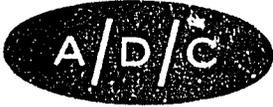


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**INDUCED INNOVATION AND  
AGRICULTURAL DEVELOPMENT**

Vernon W. Ruttan

**AGRICULTURAL DEVELOPMENT COUNCIL**  
1290 Avenue of the Americas      New York, N.Y. 10019

# Induced innovation and agricultural development

Vernon W. Ruttan

Dr Ruttan reviews the five general models in the literature on agricultural development: the frontier, conservation, urban-industrial impact, diffusion and high pay-off input models, and finds them lacking. He outlines a model of agricultural development which treats technical change as endogenous to the development process, rather than as an exogenous factor operating independently of it. This leads to an emphasis on the strong relationship between technological and institutional change and a call for institutional innovation that will result in a more effective realisation of the new technical potential.

Vernon R. Ruttan is President of the Agricultural Development Council, 1290 Avenue of the Americas, New York, NY 10019 and Room 705, HELC Int. House, 30 Orange Grove Road, Singapore 10.

<sup>1</sup> For a perspective on the limits to growth literature see Vernon W. Ruttan, 'Technology and the environment', *American Journal of Agricultural Economics* Vol 53, December 1971, pp 707-717; and Robert M. Solow, 'The economics of resources or the resources of economics', *American Economic Review*, Vol 64, May 1974, pp 1-14.

The 1970s have not been kind to the reputations of either the prophets who have attempted to plot the course of world food production or to the scholars who have attempted to understand the processes of agricultural development. Perspectives have shifted from a sense of impending catastrophe engendered by the world food crisis of the mid-1960s; to the euphoria of the new potentials opened up by the 'Green Revolution'; to the crunch on world grain supplies resulting from poor harvests in South Asia, parts of sub-Saharan Africa and the USSR in 1972-74. With the resurgence of food production (except in Eastern Europe and the USSR) in 1975 and again in 1976 it seems safe to anticipate a new round of complacency about the prospects for world food supplies and for agricultural development. Yet the simple mathematics of inelastic food demand, uncertain weather, and improvident food stock policies virtually assures at least one food crisis of global significance during the next decade.

## Agricultural growth

Renewed uncertainty about the longer-term prospects for the growth of agricultural production and for the economic welfare of rural people stems, however, from more fundamental concerns than the recent dramatic behaviour in agricultural commodity markets. There has been a convergence of scientific opinion and ideological perspective to the effect that the world is fast approaching both the physical and cultural limits to growth. The theme that 'progress breeds not welfare, but catastrophe' has again emerged from the underworld of social thought as a serious theme in scientific and philosophical inquiry.<sup>1</sup>

The tools of the economist are relatively blunt instruments with which to confront the grand theme of epochal growth and decline. Until a few decades ago comparative statics was the most powerful theoretical tool available to the economist as a guide to empirical knowledge. Even modern neoclassical growth theory is based primarily on an application of the tools of comparative statics to the analysis of alternative steady growth paths. Growth of output is narrowly determined by the growth of the labour force, the state of technology, and the stock of human and tangible capital. Technical

change has, with few exceptions, been treated as exogenous to the economic system. Institutional change has not been formally incorporated into growth theory. The story revealed to us through the application of modern macroeconomic growth theory is dull indeed compared with historical experience.

The last two decades have been highly productive in advancing both our analytical capacity and our empirical knowledge of the role of technical change in agricultural development and of the sources of productivity growth in agriculture. The dating of 'modern' agricultural growth in the now conventional model or paradigm of agricultural development begins with the emergence of a period of sustained growth in total productivity – a rise in output per unit of total input.

When growth is based on a more intensive use of traditional inputs little extra becomes available to improve the well being of rural people or to be transferred to the rest of the economy.<sup>2</sup> Little surplus has been generated by simple resource reallocation within farms, communities, or regions in the absence of technical change embodied in less expensive and more productive inputs. Only as the constraints on growth imposed by the primary reliance on indigenous inputs – those produced primarily within the agricultural sector – are released by new factors whose productivity is augmented by the use of new technology is it possible for agriculture to become an efficient source of growth in a modernising economy.

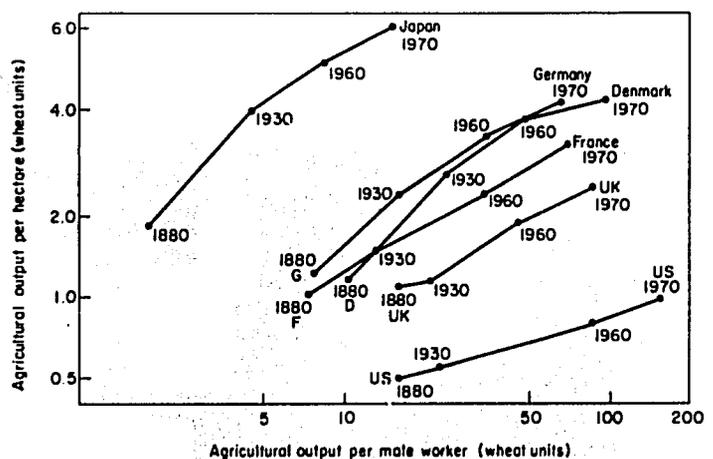
Initially, growth in the total productivity ratio has typically been dominated by growth in a single partial productivity ratio. In the USA, and the other developed countries of recent settlement, growth in labour productivity has typically 'carried' the initial burden of growth in total productivity. In countries characterised by relatively high man/land ratios at the beginning of the development process, Germany and Japan for example, growth in land productivity was largely responsible for growth in total productivity during the early years of modernisation. As modernisation has continued, there emerged a tendency for total productivity growth to be fed by a more balanced growth in the partial productivity ratios, ie growth in output per worker and per hectare (see Figure 1).

For a number of countries, however, the model outlined above has

<sup>2</sup> This argument is developed most fully in Theodore W. Schultz, *Transforming Traditional Agriculture*, Yale University Press, New Haven, 1964. See particularly pp 36-52. Following the publication of the Schultz book a view of the peasant as 'poor but efficient' rapidly emerged as a new orthodoxy replacing the earlier view that the major limit on agricultural development was the burden of custom and tradition which bore down on the peasant producer in traditional agricultural systems.

Figure 1. Historical growth paths of agricultural productivity in the USA, Japan, Germany, Denmark, France and the UK, 1880-1970.

Source: Vernon W. Ruttan, Hans P. Binswanger, Yujiro Hayami, William Wade and Adolph Weber, 'Factor productivity and growth: a historical interpretation' in Hans P. Binswanger and Vernon W. Ruttan, *Induced Innovation: Technology, Institutions and Development*, The Johns Hopkins University Press, Baltimore, forthcoming.



