	0.56	0.776	17
	(1920–65)	−0.664* (0.259)	0.485 (0.733)	0.386	0.538	7
United Kingdom[e]	(1870–1965)	−1.130* (0.025)	1.010* (0.080)	0.92	0.218	17
United States[f]	(1880–1960)	−1.357* (0.102)	1.019* (0.168)	0.970	0.083	14

land per worker (A/L) and (a) the price of land relative to labor (P_A/P_L) and (b) the price of machinery relative to labor (P_M/P_L). Similarly, a negative relationship is hypothesized between the use of power (or machinery) per worker (M/L) and (a) the price of land relative to labor (P_A/P_L) and (b) the price of machinery relative to labor (P_M/P_L).

The results of the empirical tests of the hypotheses relating to mechanical technology are not as clear-cut as in the case of biological technology (tables 10.5 and 10.6). The hypothesis that land area per worker is negatively related to *both* the price of land relative to labor and the price of machinery relative to labor is confirmed only in the historical experience of the United States, the United Kingdom, and of Germany after 1950. In all six countries, except Germany during 1880–1913, land area per worker is, as hypothesized, negatively related to the price of machinery relative to labor. The hypothesis that power per worker is negatively related to both the price of land relative to labor and the price of machinery relative to labor is confirmed in all cases except those of Denmark, and France before 1920.

In *both* tests the price of land relative to labor performed less well than the price of machinery relative to labor. And where the test was run for both an early and a late period the results tended to be weakest for the early period.

A closer look at these equations reveals the following: In the power per worker equations only two coefficients have an inconsistent positive sign and only in one case is the coefficient significantly positive. Of the fourteen negative coefficients, on the other hand, ten are significantly so.

The land per worker equations represent the most puzzling case. Of the eighteen coefficients six are positive, although only two are significantly so (of the twelve negative coefficients, eight are significantly so).

SOURCES:

[a]Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971).

[b]Adolf Weber, "Productivity in German Agriculture: 1850 to 1970," University of Minnesota Department of Agricultural and Applied Economics, Staff Paper 73-1, August 1973, p. 23.

[c]William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France and Great Britain, 1870–1965," Ph.D. diss., University of Minnesota, 1973, p. 128.

[d]Wade, "Institutional Determinants," pp. 134, 136.

[e]Wade, "Institutional Determinants," p. 149.

[f]Hayami and Ruttan, *Agricultural Development*, p. 132, Regression (W15).

NOTE: Equations are linear in logarithms. The numbers inside the parentheses are the standard errors of the estimated coefficients.

*Significant at 0.5 level (one-tail test); *I*: inconsistent with simple induced innovation hypothesis.

Table 10.4 Relationship between Use of Feed Concentrates per Hectare and Factor Prices

Country and Period	Coefficient of Prices of: Concentrates Relative to Land (P_C/P_A)	Coefficient of Prices of: Labor Relative to Land (P_L/P_A)	Coefficient of Determination (R^2)	Standard Error of Estimate (S)	Degrees of Freedom
Germany[a] (1880–1913)	−3.333*	3.974*	0.712	0.337	31
(net oil cake imports)	(0.569)	(1.221)			
(1950–68)	−1.567*	2.381*	0.973	0.337	15
	(0.254)	(0.255)			
Denmark[b] (1880–1925)	−0.680*	0.494*	0.590	0.030	7
(all imported concentrates per hectare)	(0.300)	(0.124)			
United Kingdom[c]	−3.642*	3.634*	0.970	0.137	17
(1870–1965) (all concentrates per hectare	(0.331)	(0.331)			

NOTE: Equations are linear in logarithms. The numbers inside the parentheses are the standard errors of the estimated coefficients.

SOURCES:

[a]Adolf Weber, "Productivity Growth in German Agriculture: 1850 to 1970," University of Minnesota Department of Agricultural and Applied Economics, Staff Paper 73-1, August 1973, p. 23.

[b]William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France and Great Britain, 1870–1965," Ph.D. diss., University of Minnesota, 1973, p. 128.

[c]"Institutional Determinants," p. 149.

*Significant at $P = 0.05$ (one-tail test).

Furthermore, five of the six positive coefficients are the coefficients of the land/labor price. This raises a question of whether some systematic irregularity prevents this price effect from manifesting itself in the expected manner. This behavior may be due to a fundamental or exogenous labor-saving bias in the process of technical innovation, particularly in Japan, France, and the United Kingdom. Such a bias could result from biased technology transfer opportunities by these countries from countries with higher land-labor ratios such as the United States.

The analysis presented in this section supports the hypothesis that changes in factor use in each country have been responsive to changes in relative factor prices. Fertilizer use per hectare has been responsive to the price of fertilizer and of labor relative to the price of land. And two complementary inputs—power per worker and land per worker—have been responsive to the prices of land and machinery relative to labor.

Table 10.5 Relationship between Land per Worker and Relative Factor Prices in Six Countries

Country and Period	Coefficients of Prices of: Land Relative to Labor (P_A/P_L)	Coefficients of Prices of: Machinery Relative to Labor (P_M/P_L)	Coefficient of Determination (R^2)	Standard Error of Estimate (S)	Degrees of Freedom
Japan[a]	0.159*I*	−0.219	0.751	0.016	14
(1880–1960)	(0.110)	(0.041)			
Germany[b]	−0.264*	0.066**I*	0.393	0.012	31
(1880–1913)	(0.066)	(0.018)			
	−0.177	−0.476*	0.975	0.083	15
(1950–68)	(0.139)	(0.087)			
Denmark[c]	0.148*I*	−0.357*	0.910	0.030	9
(1910–65)	(0.084)	(0.072)			
France[d]	0.398**I*	−0.088	0.323	0.189	17
(1870–1965)	(0.202)	(0.141)			
	0.050*I*	−0.498*	0.460	0.164	7
(1920–65)	(0.226)	(0.166)			
United Kingdom[e]	−0.129*	−0.139*	0.610	0.041	17
(1870–1925)	(0.033)	(0.070)			
	0.279*I*	−0.065	0.440	0.110	6
(1925–65)	(0.159)	(0.256)			
United States[f]	−0.451*	−0.486*	0.828	0.084	14
(1880–1960)	(0.215)	(0.120)			

NOTE: *Land* here means arable land per male worker in Japan, Denmark, France, and the United Kingdom; agricultural land per male worker in Germany and the United States.

[a]Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971). Land per worker (W7); power per worker (W9).

[b]Adolf Weber, "Productivity Growth in German Agriculture: 1850 to 1970," University of Minnesota Department of Agricultural and Applied Economics, Staff Paper 73-1, August 1973, p. 24. Land per worker, regressions 6 and 7; power per worker, regressions 4 and 5.

[c]William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France and Great Britain, 1870–1965," Ph.D. diss., University of Minnesota, 1973, p. 128.

[d]William W. Wade, "Institutional Determinants," pp. 134, 136.

[e]Wade, "Institutional Determinants," p. 149.

[f]Hayami and Ruttan, *Agricultural Development*, p. 130. Land per worker (W1); power per worker (W5).

*Significant at $P = 0.05$ (one-tail test); *I*: inconsistent with simple induced innovation hypothesis.

Table 10.6 **Relationship between Power Per Worker and Relative Factor Prices in Six Countries**

Country and Period	Coefficients of Prices of: Land Relative to Labor (P_A/P_L)	Coefficients of Prices of: Machinery Relative to Labor (P_M/P_L)	Coefficient of Determination (R^2)	Standard Error of Estimate (S)	Degrees of Freedom
Japan[a]	−0.665*	−0.299	0.262	0.219	14
(1880–1960)	(0.261)	(0.685)			
Germany[b]	−0.238*	−0.607*	0.978	0.069	31
(1880–1913)	(0.070)	(0.020)			
	−0.234	−1.358*	0.979	0.213	15
(1950–68)	(0.329)	(0.207)			
Denmark[c]	1.494*I*	−3.180*	0.830	0.370	9
(1910–65)	(1.010)	(0.861)			
France[d]	1.704**I*	−0.705	0.160	0.810	17
(1870–1965)	(0.880)	(0.614)			
	−0.443	−2.460*	0.550	0.705	7
(1920–65)	(0.976)	(0.715)			
United Kingdom[e]	−1.120*	−1.090*	0.810	0.075	17
(1870–1965)	(0.295)	(0.527)			
United States[f]	−1.279*	−0.920*	0.827	0.187	14
(1880–1960)	(0.475)	(0.266)			

*Significant at $P = 0.05$ (one-tail test); *I*: inconsistent with simple induced innovation hypothesis.

Note: *Power* here means horsepower per male worker, except in Germany where machinery investment per worker was employed.

[a]Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971). Land per worker (W7); power per worker (W9).

[b]Adolf Weber, "Productivity Growth in German Agriculture: 1850 to 1970," University of Minnesota Department of Agricultural and Applied Economics, Staff Paper 73–1, August 1973, p. 24. Land per worker, regressions 6 and 7; power per worker, regressions 4 and 5.

[c]William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth: Denmark, France and Great Britain, 1870–1965," Ph.D. diss., University of Minnesota, 1973, p. 128.

[d]William W. Wade, "Institutional Determinants," pp. 134, 136.

[e]Wade, "Institutional Determinants," p. 149.

[f]Hayami and Ruttan, *Agricultural Development*, p. 130. Land per worker (W1); power per worker (W5).

10.4 Agricultural Productivity Differences among Countries, 1970

In this section we explore productivity differences in agriculture among developed and developing countries on different continents for 1970, and attempt to identify sources of productivity differences among countries.

First, we measure the labor and land productivities in agriculture for forty-one countries in 1970. These countries are classified into three groups on the basis of the relative dominance of biological and mechanical technology in their development experience. Second, the different technological patterns of the three country groups are analyzed in relation to the resource endowments in each country group. Third, the labor and land productivity ratios in agriculture for each country are related to the extent of industrialization or development in the nonagricultural sector of each country. Fourth, interrelationships between labor or land productivity ratios and various factor input ratios are explored on the basis of correlation analysis to illustrate the sources of productivity differences among countries. Attention has been given to the same power/labor ratios and fertilizer/land ratios that were employed in the time series analysis. Fifth, human capital variables are related to productivity differences among countries. And finally, intercountry cross section production function estimates based on the 1970 data are made. The coefficients are used to account for differences in labor and land productivities among countries that can be attributed to variations in factor inputs and shift variables.

10.4.1 Differences in Labor and Land Productivities among Countries

We have referred to agricultural technologies which increase output per worker by substitution of more efficient sources of power and equipment per worker as *mechanical technology* and to agricultural technologies which increase output per hectare of agricultural land area as *biological technology*. By comparing differences in land and labor productivities among countries we can classify the several countries by the intensity with which they employ the two types of technologies.

The land and labor productivities presented in table 10.7 were estimated as agricultural output per hectare of agricultural land area and per male worker in terms of wheat units for 1970 using the data compiled in Appendix B. The intercountry differences in these productivity ratios are large. Measured in wheat units, agricultural output per hectare ranged from 0.11 in Paraguay to 13.63 in Taiwan. Output per male worker ranged from 2.4 in India to 198.2 in New Zealand.

Figure 10.4 is an intercountry cross-section map of the labor and land productivity ratios for 1970. The wide scatter of countries on the

Table 10.7 Factor Productivity and Input–Output Ratios in Forty-one Countries, 1970

Country	Output per male worker in wheat units Y/L (1)	Number of male workers per wheat unit of output L/Y (2)	Output in wheat units per hectare of agricultural land Y/A (3)	Hectares of agricultural land to produce one wheat unit A/Y (4)
Argentina	51.0	0.0196	0.36	2.813
Australia	186.3	0.0054	0.12	8.607
Austria	59.0	0.0169	3.00	0.333
Bangladesh	2.9	0.3501	3.00	0.334
Belgium	116.2	0.0086	9.52	0.105
Brazil	12.0	0.0835	0.83	1.211
Canada	136.1	0.0073	0.76	1.324
Chile	18.2	0.0549	0.45	2.238
Colombia	10.3	0.0974	1.03	0.976
Denmark	86.3	0.0116	5.07	0.197
Finland	64.2	0.0156	2.63	0.381
France	65.9	0.0152	3.52	0.284
Germany, Fed.	70.1	0.0143	5.37	0.186
Greece	19.6	0.0510	1.89	0.529
India	2.4	0.4251	1.32	0.757
Ireland	34.2	0.0292	1.88	0.531
Israel	72.0	0.0139	3.66	0.273
Italy	32.0	0.0313	3.83	0.261
Japan	15.3	0.0654	10.30	0.097
Mauritius	12.1	0.0827	6.80	0.147
Mexico	8.2	0.1213	0.40	2.528
Netherlands	84.8	0.0118	10.75	0.093
New Zealand	198.2	0.0050	1.55	0.646
Norway	61.3	0.0163	3.54	0.283
Pakistan	2.6	0.3858	1.33	0.750
Paraguay	5.2	0.1928	0.11	9.221
Peru	10.6	0.0939	0.33	3.077
Philippines	4.5	0.2226	1.98	0.504
Portugal	14.1	0.0708	2.21	0.452
South Africa	16.7	0.0598	0.21	4.706
Spain	19.8	0.0506	1.46	0.687
Sri Lanka	4.2	0.2394	2.67	0.375
Surinam	27.3	0.0366	9.87	0.101
Sweden	85.5	0.0117	3.03	0.330
Switzerland	47.9	0.0209	3.52	0.284

Table 10.7 (continued)

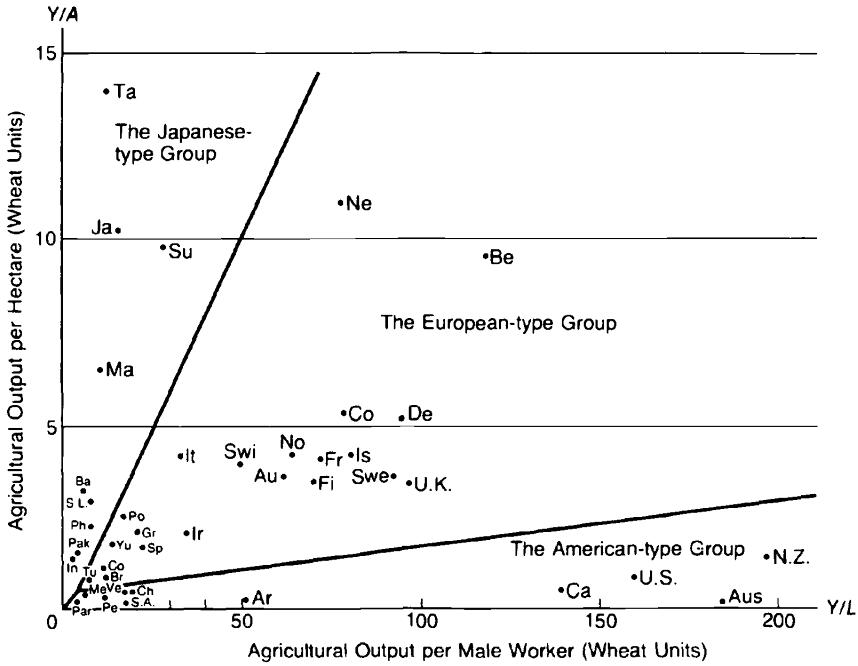
Country	Output per male worker in wheat units Y/L (1)	Number of male workers per wheat unit of output L/Y (2)	Output in wheat units per hectare of agricultural land Y/A (3)	Hectares of agricultural land to produce one wheat unit A/Y (4)
Taiwan	10.2	0.0984	13.63	0.073
Turkey	8.3	0.1200	0.83	1.199
U.K.	90.6	0.0110	2.63	0.380
U.S.	160.2	0.0062	0.98	1.024
Venezuela	16.8	0.0596	0.45	2.222
Yugoslavia	11.5	0.0873	1.52	0.660

SOURCE: Data from Appendix B.

map can be classified into three distinct resource endowment groupings on the basis of the relative importance of the two partial productivity ratios in each country's agriculture: (*a*) the countries in the new continents (and South Africa) such as New Zealand, the United States, and Australia, where labor productivity is relatively high and land productivity relatively low; (*b*) the countries in Asia (and a few in Africa and South America) such as Taiwan and Japan, where land productivity is relatively high and labor productivity relatively low; and (*c*) the countries in Europe (and a few in the Near East and South America) such as the Netherlands, Belgium, and Denmark, where labor and land productivities lie between the extremes of the other two groups.[13]

Within each group there is a scatter of countries extending out from the origin. Each scatter or path seems to reflect the long-term development process in agricultural systems characterized by alternative resource endowments. In figure 10.3 we have observed changes in labor/output ratios and land/output ratios in the course of agricultural development from 1880 to 1970 for the six developed countries. For purposes of

13. This classification is the same as based upon 1960 data in Hayami and Ruttan, *Agricultural Development*, p. 69. We have found that no fundamental changes occurred in relative international characteristics of agriculture with respect to the relative levels and combination of labor and land productivities for individual countries from 1960 to 1970. Israel and Turkey, included in the third group with European countries here, were classified into the "West Asia Mediterranean Coast Agricultural Region" in Saburo Yamada, *Comparative Analysis*. This implies that the characteristics of agriculture in the Mediterranean coast of the Near East are fundamentally the same as those of European countries.



Argentina	Ar	Netherlands	Ne
Australia	Aus	New Zealand	N.Z.
Austria	Au	Norway	No
Bangladesh	Ba	Pakistan	Pak
Belgium	Be	Paraguay	Par
Brazil	Br	Peru	Pe
Canada	Ca	Phillipines	Ph
Chile	Ch	Portugal	Po
Colombia	Co	South Africa	S.A.
Denmark	De	Spain	Sp
Finland	Fi	Sri Lanka	S.L.
France	Fr	Surinam	Su
Germany, Federal	Ge	Sweden	Swe
Greece	Gr	Switzerland	Swi
India	In	Taiwan	Ta
Ireland	Ir	Turkey	Tu
Israel	Is	United Kingdom	U.K.
Italy	It	United States	U.S.
Japan	Ja	Venezuela	Ve
Mauritius	Ma	Yugoslavia	Yu
Mexico	Me		

Fig. 10.4 International comparison of labor and land productivities, 1970

comparison, figure 10.4 was converted into figure 10.5 in which productivity ratios were reversed and expressed as land per unit of output and labor per unit of output. The diagonal lines represent constant land/labor ratios. The percentage ratio of nonagricultural employment to the total economically active population is shown in parentheses. The lines make it easy to distinguish the different resource endowment ratios among countries. The nonagricultural employment percentage represents a crude indicator of the general level of development.

A comparison of figure 10.5 with figure 10.3 indicates remarkably similar patterns between the three general historical paths (of the United States, Japan, and the European countries) in figure 10.3 and the distribution of countries within each of the three groups classified in figure 10.4. In general, (*a*) the distribution of the countries in the new continents (and South Africa) falls along the historical path of the United States; (*b*) the distribution of the Asian countries (and Mauritius and Surinum) falls along the historical path of Japan; and (*c*) the distribution of the European countries (and Israel, Turkey, Brazil, and Colombia) falls along the historical paths of the four European countries. We identify the three country groups as American, Japanese, and European-type groups, respectively. These types reflect the result of different resource endowments and choice of technology paths (between mechanical and biological technology) among countries.

10.4.2 Resource Endowments and Technology Preference

We have earlier hypothesized that resource endowments as reflected by land/labor ratios are of major importance in the choice of technology, or in inducing a country to follow a particular path of technological development. In countries where land is abundant relative to labor it is efficient to emphasize mechanical technology relative to biological technology. In countries with reverse endowment conditions, biological technology would be more efficient than mechanical technology. In the former countries, the price of land is cheap relative to labor. It is expensive in the latter.