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little meaning. The 20th century has been characterised by a massive, and continuously widening, disequilibrium in the efficiency of resource use and the welfare of rural people between rich and poor countries. Since World War II, output per hectare has been growing at approximately the same rate of about 2% per year in the developing countries as in the developed countries. But output per worker in the developing countries has been growing at only one-third the rate of that in the developed countries – about 1.5% per year compared to about 4.5% per year. And for large numbers of developing countries, and for the lagging regions in many others, even those rates remain outside the personal experience of most farm families. In these lagging regions output per hectare is growing at rates that are barely perceptible and output per worker has experienced no measurable change, not only between years but between generations. In the 'developing world' food output per person is not significantly higher today than in the mid-1930s and in many areas in Asia the number of kilograms of food grain that can be purchased with a day's labour has declined since the early 1960s.<sup>3</sup>

### **Agricultural development strategies**

During the rest of this century it is imperative that we develop and implement more effective agricultural development strategies than have been available in the past. A useful first step is to review the approaches to agricultural development available to us in the past and which will remain part of our intellectual equipment as we attempt to build on existing knowledge in the future.

Any attempt to evolve a meaningful perspective on the process of agricultural development must abandon the view of agriculture in pre-modern or traditional societies as essentially static. Historically, the problem of agricultural development is not that of transforming a static agricultural sector into a modern dynamic sector, but of accelerating the rate of growth of agricultural output and productivity consistent with the growth of other sectors of a modernising economy. Similarly, a theory of agricultural development should provide insight into the dynamics of agricultural growth, ie, into the changing sources of growth, in economies ranging from those in which output is growing at a rate of 1.0% or less to those in which agricultural output is growing at an annual rate of 4.0% or more.

There seem to me to be five general models in the literature on agricultural development:

- The frontier model.
- The conservation model.
- The urban-industrial impact model.
- The diffusion model.
- The high-payoff input model.<sup>4</sup>

#### *The frontier model*

Throughout most of history expansion of the area cultivated or grazed has represented the main way of increasing agricultural production. The most dramatic example in Western history was the opening up of the new continents – North and South America and Australia – to European settlement during the 18th and 19th centuries. With the advent of cheap transport during the latter half of

<sup>3</sup> See Michael Lipton, 'Urban bias and food policy in poor countries', *Food Policy*, Vol 1 No 1, November 1975, pp 41-52.

<sup>4</sup> A more detailed development of the conservation, the urban industrial impact, the diffusion, and the high payoff input models is presented in Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective*, The John Hopkins Press, Baltimore, 1971, pp 27-43. The discussion of the frontier model presented below draws very heavily from D.P. Grigg, *The Agricultural Systems of the World: An Evolutionary Approach*, Cambridge University Press, Cambridge, 1974 and Shigeru Ishikawa, *Economic Development in Asian Perspective*, Kinokuniya Bookstore Co Ltd, Tokyo, 1967.

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the 19th century, the countries of the new continents became increasingly important sources of food and agricultural raw materials for the metropolitan countries of Western Europe.

In earlier times, similar processes had proceeded, though at a less dramatic pace, in the peasant and village economies of Europe, Asia and Africa. The first millennium AD saw the agricultural colonisation of Europe north of the Alps, the Chinese settlement of the lands south of the Yangtze and the Bantu occupation of Africa south of the tropical forest belts. Intensification of land use in existing villages was followed by pioneer settlement, the establishment of new villages, and the opening up of forest or jungle land to cultivation. In Western Europe there were a series of successive changes from neolithic forest fallow to systems of shifting cultivation on bush and grass land followed first by short fallow systems, and in recent years by annual cropping.

Where soil conditions were favourable, as in the great river basins and plains, the new villages gradually intensified their systems of cultivation. Where soil resources were poor, as in many of the hill and upland areas, new areas were opened up to shifting cultivation or to nomadic grazing. Under conditions of rapid population growth, the limits to the frontier model were often quickly reached. Crop yields were typically low – measured in terms of output per unit of seed rather than per unit of crop area. Output per hectare and per man hour tended to decline – except in the delta areas such as in Egypt and South Asia, and the wet rice areas of East Asia. In many areas the result was to worsen the wretched conditions of the peasantry.

There are relatively few remaining areas of the world where development along the lines of the frontier model will represent an efficient source of growth during the last quarter of the 20th century. The 1960s saw the 'closing of the frontier' in most areas of South East Asia. In Latin America and Africa the opening up of new lands awaits the development of technologies for the control of pests and diseases (such as the Tsetse fly in Africa) or for the release and maintenance of productivity of problem soils. This century can be seen as the transition from a period when most of the increases in world agricultural production occurred as a result of the expansion in area cultivated to a period when most of the increase in crop and animal production will come from increases in the frequency and intensity of cultivation – from changes in land use which make it possible to crop a given area of land more frequently and more intensively and hence to increase the output per unit area and per unit of time.

#### *The conservation model*

The conservation model of agricultural development evolved from the advances in crop and livestock husbandry associated with the English agricultural revolution and the concepts of soil exhaustion suggested by the early German chemists and soil scientists. It was reinforced by the concept, in the English classical school of economics, of diminishing returns to labour and capital applied to land. The conservation model emphasised the evolution of a sequence of increasingly complex land and labour-intensive cropping systems, the production and use of organic manures, and labour-intensive capital formation in the form of physical facilities to more effectively use land and water resources.

Until well into the 20th century the conservation model of agricultural development was the only approach to intensification of agricultural production that was available to most of the world's farmers. Its application can be effectively illustrated by the development of the wet-rice culture systems that emerged in East and Southeast Asia and by the labour and land intensive systems of integrated crop-livestock husbandry which increasingly characterised European agriculture during the 18th and 19th centuries. During the English agricultural revolution more intensive crop-rotation systems replaced the open three-field system in which arable land was allocated between permanent crop land and permanent pasture. This involved the introduction and more intensive use of new forage and green manure crops and an increase in the availability and use of animal manures. This 'new husbandry' permitted the intensification of crop-livestock production through the recycling of plant nutrients, in the form of animal manures, to maintain soil fertility. The inputs used – the plant nutrients, the animal power, land improvements, physical capital and the agricultural labour force – were largely produced or supplied by the agricultural sector itself.

Agricultural development, within the framework of the conservation model, clearly was capable in many areas of the world of sustaining rates of growth in agricultural production around 1.0% per year over relatively long periods of time. This rate is not compatible, however, with modern rates of growth in the demand for agricultural output which typically fall between 3-5% in the developing countries.

#### *The urban-industrial impact model*

In the conservation model locational variations in agricultural development were related primarily to differences in environmental factors. It stands in sharp contrast to models which interpret geographical differences in the level and rate of economic development primarily in terms of the level and rate of urban-industrial development.

Initially, the urban-industrial impact model was formulated by von Thunen in Germany to explain geographical variations in the intensity of farming systems and in the productivity of labour in an industrialising society. In the USA it was extended to explain the more effective performance of the input and product markets linking the agricultural and non-agricultural sectors in regions characterised by rapid urban-industrial development than in regions where the urban economy had not made a transition to the industrial stage. In the 1950s interest in the urban-industrial impact model reflected a concern with the failure of agricultural resource development and price policies adopted in the 1930s to remove the persistent regional disparities in agricultural productivity and in rural incomes.