In countries of the American type, where the land/labor ratio was relatively high, ranging from 21 hectares per male worker (Mexico) to 180 (Canada) (even leaving aside the exceptional case of 1604 in Australia), the hectares used to produce one wheat unit of output (land/output ratio) ranged from 0.65 (New Zealand) to 9.22 (Paraguay), and the man years per wheat unit of output (labor/output ratio) ranged from 0.005 (New Zealand) to 0.193 (Paraguay). The land/labor ratio of the United States was 25 in 1880 and 164 in 1970, which roughly corresponds to the present range of resource endowment conditions of the group. The labor/output ratio of the United States in 1880 was 0.077, roughly comparable with 0.060 of Venezuela and 0.094 of

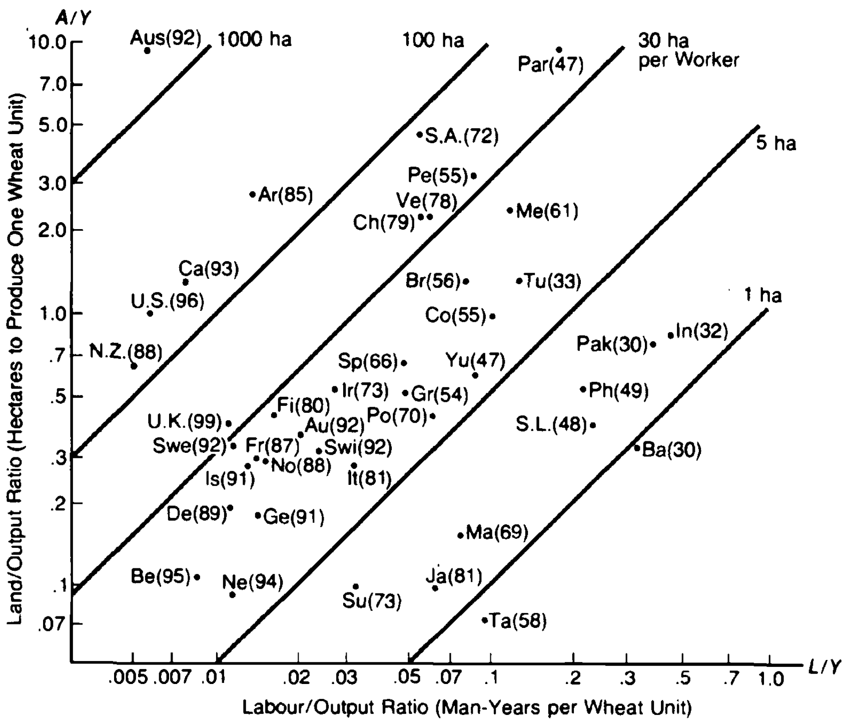


Fig. 10.5 International comparison of labor/output and land/output ratios (in logs), 1970. Source: table 10.7. Note: Diagonal lines represent land/labor ratios and numbers in parentheses are percentage ratios of nonagricultural workers to the total economically active population.

Peru in 1970. The land/output ratio of the United States in 1880 was 1.95, also roughly comparable with 2.22 of Venezuela and 2.24 of Chile in 1970.[14] In those countries of the group, such as New Zealand, the United States, and Canada, where land/labor ratios were all over 100 hectares per worker, labor/output ratios were as small as 0.005–0.117 (very high labor productivity) but land/output ratios were as high as 0.65–1.32 (low land productivity) in 1970. It is evident that mechanical technology was strongly emphasized relative to biological technology in this group.

Contrary to the above group, in the countries of the Japanese type, where the land/labor ratio was very low, ranging from only 0.8 hectares (Taiwan) to 2.8 (Surinam), the technological choice was reversed. Labor/output ratios were high, ranging from 0.037 (Surinam) to 0.425 (India), but land/output ratios ranged from 0.07 (Taiwan) to 0.76 (India). The ratios of land/labor, land/output, and labor/output in Japan in 1880 were 0.66, 0.35, and 0.53, respectively, which were roughly comparable with the present situations of India, Pakistan, Bangladesh, Philippines, and Sri Lanka. The technological leaders in this group, Taiwan and Japan, certainly chose to follow a path which gave a strong priority to biological technology relative to mechanical technology.

In the European countries, where the land/labor ratio ranged from 6.4 (Portugal) to 34.4 (The United Kingdom), intermediate between the two extreme groups, labor/output and land/output ratios were also intermediate. The ratios ranged from 0.009 and 0.11 of Belgium to 0.120 and 1.20 in Turkey. In 1880, land/labor ratios were 6.3, 7.0, 8.9, and 14.7 hectares for Germany, France, Denmark, and the United Kingdom, respectively. These are comparable with many of the present European-type countries. And labor/output and land/output ratios of the four countries in 1880 were also comparable with the ratios in countries such as Turkey, Brazil, Colombia, and Yugoslavia in 1970.

Thus resource endowments must be considered as an important factor in determining both the choice of technology and inducing an efficient path of technological development over time.

10.4.3 Industrialization and Technological Improvements

It is generally accepted that the potential for agricultural development in a country is strongly conditioned by the level of domestic industrial or nonagricultural development.[15] The close association between agri-

14. The 1880 data cited here are from tables 10.1 and 10.2. See also Appendix B.

15. See Hayami and Ruttan, *Agricultural Development*, pp. 74–81; Yujiro Hayami, "Industrialization and Agricultural Productivity: An International Comparative Study," *The Developing Economies*, 6 (September 1968): 3–21; and

cultural and industrial development holds not only for historical time sequences of individual countries but is also apparent in the intercountry cross-sectional phenomena.

Movements of land/output and labor/output ratios toward the lower left-hand corner along the same diagonal lines in figure 10.5 represent improvements in the two partial productivities under similar resource endowments of land/labor ratio conditions. And the figure reveals that the ratio of nonagricultural employment, an indicator of industrialization, for individual countries is highly correlated with movements toward the lower left-hand corner in each country group: from 47% (Paraguay) to 96% (the United States) in the American-type group; from 30% (Pakistan) to 81% (Japan) in the Japanese-type group; and from 33% (Turkey) to 95% (Belgium) in the European-type group. This association of technological improvements with industrialization in intercountry cross sections is consistent with the historical experience of the six developed countries.

Industrialization or growth of the nonagricultural sector can contribute to improvements in agricultural technology in many ways. Industrial development can (*a*) reduce the cost of modern agricultural inputs, such as fertilizer, chemicals, and machinery, produced by the industrial sector; (*b*) expand the rate of growth in the demand for farm products; and (*c*) increase the demand for labor. Educational development in rural areas can make farmers more productive. Advancement of knowledge in general sciences can increase the productivity of applied research in the agricultural sciences and technology. Investment in physical and institutional infrastructure develops productivity of resources devoted to agricultural production and marketing.

In the following paragraphs we will investigate interrelationships among the labor and land productivities and various factor-factor ratios to search for sources of intercountry differences in agricultural productivity. Special attention will be given to the intensity in the use of modern technical inputs as measured by power relative to labor and fertilizer relative to land.[16]

Bruce F. Johnston and Peter Kilby, *Agriculture and Structural Transformation: Economic Strategies in Late Developing Countries* (New York: Oxford University Press, 1975), for related discussions on industrialization and agricultural productivity.

16. Only physical farm inputs will be taken into account because of data availability in the study. See Hayami and Ruttan, *Agricultural Development*, pp. 90–101 for an intercountry comparative study for 1960 on sources of agricultural productivity differences including the effect of both education and modern physical inputs. See also Yujiro Hayami, et al., *Century of Agricultural Growth* for an in-depth analysis of the Japanese case.

10.4.4 Productivity Differences and Factor Proportions

Among the countries along the same land/labor ratio lines (fig. 10.5), both labor/output and land/output ratios tended to be smaller in developed countries than in less developed countries. This is because, as noted earlier, the two partial productivities are not independent but are linked through the land/labor ratio.[17] Figure 10.6 shows this relation more explicitly than figure 10.5. A higher level of labor productivity (the diagonal lines toward the upper right) can be achieved through either an increasing of the land/labor ratio, higher land productivity, or both. Developed countries in the American-type group have achieved high labor productivity principally by increasing their land/labor ratios. Those in the Japanese-type group have achieved higher labor productivity through higher land productivity. The European-type countries have experienced a more balanced pattern of productivity growth. However, the United Kingdom and Sweden are closer to the American pattern and the Netherlands and Belgium closer to the Japanese pattern.

The sources of productivity differences can be divided into two types. As noted earlier, differences in labor productivity are associated with differences in the adoption of mechanical technology. Differences in land productivity are associated with differences in the development and adoption of biological technology.

The most typical source of increase in labor productivity is more intensive use of mechanical power by farmers. The substitution of mechanical power for labor permits a rise in both the land/labor ratio and in output per worker. Figure 10.7 confirms the close association of tractor horsepower per male worker (tractor/labor ratio) and agricultural output per male worker (labor productivity) in both 1960 and 1970. In 1970 the correlation coefficient (r) was .93 for all countries —though only tractors and garden tractors (in terms of horsepower) were counted as farm machinery. The coefficient was particularly high (.96) for the American-type group. It was somewhat lower (.93) for the European-type group and even lower (.84) for the Japanese-type group.

This implies that the role of mechanical technology is critically important in achieving high levels of labor productivity. Mechanization is economically efficient, however, only in situations characterized by a high land-labor ratio and a high wage-land price ratio. The hypothesis that the use of power (or machinery) per worker is negatively related to both the price of land relative to labor and of machinery relative to labor was generally confirmed in the time series analysis. The hypothesis seems also to be plausible in international, cross-sectional perspec-

17. See footnote 5.

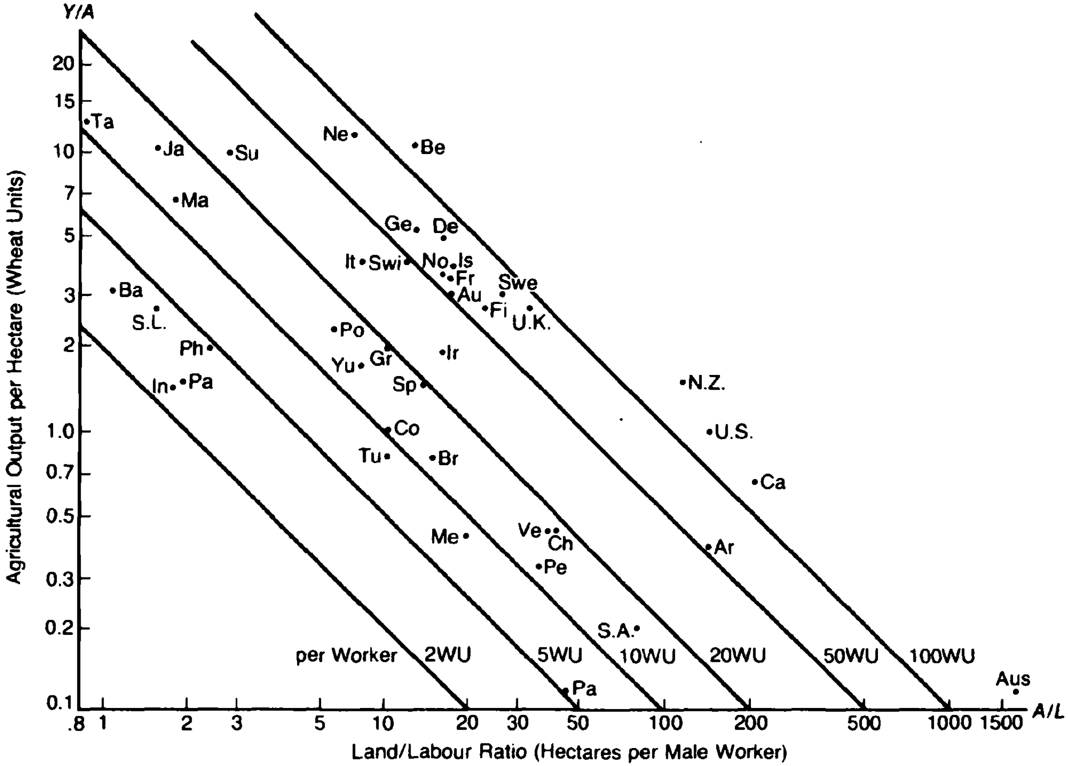


Fig. 10.6 International comparison of land/labor ratios, land productivity, and labor productivity (in logs), 1970. Source: table 10.7 and table 10.A.2. Note: Diagonal lines represent constant output/labor ratios.

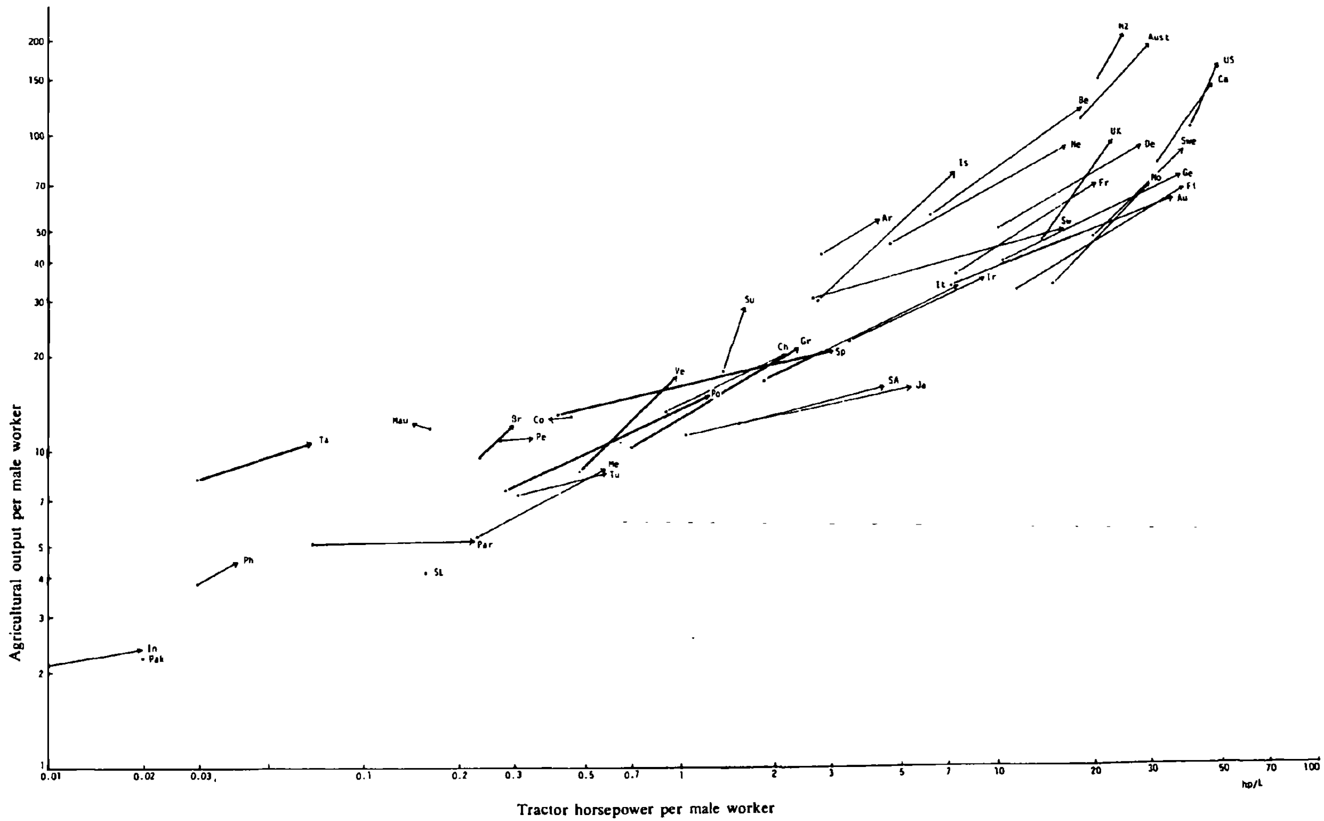


Fig. 10.7 Intercountry cross section comparisons of changes in agricultural output per male worker and in tractor horsepower per male worker, 1960–70 (in logs). Sources: table 10.7 and table 10.A.2 for 1970; and Hayami and Ruttan, *Agricultural Development*, for 1960.

tive. Because of the lack of international land price data, we could not test the relationship as rigorously in the cross section as in the time series analysis. However, a regression of tractor horsepower per male worker against the price of machinery relative to labor in figure 10.8 does confirm the plausibility of the hypothesized relationship in the cross section data. The correlation coefficient was 0.83. The elasticity coefficient was statistically significant in the following simple regression.

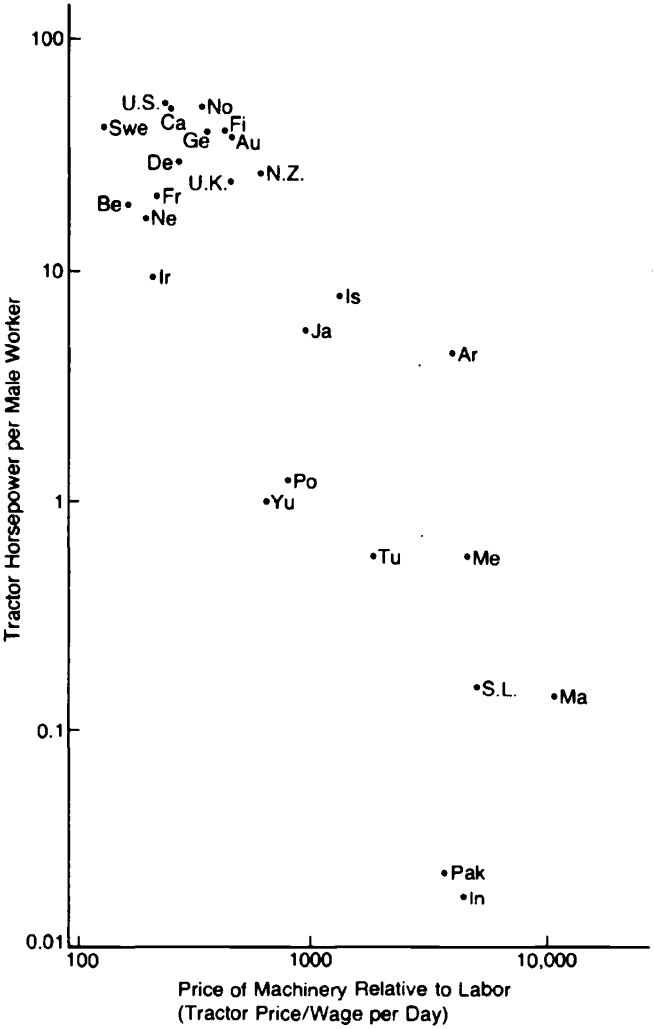


Fig. 10.8 International comparison of tractor horsepower per male worker and price of machinery relative to labor (in logs), 1970. Sources: tables 10.A.2 and 10.A.3.

$$\ln (M/L) = 12.230 - 1.605 \ln (P_M/P_L)$$
$$(0.221)$$
$$R^2 = 0.695$$

(here 1.605 is significant at $P = 0.01$ [one-tail test]), and where M, L, P_M, and P_L represent machinery horsepower, the number of male farm workers, tractor price, and wage rate per day.

In developed countries—as New Zealand, United States, Canada, and Australia—where the ratio was more than 100 hectares per worker, the tractor/labor ratio was in the 27–53 horsepower range per worker. But in developing countries such as Mexico, Peru, and Venezuela, where the land/labor ratio was 20–40, the tractor/labor ratio was merely 0.4–1.0. The initial resource endowment conditions of the respective countries are clearly a primary source of the present differences in land/labor ratios among countries. It should be noted, however, that even in the United States it was only 25 hectares per worker in 1880. This is roughly equivalent to the level in many of the present developing countries in the American-type group. In these countries the development of mechanical technology is already a critical factor in expanding the land area that is cultivated per worker and hence in raising labor productivity (see fig. 10.7).

Unfortunately, we have not been able to explore the effect of relative factor prices on choice of biological technology in the cross section analysis. Biological technology refers not to a single technique but to an associated bundle of various technologies, particularly the use of improved varieties with more fertilizer and better irrigation. In this analysis we continue the tradition of using fertilizer as a proxy for the whole complex of biological technology. We again emphasize that this represents a gross oversimplification, though one convenient for expositional purposes.