The rationale for this model was developed in terms of more effective factor and product markets in areas of rapid urban-industrial development. Industrial development, stimulated agricultural development by expanding the demand for farm products; by supplying the industrial inputs needed to improve agricultural productivity; and by drawing away surplus labour from agriculture. The empirical tests of the model have repeatedly confirmed the importance of a strong non-farm labour market as a stimulus to higher labour productivity in agriculture.



The policy implications of the model appear to be most relevant for the less developed regions of the highly industrialised countries or lagging regions of the more rapidly growing developing countries. Agricultural development policies based on the urban-industrial impact model appear to be particularly inappropriate in those countries where the 'pathological' growth of urban centres is a result of population pressures in rural areas running ahead of employment growth in urban areas.

*The diffusion model*

The diffusion approach to agricultural development rests on the empirical observation of substantial differences in land and labour productivity among farmers and regions. The route to agricultural development, in this view, is through more effective dissemination of technical knowledge and a narrowing of the productivity differences among farmers and among regions. The diffusion of better husbandry practices was a major source of productivity growth even in pre-modern societies. Prior to the development of modern agricultural research systems substantial effort was devoted to crop exploration and introduction. Even in nations with well-developed agricultural research systems a significant effort is still devoted to the testing and refinement of farmers' innovations and to testing and adaptation of exotic crop varieties and animal species.

This model provided the major intellectual foundation of much of the research and extension effort in farm management and production economics since the emergence, in the latter years of the 19th century, of agricultural economics and rural sociology as separate sub-disciplines linking the agricultural and the social sciences. The developments which led to the establishment of active programmes of farm management research and extension occurred at a time when experiment-station research was making only a modest contribution to agricultural productivity growth. A further contribution to the effective diffusion of known technology was provided by the research of rural sociologists on the diffusion process. Models were developed emphasising the relationship between diffusion rates and the personality characteristics and educational accomplishments of farm operators.

The insights into the dynamics of the diffusion process, when coupled with the observation of wide agricultural productivity gaps among developed and developing countries and a presumption of inefficient resource allocation among 'irrational tradition-bound' peasants, produced an extension or a diffusion bias in the choice of agricultural development strategy in many developing countries during the 1950s. The limitations of the diffusion model as a foundation for the design of agricultural development policies became increasingly apparent as technical assistance and community development programmes, based explicitly or implicitly on the diffusion model, failed to generate either rapid modernisation of traditional farms and communities or rapid growth in agricultural output.

*The high-payoff input model*

The inadequacy of policies based on the conservation, urban-industrial impact, and diffusion models led, in the 1960s, to a new perspective. In this, the key to transforming a traditional agricultural

sector into a productive source of economic growth is investment designed to make modern, high-payoff inputs available to farmers in poor countries. Peasants, in traditional agricultural systems, were viewed as rational, efficient resource allocators. They remained poor because, in most poor countries, there were only limited technical and economic opportunities to which they could respond. The new, high-payoff inputs, were classified into three categories:

- The capacity of public and private sector research institutions to produce new technical knowledge.
- The capacity of the industrial sector to develop, produce, and market new technical inputs.
- The capacity of farmers to acquire new knowledge and use new inputs effectively.

The enthusiasm with which the high payoff input model has been accepted and translated into economic doctrine has been due in part to the proliferation of studies reporting high rates of return to public investment in agricultural research (see Table 1). It was also due to the success of efforts to develop new, high-productivity grain varieties suitable for the tropics. New high-yielding wheat varieties were developed in Mexico, beginning in the 1950s, and new high-yielding rice varieties were developed in the Philippines in the 1960s. These varieties were highly responsive to industrial inputs, such as fertiliser and other chemicals, and to more effective soil and water management. The high returns associated with the adoption of the new varieties and the associated technical inputs and management practices have led to rapid diffusion of the new varieties among farmers in several countries in Asia, Africa, and Latin America (see Table 2).

### **An induced innovation model**

The high-payoff input model remains incomplete as a theory of agricultural development. Typically, education and research are public goods not traded through the market place. The mechanism by which resources are allocated among education, research, and other alternative public and private sector economic activities was not fully incorporated into the model. It does not explain how economic conditions induce the development and adaption of an efficient set of technologies for a particular society. Nor does it attempt to specify the processes by which input and product price relationships induce investment in research in a direction consistent with a nation's particular resource endowments.

These limitations in the high-payoff input model led to efforts to develop a model of agricultural development in which technical change is treated as endogenous to the development process, rather than as an exogenous factor that operates independently of other development processes.<sup>3</sup> The induced innovation perspective was stimulated by historical evidence that different countries had followed alternative paths of technical change in the process of agricultural development (Figure 1) and by a consideration of the wide productivity differentials among countries (Figures 2 and 3).

The productivity levels achieved by farmers in the most advanced countries in each productivity grouping (Figures 1, 2 and 3) can be seen as arranged along a productivity frontier. This frontier reflects

<sup>3</sup> Hayami and Ruttan, *op cit*, Ref 4, pp 53-63 and 111-135.