The association between fertilizer consumption per hectare of agricultural land and land productivity levels is shown in figure 10.9. In both 1960 and 1970 there was a close association between fertilizer use per hectare and output per hectare. In 1970 the correlation coefficient was .89 for all forty-one countries. It was .81 for the American-type group, .89 for the European-type group, and .86 for the Japanese-type group. Thus it was relatively high for each resource endowment grouping. In contrast to the case of tractor use, the intensive use of fertilizer is important in raising land productivity not only in the biological-technology–oriented Japanese-type countries, but also even in the mechanical-technology–oriented countries of the American-type group. The lower level of labor productivity of developing countries such as Paraguay, Mexico, and Peru in the American-type group is not only due to their

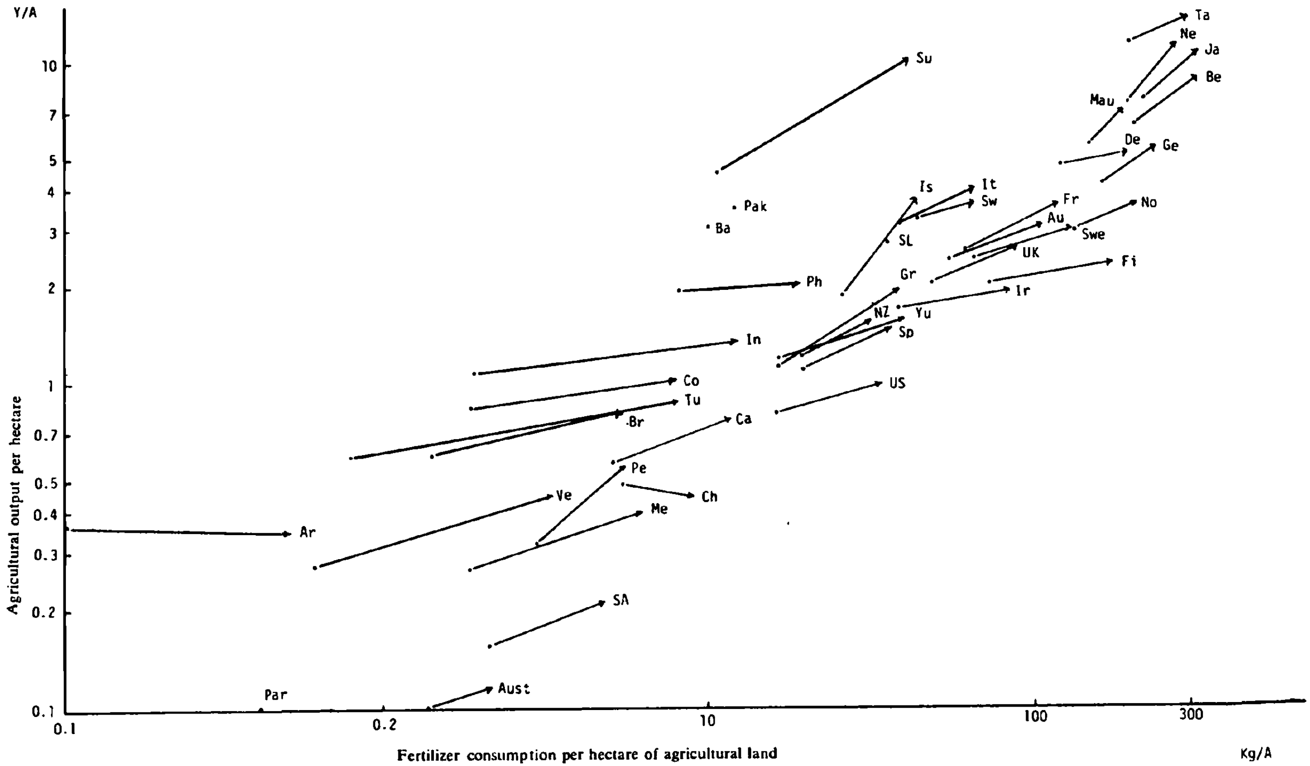


Fig. 10.9 Intercountry cross section comparison of changes in agricultural output per hectare and in fertilizer consumption per hectare of agricultural land, 1960–70 (in logs). Source: table 10.7 and table 10.A.2, and Hayami and Ruttan, *Agricultural Development*, for 1960.

lower land/labor ratios but is also due to low land productivity. In these, as in other countries, low land productivity is associated with low levels of fertilizer use. The low level of fertilizer use typically reflects the low level of biological technology that is available to farmers and/or relatively high fertilizer prices.

Comparing each country's relative position in figure 10.7 with the same country's position in figure 10.9, we can observe the contrast among the three types of resource endowment groupings. For instance, the tractor/labor ratio was the highest but the fertilizer/land ratio was moderate for the United States. This contrast was exactly the reverse for Japan. For developed countries such as Belgium and the Netherlands in the European-type group, both ratios were relatively high.[18]

Both fertilizer and tractors are industrial products. Intensity in the use of these inputs is generally associated with the level of industrialization in individual countries. This results in a high correlation between the level of use of the two inputs in the intercountry cross section comparisons. The correlation coefficients are .84 for all countries, .93 for the American-type group, .91 for the European, and .81 for the Japanese-type group. This implies that higher labor productivity is associated not only with more tractor use per worker but also with more fertilizer use per worker ($r = .92$ between labor productivity and the fertilizer/labor ratio for all countries, .89 for the American-type group, .94 for the European-type group, and .83 for the Japanese-type group). In a technical sense, fertilizer is a substitute for land. But such a high correlation between the two variables confirms the important role of other current inputs (including agricultural chemicals, feed, and fuel) in addition to fertilizer in increasing labor productivity. This is of course consistent with the Japanese experience where yield increases have until recently represented a dominant source of labor productivity.

Factor-factor combinations among labor, land, fertilizer, and tractor horsepower have been discussed in relation to intercountry differences in labor or land productivities. In addition, farm capital stock such as livestock and perennial plants are also important agricultural resources that are used in agricultural production. Differences in the intensity of such capital inputs relative to labor or land (capital/labor or capital/land ratio) among countries must also account, in part, for the productivity differences among the several countries.

18. In Hayami and Ruttan, *Agricultural Development*, fig. 4–2, p. 72, both ratios were compared internationally for 1960. Comparing the 1960 results with the present study for 1970, relative positions of the United States and Japan were unchanged; however, relative levels of tractor/labor ratio in the developed European countries have become closer to the United States level during 1960–70 mainly due to considerable decreases in agricultural labor in those countries.

However, interrelationships between these ratios and productivity levels are not as clear-cut as in the cases of tractors and fertilizer. The correlation coefficient was .77 between the livestock/labor ratio and the labor productivity ratio and .73 between the livestock/land ratios and the land productivity ratio for all countries. It was also quite low on a regional basis (except for .86 for the first relationship in the American-type group). In the case of perennial plants, it was even lower. The ratio was .48 between perennial plants/land ratio and land productivity ratio for all countries. There was almost no correlation between perennial plants/labor ratio and labor productivity. Although such a low correlation might be due to the crudeness of our estimates for perennial plants, we conclude that productivity gaps among countries are much more closely associated with differences in the use of modern technical inputs produced in the industrial sector such as tractors and fertilizer than with differences in these forms of farm-produced capital stock.

The aggregate stock of fixed farm capital, which includes all three types of tangible fixed capital analyzed in this study (livestock, perennial plants, and tractors), is closely associated with the labor and land productivity ratios.[19] Excluding eight countries where data on perennial plants were not available, the correlation coefficient between the capital/labor ratio and the labor productivity ratio was .76 for all countries. But it was .91 for the American-type group and only .42 for the Japanese-type group (and .64 for the European-type group). This seems to imply that capital intensity is a more important factor accounting for differences in labor productivity in the American-type group, but less important in the Japanese-type group. The role of current inputs such as fertilizer would be more critical in determining agricultural productivity for the Japanese-type group. We can observe such differences among the different country groups in figure 10.10.

The correlation coefficient between the capital/land ratio and the land productivity ratio was .88 for all countries (excluding the eight countries). It was .86 in the European country group, .78 in the American-type group, and .57 in the Japanese-type group. In European countries, land productivity has been a more important concern in agricultural production than in the American-type countries. In the Japanese-type group, the contribution of capital intensity to land productivity

19. Farm capital stock estimated here includes livestock, tractors, and agricultural perennial plants only. Thus the coverage of the estimates is incomplete. Aggregation was made using Japan weights due to data availability. The estimates are therefore in terms of Japanese price relatives. See Appendix B for the estimating procedures and data. Because of the lack of data, the value of perennial plants was not included in the estimated capital stock for Bangladesh, Canada, Finland, Mauritius, Norway, Pakistan, Sweden, and the United Kingdom.

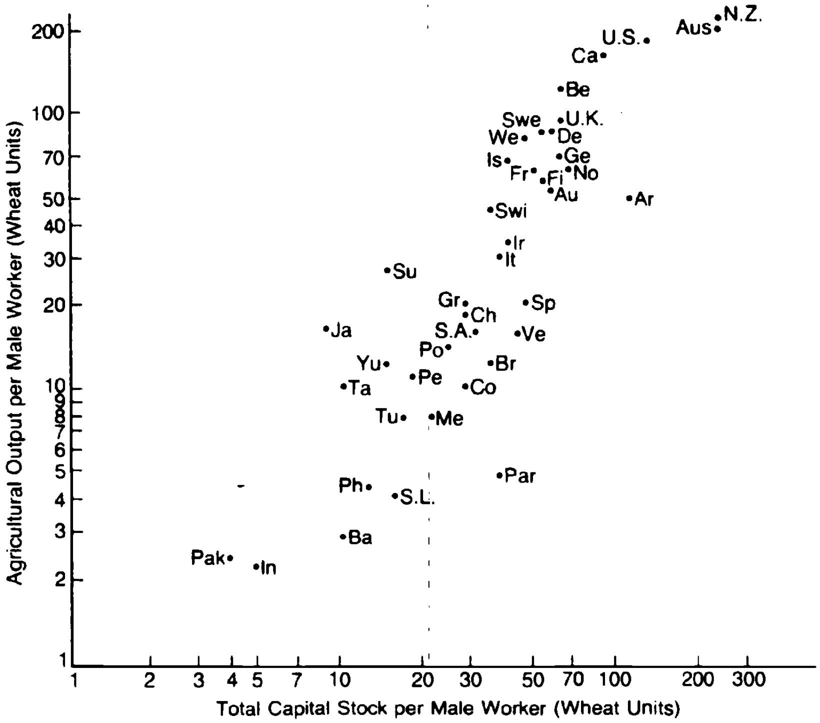


Fig. 10.10 International comparison of capital stock and agricultural output per male worker (in logs), 1970. Source: table 10.7 and table 10.A.2.

is only slightly more important than labor intensity, judging from the magnitude of the correlation coefficient.[20]

The data presented in figure 10.11 suggest that in spite of the continued differences in intensity of factor use among the three country groups there was a tendency for both the Japanese-type group and the American-type group to converge toward the European pattern of factor use between 1960 and 1970. The countries in the Japanese-type group which had achieved the highest level of fertilizer use per hectare in 1960, such as Japan, Taiwan, and Sri Lanka, experienced more rapid growth in tractor horsepower per worker than in fertilizer use per hectare between 1960 and 1970. In contrast, the countries in the American-type

20. It is not to deny the importance of capital stock in agricultural production in Asia. According to Yamada, *Comparative Analysis*, in countries where capital intensity is high, such as Japan, Taiwan, Malaysia, Hong Kong, and Sri Lanka, agricultural productivity is also relatively high.

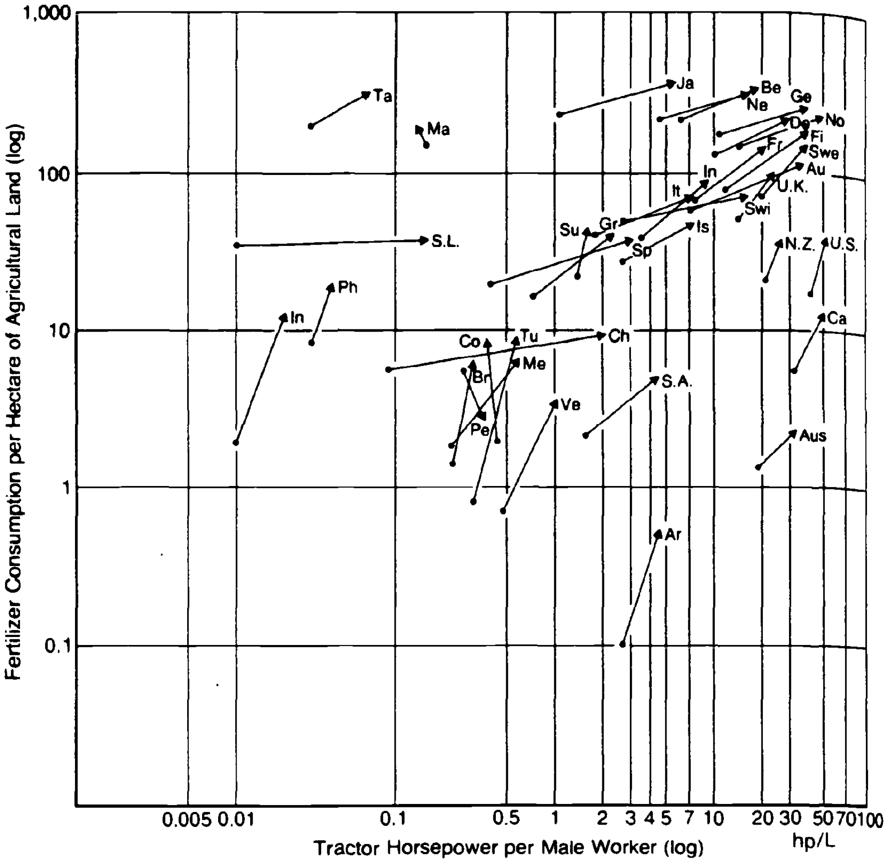


Fig. 10.11 Intercountry cross section comparison of changes in tractor horsepower per male worker and in fertilizer consumption per hectare of agricultural land, 1960–70 (in logs). Source: table 10.7 and table 10.A.2 for 1970; Hayami and Ruttan, *Agricultural Development*, for 1960.

group experienced more rapid increases in fertilizer use per hectare than in tractor horsepower per worker.

The effects of these changes in factor use and factor productivity during the 1960–70 decade were not completely consistent with our expectations. The data presented in figure 10.7 suggest that the incremental impact of additional inputs of tractor horsepower on output per worker between 1960 and 1970 was greater in the countries that had already achieved high levels of mechanization than in countries characterized by a lower level of mechanization. Similarly, the data presented in figure 10.9 suggest that the incremental impact of additional fertilizer consumption per hectare between 1960 and 1970 was greater in the countries that had already achieved high levels of fertilizer use per hectare.

This result is somewhat surprising since it was anticipated that the new "seed-fertilizer" or "green revolution" technology that was introduced in many developing countries in the mid and late 1960s would result in rapid growth in both fertilizer use and output per hectare in countries where appropriate biological technology had previously not been available. One possible explanation is that the diffusion of new biological technology had not proceeded fast enough by 1970 to exert a major impact on the patterns of productivity growth, and that the 1960–70 trends in factor use and factor productivity simply reflected the continuing momentum of historical differences in the access to mechanical and biological technology between the more advanced and the developing countries. A second alternative is that the smaller incremental contribution of increases in the use of mechanical power per worker and of fertilizer per hectare was due to lags in the introduction of complementary components in the bundle of techniques which constitutes an efficient biological or mechanical technology.

This point is illustrated with reference to the new seed-fertilizer technology in figure 10.12.

Curve A_0D_0 represents the envelope of response curves (the metaproduction function) relating fertilizer use per hectare (F/A) to yield per hectare (Y/A) for countries A, C, and D in period 0. The response curve A_0 is characteristic of a country which has access to a relatively low level of biological technology in period 0. The response curves C_0 and D_0 are characteristic of countries which have access to more advanced levels of biological technology in period 0.

The differences between the several response curves could reflect, for example, different levels of adoption of irrigation technology. The curve a_0d_0 represents the relationship between the level of biological technology and the optimum level of fertilizer use per hectare in each country. The effect of the introduction, between period 0 and period 1, of an advance in the level of biological technology, such as more fertilizer-responsive crop varieties, is to shift the individual country response curves up and to the right. If there is complementarity between irrigation technology and the new seed-fertilizer technology, the effect is a biased shift in the individual response curves. The countries characterized by low levels of biological technology in 1960 were in a weaker position to take advantage of the new seed-fertilizer technology than countries characterized by higher levels of biological technology in 1960. The new metaproduction function is shown as A_1C_1 and the new biological tech-

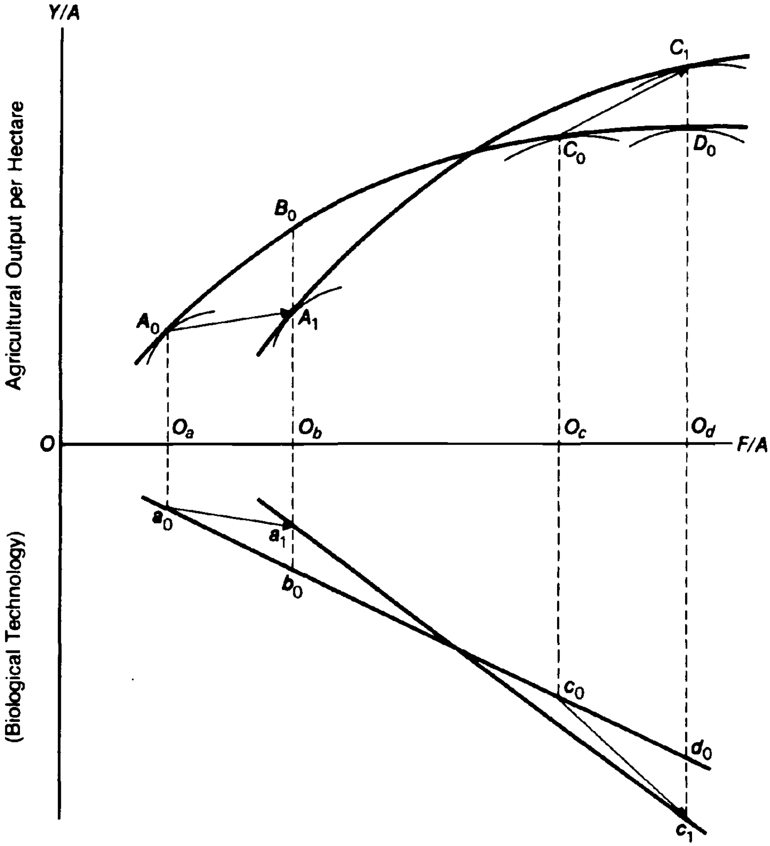


Fig. 10.12 Impact of fertilizer-using bias on fertilizer use and output per hectare

nology function is shown as a_1c_1. The changes in fertilizer use and yield per hectare presented in figure 10.9 are consistent with a shift in the metaproduction function such as that illustrated in figure 10.12.

10.4.5 Productivity Differences and Human Capital

So far, factor-factor combinations among conventional inputs have been discussed in relation to intercountry differences in labor or land productivities. In addition, the levels of nonconventional inputs such as education, research, and extension act to shift the production function and hence contribute to intercountry productivity differences in agriculture. As the proxies for these human capital inputs, two kinds of measures of education levels were related to the productivity differences:

(*a*) the school enrollment ratio for the primary and secondary levels, which represents the level of general education (GE), and (*b*) the number of graduates from agricultural colleges per 10,000 male farm workers, which stands for the level of education in the agricultural sciences and technology (TE). General education is hypothesized to influence the efficiency with which farmers make decisions with respect to the use of resources and their acquisition of skill in the use of resources. Agricultural graduates represent the major source of technological personnel for agricultural research and extension. In an attempt to convert the enrollment ratio into a measure of the stock of education, a series of averages of the data for 1960, 1965, and 1970 was used. And to check a possible lag in the effect of the general education on the adult farmers, the 1955–60–65 averages series were applied alternatively.