Table 1. Summary studies of agricultural research productivity

| Study                                   | Country      | Commodity   | Time period   | Annual internal rate of return %         |
|---|--------------|---|---------------|--|
| <b>Direct cost benefit studies</b>      |              |   |               |  |
| Griliches, 1958                         | USA          | Hybrid corn   | 1940-55       | 35-40                                    |
| Griliches, 1958                         | USA          | Hybrid sorghum  | 1940-57       | 20                                       |
| Peterson, 1966                          | USA          | Poultry   | 1915-60       | 21-25                                    |
| Evenson, 1969                           | South Africa | Sugarcane   | 1945-62       | 40                                       |
| Ardito Barletta, 1970                   | Mexico       | Wheat   | 1943-63       | 90                                       |
| Ardito Barletta, 1970                   | Mexico       | Maize   | 1943-63       | 35                                       |
| Ayer, 1970                              | Brazil       | Cotton  | 1924-67       | 77+                                      |
| Schmitz & Seckler, 1970                 | USA          | Tomato harvester  | 1958-69       |  |
|   |              | with no compensation to displaced workers                           |               | 37-46                                    |
|   |              | assuming compensation of displaced workers for 50% of earnings loss |               | 18-28                                    |
| Hines, 1972                             | Peru         | Maize   | 1954-67       | 35-40 <sup>a</sup><br>60-65 <sup>b</sup> |
| Hayami & Akino 1975                     | Japan        | Rice  | 1915-60       | 25-27                                    |
| Hayami & Akino, 1975                    | Japan        | Rice  | 1930-61       | 73-75                                    |
| Hertford, Ardila, Rocha & Trujillo 1975 | Colombia     | Rice  | 1957-72       | 60-82                                    |
|   | Colombia     | Soybeans  | 1960-71       | 79-86                                    |
|   | Colombia     | Wheat   | 1953-73       | 11-12                                    |
|   | Colombia     | Cotton  | 1953-72       | none                                     |
| Peterson & Fitzharris, 1975             | USA          | Aggregate   | 1937-42       | 50                                       |
|   |              |   | 1947-62       | 51                                       |
|   |              |   | 1957-62       | 49                                       |
|   |              |   | 1957-72       | 34                                       |
| <b>Sources of growth studies</b>        |              |   |               |  |
| Tang, 1963                              | Japan        | Aggregate   | 1880-1938     | 35                                       |
| Griliches, 1964                         | USA          | Aggregate   | 1949-69       | 35-40                                    |
| Latimer, 1964                           | USA          | Aggregate   | 1949-69       | Not significant                          |
| Peterson, 1966                          | USA          | Poultry   | 1915-60       | 21                                       |
| Evenson, 1968                           | USA          | Aggregate   | 1949-69       | 47                                       |
| Evenson, 1969                           | South Africa | Sugarcane   | 1915-68       | 40                                       |
| Evenson, 1969                           | Australia    | Sugarcane   | 1915-68       | 50                                       |
| Evenson, 1969                           | India        | Sugarcane   | 1945-68       | 60                                       |
| Ardito Barletta, 1970                   | Mexico       | Crops   | 1943-63       | 45-93                                    |
| Jha & Evenson, 1973                     | India        | Aggregate   | 1953-71       | 40                                       |
| Kahlon, Saxena, Bal, & Jha, 1975        | India        | Aggregate   | 1960/61-72/73 | 63                                       |

<sup>a</sup>Returns to maize research only.

<sup>b</sup>Returns to maize research plus cultivation 'package'.

**Sources.** The following estimates are presented in *Resource Allocation and Productivity* edited by Thomas M. Arndt, Dona G. Dalrymple and Vernon W. Ruttan, University of Minnesota Press, Minneapolis, 1977; Y. Hayami, and M. Akino, 'Organisation and productivity of agricultural research systems in Japan' pp 29-59; R. Hertford, J. Ardila, A. Rocha and C. Trujillo, 'Productivity of agricultural research in Colombia' pp 86-123; A.S. Kahlon, H.K. Bal, P.N. Saxena, and D. Jha, 'Returns to investment in research in India' pp 124-147; and W.L. Peterson, and J.C. Fitzharris, 'The organisation and productivity of the federal-state research system in the United States' pp 60-85. The other estimates have been summarised by James K. Boyce and Robert E. Evenson in *Agricultural Research and Extension Systems*, The Agricultural Development Council, New York, 1975. The individual estimates are: N. Ardito Barletta, 'Costs and social benefits of agricultural research in Mexico', PhD dissertation, University of Chicago, Chicago, 1970; H. Ayer, 'The costs, returns and effects of agricultural research in a developing country: the case of cotton seed research in São Paulo, Brazil', PhD dissertation, Purdue University, Lafayette, 1970; R. Evenson, 'International transmission of technology in sugarcane production', Mimeo, Yale University, New Haven, 1969; R. Evenson, 'The contribution of agricultural research and extension to agricultural production', PhD dissertation, University of Chicago, Chicago, 1968; R.E. Evenson and D. Jha, 'The contribution of agricultural research systems to agricultural production in India', *Indian Journal of Agricultural Economics*, Vol 28, 1973, pp 212-230; Z. Griliches, 'Research costs and social returns: hybrid corn and related innovations', *Journal of Political Economy*, Vol 66, 1958, pp 419-431; Z. Griliches, 'Research expenditures, education and the aggregate agricultural production function', *American Economic Review*, Vol 54 No 6, December 1974, pp 961-974; J. Hines, 'The utilization of

research for development: two case studies in rural modernization and agriculture in Peru', PhD dissertation, Princeton University, Princeton, 1972; R. Latimer, 'Some economic aspects of agricultural research and extension in the U.S.', PhD dissertation, Purdue University, Lafayette, 1964; W.L. Peterson, 'Returns to poultry research in the United States', *Journal of Farm Economics*, Vol 49, August 1987, pp

656-669; A. Schmitz and D. Seckler, 'Mechanised agriculture and social welfare: the case of the tomato harvester', *American Journal of Agricultural Economics*, Vol 52 No 4, November 1970, pp 569-577; and A. Tang, 'Research and education in Japanese agricultural development', *Economic Studies Quarterly*, Vol 13 February-May 1963, pp 27-41 and 91-99.

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**Table 2. Estimated area planted to high-yielding varieties in Asia and the Near East (ha)**