The association between these human capital measures and labor productivity levels in 1970 is shown in figures 10.13 and 10.14. The correlation coefficient between TE and labor productivity was relatively high —.86 as compared to .74 between $GE_{60\text{-}65\text{-}70}$ and labor productivity and .76 between $GE_{55\text{-}60\text{-}65}$ and labor productivity for all forty-one countries. It is interesting that the correlation coefficients were even higher within the different three-country groups: the correlation coefficient between TE and labor productivity was .92 for the American-type group, .85 for the European-type group, and .79 for the Japanese-type group; the correlation coefficient between $GE_{55\text{-}60\text{-}65}$ and labor productivity was .92 for the American-type group, .87 for the European-type group, and .78 for the Japanese-type group (see figs. 10.13 and 10.14).

The relationships between the human capital measures and land productivity are not as clear for the entire group of forty-one countries (fig. 10.15). The correlation coefficients between land productivity and $GE_{55\text{-}60\text{-}65}$ and $GE_{60\text{-}65\text{-}70}$ were only .22 and .17, respectively. One possible reason for such a low correlation is that the human capital measures employed here were normalized on a per capita base but not on a unit land area base. Even so, when we disaggregated by productivity groupings there was a reasonably high correlation by the three country groups: the correlation coefficient between $GE_{55\text{-}60\text{-}65}$ and land productivity was .58 for the American-type group, .77 for the European-type group, and .67 for the Japanese-type group, respectively (fig. 10.16).

The relationships between TE and land productivity are similar: the correlation coefficient was .54 for the American-type group, .72 for the European-type group, and .78 for the Japanese-type group, while it was only .21 for all forty-one countries.

These observations support the proposition that human capital as measured by general and technical education plays a significant role in increasing land productivity as well as in increasing labor productivity under conditions of similar labor/land endowments.

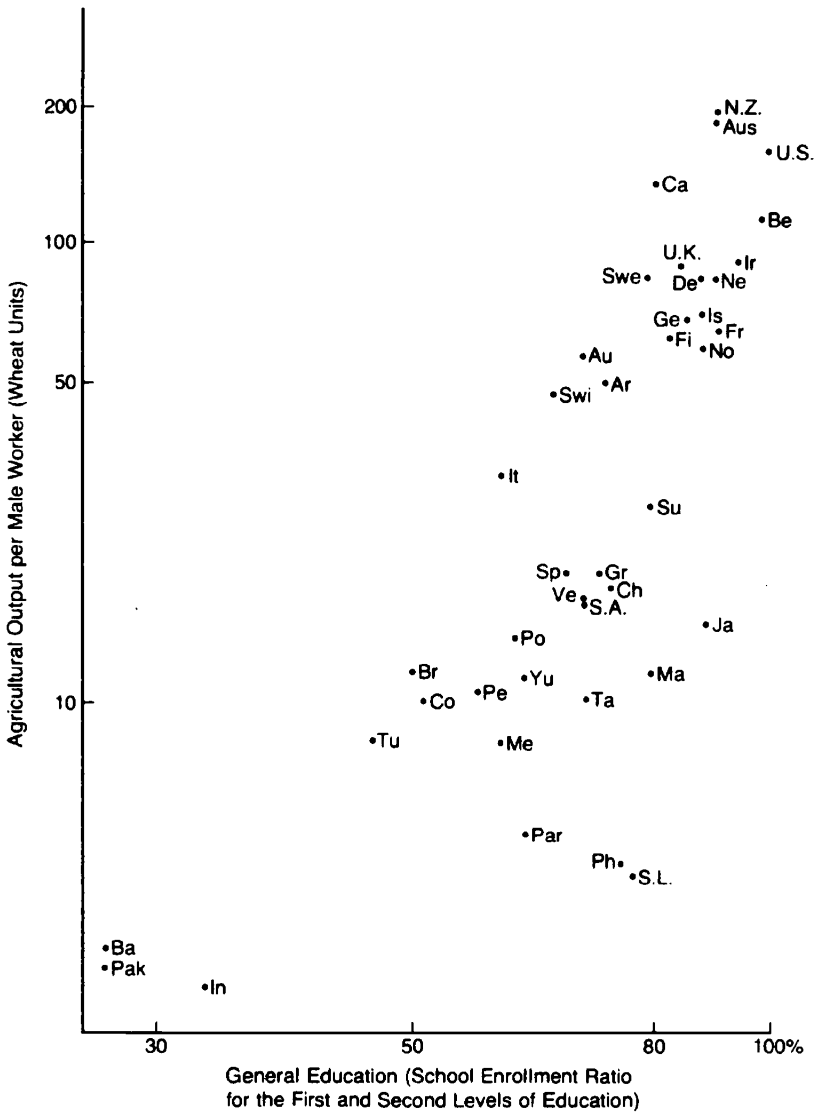


Fig. 10.13 International comparison of general education and agricultural output per male worker (in logs), 1970. Source: table 10.7 and table 10.A.3. Note: The 1955–60–65 average is used for the general education statistics.

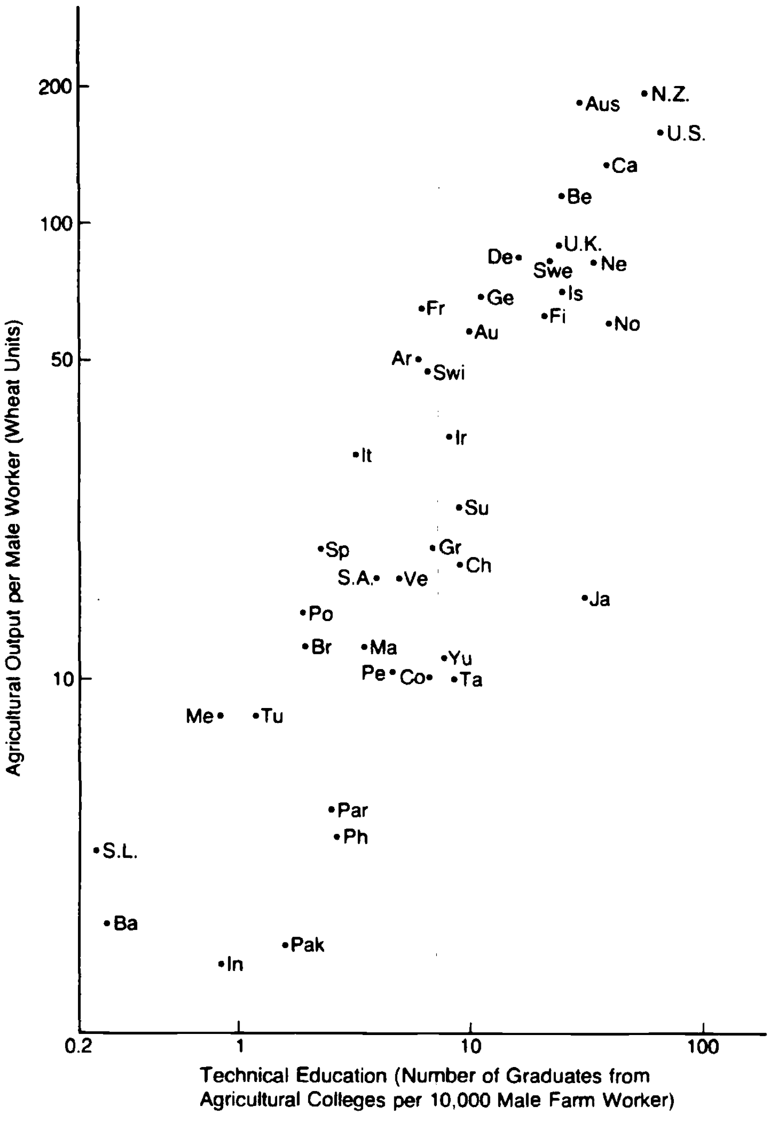


Fig. 10.14 International comparison of technical education and agricultural output per male worker (in logs), 1970. Source: table 10.7 and table 10.A.3.

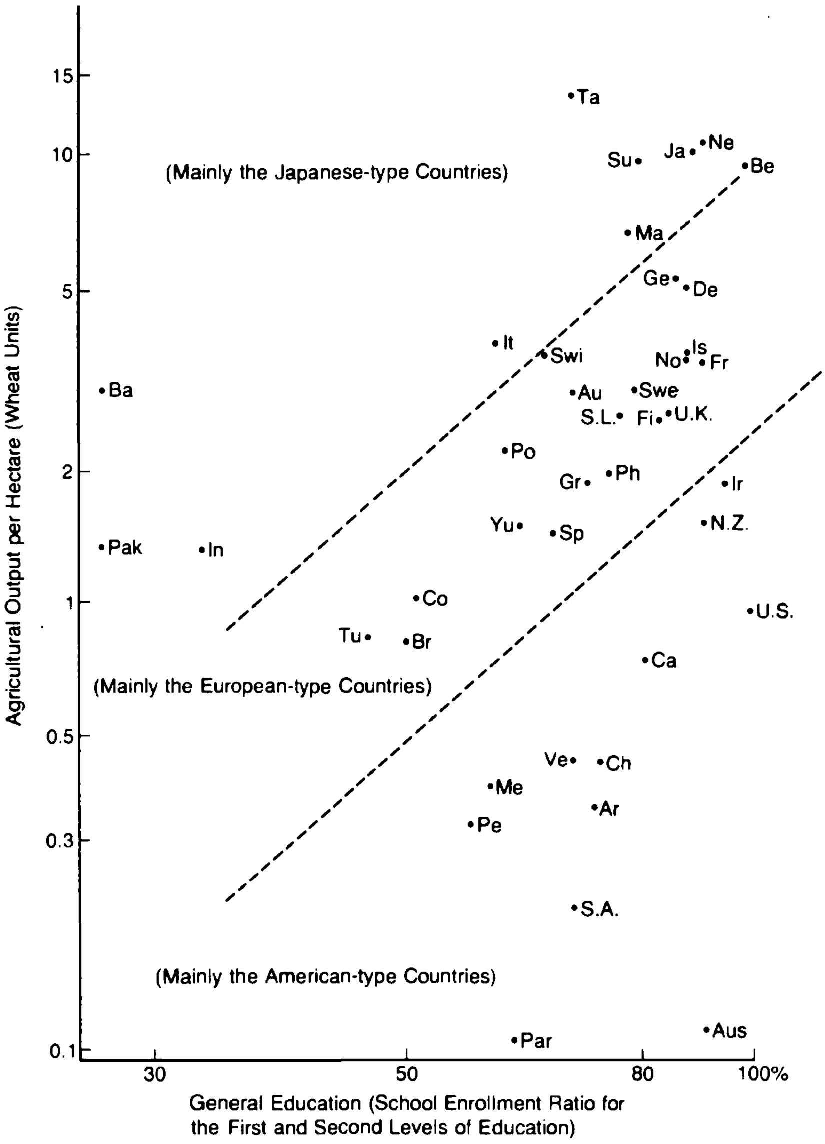


Fig. 10.15 International comparison of general education and agricultural output per hectare of agricultural land (in logs), 1970. Source: table 10.7 and table 10.A.3. Note: The 1955–60–65 average is used for the general education statistics.

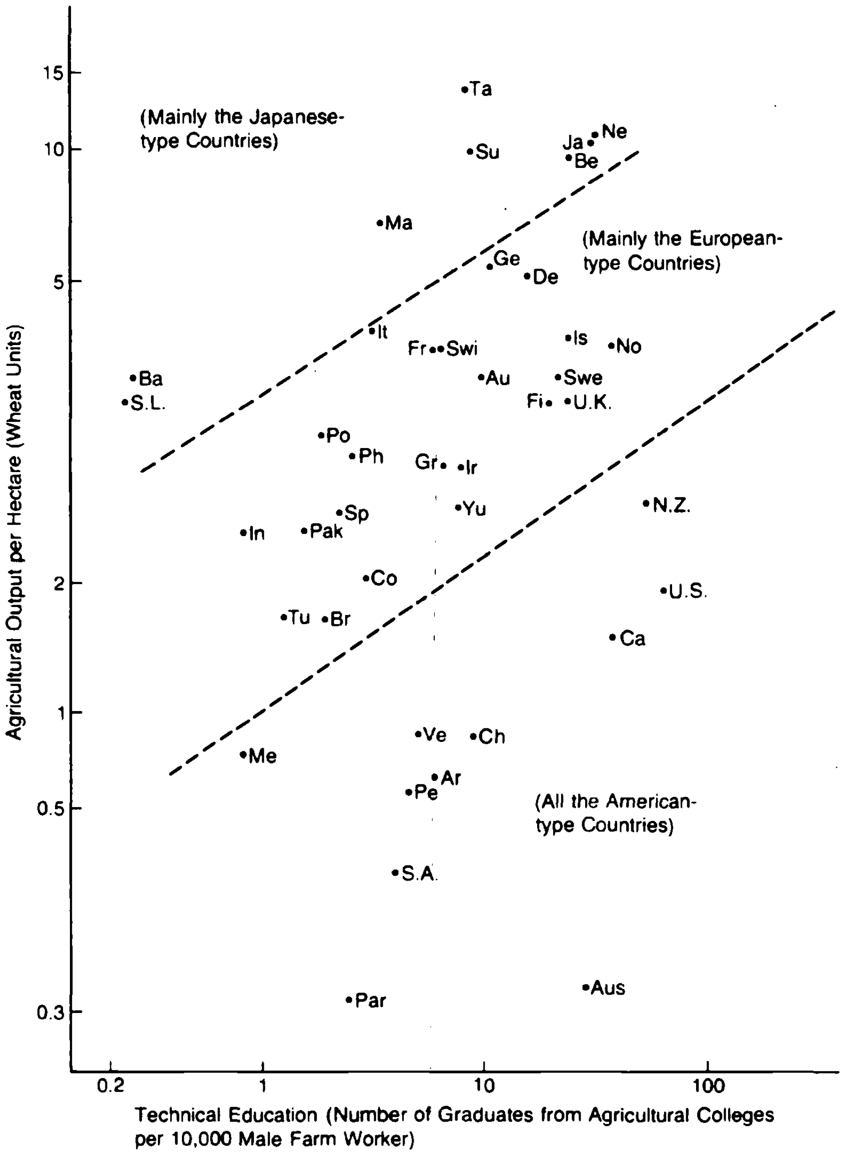


Fig. 10.16 International comparison of technical education and agricultural output per hectare of agricultural land (in logs), 1970. Sources: table 10.7 and table 10.A.3.

10.5 Accounting for Productivity Differences among Countries

In the section above, we have explored interrelationships between productivity differences and each of the various factor endowment ratios. Each factor-factor combination, however, affects productivity in association with other factor combinations. To identify the sources of the productivity differences among countries more precisely, cross-country production functions were estimated. The sources of the productivity differences were then analyzed following the accounting method employed by Hayami and Ruttan.[21] The material presented in this section should be regarded as preliminary at this time since we are continuing to experiment with functional form and specification.

The production function is of the Cobb-Douglas (linear in the logarithms) form. The coefficients of the Cobb-Douglas production function can be interpreted as indicating the elasticities of production with respect to inputs and the relative importance of each factor as a source of difference in output among countries. Differences in agricultural output per worker (or per hectare of land) can be accounted for by differences in the level of various inputs per worker (or per hectare of land) weighted with the respective production coefficients.

The specific variables used in the study include such conventional inputs as labor, land, livestock, fertilizer, and machinery, and the nonconventional shift variables, general education (the school enrollment ratio for the primary and secondary levels) and technical education (the number of graduates per 10,000 male farm workers).[22] All variables are for 1970 except for the school enrollment ratio of which two series of the averages for 1955, 1960, and 1965, and for 1960, 1965, and 1970 were used in order to convert the enrollment ratio into a measure of the stock of general education and to check for a possible lag in the

21. Though the data used in this study were new for 1970, the method for the accounting is the same as chapter 5, "Sources of Agricultural Productivity Differences among Countries," in Hayami and Ruttan, *Agricultural Development*, pp. 86–107. See the chapter for discussions on the conceptual framework and details of the method and related studies. It is recognized that use of the Cobb-Douglas production function is not entirely consistent with the factor complementarity hypothesis outlined in figure 10.1. One solution to this problem, the estimation of individual factor augmentation coefficients, has been employed by Hans Binswanger, "Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review* 64 (December 1974): 964–76.

22. Perennial plants were also included in some specifications of production function estimate. Its estimated coefficient was statistically significant at $P = 0.005$ (one-tail test) but some other coefficients became negative in sign and statistically nonsignificant. Besides the variable data were lacking for the eight countries as mentioned in note 19. Hence it was excluded from the production function employed in analysis and from accounting for productivity differences.

effect of general education to the first and second levels on the farmers' decision-making and technical capacity.

Three kinds of regression models were estimated: (*a*) an ordinary unrestricted aggregate production function for the agricultural sector; (*b*) a production function on a per worker basis in which output per worker was regressed on conventional inputs per worker and on nonconventional inputs; and (*c*) a production function on a per hectare basis in which output per hectare was regressed on conventional inputs per hectare and on nonconventional inputs.[23] In (*b*) and (*c*) constant returns to scale were assumed and the sum of the coefficients of conventional inputs was held equal to one. The estimates were based on the data for all forty-one countries.[24] The results are summarized in table 10.8. In general the production coefficients estimated under different specifications were statistically significant except those for land and general education.[25]

The *fertilizer coefficients* were all statistically significant. They ranged from .23 to .32. This is well above the range of .09 to .16 estimated by Hayami and Ruttan for 1960.[26] The results of the regression analysis are consistent with the impression, based on figure 10.8, that between 1960 and 1970 the incremental contribution of fertilizer to output per hectare was greatest in those countries that were already using relatively high levels of fertilizer per hectare. In contrast to the fertilizer coefficient, no statistically significant *land coefficients* were estimated for 1970. This is in contrast to the 1960 results obtained by Hayami and Ruttan which typically fell in the .06–.07 range. It seems reasonable to hypothesize that at least part of this change in the fertilizer coefficient relative to the coefficient for land was due to a combination of decline

23. The production function was estimated for various groups of countries: for instance, (*a*) the American, Japanese, and European-style factor endowment groups, and (*b*) highly developed, moderately developed, and less developed country groups. Also, various regression specifications were applied in addition to those listed in table 10.8. However, most of the results were implausible because some of the coefficients were negative in sign and/or statistically nonsignificant.

24. In Hayami and Ruttan's work, the sample size of estimated regressions was 37 or 38. For comparison purposes, Bangladesh, Pakistan, Paraguay, Portugal, and Yugoslavia were also dropped from some 1970 regressions. However, there were no significant differences in the estimated coefficient in regression of the same specification between the sample sizes of forty-one and thirty-six.

25. It is possible that the low coefficient for land in 1970 may also be due in part to the high intercorrelation between land and livestock. In 1970 the correlation coefficient between land and livestock was .92. High intercorrelation was also observed between fertilizer and tractor horsepower (.84) and between labor and livestock (.76).

26. Hayami and Ruttan, *Agricultural Development*, p. 93 (Table 5–1).

Table 10.8 **Estimates of the International Cross Section Production Function for Agriculture, 1970**

	Regression[a]								
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
Labor	.209** (.063)	.317** (.086)	.325** (.090)	.265[b]	.389[b]	.398[b]	.265** (.062)	.389** (.068)	.398** (.079)
Land	.026 (.074)	.024 (.075)	.019 (.074)	.019 (.079)	.011 (.077)	.005 (.075)	.019[b]	.011[b]	.005[b]
Livestock	.247** (.102)	.223* (.109)	.234* (.104)	.244* (.109)	.230* (.113)	.244* (.106)	.244* (.109)	.230* (.113)	.244* (.106)
Fertilizer	.312** (.082)	.247** (.088)	.243** (.089)	.323** (.087)	.237** (.090)	.226** (.090)	.323** (.087)	.237** (.090)	.226** (.090)
Machinery	.117* (.067)	.118* (.070)	.113* (.066)	.149* (.069)	.133* (.072)	.126* (.067)	.149* (.069)	.133* (.072)	.126* (.067)
General education 60–65–70 average		−.034 (.329)			.075 (.334)			.075 (.334)	
55–60–65 average			.075 (.316)			.264 (.299)			.264 (.299)
Technical education		.140* (.076)	.135* (.075)		.170* (.076)	.155* (.076)		.170* (.076)	.155* (.076)
Coef. of det.	.947	.952	.952	.923	.934	.935	.919	.930	.932
Sum of coef. for conventional inputs	.911	.929	.934	1.000	1.000	1.000	1.000	1.000	1.000

in the price of fertilizer and an induced shift in the metaproduction function associated with the introduction of the new seed-fertilizer "green revolution" technology between 1960 and 1970.