| Country               | 1965/66 | 1966/67   | 1967/68   | 1968/69                | 1969/70   | 1970/71   | 1971/72    | 1972/73                | 1973/74                  | 1974/75<br>(prelim)       |
|-----------------------|---------|-----------|-----------|------------------------|-----------|-----------|------------|------------------------|--------------------------|---------------------------|
| Area planted to wheat |         |           |           |                        |           |           |            |                        |                          |                           |
| Asia                  |         |           |           |                        |           |           |            |                        |                          |                           |
| Bangladesh            | --      | --        | --        | 8 400                  | 9 100     | 13 500    | 15 000     | 21 450                 | 29 100                   | 33 200                    |
| India                 | 3 000   | 540 900   | 2 942 000 | 4 792 700              | 5 004 300 | 6 542 500 | 7 858 100  | 10 007 000             | 10 911 000               | 11 778 400                |
| Nepal                 | 1 400   | 8 600     | 24 800    | 63 800                 | 71 500    | 98 200    | 115 900    | 170 300                | 208 800                  | 246 900                   |
| Pakistan              | 4 900   | 101 200   | 957 100   | 2 387 700              | 2 681 500 | 3 128 300 | 3 286 200  | 3 375 200              | 3 472 300                | 3 682 800 <sup>1</sup>    |
| Total                 | 9 300   | 648 700   | 3 913 900 | 7 242 600              | 7 771 000 | 9 782 500 | 11 275 200 | 13 573 950             | 14 619 200               | 15 741 300                |
| Near East             |         |           |           |                        |           |           |            |                        |                          |                           |
| Afghanistan           | --      | 1 800     | 22 000    | 122 000                | 146 000   | 232 000   | 255 000    | 450 000                | 475 000                  | 522 000                   |
| Algeria               | --      | --        | --        | --                     | 5 100     | 140 000   | 320 000    | 600 000                | na                       | na                        |
| Egypt                 | --      | --        | --        | --                     | --        | 150       | 1 800      | 20 100                 | 212 800                  | 78 600                    |
| Iran                  | --      | --        | --        | 10 000                 | 37 000    | 63 000    | 125 000    | 138 000                | 261 000 <sup>1</sup>     | 292 500 <sup>1</sup>      |
| Iraq                  | --      | --        | 6 400     | 41 700                 | 195 200   | 125 000   | 950 000    | 595 000                | 700 000                  | 750 000                   |
| Lebanon               | --      | --        | 50        | 400                    | 2 500     | 7 000     | 12 000     | 20 000                 | na                       | na                        |
| Morocco               | --      | --        | 200       | 4 900                  | 46 500    | 90 000    | 206 000    | 294 000                | 375 100                  | 300 000                   |
| Saudi Arabia          | --      | --        | --        | --                     | --        | --        | --         | 150                    | 2 000                    | 10 000                    |
| Syria                 | --      | --        | --        | --                     | --        | 38 000    | 75 000     | 121 000                | 224 000                  | 269 000                   |
| Tunisia               | --      | --        | 800       | 12 000                 | 53 000    | 102 000   | 60 000     | 99 000                 | 55 000                   | 54 900                    |
| Turkey                | --      | 600       | 170 000   | 579 000                | 623 000   | 640 000   | 650 000    | na                     | na                       | na                        |
| Total                 | --      | 2 400     | 199 450   | 770 000                | 1 108 300 | 1 437 150 | 2 654 800  | 2 987 250 <sup>2</sup> | 3 574 900 <sup>2,3</sup> | 3 547 000 <sup>2,3</sup>  |
| Area planted to rice  |         |           |           |                        |           |           |            |                        |                          |                           |
| Asia                  |         |           |           |                        |           |           |            |                        |                          |                           |
| Bangladesh            | --      | 200       | 67 200    | 154 200                | 263 900   | 460 100   | 623 600    | 1 064 400              | 1 584 800                | 1 443 600                 |
| Burma                 | --      | --        | 3 400     | 166 900                | 143 000   | 190 900   | 185 100    | 199 200                | 252 600                  | 332 200                   |
| India                 | 7 100   | 888 400   | 1 758 000 | 2 681 000              | 4 253 600 | 5 454 000 | 7 199 400  | 8 107 400              | 9 718 200                | 11 045 200                |
| Indonesia             | --      | --        | --        | 198 000                | 831 000   | 902 600   | 1 332 900  | 1 928 000              | 3 100 800                | 3 440 000                 |
| Korea (South)         | --      | --        | --        | --                     | --        | --        | 2 700      | 187 500                | 139 000                  | 306 900                   |
| Laos                  | --      | 360       | 1 200     | 2 000                  | 2 000     | 53 600    | 30 000     | 50 000                 | na                       | na                        |
| Malaysia (West)       | 42 300  | 62 700    | 90 700    | 96 100                 | 132 400   | 164 600   | 197 400    | 212 200                | 217 000                  | na                        |
| Nepal                 | --      | --        | --        | 42 500                 | 49 800    | 67 800    | 81 600     | 177 300                | 205 100                  | 222 600                   |
| Pakistan              | --      | 80        | 4 000     | 308 000                | 501 400   | 550 400   | 728 500    | 647 100                | 636 600                  | 630 900                   |
| Philippines           | --      | 82 600    | 701 600   | 1 011 800 <sup>1</sup> | 1 353 900 | 1 665 400 | 1 826 800  | 1 679 900              | 2 176 600                | 2 175 000                 |
| Sri Lanka             | --      | --        | --        | 7 000                  | 26 300    | 30 700    | 70 900     | 231 900                | 368 400                  | 352 100                   |
| Thailand <sup>1</sup> | --      | --        | --        | --                     | 3 000     | 30 000    | 100 000    | 300 000                | 400 000                  | 450 000                   |
| Vietnam               | --      | --        | 500       | 40 000                 | 204 000   | 502 000   | 674 000    | 835 000                | 890 000                  | 900 000 <sup>1</sup>      |
| Total                 | 49 400  | 1 034 300 | 2 653 500 | 4 707 500              | 7 784 300 | 9 972 100 | 13 052 900 | 15 619 900             | 19 703 100 <sup>4</sup>  | 21 565 500 <sup>4,5</sup> |
| Near East             |         |           |           |                        |           |           |            |                        |                          |                           |
| Egypt                 | --      | --        | --        | --                     | --        | --        | --         | --                     | na                       | 6 800                     |
| Iraq                  | --      | --        | --        | --                     | --        | --        | --         | 5 000                  | 12 000                   | 16 000                    |
| Total                 | --      | --        | --        | --                     | --        | --        | --         | 5 000                  | 12 000                   | 21 800                    |

<sup>1</sup> Unofficial estimate.

<sup>2</sup> Including Turkey at 1971/72 level.

<sup>3</sup> Including Algeria and Lebanon at 1972/73 level.

<sup>4</sup> Including Laos at 1972/73 level.

<sup>5</sup> Including Malaysia at 1973/74 level.

Source: Dana G. Dalrymple, *Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Development Nations*, Foreign Agricultural Economic Report No 95, US Department of Agriculture, Washington, August 1976, pp 110-113.

the level of technical progress and factor inputs achieved by the most advanced countries in each resource endowment classification. These productivity levels are not immediately available to farmers in most low productivity countries. They can only be made available if the investment in agricultural research capacity needed to develop technologies that are appropriate to the natural and institutional environments of the low productivity countries and if the investment in physical and institutional infrastructure needed to realise the new production potential opened up by advances in technology is undertaken.

*Alternative paths of technological development*

There is clear evidence that technology can be developed to facilitate the substitution of relatively abundant and hence cheap factors for relatively scarce and hence expensive factors of

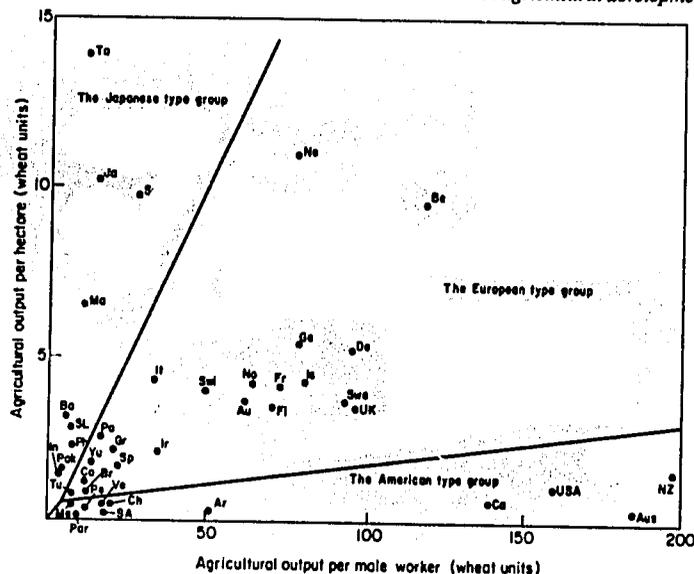


Figure 2. International comparison of labour and land productivities, 1970.