The *labor coefficients* for 1970 were almost all statistically significant. They ranged, in the several regressions, from .21 to .40. This was lower than the estimates obtained by Hayami and Ruttan for 1960, which ranged from .34 to .47. In contrast to the decline in the labor coefficients there was a tendency for the machinery coefficients to rise between 1960 and 1970. The *machinery coefficients* ranged from .11 to .15 in 1970, in contrast to .10 or below in 1960. Thus the results of the regression analysis are consistent with the impression, based on figure 10.7, that between 1960 and 1970 the incremental contribution of mechanization to output per worker was greatest in those countries that were already the most highly mechanized. The results suggest a machinery-using bias in technical change leading to increased substitution of machinery for labor between 1960 and 1970.

The *livestock coefficient* for 1970 ranged from .11 to .15. This was approximately in the same range as the Hayami-Ruttan results for 1960.

The *general education coefficient* was negative in Q2 where the averages of 1960, 1965, and 1970 were used. In the case where the averages of 1955, 1960, and 1965 were used, the general education coefficient ranged from .08 to .26, though it was still not statistically significant. The coefficient of the other nonconventional variable, technical education, however, was significant statistically, ranging from .14 to .17. This was the same level as .14–.18 for 1960 estimated by Hayami and Ruttan while the general education coefficient level estimated here was lower than the range of .29–.32 that was estimated for 1960 on a national aggregate basis as in the present study by Hayami and Ruttan. We do not know why the general education variable performed less effectively in the 1970 cross section study than in the earlier 1960 cross section study by Hayami and Ruttan.

SOURCE: Based on the data from Appendix B.

NOTES: Equations are linear in logarithms. The standard errors of the estimated coefficients are inside the parentheses.

[a]In regressions Q1, Q2, and Q3, both output and factor inputs are expressed in actual units. These three equations are estimated on an unrestricted basis.

In regressions Q4, Q5, and Q6, the output and the conventional inputs (i.e., land, livestock, fertilizer, and machinery) are expressed in per-worker terms. The sum of the conventional coefficients was restricted to equal one.

In regressions Q7, Q8, and Q9, the output and the conventional factor inputs (i.e., labor, livestock, fertilizer, and machinery) were expressed on a per-hectare basis and the sum of coefficients was restricted to equal one.

[b]Implicit coefficient.

*Significant at $P = 0.05$ (one-tail test).

**Significant at $P = 0.01$ (one-tail test).

In spite of the limitations in the 1970 cross section regression results, the following set of production elasticities was adopted for accounting purposes: .35 for labor, .02 for land, .25 for livestock, .25 for fertilizer, .13 for machinery, .25 for general education, and .15 for technical education.[27] We would feel more comfortable about the growth accounting exercise, however, if the land coefficients were higher while the fertilizer coefficients were lower and the general education coefficients were more firm.

Accounting for productivity differences was attempted between the United States and five different countries: (*a*) Argentina, a less-developed country in the American-type group; (*b*) Japan, a developed and India a less-developed country in the Japanese-type group; and (*c*) Denmark, a developed and Turkey a less-developed country in the European-type group.

The sources of differences in labor productivity between the United States and these five countries are presented in table 10.9. Each column compares the percentage differences in agricultural output per worker between each country and the United States, with the linear combinations of percentage differences in input variables weighted by the specified production elasticities. The index with the output-per-worker difference set equal to 100 is shown in parentheses.

The difference in agricultural output per worker between the United States and India was 98%; between the United States and Turkey the difference was 95%; and between the United States and Argentina the difference was 68%. The difference was 90% in the case of Japan and 46% in the case of Denmark. The four conventional variables included

27. The adopted set of coefficients for accounting in the Hayami and Ruttan work were .40 for labor, .10 for land, .25 for livestock, .15 for fertilizer, and .10 for machinery, .40 for education, and .15 for research and extension.

In a recent study Robert E. Evenson and Yoav Kislev, *Agricultural Research and Productivity* (New Haven: Yale University Press, 1975), have used a Cobb-Douglas type production function and data for 1960 and for 1955–60–65–68 to estimate international cross section production functions. The data base utilized is similar to that used by Hayami and Ruttan in *Agricultural Development*, but they added 1968 data and a new variable based on publication in agricultural sciences from 1948 to 1960 to represent research or the stock of knowledge. A comparison of the production function coefficients obtained by Evenson-Kislev and Hayami-Ruttan with the estimates obtained in this study is presented in table 10.11.

Thus the estimated coefficients of the variables were not always stable nor statistically significant in different specifications of the production function in their studies, and differed in many cases from those estimated by Hayami and Ruttan and from those in the present study. The results of these several research efforts indicate a need for further studies of the functional form and specification of the production function and of the methods used in accounting for productivity differences among countries.

Table 10.9 **Accounting for Differences in Labor Productivity in Agriculture between the United States and Selected Countries, 1970**

Country	American-type group	Japanese-type group		European-type group	
	Less-developed Argentina	Developed Japan	Less-developed India	Developed Denmark	Less-developed Turkey
Difference in output per male worker, percent	68.2(100)[a]	90.4(100)	98.5(100)	46.1(100)	94.8(100)
Land	0.3(0)	2.0(2)	2.0(2)	1.8(4)	1.9(2)
Livestock	1.6(2)	24.2(27)	23.8(24)	11.3(25)	22.8(24)
Fertilizer	24.7(36)	22.8(25)	24.9(25)	10.1(22)	24.6(26)
Machinery	11.9(17)	11.6(13)	13.0(13)	5.6(12)	12.9(14)
Percent of difference explained by the four variables	38.5(56)	60.6(67)	63.7(65)	28.8(62)	62.2(66)
General education	6.8(10)	2.8(3)	16.8(65)	3.0(7)	13.5(14)
Technical education	13.6(20)	7.9(9)	14.8(15)	11.3(25)	14.7(16)
Percent of difference explained by human capital	20.4(30)	10.7(12)	31.6(32)	14.3(31)	28.2(30)
Percent of difference explained: total	58.9(86)	71.3(79)	95.3(97)	43.1(93)	90.4(95)

[a]Numbers inside parentheses are percentages with output per worker set equal to 100.
Accounting formula:

$$\frac{y_o - y_a}{y_a} = .02\,\frac{a_o - a_a}{a_a} + .25\,\frac{s_o - s_a}{s_a} + .25\,\frac{f_o - f_a}{f_a} + .13\,\frac{m_o - m_a}{m_a} + .25\,\frac{E_o - E_a}{E_a} + .15\,\frac{U_o - U_a}{U_a},$$

where y, a, s, f, and m are respectively output, land, livestock, fertilizer, and machinery per male worker; E and U are respectively the general education (school enrollment ratio) and the technical education variable; lower-case letter o denotes other country and a denotes United States.

in the production function accounted for 56–67% of the differences in agricultural output per worker between the United States and these countries.

Fertilizer and machinery were important sources of productivity differences between the United States and all the other countries. Livestock was also important except for Argentina, where livestock intensity per worker is similar to the United States. Land was not a significant source of difference in labor productivity between the United States and other countries in the present study. The coefficient of land in the estimated production function that was used as the accounting weight was very low (table 10.8).

The nonconventional human capital variables accounted for 30–32% of the difference in output per worker between the United States and Argentina, India, Denmark, and Turkey but only 12% of the difference between the United States and Japan. Technical education alone accounted for 15–25% of the difference between the United States and Argentina, India, Denmark, and Turkey, and 9% of the difference between the United States and Japan. Thus, even if the general education variable were to be dropped, because of its weak coefficient in the 1970 estimates, human capital would remain an important factor in accounting for intercountry productivity differences.

The case of Argentina is particularly interesting because land and labor endowments are essentially similar to the United States. The differences in output per worker due to technology embodied in fertilizer and machinery, together with the lower level of investment in technical and general education, account for most of the differences in output per worker between the United States and Argentina. The case of Japan is interesting because traditional resource endowments and embodied technology account for such a large share of the difference and human capital investment for such a small share. The case of Denmark is of interest because such a small share of the difference is explained by the variables captured by the cross-country metaproduction functions. Differences in human capital investment are highly important in all countries except Japan (table 10.9).

The sources of differences in agricultural output per hectare of agricultural land between Japan and the other countries are also presented in table 10.10. The difference in the output/land ratio between Japan and each country was 97% for Argentina, 87–92% for India, the United States, and Turkey, and 51% for Denmark. The percentage of the productivity differences accounted for by the four conventional variables ranged from 45% for India to 97% for the United States.

Technical inputs accounted for 35% of the differences in land productivity between Japan and India. Since the labor/land ratio in India does not differ very much from Japan, it accounted for only 7% of the

Table 10.10 Accounting for Differences in Land Productivity in Agriculture between Japan and Selected Countries, 1970

Country	Japanese-type group	American-type group		European-type group	
	Less-developed India	Developed U.S.	Less-developed Argentina	Developed Denmark	Less-developed Turkey
Difference in output per hectare, percent	87.2(100)[a]	90.5(100)	96.5(100)	50.8(100)	91.9(100)
Labor	5.9(7)	34.7(38)	34.6(36)	31.9(63)	29.8(32)
Livestock	−3.6(−4)	18.4(20)	18.2(19)	−9.2(−18)	15.5(17)
Fertilizer	24.1(28)	22.4(25)	25.0(26)	9.9(19)	24.4(27)
Machinery	13.0(15)	11.9(13)	12.9(13)	6.9(14)	12.8(14)
Percent of difference explained by the four variables	39.4(45)	87.4(97)	90.7(94)	39.5(78)	82.5(90)
General education	15.7(18)	−3.1(−3)	4.5(5)	0.3(1)	12.1(13)
Technical education	14.6(17)	−16.5(−18)	12.1(13)	7.3(14)	14.4(16)
Percent of difference explained by human capital	30.3(35)	−19.6(−22)	16.6(17)	7.6(15)	26.5(29)
Percent of difference explained: total	69.7(80)	67.8(75)	107.3(111)	47.1(93)	109.0(119)

NOTE: The accounting formula is the same as table 10.9, except that the variables are normalized on a per-hectare rather than a per-worker basis.

[a]Numbers inside parentheses are percentages with output per worker set equal to 100.

productivity difference. This was almost balanced by the negative contribution of the livestock/land ratio. In comparisons between Japan and the United States, 25 and 13% of the productivity differences were accounted for by fertilizer and by tractor use per hectare, respectively. In addition, 27 and 20% of the productivity gap was accounted for by labor and livestock. The sources of the differences in land productivity between Japan, Argentina, and Turkey are very similar to the differences between Japan and the United States. Between 32 and 38% of the difference was accounted for by labor, 17–20% by livestock, 25–27% by fertilizer, and 13–14% by machinery. More than half the difference in land productivity between Denmark and Japan was accounted for by differences in labor intensity. One-third of the productivity difference was accounted for by fertilizer and machinery. Since the livestock/land ratio in Denmark is much larger than Japan, livestock carries a negative weight of 18%. The four conventional variables account for 78% of the land productivity difference between these two countries. Human capital is also an important source of differences in land productivity among countries as well as in labor productivity. It is particularly important in accounting for the differences between Japan and India and Turkey.

The differences between the weights used in accounting for cross-section productivity differences among countries in this study and those used in the earlier Hayami-Ruttan study have been mentioned several times. These differences appear to be due in part to nonneutral shifts in the coefficients for fertilizer relative to land and of machinery relative to labor. It is also possible that the indexes of mechanical technology, biological technology, and human capital are biased or that the functional form used in the estimation is not entirely satisfactory. An attempt was made to test the sensitivity of the particular results shown in tables 10.9 and 10.10 by using the 1960 Hayami-Ruttan weights in accounting for the 1970 productivity differences among the six countries. In general the percent of the total variation in land and labor productivity explained by using the 1960 weights did not differ greatly from the variation explained using 1970 weights. There was, however, a tendency for less of the total differences in labor and in land productivity to be explained by the four conventional variables and more by the human capital variables when the 1960 weights were used than when the 1970 weights were used.

The analysis of the shifts in productivity coefficients and the sources of productivity differences presented above suggests that technical inputs such as fertilizer and machinery have become even more important relative to raw land and labor in accounting for productivity differences in 1970 than in 1960. However, it should be kept in mind, in interpreting these results, that both the index of biological technology (fertilizer/

hectare) and the index of mechanical technology (horsepower/worker) are clearly incomplete and may often be biased measures. In the case of biological technology, for example, it would be desirable, as implied earlier, to include other measures of biological technology such as the level of irrigation and the adoption of new crop varieties (see fig. 10.12). The effect of omission of other components of biological technology may be an upward bias in the coefficient of biological technology in 1970 relative to 1960 as a result of differences in the availability of complementary biological technology between the low-fertilizer-input and the high-fertilizer-input countries. Similarly the coefficient for mechanical technology may be biased upward in 1970 relative to 1960 due to differences in the availability of complementary components of mechanical technology.

10.6 Perspective

It is useful at this point to restate the problem that must be solved in any test of induced innovation. In figure 10.1 assume that the labor/land factor ratio in Japan can be represented by a line from the origin through *P* and that the labor/land factor ratio in the United States can be represented by a line from the origin through *Q*. Assume also that the slope of the line *BB* represents the factor price ratio in Japan, where land is expensive relative to labor, while the slope of *CC* represents the factor price ratio in the United States, where labor is expensive relative to land. If the substitution possibilities of the available agricultural technology can be represented by an isoquant map with little curvature such as $I^*_0 I^*_0$, the differences in factor ratios between Japan and the United States could be explained by simple substitution due to factor price change along a common production function. If, however, the possibilities of substitution between labor and land are represented by I_0 in Japan and I_1 in the United States, the points *P* and *Q* would not represent alternative factor combinations along production functions with equal factor intensity characteristics.

The results of both the time series and the cross section analysis are consistent with the induced innovation hypothesis. Yet they do not represent an adequate test of the hypothesis.[28] The analysis presented does not allow us to determine whether the changes in factor use describe (*a*) the effect of agricultural producers responding to the economic value of land relative to fertilizer or of labor relative to machinery along

28. For a rigorous test of the induced innovation hypothesis in U.S. agriculture see Hans P. Binswanger, "The Measurement of Technical Change Biases." Binswanger concludes that in the U.S. long-term decline in fertilizer prices did induce a fertilizer-using bias in technical change. In the case of mechanical technology both price-induced and autonomous effects were important.

an unchanging neoclassical macro production function, or (*b*) whether the production function available to farmers has itself shifted to the left over time and among countries as a result of the response of the technical efforts of scientists, engineers, and inventors to changing factor price relationships. The magnitude of the shifts in relative factor prices and factor use presented in the time series analysis and of the differences in factor use among countries does, however, create a presumption that the induced innovation process was involved.

The results of this analysis are consistent with the conclusion that Hayami and Ruttan drew in their earlier work—that failure to take full advantage of the potential growth from human capital and technical inputs represents a significant constraint on agricultural development. The results of the 1970 cross section analysis of the contribution of general education to agricultural productivity are somewhat less clear-cut than the results of the 1960 cross section analysis. Nevertheless, the body of evidence examined in this and in the earlier study tends to reinforce the conclusion that variations in technical inputs and human capital are typically more important than limitations in resource endowments in accounting for differences in output per worker. In the developed countries human capital and technical inputs have become the dominant sources of output growth. Differences in the natural resource base have accounted for an increasingly less significant share of the widening productivity gap among nations. Productivity differences in agriculture are increasingly a function of investments in the education of rural people and in scientific and industrial capacity rather than natural resource endowments. The decline in the coefficients for labor and land relative to the other coefficients in the relatively short period since the Hayami-Ruttan study provides additional support, over and above the relationships reported in this paper, of the declining importance of "raw" land and labor in accounting for productivity differences.

The embodiment of advances in science and technology in the inputs available to farmers clearly represents a necessary condition for releasing the constraints on agriculture imposed by inelastic supplies of traditional factors. Yet for a country in the early stages of economic development technical innovations are among the more difficult products to produce. Indeed, it seems useful to raise the question of whether, under modern conditions, the forces associated with the international transfer of agricultural technology are so dominant as to vitiate the process of induced technical change.

It might be argued, for example, that the dominance of the developed countries in science and technology raises the cost, or even precludes the possibility, of the invention of location-specific biological and mechanical technologies adapted to the resource endowments of a particular country or region. This argument has been made primarily with

Table 10.11 **Various Estimates of Agricultural Production Function Coefficients from Intercountry Data**

	Evenson-Kislev		Hayami-Ruttan			Present study
	1960	1955–60–65–68	1960	1965	1955–60–65	1970
Labor	.274–.438**	−.012–.259*	.335–.474**	(.390)	(.405)	.209–.398**
Land	−.002–.038	−.010–.190*	.056–.097	.043	.066**	.005–.024
Livestock	.285–.311**	.296–.450**	.191–.263**	.273**	.286**	.223–.244**
Fertilizer	.018–.173**	.048–.222**	.090–.161*	.142**	.137**	.226–.323**
Machinery	.140–.197**	.018–.138**	.040–.192*	.152**	.106**	.113–.149**
General education	.130–.168	.075–.128*	.290–.324	.356	.243**	−.034–.264
Technical education	.168–.175*	−.009–.087*	.139–.195**	.099**	.122**	.135–.170**
Research	.088–.091**	.046–.148**				

**Statistically significant at $P = 0.05$ (one-tail test).
*Statistically significant in some cases.
NOTE: Parentheses denote an implicit coefficient.

reference to the diffusion of mechanical technology from the developed to the developing countries. It has been argued that the pattern of organization of agricultural production adopted by the more developed countries—dominated by the large-scale mechanized systems of production employed in both the socialist and nonsocialist economies—precludes an effective role for an agricultural system based on small-scale commercial or semicommercial farm production units.

The potential for the development of technologies that are specific to national or regional factor endowments is, however, enhanced by the fact that in agriculture technology is highly location-specific, and even mechanical technology is relatively location-specific. It is apparently the location-specific character of agricultural technology that is responsible for the relationships between changes in factor use and productivity between 1960 and 1970 (figs. 10.7 and 10.9).

The transfer of agricultural technology occurs more through a process of adaptation to local environmental conditions than as a result of the direct transfer of materials and designs. The ability to borrow technology is dependent on the institutionalization of indigenous research and development capacity in agricultural science and technology. Thus, in order for a country or a region to acquire the capacity to borrow or transfer technology, it also needs to develop the capacity to adapt and invent technologies which are specific to its own factor endowments.[29]

In our judgment, failure to effectively institutionalize public sector agricultural research can result in serious distortion of the pattern of technical change and resource use. The homogeneity of most agricultural products and the relatively small size of the farm firm make it impossible for the individual agricultural firm to either bear the research costs or capture a significant share of the gains from scientific and technical innovation. Innovation in mechanical technology, however, has been much more responsive than biological technology to the inducement mechanism as it functions in the private sector. It has typically been more difficult for the innovating firm to capture more than a small share of the increased income stream resulting from innovation in biological than in mechanical technology.

Failure to balance the effectiveness of the private sector in responding to inducements to advances in mechanical technology (and in those areas of biological and chemical technology in which advances in knowledge can be embodied in proprietary products) with institutional innovations capable of an equally effective response to inducements to advances in biological technology leads to a bias in the productivity

29. See Robert E. Evenson and Hans P. Binswanger, "Technology Transfer and Research Resource Allocation," in Hans P. Binswanger and Vernon W. Ruttan, eds., *Induced Innovation: Technology Institutions and Development* (Baltimore: The Johns Hopkins University Press, 1978).

path that is inconsistent with factor endowments—particularly with the factor endowments of the more labor-intensive LDCs. The labor force explosion anticipated in rural areas of the LDCs in the 1970s implies that failure to design agricultural technologies consistent with higher population densities in rural areas will be extremely costly. It is possible to provide at least a partial response to this concern.

The test of the next decade for many of the developing countries will be whether they are prepared to seize the relatively inexpensive sources of growth opened up by investment in human capital and in the new potentials that can be made available through advances in biological technology.

Appendix A

Output, Factor Productivity, and Factor Price Data for Japan, Germany, Denmark, France, United Kingdom, and the United States, 1880–1970

Appendix A first appeared in Hans P. Binswanger and Vernon W. Ruttan, eds., *Induced Innovation: Technology Institutions and Development* (Baltimore: The Johns Hopkins University Press, 1978).

Table 10.A.1 **Japan: Output, Factor Productivity, and Factor Price Data, 1880–1970**

Year	Output (Y) Wheat Units (000) (1)	Index (1880 = 100) (2)	Male Labor (L) Number (000) (3)	Index (1880 = 100) (4)	Agricultural Land (A) Hectares (000) (5)	Index (1880 = 100) (6)	Wheat Units per Man Year (Y/L) (7)
1880	15,706	100.0	8,332	100.0	5,493	100.0	1.89
1890	18,795	119.7	8,354	100.3	5,712	104.0	2.25
1900	21,755	138.5	8,475	101.6	6,024	109.7	2.57
1910	26,755	170.3	8,527	102.3	6,466	117.7	3.14
1920	32,249	205.3	7,626	91.5	6,940	126.3	4.23
1925	32,674	208.0	7,386	88.6	6,875	125.2	4.42
1930	35,079	223.3	7,631	91.6	6,931	126.2	4.60
1940	37,060	236.0	6,263	75.2	7,088	129.0	5.92
1950	34,608	220.3	7,692	92.4	6,792	123.6	4.50
1960	52,436	333.9	6,232	74.8	7,048	128.3	8.41
1970	67,305	428.5	4,267	51.2	6,713	122.4	15.77

NOTE: Data are five-year averages centered on year shown.

SOURCE: Yujiro Hayami, *A Century of Agricultural Growth in Japan*, (Minneapolis and Tokyo: University of Minnesota Press and University of Tokyo Press, 1975).

Output: table A-1 (col. 8), spliced with 1958–62 value of output in wheat units from Yujiro Hayami and Vernon Ruttan, *Agricultural Development, An International Perspective*, table A-5.

Land: table A-4, (col. 3), multiplied by 1.14, the ratio of agricultural land to arable land

Table 10.A.2 **Germany: Output, Factor Productivity, and Factor Price Data, 1880–1970**

Year	Output (Y)[a] Wheat units (000) (1)	Index (1880 = 100) (2)	Male Labor (L) Number (000) (3)	Index (1880 = 100) (4)	Agricultural Land (A) Hectares (000) (5)	Index (1880 = 100) (6)	Wheat Units per Man year (Y/L) (7)
1880	45,137	100.0	5,684	100.0	36,040[b]	100.0	7.94
1890	52,061	115.3	5,520	97.1	35,320	98.0	9.43
1900	65,927	146.1	5,452	95.9	35,094	97.4	12.09
1910	75,367	167.0	5,746	101.1	34,878	96.8	13.12
1920	—	—	—	—	—	—	—
1925[c]	60,458 (72,103)	— (159.7)	4,808	84.6	29,249	81.2	12.57
1930	72,688 (86,644)	— (192.0)	4,547	80.0	29,375	81.5	15.99
1938[d]	83,556 (99,599)	— (220.7)	3,285	57.8	28,537	79.2	25.44
1950[e]	39,248 (97,947)	— (217.0)	2,258	39.7	14,033	38.9	17.38
1960	57,023 (142,550)	— (315.8)	1,613	28.4	14,239	39.5	35.35
1968[f]	72,073 (180,183)	— (399.2)	1,214	21.4	13,871	38.5	59.37
1970[g]	74,073 (185,964)	— (412.0)	1,142	20.1	13,578	37.7	71.40[h]

NOTE: Data are five-year averages, centered on data shown except as follows: (a) 1880–82; (b) 1925 only; (c) 1938 only; (d) 1950 only. Wheat units and indexes shown in parentheses have been adjusted for changes in land area in order to provide a long-term output series for an "undivided Germany."

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L)[a] (11)	Wage Rate (M/day) (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.530	2.86	.350	.659	(.183)	(343)	(1,874)
.444	3.29	.304	.684	.183	343	1,874
.390	3.61	.277	.711	.371	968	2,609
.319	4.14	.242	.758	.469	1,613	3,439
.236	4.65	.215	.910	1.472	3,882	2,637
.226	4.75	.210	.931	1.424	3,822	2,683
.218	5.06	.198	.908	1.098	3,206	2,920
.169	5.23	.191	1.132	—	—	—
.222	5.10	.196	.883	—	—	—
.119	7.44	.134	1.131	484.	1,429,528	2,954
.0634	10.03	.0997	1.573	1,794.	2,358,431	1,315

in the 1960 Census of Agriculture.
Labor: table A-3, (col. 1).
Price of labor: table A-8, (col. 2); 1890 value used for 1880.
Price of land: table A-2, (col. 4); 1890 value used for 1880.

[a]This diverges from revisions sent us by Hayami in May 1974, because Hayami did not use his latest data, as we did here, but instead calculated from Hayami and Ruttan, *Agricultural Development*, table S-2.

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L) (11)	Wage Rate (M/day) (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.1259	1.25	.798	6.34	1.36	1,315	967
.1060	1.47	.678	6.40	1.38	1,315	953
.0827	1.88	.532	6.44	1.68	1,368	814
.0762	2.16	.463	6.07	2.07	1,869	903
—	—	—	—	—	—	—
.0795	2.07	.484	6.08	3.07	2,730	889
.0626	2.47	.404	6.46	3.98	2,345	589
.0393	2.93	.342	8.69	3.50	2,188	625
.0575	2.80	.358	6.22	7.56	4,359	577
.0283	4.01	.250	8.83	18.00	6,812	378
.0168	5.20	.193	11.43	34.56	10,348	299
.0140	5.40	.185	12.20	42.12	11,448	244

SOURCE: 1880–1968 data from Adolf Weber, "Productivity Growth in German Agriculture, 1950 to 1970," University of Minnesota Department of Agricultural and Applied Economics, Staff Paper P73-1, August 1973; 1970: data provided by Adolf Weber, private communication, March 1974, from the same sources as for 1880–1968.

Table 10.A.3 **Denmark: Output, Factor Productivity, and Factor Price Data, 1880–1970**

	Output (Y)		Male Labor (L)		Agricultural Land (A)		Wheat Units per Man Year
Year	Wheat Units (000) (1)	Index (1880 = 100) (2)	Number (000) (3)	Index (1880 = 100) (4)	Hectares (000) (5)	Index (1880 = 100) (6)	(Y/L) (7)
1880	3,408	100.0	321	100.0	2,859	100.0	10.62
1890	3,882	113.9	326	101.6	2,913	101.9	11.91
1900	4,428	129.9	312	97.2	2,912	101.9	14.19
1910	5,837	171.3	346	107.8	2,883	100.8	16.87
1920	6,341	186.1	395	123.1	3,172	110.9	16.05
1925	6,830	200.4	404	125.9	3,217	112.5	16.91
1930	9,518	279.3	395	123.1	3,229	112.9	24.10
1940	9,015	264.5	391	121.8	3,218	112.6	23.06
1950	10,956	321.5	342	106.5	3,141	109.9	32.04
1960	14,378	421.9	303	94.4	3,094	108.2	47.45
1970	15,665	459.7	166	51.7	2,975[a]	104.1	94.37

NOTE: Data are five-year averages centered on the year shown except for (a) 1970 only.

SOURCE: 1880–1960 data from William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth" (tables D-1 and D-4), Ph.D. diss.,

Table 10.A.4 **France: Output, Factor Productivity, and Factor Price Data, 1800–1970**

	Output (Y)		Male Labor (L)		Agricultural Land (A)		Wheat Units per Man Year
Year	Wheat Units (000) (1)	Index (1880 = 100) (2)	Number (000) (3)	Index (1880 = 100) (4)	Hectares (000) (5)	Index (1880 = 100) (6)	(Y/L) (7)
1880	36,589	100.0	4,970	100.0	34,594	100.0	7.36
1890	38,139	104.2	4,580	92.2	34,429	99.5	8.33
1900	40,636	111.1	5,020	101.0	35,200	101.8	8.09
1910	45,457	124.2	4,910	98.8	36,799	106.4	9.26
1920	46,146	126.1	4,540	91.3	36,219	104.7	10.16
1925	49,848	136.2	4,290	86.3	36,294	104.9	11.62
1930	53,464	146.1	4,040	81.3	35,566	102.8	13.23
1940	48,657	133.0	3,860	77.7	33,488	96.8	12.61
1950	51,311	140.2	3,300	66.4	33,562	97.0	15.55
1960	86,093	235.3	2,580	51.9	34,681	100.3	33.37
1970	122,346	334.4	2,041[b]	41.1	33,035[b]	95.5	59.94

NOTE: Data are five-year averages centered on the year shown except for (a) 1968 only and (b) 1970 only.

SOURCE: 1880–1960 data from William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth" (tables F-1, F-4) Ph.D. diss., Uni-

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L) (11)	Wage Rate (M/day) (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.0942	1.192	.839	8.91	1.6	611	382
.0840	1.333	.750	8.94	1.7	536	315
.0705	1.521	.658	9.33	2.1	536	255
.0592	2.025	.494	8.33	2.8	701	250
.0623	1.999	.500	8.03	5.9	1,413	240
.0592	2.123	.471	7.96	6.2	—	—
.0415	2.948	.339	8.18	5.2	1,186	228
.0434	2.801	.357	8.23	7.8	1,233	158
.0312	3.488	.287	9.18	21.5	2,459	114
.0211	4.647	.215	10.21	35.6	5,908	166
.0106	5.266	.190	17.92	71.9	12,743	177

University of Minnesota, 1973. 1970 data provided by William Wade, private communication, from the same sources as 1880–1960.

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L) (11)	Wage Rate (M/day)[a] (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.1358	1.06	.946	6.96	2.28	1,778	780
.1201	1.11	.903	7.52	2.43	1,674	689
.1235	1.15	.866	7.01	2.69	1,584	589
.1080	1.24	.810	7.49	3.00	1,583	528
.0984	1.27	.785	7.98	11.5	2,831	246
.0861	1.37	.723	8.45	14.9	4,055	272
.0756	1.50	.665	8.80	20.6	5,405	262
.0793	1.45	.688	8.68	33.1	5,200	157
.0643	1.53	.654	10.17	479.4	125,000	261
.0300	2.48	.403	13.44	1,508.0	250,000	166
.0167	3.70	.270	16.19	37.5†	7,960†	212

versity of Minnesota, 1973. 1970 data provided by William W. Wade, private communication, from the same sources as 1880–1960.

†In new francs. One new franc is equal to 100 old francs.

Table 10.A.5 **United Kingdom: Output, Factor Productivity, and Factor Price Data, 1880–1970**

Year	Output (Y)		Male Labor (L)		Agricultural Land (A)		Wheat Units per Man Year (Y/L)
	Wheat Units (000) (1)	Index (1880 = 100) (2)	Number (000) (3)	Index (1880 = 100) (4)	Hectares (000) (5)	Index (1880 = 100) (6)	(7)
1880	20,847	100.0	1,288	100.0	18,949	100.0	16.19
1890	21,696	104.1	1,235	95.9	19,331	102.0	17.57
1900	21,040	100.9	1,178	91.5	19,602	103.4	17.86
1910	21,696	104.1	1,221	94.8	19,484	102.8	17.77
1920	21,696	104.1	1,154	89.4	19,121	100.9	18.80
1925	21,889	105.0	1,199	93.1	19,798	104.5	18.26
1930	23,163	111.1	1,151	89.4	19,611	103.5	20.12
1940	27,332	131.1	1,079	83.8	19,453	102.7	25.33
1950	31,502	151.1	985	76.5	19,518	103.0	31.98
1960	38,605	185.2	853	66.2	19,894	105.0	45.26
1970	49,203	236.0	562	43.6	18,831[a]	99.4	87.55

NOTE: Data are five-year averages centered on the year shown, except for (a) 1970 only.

SOURCES: 1880–1960 data from William W. Wade, "Institutional Determinants of Technical Change and Agricultural Productivity Growth" (tables G-1 and G-4), Ph.D. diss.,

Table 10.A.6 **United States: Output, Factor Productivity, and Factor Prices Data, 1880–1970**

Year	Output (Y)		Male Labor (L)		Agricultural Land (A)		Wheat Units per Man Year (Y/L)
	Wheat Units (000) (1)	Index (1880 = 100) (2)	Number (000) (3)	Index (1880 = 100) (4)	Hectares (000) (5)	Index (1880 = 100) (6)	(7)
1880	103,711	100.0	7,959	100.0	202,000	100.0	13.0
1890	123,416	119.0	9,142	115.0	235,000	116.4	13.5
1900	160,753	155.0	9,880	124.1	318,000	157.4	16.3
1910	170,087	164.0	10,359	130.2	333,000	164.9	16.4
1920	186,681	180.0	10,221	128.4	363,000	179.7	18.3
1925	199,126	192.0	9,818	123.4	350,000	173.3	20.3
1930	211,571	204.0	9,414	118.3	381,000	188.6	22.5
1940	240,611	232.0	8,487	106.6	411,000	203.5	28.4
1950	295,578	285.0	6,352	79.8	451,000	223.3	46.5
1960	352,619	340.0	3,973	49.9	435,000	215.3	88.8[a]
1970	417,957	403.0	2,655	33.4	426,000	210.9	157.4

NOTE: Data are five-year averages centered on year shown.

SOURCE: 1880–1960 data from Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development, An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971), table C-2 and table A-2. 1970 value: USDA; Agricultural Statistics, 1973, Index of average value per acre, March value, table 619; Changes in Production and Efficiency,

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L) (11)	Wage Rate (M/day) (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.0618	1.10	.909	14.71	2.6	2,588	995
.0569	1.12	.891	15.65	2.5	2,174	870
.0559	1.07	.932	16.64	2.6	2,065	794
.0563	1.11	.898	15.96	2.8	2,065	738
.0532	1.13	.881	16.57	7.9	1,720	218
.0548	1.11	.904	16.51	5.5	1,512	275
.0497	1.18	.847	17.04	5.8	1,096	189
.0395	1.41	.712	18.03	7.2	1,730	240
.0313	1.61	.620	19.82	17.1	4,051	237
.0221	1.94	.515	23.32	28.8	6,076	211
.0114	2.61	.383	33.51	55.5[a]	11,260	203

University of Minnesota, 1973. 1970 data provided by William Wade, private communication from the same sources as 1880–1960.

Man Years per Wheat Unit (L/Y) (8)	Wheat Units per Hectare (Y/A) (9)	Hectares to Produce One Wheat Unit (A/Y) (10)	Land (Hectares) per Worker (A/L) (11)	Wage Rate (M/day) (P_L) (12)	Land Price (M/ha) (P_A) (13)	Days Labor to Buy One Hectare (P_A/P_L) (14)
.07670	.513	1.95	25.4	.90	163	181
.07410	.526	1.90	25.7	.95	132	139
.06150	.506	1.98	32.2	1.00	129	129
.06090	.511	1.96	32.1	1.35	213	158
.05480	.514	1.94	35.5	3.30	352	107
.04930	.569	1.76	35.6	2.35	269	114
.04450	.555	1.80	40.5	2.15	247	115
.03530	.585	1.71	48.4	1.60	180	113
.02150	.655	1.53	71.0	4.50	389	86
.01130	.811	1.23	109.5	6.60	711	108
.00635	.981	1.02	160.5	11.58	1,247	108

1973, table 21, Index of total hours used for farmwork; Changes in Production and Efficiency, 1973, table 25, Index of farm real estate; Changes in Production and Efficiency, 1973, table 2, Index of output.

[a]Differs from Hayami and Ruttan, table 8-1, col. (6). 1960 value in 8-1 is incorrect. 1960 wheat units = 352619. Table A-2; 1960. Workers = 3973. Table C-2, col. 4–9.

Appendix B

Intercountry Cross Section Data for 1970

In this appendix we explain the data used for the intercountry comparison of agricultural productivities.[1] Data were collected or estimated for forty-one countries for 1970.[2] However, to reduce the effects of yearly fluctuation, agricultural output and fertilizer consumption were measured as 1968–72 averages and 1969–71 averages, respectively.

Agricultural Output (A1)

The output variable estimated in this study[3] is specified as gross agricultural output, net of agricultural intermediate products such as seed and feed (including imported feed). The series of 1968–72 average outputs were extrapolated from the 1962–66 data, which were estimated in Yujiro Hayami et al. (1971) using the Food and Agricultural Organization's index numbers of total agricultural production (FAO, 1972) for the respective countries.[4]

1. The intercountry cross section data for 1970 used in this study were estimated partly on the basis of the intercountry data for 1962–66 compiled in Yujiro Hayami in association with Barbara B. Miller, William W. Wade, and Sachiko Yamashita, *An International Comparison of Agricultural Production and Productivities*. University of Minnesota Agricultural Experiment Station Technical Bulletin 277, March 1971. The data and analysis are recompiled in Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore: The Johns Hopkins University Press, 1971). To maintain comparability, the concepts and methods of estimating inputs and output variables for 1970 are the same, although input categories of agricultural perennial plants stock and an aggregate of various fixed capital stock, which were not counted in the above studies at all, are estimated also in addition to them in this study. More detailed explanations on the concepts and methods are available in the above sources.

2. The number of the countries of which data were compiled in the Hayami-Ruttan studies was forty-three. However, due to the lack of data for 1970, Libya, Syria, and the United Arab Republic were excluded in this study. Instead, the old Pakistan was divided into the independent Bangladesh and the new Pakistan, resulting in the number of the countries analyzed in this study being forty-one.

3. Recently we estimated a series of aggregated agricultural production for Asian countries by using wheat-based price relatives for the 1961–65 period which were originally utilized in the FAO index numbers of agricultural production in Saburo Yamada, *A Comparative Analysis of Asian Agricultural Productivities and Growth Patterns* (Tokyo: Asian Productivity Organization, 1975). We could use the same weighting method in estimating agricultural production for this study. However, it would involve a major effort and would involve more time than the schedule for the present conference would permit.

4. The ratio of the 1968–72 average to the 1962–66 average of the index numbers (1961–65 = 100) was multiplied by the 1962–66 average of agricultural output in terms of wheat units estimated in Hayami et al., *International Comparison*, for each country. For Taiwan, the 1969–71 average was used instead of the 1968–72 average because of the lack of data.

The 1962–66 data were extended from the 1957–62 output data by using the old series of the FAO production index as well.

> The series of 1957–62 average outputs were estimated as follows: (a) deduct the seed, feed (including imported feed), eggs for hatching, and milk for calf rearing from the quantities of individual agricultural commodities produced, (b) aggregate the quantities by the three sets of wheat relative prices derived from the farm-gate prices (or the imported prices of commodities not produced domestically) for the U.S.A., Japan and India, to produce three aggregate output series, and (c) combine these three series into a single composite series by taking their geometrical means.[5]

Data on the quantities produced were taken from *Production Yearbook* of FAO and data for the deduction of seed and feed from FAO's *Food Balance Sheets*.