Source: Saburo Yamada and Vernon W. Ruttan, 'International comparisons of productivity in agriculture', paper presented at The National Bureau of Economic Research Conference on Productivity Measurement, Williamsburg Virginia, November 13 and 14, 1975.

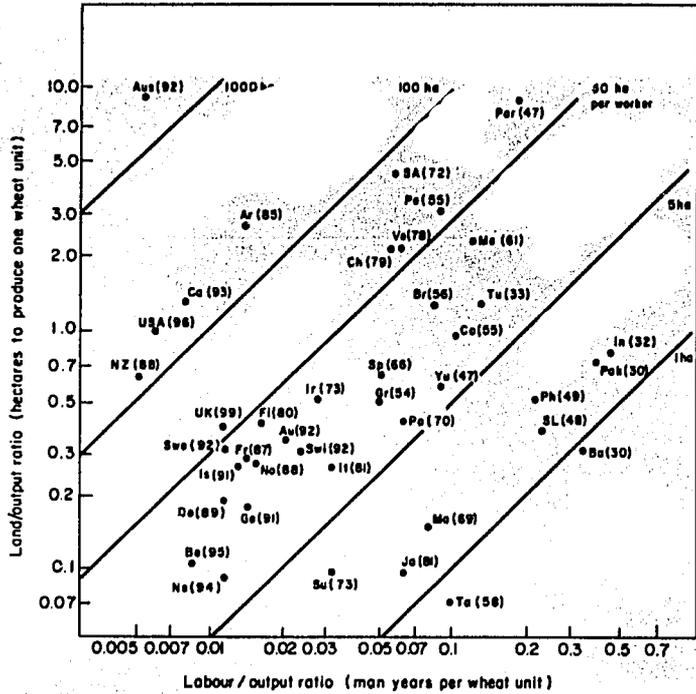
Note: Symbol keys for all figures:

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

production. The constraints imposed on agricultural development by an inelastic supply of land have, in economies such as Japan and Taiwan, been offset by the development of high-yielding crop varieties designed to facilitate the substitution of fertiliser for land. The constraints imposed by an inelastic supply of labour, in countries such as the USA, Canada, and Australia, have been offset by technical advances leading to the substitution of animal and mechanical power for labour. In both cases the new technology – embodied in new crop varieties, new equipment, or new production practices – may not always be substituted for land or labour by themselves. Rather the new technologies may serve as catalysts to facilitate the substitution of the relatively abundant factors, such as fertiliser or mineral fuels, for the relatively scarce factors.

In agriculture, two kinds of technology generally correspond to this taxonomy: mechanical technology to 'labour-saving' and biological (or biological and chemical) technology to 'land-saving'. The primary effect of the adoption of mechanical technology is to facilitate the substitution of power and machinery for labour. Typically this results in a decline in labour use per unit of land area. The substitution of animal or mechanical power for human labour enables each worker to extend his efforts over a larger land area. The primary effect of adoption of biological technology, is to facilitate the substitution of labour and/or industrial inputs for land. This may occur through increased recycling of soil fertility by more labour-intensive conservation systems; through use of chemical fertilisers; and through husbandry practices, management systems, and inputs such as insecticides which permit an optimum yield response.

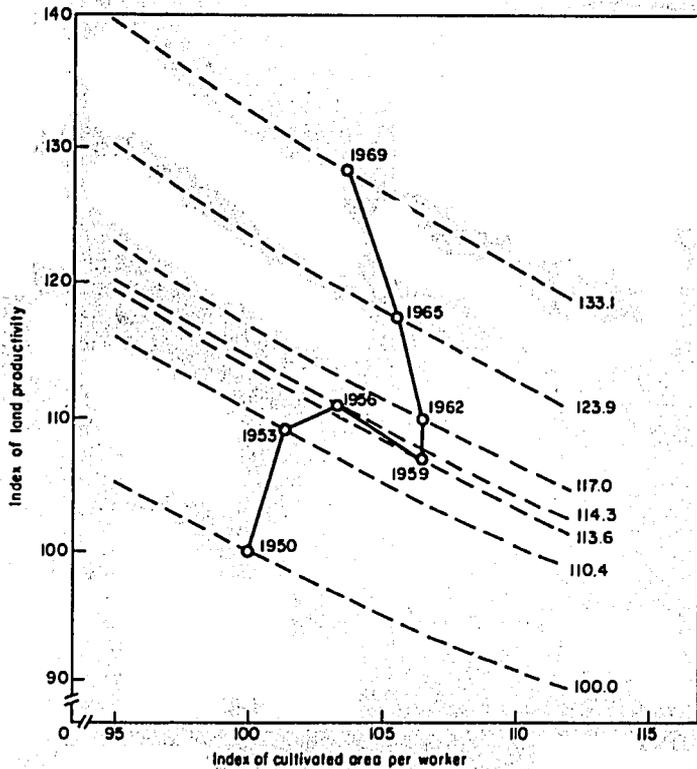
Historically, there has been a close association between advances in output per unit of land area and advances in biological technology; and between advances in output per worker and advances in mechanical technology. These historical differences have given rise to the cross-sectional differences in productivity and factor use illustrated in Figures 2 and 3. Advances in biological technology may



**Figure 3.** International comparison of labour/output and land/output ratios in situations characterised by different land/labour ratios.

Diagonal lines represent constant land/labour ratios and numbers in parentheses are percentage ratios of non-agricultural workers to the total economically active population.

Source: Saburo Yamada and Vernon W. Ruttan, 'International comparisons of productivity in agriculture' Paper Presented at The National Bureau of Economic Research Conference on Productivity Measurement, Williamsburg Virginia, November 13 and 14, 1975.



**Figure 4.** Historical growth path of labour productivity in relation to land productivity, and cultivated area per worker in Philippine agriculture, 1948-1968.

Source: Cristina Crisostomo and Randolph Barker, 'Agricultural growth in the Philippines, 1948-1971' in Yujiro Hayami, Vernon W. Ruttan and Herman Southworth, *Agricultural Growth in Japan, Taiwan, Korea and the Philippines*, The University Press of Hawaii, Honolulu, in press.

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also result in increases in output per worker if the rate of growth of output per hectare exceeds the rate of growth of the agricultural labour force.

In the Philippines, for example, growth in output per worker prior to the mid-1950s was due primarily to expansion in the area cultivated per worker. Since the early 1960s growth in output per worker has been due to increase in output per unit of land area (see Figure 4).

#### *Induced technical innovation*

An examination of the historical experience of the USA and Japan, illustrates the theory of induced technical innovation. In the USA it was primarily the progress of mechanisation, first using animal and later tractor motive power, which facilitated the expansion of agricultural production and productivity by increasing the area operated per worker. In Japan it was primarily the progress of biological technology such as varietal improvement leading, for example, to increased yield response to higher levels of fertiliser application, which permitted rapid growth in agricultural output in spite of severe constraints on the supply of land. These contrasting patterns of productivity growth and factor use can best be understood in terms of a process of dynamic adjustment to changing relative factor prices.