However, there were no estimates of 1965 (1962–66 average) agricultural output for Mauritius, Paraguay, and Surinam in Hayami et al. (1971). For these countries, 1968–72 output was extrapolated from 1960 (1957–62 average) data in the book using the growth rate between 1962–66 and 1968–72 in the FAO indices of the respective countries. Since data for Pakistan in the book were those before the independence of Bangladesh, 1965 output of the old Pakistan was divided into the present two countries by using the relative ratios of agricultural production between the two for 1961–65 estimated in Yamada (1975).

Number of Male Workers in Agriculture (A2)

The number of male workers in agriculture (farm workers) was estimated from the data of the economically active male population in agricultural occupations (agriculture, forestry, hunting, and fishing), published in the *Yearbook of Labor Statistics*, various issues, by the International Labor Organization (ILO).

Due to the lack of adequate conversion factors, the number of male workers in agriculture for 1970 was transformed from the population in agricultural occupations for 1970 using 1960 conversion factors, i.e., the ratios of agricultural output to the output of agriculture, forestry, and fishing combined, assuming that labor productivities are equal between these agricultural occupations. The conversion factors were derived from Hayami and Ruttan (1971), table A–2.

For countries where 1970 data for the economically active male population in the agricultural occupations are not available in the ILO yearbooks, several methods were used for estimating 1970 data: (*a*) extrapolations or interpolations were conducted by using the growth rates between the nearby years data that are available in the ILO year-

5. Ibid., p. 5.

books of Hayami et al. (1971), for Australia, Austria, Greece, India, Ireland, New Zealand, Taiwan, and Turkey; (*b*) the ratios of male workers to the total workers in agriculture for a nearby year when the data were available in the ILO yearbooks were multiplied by the numbers of the total agricultural workers for 1970 which appeared in FAO (1972), table 5, for Bangladesh, Colombia, France, Mauritius, Netherlands, Pakistan, Paraguay, Spain, Sri Lanka, Surinam, and United Kingdom; (*c*) 1971 data in the ILO yearbook were used for 1970 for Yugoslavia.

In the case of Japan, the number of agricultural (farm) male workers was inferred from Bureau of Statistics (1971), pp. 73–74, instead of the ILO data, because the equal productivity assumption between agriculture and the other agricultural occupations is not plausible in Japan.[7]

Agricultural Land Area (A3)

The agricultural land area is the sum of the areas of arable land, land under permanent crops, and permanent meadows and pastures, available in FAO, *Production Yearbook*, various issues. Since we could not find appropriate weights for aggegation, the summation was made without weighting.

In countries where 1970 data for agricultural land area are not available, extrapolations or interpolations were made by using the growth rates between the nearby years data that are available in the FAO data. These countries are Argentina, Austria, Canada, Chile, Greece, India, Paraguay, Peru, Portugal, South Africa, Surinam, Switzerland, Taiwan, United Kingdom, United States, and Venezuela. Data for Bangladesh and Pakistan are referred from Yamada (1975), table 4.

Farm Capital Stock (A4–A7 and A9–A11)

Farm capital stock specified in this study is the aggregate value of livestock, agricultural machinery, and agricultural perennial plants. Values of agricultural buildings and structures, including irrigation facilities, were excluded due to lack of data. The estimation of each category of capital stock and aggregation method used in the study is as follows:

Livestock (A9)

The total value of livestock aggregates the various kinds of animals in terms of livestock units for each country. Data for the numbers of livestock animals existing on farms are taken from FAO (1972). The

6. Ibid., p. 6.

7. If we apply the same method for Japan as for other countries, the number of male workers in agriculture is 3,419 thousand in 1970, which is too small compared with the data in Japan's *Labor Force Survey*.

kind of animals and the livestock units as the aggregation weights are camels 1.1; horses, mules, and buffalo, 1.0; cattle and asses, 0.8; pigs, 0.2; sheep and goats, 0.1; and poultry, 0.01. These units appear in FAO (1971), p. 716.

Machinery (A10)

Only agricultural tractors and garden tractors are counted as agricultural machinery in the study. These numbers were aggregated in terms of horsepower by assuming that the average horsepower of farm tractors and garden tractors was 30 and 5, respectively. Data for the number of tractors in 1970 were taken from FAO (1972).

Perennial Plants (A11)

For available data, different kinds of perennial plants should preferably be weighted by their respective prices for weights and added to get an aggregate value of capital stock. But due to the lack of data on tree population or area planted to various perennial plants and unit values of perennial plants, the total area of land under permanent crops was used as a crude approximate indicator for the total amount of perennial plants as capital stock. Data for 1970 are taken from FAO, *Production Yearbook*, various issues. For countries where 1970 data were not available, extrapolations or interpolations were conducted by using the growth rates for a nearby period (Austria, India, Peru, and Switzerland), or data for a nearby year (Argentina, Chile, Greece, Paraguay, Portugal, South Africa, Surinam, United States, and Venezuela). For countries where no information is available at all for land under permanent crops, perennial plants as capital stock were not estimated.

Aggregated Value of Livestock, Perennial Plants, and Machinery (A4–A7)

The weights for aggregating the volumes of livestock, perennial plants, and machinery into an aggregated value of farm fixed capital stock should preferably be their average or representative relative prices of all countries. However, the average prices of all countries were not used due to lack of data; instead the relative prices in terms of wheat units for Japan in 1961–65 were used as the aggregating weights.

The estimated average prices assumed in this analysis are as follows: 60 thousand yen per one livestock unit, 25 thousand yen per one tractor horsepower, and 680 thousand yen per one hectare of land under permanent crops. These were estimated on the basis of various issues of *Noson Bukka Chingin Chosa Hokokusho (Survey Reports on Prices and Wages in Rural Areas), Nogyo oyobi Nokano Shakai Kanjo (Social Accounts of Agriculture and Farm Households)* and *Norinsho Tokei*

Hyo (Statistical Yearbook), all of Japan's Ministry of Agriculture and Forestry.[8]

In calculating the wheat units for each category of the capital, each of these prices was divided by 1961–65 price per ton of wheat taken from the *Price Survey* mentioned above. The weights in terms of wheat units are 1.74 per livestock unit, 0.72 per tractor horsepower unit, and 19.79 per hectare of land under permanent crops, respectively.[9]

Fertilizer Consumption (A8)

The data on fertilizer input in terms of total physical weights of *N*, P_2O_5, and K_2O contained in commercial fertilizers consumed in 1969–71 are taken from FAO (1972).

Ratio of Nonagricultural Labor (A12)

As an indicator of industrialization, the ratios of workers in nonagricultural occupations (other than agriculture, forestry, hunting, and fishing) to the total number of the economically active population were calculated for respective countries from the data published in ILO, *Yearbook of Labor Statistics*, various issues, and FAO (1972).

General Education–School Enrollment Ratio (A13)

The school enrollment ratio is the ratio of the number enrolled in the first and second levels of education to the population of potential enrollment. It represents the increase in the level of education. In order to convert the enrollment ratio into a measure of the stock of education, the averages of the data for 1960, 1965, and 1970, and alternatively those for 1955, 1960, and 1965, were used. The data were taken from UNESCO, *Statistical Yearbook*, 1972, and Hayami and Ruttan (1971) table A–5.

Technical Education–Number of Graduates from Agricultural Colleges per 10,000 Male Farm Workers (A14)

The number of graduates from agricultural colleges per 10,000 male farm workers was considered as a proxy variable for the level of technical education in agriculture. The data source is UNESCO, *Statistical Yearbook*, 1972 and 1973.

8. More detailed explanations on the estimating procedures are available in Yamada, *Comparative Analysis*.

9. It should be mentioned that the capital stock estimates are not nearly precise, particularly those of machinery items, as only the tractors were taken into account. In addition, aggregating weights were based on Japan data, and hence the estimates are Japan-biased.

Farm Wage Rate (A15)

The farm wage rate is defined as the wage received by a male farm worker per day. Hourly, weekly, and monthly wages presented in FAO, *Production Yearbook* (1973) are converted into daily wages by assuming eight work hours in a day, six work days in a week, and twenty-four work days in a month.

Tractor Price (A16)

Tractors and farm machinery prices paid by farmers are only available for Australia, Germany, Japan, and the United States in FAO, *Production Yearbook*. For other countries in this study the average import price of tractors for 1970 derived from FAO, *Trade Yearbook* (1972) were used as a proxy indicator of the tractor price.

Table 10.B.1 Major Intercountry Cross Section Statistical Series, 1970

Country	Agricultural output (A1) 1,000 wheat units	Number of male workers in agriculture (A2) 1,000's	Agricultural land area (A3) 1,000 hectares	Farm capital stock (WU): Livestock (A4) 1,000 wheat units	Farm capital stock (WU): Machinery (A5) 1,000 wheat units	Farm capital stock (WU): Perennial plants (A6) 1,000 wheat units	Farm capital stock (WU): Total (A7) 1,000 wheat units	Fertilizer consumption (A8) 1,000 metric tons	Livestock (A9) 1,000 livestock units	Tractor horsepower (A10) 1,000 horsepower	Land area under permanent crops (A11) 1,000 hectares	Ratio of nonagricultural workers (A12) Percent
Argentina	60,950	1,196	171,460	84,954	3,888	42,865	131,707	87	48,824	5,400	2,177	85.2
Australia	57,759	310	497,108	64,262	7,236	3,465	74,963	1,023	36,932	10,050	176	91.6
Austria	11,685	198	3,896	4,808	5,466	1,871	12,145	418	2,763	7,592	95	83.9
Bangladesh	29,727	10,406	9,917	41,210	28	—	41,238	100	23,684	39	—	29.5
Belgium	15,218	131	1,599	6,201	1,878	669	8,748	496	3,564	2,608	34	95.4
Brazil	116,731	9,752	141,356	195,788	2,147	158,209	356,144	879	112,522	2,982	8,035	55.8
Canada	51,178	376	67,780	21,191	13,642	—	34,833	799	12,179	18,947	—	92.5
Chile	7,804	429	17,466	7,012	659	3,899	11,570	158	4,030	915	198	78.8
Colombia	22,693	2,211	22,138	32,192	602	28,708	61,502	184	18,501	836	1,458	54.8
Denmark	15,098	175	2,975	7,287	3,794	295	11,376	603	4,188	5,269	15	88.9
Finland	7,382	115	2,810	3,296	3,398	—	6,694	482	1,894	4,720	—	79.7
France	116,148	1,763	33,035	40,231	27,864	33,158	101,253	4,605	23,121	38,700	1,684	86.6
Germany, Fed.	72,852	1,039	13,575	28,922	29,971	10,593	69,486	3,197	16,622	41,626	538	91.1
Greece	16,337	834	8,633	5,277	1,440	16,756	23,473	336	3,033	2,000	851	53.5
India	235,869	100,263	178,617	368,205	1,361	83,643	453,209	2,265	211,612	1,890	4,248	32.3
Ireland	9,029	264	4,794	9,946	1,814	59	11,819	404	5,716	2,520	3	73.1
Israel	4,539	63	1,241	654	360	1,693	2,707	57	376	500	86	91.4
Italy	77,241	2,415	20,180	21,402	13,937	58,007	93,346	1,339	12,300	19,357	2,946	81.0
Japan	66,519	4,350	6,458	11,536	17,514	11,814	40,864	2,174	6,630	24,325	600	80.9
Mauritius	762	63	112	87	6	—	93	21	50	9	—	68.5
Mexico	38,470	4,668	97,258	63,717	1,987	33,335	99,039	606	36,619	2,760	1,693	60.5
Netherland	23,574	278	2,193	9,246	3,378	847	13,471	623	5,314	4,692	43	93.6

Table 10.B.1 (continued)

Country	Agricultural output (A1) 1,000 wheat units	Number of male workers in agriculture (A2) 1,000's	Agricultural land area (A3) 1,000 hectares	Farm capital stock (WU) Livestock (A4) 1,000 wheat units	Machinery (A5)	Perennial plants (A6)	Total (A7)	Fertilizer consumption (A8) 1,000 metric tons	Livestock (A9) 1,000 livestock units	Tractor horsepower (A10) 1,000 horsepower	Land area under permanent crops (A11) 1,000 hectares	Ratio of nonagricultural workers (A12) Percent
New Zealand	21,014	106	13,584	23,152	2,063	276	25,491	455	13,306	2,865	14	88.3
Norway	3,374	55	954	2,020	2,015	—	4,035	201	1,161	2,798	—	88.4
Pakistan	32,583	12,571	24,447	55,289	216	—	55,505	297	31,775	300	—	29.5
Paraguay	1,499	289	13,823	9,347	48	2,402	11,797	5	5,372	66	122	46.7
Peru	9,878	928	30,393	12,156	237	4,765	17,158	89	6,986	329	242	54.9
Philippines	20,617	4,590	10,400	13,979	117	47,315	61,411	205	8,034	162	2,403	48.6
Portugal	9,338	661	4,221	3,706	608	11,735	16,049	155	2,130	845	596	70.4
South Africa	24,113	1,443	113,482	25,686	4,752	9,451	39,892	554	14,762	6,600	480	72.0
Spain	50,329	2,546	34,560	14,907	5,872	96,264	117,043	1,274	8,567	8,156	4,889	66.3
Sri Lanka	6,444	1,543	2,418	3,760	173	21,344	25,277	86	2,161	240	1,084	47.7
Surinam	464	17	47	77	20	158	255	2	44	28	8	73.2
Sweden	10,426	122	3,443	3,604	3,672	—	7,276	501	2,071	5,100	—	91.9
Switzerland	7,669	160	2,176	3,525	1,966	354	5,845	148	2,026	2,730	18	92.4
Taiwan	11,735	1,155	861	1,977	62	10,731	12,770	268	1,136	82	545	58.0
Turkey	44,630	5,357	53,513	36,074	2,257	50,899	89,230	450	20,732	3,135	2,585	33.1
U.K.	50,260	555	19,099	27,619	9,838	—	37,457	1,743	15,873	13,664	—	97.2
U.S.	424,115	2,648	434,220	201,066	101,491	34,851	337,408	15,259	115,555	140,960	1,770	95.7
Venezuela	9,507	567	21,122	13,692	415	12,838	26,945	72	7,869	576	652	78.2
Yugoslavia	22,162	1,934	14,626	13,353	1,444	13,944	28,738	628	7,674	2,006	708	46.6

Table 10.B.2 **Various Factor Inputs per Male Worker and per Hectare of Agricultural Land, 1970**

Country	Factor inputs per male worker						Factor inputs per hectare of agricultural land					
	Agricultural land area (F1)	Fertilizer consumption (F2)	Livestock (F3)	Tractor horsepower (F4)	Area under permanent crops (F5)	Total capital stock (F6)	Number of male workers (F7)	Fertilizer consumption (F8)	Livestock (F9)	Tractor horsepower (F10)	Area under permanent crops (F11)	Total capital stock (F12)
	hectares	kilograms	livestock units	horsepower	hectares	wheat units	number	kilograms	livestock units	horsepower	hectares	wheat units
Argentina	143.4	73	40.8	4.52	1.82	110	0.007	0.5	0.28	0.031	0.013	0.77
Australia	1,603.6	3,300	119.1	32.42	0.57	242	0.001	2.1	0.07	0.020	0.001	0.15
Austria	19.7	2,111	14.0	38.34	0.48	61	0.051	107.3	0.71	1.949	0.024	3.12
Bangladesh	1.0	10	2.3	0.01	—	10	1.049	10.1	2.39	0.004	—	4.16
Belgium	12.2	3,786	27.2	19.91	0.26	67	0.082	310.2	2.23	1.631	0.021	5.47
Brazil	14.5	90	11.5	0.31	0.82	37	0.069	6.2	0.80	0.021	0.057	2.52
Canada	180.3	2,125	32.4	50.39	—	93	0.006	11.8	0.18	0.280	—	0.51
Chile	40.7	368	9.4	2.13	0.46	27	0.025	9.0	0.23	0.052	0.011	0.66
Colombia	10.0	83	8.4	0.38	0.66	28	0.100	8.3	0.84	0.038	0.066	2.78
Denmark	17.0	3,446	23.9	30.11	0.09	65	0.059	202.7	1.41	1.771	0.005	3.82
Finland	24.4	4,191	16.5	41.04	—	58	0.041	171.5	0.67	1.680	—	2.38
France	18.7	2,612	13.1	21.95	0.96	57	0.053	139.4	0.70	1.171	0.051	3.07
Germany, Fed.	13.1	3,077	16.0	40.06	0.52	67	0.077	235.5	1.22	3.066	0.040	5.12
Greece	10.4	403	3.6	2.40	1.02	28	0.097	38.9	0.35	0.232	0.099	2.72
India	1.8	23	2.1	0.02	0.04	5	0.561	12.7	1.18	0.011	0.024	2.54
Ireland	18.2	1,530	21.7	9.55	0.01	45	0.055	84.3	1.19	0.526	0.001	2.47
Israel	19.7	905	6.0	7.94	1.37	43	0.051	45.9	0.30	0.403	0.069	2.18
Italy	8.4	554	5.1	8.02	1.22	39	0.120	66.4	0.61	0.959	0.146	4.63
Japan	1.5	500	1.5	5.59	0.14	9	0.674	336.6	1.03	3.767	0.093	6.33
Mauritius	1.8	333	0.8	0.14	—	1	0.563	187.5	0.45	0.080	—	0.83
Mexico	20.8	130	7.8	0.59	0.36	21	0.048	6.2	0.38	0.028	0.017	1.02
Netherland	7.9	2,241	19.1	16.88	0.15	48	0.127	284.1	2.42	2.140	0.020	6.14

Table 10.B.2 (continued)

Country	Factor inputs per male worker						Factor inputs per hectare of agricultural land					
	Agricultural land area (F1)	Fertilizer consumption (F2)	Livestock (F3)	Tractor horsepower (F4)	Area under permanent crops (F5)	Total capital stock (F6)	Number of male workers (F7)	Fertilizer consumption (F8)	Livestock (F9)	Tractor horsepower (F10)	Area under permanent crops (F11)	Total capital stock (F12)
	hectares	kilograms	livestock units	horsepower	hectares	wheat units	number	kilograms	livestock units	horsepower	hectares	wheat units
New Zealand	128.2	4,292	125.5	27.03	0.13	240	0.008	33.5	0.98	0.211	0.001	1.88
Norway	17.4	3,655	21.1	50.87	—	73	0.058	210.7	1.22	2.933	—	4.23
Pakistan	1.9	24	2.5	0.02	—	4	0.514	12.1	1.30	0.012	—	2.27
Paraguay	47.8	17	18.6	0.23	0.42	41	0.021	0.4	0.39	0.005	0.009	0.85
Peru	32.8	96	7.5	0.35	0.26	18	0.031	2.9	0.23	0.011	0.008	0.56
Philippines	2.3	45	1.8	0.04	0.52	13	0.441	19.7	0.77	0.016	0.231	5.90
Portugal	6.4	234	3.2	1.28	0.90	24	0.157	36.7	0.50	0.200	0.141	3.80
South Africa	78.6	384	10.2	4.57	0.33	28	0.013	4.9	0.13	0.058	0.004	0.35
Spain	13.6	500	3.4	3.20	1.92	46	0.074	36.9	0.25	0.236	0.141	3.39
Sri Lanka	1.6	56	1.4	0.16	0.70	16	0.638	35.6	0.89	0.099	0.448	10.45
Surinam	2.8	118	2.6	1.65	0.47	15	0.362	42.6	0.94	0.596	0.170	5.43
Sweden	28.2	4,107	17.0	41.80	—	60	0.035	145.5	0.60	1.481	—	2.11
Switzerland	13.6	925	12.7	17.06	0.11	37	0.074	68.0	0.93	1.255	0.008	2.69
Taiwan	0.8	232	1.0	0.07	0.47	11	1.341	311.3	1.32	0.095	0.633	14.83
Turkey	10.0	84	3.9	0.59	0.48	17	0.100	8.4	0.39	0.059	0.048	1.67
U.K.	34.4	3,141	28.6	24.62	—	67	0.029	91.3	0.83	0.715	—	1.96
U.S.	164.0	5,762	43.6	53.23	0.67	127	0.006	35.1	0.27	0.325	0.004	0.78
Venezuela	37.3	127	13.9	1.02	1.15	48	0.027	3.4	0.37	0.027	0.031	1.28
Yugoslavia	7.6	325	4.0	1.04	0.37	15	0.132	42.9	0.52	0.137	0.048	1.96

SOURCE: Table 10.A.1.