*In the USA* the long term rise in wage rates relative to the prices of land and machinery encouraged the substitution of land and power for labour. This substitution generally involved progress in the application of mechanical technology to agricultural production. The more intensive application of mechanical technology depended on the invention of technology which was more extensive in its use of equipment and land relative to labour. For example, the Hussey or McCormick reapers in use in the 1860s and 1870s required the use, over a harvest period of about two weeks, of five workers and four horses to harvest 140 acres of wheat. When the binder was introduced it was possible for a farmer to harvest the same acreage of wheat with two workers and four horses. The process illustrated by the substitution of the binder for the reaper has been continuous. As the limits to horse mechanization were reached in the early part of this century the process was continued by the introduction of the tractor as the primary source of motive power. The process has continued with the substitution of larger and more highly powered tractors and the development of self-propelled harvesting equipment.

*In Japan* the supply of land was inelastic and its price rose relative to wages. It was not, therefore, profitable to substitute power for labour. Instead, the new opportunities arising from continuous decline in the price of fertiliser relative to the price of land were exploited through advances in biological technology. Varietal improvement was directed, for example, toward the selection and breeding of more fertiliser responsive varieties of rice. The enormous changes in fertiliser input per hectare that have occurred in Japan since 1880 reflect not only the effect of the response by farmers to lower fertiliser prices but the development by the Japanese agricultural research system of 'fertiliser consuming' rice varieties in order to take advantage of the decline in the real price of fertiliser.

The effect of relative prices in the development and choice of technology is illustrated with remarkable clarity for fertiliser in Figure

5 in which the US and Japanese data on the relationship between fertiliser input per hectare of arable land and the fertiliser land price ratio is plotted for the period 1880-1960. In both 1880 and 1960 US farmers were using less fertiliser than Japanese farmers. However, despite enormous differences in both physical and institutional resources the relationship between these variables has been almost identical in the two countries. As the price of fertiliser declined relative to other factors both Japanese and American scientists responded by inventing crop varieties which were more responsive to the lower prices of fertiliser – although American scientists always lagged behind by a few decades in the process because the lower price of land relative to fertiliser resulted in a lower priority being placed on yield increasing technology in the USA than in Japan.

It is possible to illustrate the same process with cross section data for mechanical technology. Variations in the level of tractor horsepower per worker among countries is very largely a reflection of the price of labour relative to the price of power (see Figure 6). As wage rates have risen in countries with small farms, such as Japan and Taiwan, it has been possible to adapt mechanical technology to the size of the farm.

The effect of a rise in the price of fertiliser relative to the price of land or of the price of labour relative to the price of machinery has

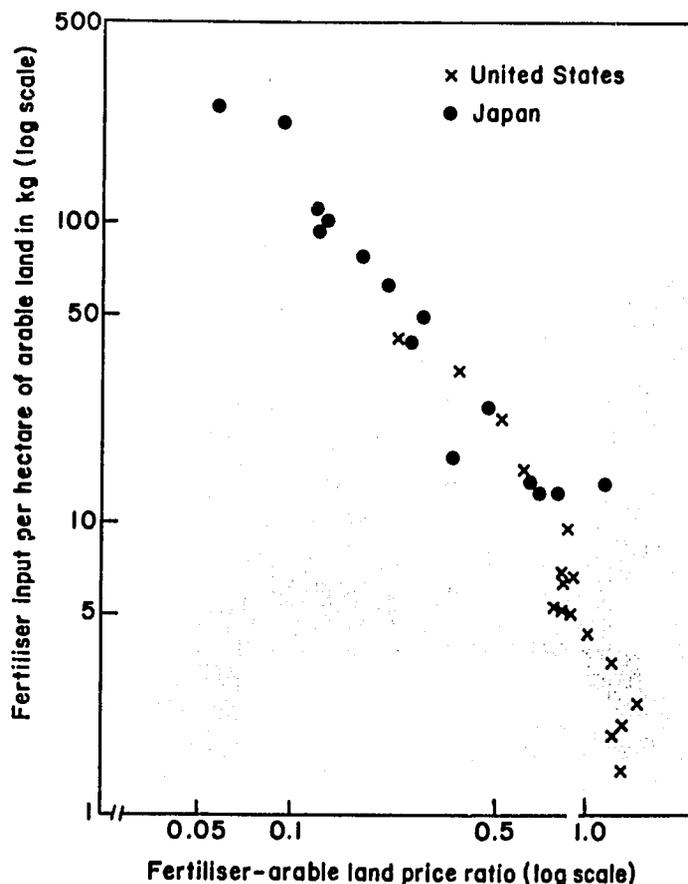
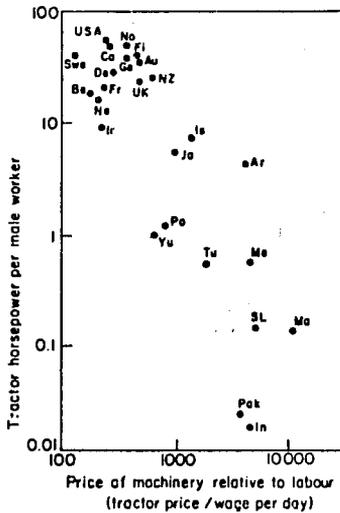


Figure 5. Relation between fertiliser input per hectare of arable land and the fertiliser: arable land price ratio.

Source: Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective*, The Johns Hopkins University Press, Baltimore, 1971, p 127.

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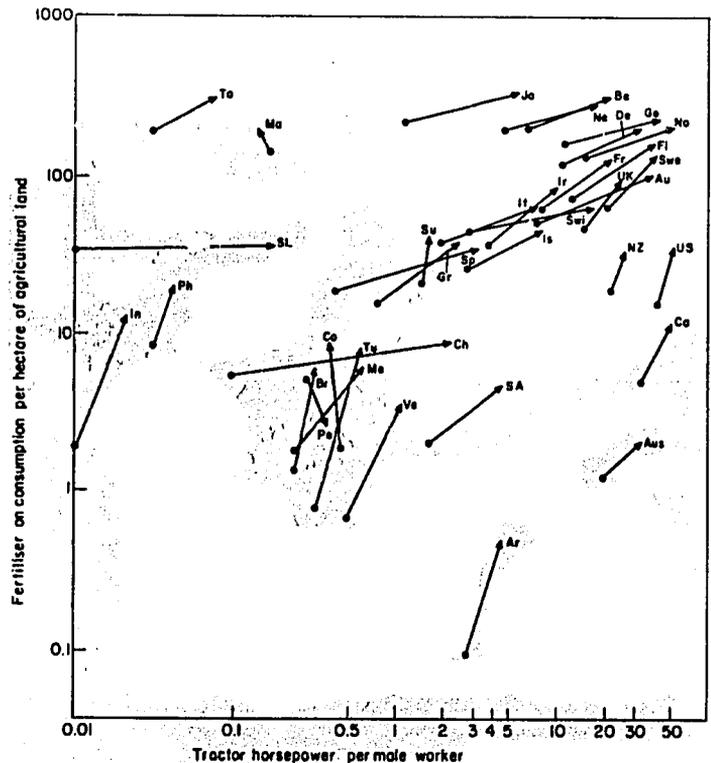
**Figure 6.** Relation between tractor horsepower per male worker and the price of machinery relative to labour, 1970.