Table 10.B.3 **Intercountry Cross Section Data for Human Capital and Prices, 1970**

Country	School enrollment ratio: 1955–60–65 average (A13-1)	School enrollment ratio: 1960–65–70 average (A13-2)	Number of graduates from agricultural colleges per 10,000 farm workers, 1970 (A14)	Farm wage rate per day, 1970 (A15)	Tractor price 1970 (A16)
	Percent		Persons	U.S. dollars	
Argentina	73	76	6.04	2.41	9,743
Australia	91	91	28.68		3,147
Austria	70	89	10.05	4.78	2,047
Bangladesh	n.a.	26	0.26		4,979
Belgium	99	93	25.11	7.04	1,154
Brazil	50	57	1.97		17,990
Canada	81	91	38.78	11.95	2,985
Chile	74	78	9.16		2,273
Colombia	51	54	2.97		3,626
Denmark	88	86	16.23	6.59	1,768
Finland	83	80	20.26	5.52	2,348
France	91	90	6.13	3.78	822
Germany, Fed.	86	88	11.06	5.63	2,029
Greece	72	83	6.73		2,182
India	33	41	0.84	0.38	1,661
Ireland	95	89	8.11	5.83	1,241
Israel	88	80	24.92	4.46	5,921
Italy	60	72	3.25		2,511
Japan	89	93	31.41	4.19	4,008
Mauritius	78	66	3.49	1.06	11,103
Mexico	59	57	0.83	1.70	7,849
Netherlands	91	86	33.31	8.96	1,717
New Zealand	91	90	57.36	4.85	3,000
Norway	88	92	38.73	9.83	3,294
Pakistan	27	26	1.60	1.43	5,241
Paraguay	62	64	2.46		4,072
Peru	57	72	4.57		8,723
Philippines	75	84	2.71		5,777
Portugal	61	74	1.91	2.54	2,046
South Africa	70	68	4.00		2,948
Spain	67	78	2.30		3,138
Sri Lanka	77	75	0.24	0.57	2,905
Surinam	80	80	9.00		5,517
Sweden	79	92	22.21	13.56	1,768
Switzerland	66	70	6.63		1,719
Taiwan	70	70	8.50		
Turkey	46	59	1.27	3.32	6,114
U.K.	85	89	24.27	7.67	3,460
U.S.	100	100	65.96	11.70	2,819
Venezuela	70	70	5.04		4,930
Yugoslavia	n.a.	78	7.91	3.21	2,131

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Comment G. Edward Schuh

The Yamada-Ruttan paper represents an attempt to interpret several bodies of data on partial productivity within the framework of the induced innovation hypothesis. This approach provides a richer interpretation of data on partial productivity than is usually obtained, and enables us to move beyond the mere reporting of productivity measures —important as that is to furthering our knowledge. The use of the induced innovation hypothesis provides a means of understanding development processes and development experience in a way that enables us to extend development theory while at the same time confronting that theory with a reasonably rich body of data.

The Yamada-Ruttan paper is a continuation of the work reported in Hayami and Ruttan's book, *Agricultural Development: An International Perspective.* Hayami and Ruttan reactivated Hicks's micro theory of induced innovations and applied it at the macro level in agriculture—a sector where an important share of the research has to be socialized— or in the public sector. Their particular interpretation of the theory provides insight with which to understand agricultural development processes, especially in the instrumental role they give to innovation activities. Their basic model rests on a distinction between the primary inputs of land and labor; secondary inputs of conventional capital, represented by mechanization, fertilizers, livestock, and permanent crops;

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and human capital variables, represented by general education and technical education. Innovations are specified as of two basic kinds. Biological innovations such as improved plants are viewed as a means of facilitating the substitution of fertilizer for land, while mechanical innovations are viewed as a means of facilitating the substitution of land and capital for labor.

Analytical interest focuses on the sources of productivity of land and labor, and separability of the production function is assumed so that within a range the forces determining the productivity of land can be viewed as relatively independent of the forces determining the productivity of labor. The two partial productivity measures are linked through the ratio of land area per worker. Thus $Y/L = (A/L)\ (Y/A)$, where $Y =$ output, $L =$ labor, and $A =$ land area. Growth in land area per worker (A/L) is also assumed to be relatively independent of output per worker.

These ideas gave rise to the concept of a metaproduction function, which the authors define in this paper as the envelope of the production points for the most efficient countries. (In previous work the metaproduction function has been equated with Ahmad's [1966] innovation possibility curve [IPC], which can be regarded as the envelope of neoclassical production functions which might be invented.) The metaproduction function describes a technological frontier which countries now lying inside it can achieve by appropriate borrowing and adaptive research activities and by investment in human capital, extension, and rural infrastructure.

Viewed in this framework, technological innovation is given the very instrumental role of opening up new areas along an innovation possibility curve, and facilitating the substitution of inputs produced in the industrial sector for primary inputs in agriculture. In the hands of Hayami and Ruttan, this factor substitution led to a theory of output growth, for it was postulated that inelasticity in factor supply of primary inputs such as land and labor imposed constraints on output growth. Biological and mechanical innovations which facilitate factor substitution permit these constraints to be eased, and a more rapid rate of output growth is the result.

The contribution of the present paper is to analyze two additional sets of data not available for the Hayami-Ruttan study. The first is a set of time series data on Germany, Denmark, France, and the United Kingdom—four developed countries which supplement the previous detailed record of the development of agriculture in Japan and the United States. The second is a set of cross-sectional data on forty-one countries for 1970, which supplements the 1960 data used in the previous study. These latter data are used to reestimate the parameters of the aggregate production function, and the new parameter estimates are then used to account for differences in productivity among countries.

There is a wealth of material presented for such a short paper. The highlights of the results obtained are as follows:

1. The first part of the paper reviews the evidence on long-term output and productivity growth in the six developed countries. The analysis shows that there were enormous differences in factor endowment among the six countries in 1880, and that these differences remained large in 1970 despite the enormous adjustments in factor use that had taken place. Those countries in which land area per worker was relatively limited in 1880 depended primarily on increases in output per hectare as a primary source of growth, and have been able to achieve rates of growth in total output and in output per worker that have been roughly comparable to the rates achieved by countries with more favorable resource endowments. Growth rates in output and in land and labor productivity have risen sharply in most countries since 1930. In contrast to growth rates of less than 2% in these variables prior to 1930, modern growth rates range in the neighborhood of 2–4% in output, over 5% in output per worker, and 2–4% in output per hectare.

2. In the second part of the paper an analysis is made of the relationship between factor prices and the pattern of factor use associated with growth in output and factor productivity in the six developed countries. The statistical results, using time series data for each of the countries, support the hypothesis that changes in factor use have been responsive to changes in relative factor prices. Fertilizer use per hectare has been responsive to the prices of fertilizer and of labor relative to the price of land. And the two complementary inputs—power per worker and land per worker—have been responsive to the prices of land and machinery relative to labor, although the statistical results are less strong in this case.

3. The third section of the paper is devoted to an examination of contemporary productivity differences among countries. Data are synthesized on land and labor productivities for forty-one countries in 1970. These countries are classified into three types of country groups on the basis of the relative dominance of biological and mechanical technology in their development experience, and differences in the technological patterns are analyzed in relation to the resource endowments for the respective country groups. The level of technological improvement is then related to the extent of industrialization or development in the nonagricultural sector of each country, and interrelationships between the land and labor productivity ratios and various input ratios are explored on the basis of correlation analysis to illustrate the sources of productivity differences among countries.

The intercountry differences in productivity ratios are quite large. The grouping of the countries is according to whether they are similar to the U.S., Japan, or the European countries. The authors note that in terms of their level of development the countries tend to align themselves in such a way as to be consistent with the historical paths followed by each of these three countries or groups of countries. Simple correlation analysis suggests again that resource endowments are an important factor both in determining the choice of technology and in inducing an efficient path of technological development over time. A strong association between industrialization and technological improvements is found. Relationships between human capital variables and labor productivity are found to be strong, but the association of these variables with land productivity is somewhat weaker.

4. In the fourth section of the paper the cross-sectional data on the forty-one countries are used to fit the parameters of a Hayami-Ruttan metaproduction function. These parameters are in turn used to account for the differences in productivity among selected countries. The production function is the Cobb-Douglas type and the specified inputs include conventional inputs as well as nonconventional inputs such as general and technical education.

The statistical results of estimating the production function were not as good as Hayami and Ruttan obtained with the 1960 data. Neither land nor general education had statistically significant coefficients, and the coefficient for fertilizer almost doubled compared to the estimate obtained with 1960 data.

Using somewhat arbitrary production elasticities, an analysis is made of the differences in labor productivity between the U.S. and five other countries (including Japan), and of the differences in land productivity between Japan and the other five countries (including the U.S.). The four conventional inputs account for 56–67% of the differences in output per worker between the U.S. and the other four countries. Differences in human capital account for around 30% of the difference in output per worker between the U.S. and four of the countries, but in the case of Japan, it accounts for only 12% of the difference.

In the case of land productivity, the four conventional inputs account for between 45 and 97% of the observed differences among the selected countries. The human capital variables also account for an important share of the differences in land productivity, and are particularly important in accounting for the differences between Japan and India and Turkey.

In a final section Yamada and Ruttan remind us that, although consistent with the induced innovation hypothesis, their results do not provide a rigorous test of that hypothesis. They believe that the evidence they produce is so strong, however, that there is a presumption that the induced innovation hypothesis was involved. In their view the results of their analysis support a conclusion that failure to take advantage of the potential growth from human capital and technical inputs represents a significant constraint on agricultural development around the world, and that differences in the natural resource base account for an increasingly less significant share of the widening productivity gap among countries.

In viewing the less developed countries, with their expected labor force explosion in the years ahead, Yamada and Ruttan believe that failure to effectively institutionalize public-sector agricultural research can seriously distort the pattern of technical change and resource use. The point is that the private sector will have ample incentive to produce mechanical innovations and those biological innovations that can be embodied in proprietary products. The private sector will *not* have adequate incentives to produce other biological innovations, however, with the result that the productivity path will not be consistent with factor endowments, especially in the more labor-intensive less developed countries.

As this brief overview should have made clear, the Yamada-Ruttan paper is a particularly rich bag, and it is difficult, in a brief synthesis, to do justice to the richness and diversity of the material presented. The authors have done yeomanly duty in bringing data together, in presenting them in imaginative and enlightening ways, and in attempting to interpret them with a larger body of development theory.

Similarly, the importance of the subject—productivity in agriculture—can hardly be denied. The problem of world hunger has dominated newspaper headlines over the last three years. It is generally recognized that the world's burgeoning population growth will be fed only with a sizable and sustained increase in productivity. Equally as important, the bulk of the world's poor are concentrated in agriculture. Their lot can be improved only through growth in productivity.

In many respects, however, the present paper is disappointing. It fails to capitalize fully on the new sets of data it uses, and treats some rather serious statistical problems in a rather cavalier fashion. When statistical results do not support preconceived notions of how the world is, the authors have somewhat of a tendency to stay with their preconceived notions. And some rather serious measurement problems or problems of correspondence are quietly swept under the rug.

In commenting on the Yamada-Ruttan paper I would like to focus on five main issues.

1. The maintained hypothesis. Considerable effort by the authors has gone into synthesizing time series data on four additional developed countries for comparison with the experience of Japan and the United States, and into generating a new set of cross-sectional data on forty-one

countries. The analysis of these data would have been considerably enriched if some a priori hypotheses about development experience had been specified and tested. The original Hayami-Ruttan analysis was rich in ideas about the role of institutional arrangements and how they might influence the technological path chosen. The theory was also capable of generating hypotheses about particular paths of development that might have been expected to be taken over the last decade, given knowledge about changes in factor price ratios. Yet the reader finds only tangential reference to such a priori thought which might have enriched the analysis of these important sets of data. We are left almost totally in the dark about why these particular four developed countries were chosen; we see no discussion of how different institutional arrangements might have influenced the particular development paths chosen; and we see little a priori discussion of how production elasticities of the aggregate production function might have been expected to change over time, if at all, or of how the development experience in 1970 might be expected to differ from the experience observed in 1960. Instead, the new data are analyzed rather mechanically, in much the same way as in the previous study, with little attention given to a priori hypotheses or to how they might be tested with the data.

As a result, there is a general tendency to fail to answer some important "why" questions. For example, why did output per hectare rise less rapidly in Denmark during 1930–70 than during 1880–1930? Why did France experience the most dramatic transition of any of the six countries between 1880–1930 and 1930–70? Why was the U.S. persistently on a quite different growth path than the other five countries? Why was Denmark the only country that experienced a sustained decline in land per worker?

2. The specification of the production function. The Cobb-Douglas production function is at best a crude approximation to the metaproduction function, or to the underlying theoretical model that the authors lay out. It was useful as the basis for a first test of the Hayami-Ruttan model. But if the authors want to advance our knowledge beyond that first approximation, they need to probe more deeply. Just a couple of points are worth noting. First, discussion early in the paper focuses on complementarity between some inputs and strong substitutability among others. Yet the Cobb-Douglas does not permit us to accomodate these differences. Similarly, the Cobb-Douglas assumes an elasticity of substitution of one. Yet their own statistical results suggest that the elasticity of substitution beween machinery horsepower and labor is greater than one.

These problems are troublesome. At the least the problems should be addressed. More importantly, if the authors are to capitalize on the insights offered by the Hayami-Ruttan model, they need to specify a production function that can accommodate the implications of that model.

3. Statistical problems. There are a number of statistical problems in the paper, some of which are rather obvious, others of which are more subtle. In the first place, the land and labor productivity equations consistent with the Cobb-Douglas production function contain for estimational purposes exactly the same variables on the right-hand side as the original production function. The only difference is that the coefficient of the input whose productivity is being considered is now equal to the production elasticity of the production function minus one, which means that the estimated coefficient will typically be negative. The coefficients of all other variables will be exactly the same as in the original production function. Put differently, there is little to be gained from estimating the parameters of both the production function and the productivity equations. In a Cobb-Douglas world they are virtually the same.

This problem would not be so serious if it were not that Yamada and Ruttan use a production elasticity of .25 for education in accounting for differences in productivity among countries, apparently on the basis that its coefficient was a statistically insignificant .26 in one version of each of the two productivity equations. These results must be taken with a grain of salt, for the productivity equations are improperly specified and hence add little to our knowledge. In point of fact, the authors have *no* statistical support for the role of general education in the production function from this particular set of data, or at least from this set of regressions.

A second statistical problem has to do with the problem of intercorrelation. This problem comes up in the lack of statistical significance for the coefficient of land and the small size of this coefficient. I agree with the authors that the importance of land is often exaggerated in the discussion of agricultural development. But to accept the notion that land has virtually no importance in the production function is to ask a bit much, especially with the particular set of countries included in their sample. What has likely happened is that the fertilizer variable has picked up the effect of the land input. These two variables would be expected to be highly interdependent, and it is worth noting that the increase in the fertilizer coefficient, compared to the 1960 data, is approximately equal to the decline in the coefficient of land. These shifts in coefficient values are very likely statistical artifacts, and of no economic significance—despite the authors' inclinations to give them an economic interpretation.

More generally, the authors are rather cavalier about statistical problems in general. Little attention is given to evaluating the statistical results obtained, or to the use of alternative procedures whereby the statistical results might have been improved.[1] Such procedures might have been especially useful in the case of the lack of statistical significance for the coefficients of both land and general education. A more careful statistical evaluation of the production function was an imperative in light of the desire to use the production elasticities in accounting for the sources of differences in productivity among countries.

4. Problems of measurement. The disappointing statistical results with the aggregate production function may also be due to measurement problems. Education is a good example. Its quality varies widely from one country to another, as does the nature of training and the goals of education. The surprise is probably that such a crude measure of education worked in the previous study, not that it performed so badly in the present case.

The problem with land is even more severe. This variable is measured as the simple sum of the areas in arable land, land under permanent crops, and permanent meadows and pastures. In other words, a hectare of pasture land on the frontier of Brazil is given the same weight as a hectare of prime Iowa farmland, or as a hectare of land on the Indo-Gangetic plain that can grow two and in some cases three crops per year.

Land is really a proxy for a very complex set of variables in these models, ranging from inherent soil quality in terms of nutrients and soil characteristics, to rainfall, temperature, and distribution of rainfall. Moreover, the degree of multiple cropping and interplanting varies widely from one place to another within a country, and from one country to another. The implication, of course, is that it makes little sense to just add up such widely differing units of an input. And if one does, he should not be very surprised that the result does not perform very well in a regression analysis.

One can sympathize with the difficulty of attempting to come to grips with this problem. But the warning flag has to be raised when the estimated coefficients do not meet the usual statistical tests. This reviewer admits to having little confidence in the results presented in the section which attempts to account for differences in productivity among the selected countries. A coefficient of .25 was used for education, when there was absolutely no statistical support for this variable in the estimation of the production function. A coefficient of .02 was used for land, yet this also was derived from a coefficient that was not statistically significant, and all the a priori information that one has suggests that land has a greater role in the production process than a coefficient of .02 implies.

1. The problem of simultaneity rears its ugly head on a number of occasions, especially when land values are used as explanatory variables. Little appreciation for that problem is found in the paper.

These difficulties are brought to the fore by the tendency of the authors to come down so heavily on the side of the human capital variables. Clearly, if one puts so little weight on land and such a large weight on general education, the results are almost foreordained.

5. Additional variables or alternative interpretations. Hayami and Ruttan and their immediate intellectual forebears in the field of agricultural development have substantially broadened our perspectives on the development process by incorporating social or infrastructure variables such as research and education into the aggregate production function. Clearly, that is to focus attention on two important variables, and the theoretical and empirical evidence for these previously omitted variables is relatively strong. But an objective observer can still be concerned about misspecification, especially in the context of drawing on international data.

Perhaps the two variables of most importance are economies of scale and specialization in production. The evidence on the first is rather mixed, but at the same time it is fair to say that few of the tests that have been made have been very rigorous or robust. On the gains from specialization in production, we know even less. But as agricultural sectors develop there is a tendency for geographic specialization in production as well as for firm specialization in production to take place. For example, farms in the American Midwest have evolved from general farms with a wide range of production activities to specialized farms with only one or two products. Moreover, there have been large shifts in the location of production within the U.S.

The problem with both of these factors, especially in the present context, is that both tend to be correlated with the level of development. Farm enlargement occurs as labor is drained out of agriculture, and specialization in production also tends to occur as development proceeds. Like it or not, general education is a good proxy for the level of development in an economy. What we do not know is whether the coefficient for education is picking up the effect of these other variables, or whether it is reflecting the effect of education as a quality adjustment for labor. That is, the problem of specification bias is still with us.

It should also be noted that general education plays a dual role in agricultural development. Although it makes labor more productive within agriculture, it at the same time increases the employability of the labor in the nonfarm labor market, thereby accelerating the rate of out-migration from agriculture, other things being equal. If this input "supply" effect should outweigh the input "demand" effect, the relationship between education and land productivity would be expected to be weak, especially in simple correlations.

To conclude on a somewhat more positive note, we are still in Yamada and Ruttan's debt, despite these statistical problems and the associated problems of interpretation. Future students of agricultural development will be indebted to them for the additional data they have synthesized. And the attempt to link the level of urban industrialization to the Hayami-Ruttan model, even if only informally, is promising.

But perhaps the most important strength of the paper is the attempt to interpret the productivity data with a theory of agricultural development. This enriches the interpretation of the data and provides insights into a more general economic problem. The Hayami-Ruttan model is a particularly insightful way of viewing the agricultural development process. It is simple but powerful in what it enables us to dig out of the data.

References

Ahmad, S. On the theory of induced innovation. *Economic Journal* 76 (1966): 344–57.