Source: Saburo Yamada and Vernon W. Ruttan, 'International Comparisons of productivity in agriculture', paper presented at The National Bureau of Economic Research Conference on Productivity Measurement, Williamsburg Virginia, November 13 and 14, 1975.

been to induce advances in biological and mechanical technology. The effect of the introduction of lower cost and more productive biological and mechanical technology has been to induce farmers to substitute fertiliser for land and mechanical power for labour. These responses to differences in resource endowments among countries and to changes in resource endowments over time by agricultural research institutions, by the farm supply industries, and by farmers, have been remarkably similar in spite of differences in culture and tradition.

During the last two decades, as wage rates have risen rapidly in Japan and as land prices have risen in the USA there has been a tendency for the pattern of technological change in the two countries to converge (see Figure 7). In the 1960s fertiliser consumption per hectare rose more rapidly in the USA than in Japan and tractor horsepower per worker rose more rapidly in Japan than in the USA. Both countries appear to be converging toward the European pattern of technical change in which increases in output per worker and increases in output per hectare occur at approximately equal rates.

There will be further changes in the future. In the early and mid-1970s the price of energy has risen. This has affected both the price of fuel and the price of fertiliser. It is unlikely that declining fertiliser price will in the future be as important a factor in determining the direction of biological technology as during the past century. Higher fertiliser prices have already induced a substantial increase in the research resources devoted to the investigation of potential biological and organic sources of plant nutrition. It is possible that the



**Figure 7.** Intercountry cross-section comparison of changes in tractor horsepower per male worker and in fertiliser consumption per hectare, 1960-70 (log scale).

Source: Saburo Yamada and Vernon W. Ruttan, 'International comparisons of productivity in agriculture' Paper Presented at the National Bureau of Economic Research Conference on Productivity Measurement, Williamsburg Virginia, November 13 and 14, 1975.

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momentum of advance in biological technology will, during the next several decades, be faced with the necessity of a transition comparable to the shift from the horse to the tractor as a source of motive power in the area of mechanical technology. In most developing countries, however, fertiliser prices at the farm level should continue to decline for some time with the expansion of domestic capacity and the improvement of the marketing and transport systems. Growth of fertiliser use per hectare will continue to be an important source of productivity growth in most developing countries during the next several decades.

### **Induced institutional innovation**

In discussing the theory of induced technical change in agriculture<sup>6</sup> we need to consider the personal behaviour of individual research scientists or the institutional behaviour of the agricultural experiment stations or research institutes which support their research. In most countries which have been successful in achieving rapid rates of technical progress in agriculture, 'socialisation' of agricultural research has been deliberately employed as an instrument of modernisation in agriculture. The induced innovation model of technical change in agriculture implies that both research scientists and research administrators are responsive to differences in resource endowments and to changes in the economic environment in which they work.

The response of research scientists and administrators represents the critical link in the inducement mechanism. The model does not imply that it is necessary for individual scientists or research administrators in public institutions consciously to respond to market prices, or directly to farmers' demands for research results, in the selection of research objectives. They may, in fact, be motivated primarily by a drive for professional achievement and recognition. Or, they may view themselves as responding to an 'obvious and compelling need' to remove the constraints on growth of production or on factor supplies. It is only necessary that there exists an effective incentive mechanism to reward the scientists or administrators, materially or by prestige, for their contributions to the solution of problem that are of social or economic significance.

The response in the public research sector is not limited to the field of applied science. Scientists trying to solve practical problems often consult with or ask cooperation of those working in more basic fields.

If research workers in the basic sciences are sensitive to the needs of applied researchers for new theory and new methodology they are in effect responding to the needs of society. It is not uncommon that major breakthroughs in basic science or supporting science are created through the process of solving the problems raised by research workers in the more applied fields. The response by the scientific community to the recent rise in the price of fossil fuel based inputs represents a dramatic example of the induced innovation process. Increases in the price of nitrogen fertiliser have induced a shift in scientific resources toward more intensive research and development activity on the biological and organic sources of plant nutrition. The low productivity of agricultural scientists in many developing countries is due to the fact that many societies have not yet succeeded in developing incentives that lead to the focussing of scientific effort on the significant problems of domestic agriculture.

<sup>6</sup>The theory of induced institutional innovation is developed more fully in Hans P. Binswanger and Vernon W. Ruttan, *Induced Innovation: Technology Institutions and Development*, The John Hopkins University Press, Baltimore, in press. The discussion of research resource allocation in this section draws on Walter L. Fishel, ed, *Resource Allocation in Agricultural Research*, University of Minnesota Press, Minneapolis, 1971 and in Thomas M. Arndt, Dana Dalrymple and Vernon W. Ruttan, eds, *Resource Allocation and Productivity in National and International Agricultural Research*, University of Minnesota Press, Minneapolis, 1977.

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Under such conditions scientific skills atrophy or are directed to the reward systems of the international scientific community.

It is not argued, however, that technical change in agriculture is wholly of an induced character. There is a supply (exogenous) dimension, stemming from autonomous development in the basic sciences, as well as a demand (endogenous) dimension. Technical change in agriculture reflects, in addition to the effects of resource endowments and growth in demand, the progress of general science and technology. Progress in general science which lowers the 'cost' of technical change may influence the direction of technical change in agriculture in a manner that is unrelated to changes in factor proportions and product demand. Similarly, advances in science and technology in the developed countries, in response to their own resource endowments, may result in a bias in the technical opportunities that become available in the developing countries. Even in these cases, the rate of adoption and the impact on productivity will be strongly influenced by the conditions of resource supply and product demand, as these forces are reflected through input and product markets.

### **Disequilibrium in agriculture**

During the last two decades the institutional capacity to generate technical changes adapted to national and regional resource endowments has been established in many developing countries. More recently, these emerging national systems have been buttressed by a new system of international crop and animal research institutes listed in Table 3. These new institutes have become both important sources of new knowledge and technology and increasingly effective communication links among the developing national research systems.

Both the new international system and many of the new national systems have been highly productive. The evidence cited in Table 1 shows that in India, for example, investment in agricultural research has generated annual rates of return in the range of 40-60%. Rates of return in this range are, however, not an entirely valid source of self congratulation. While they testify to the efficient allocation of the research resources that society has made available to the agricultural science community they also indicate a continuing under-investment in agricultural research.

At a global level, it is clear that a fundamental source of the continuing disequilibrium in agricultural productivity and in the well being of rural people has been the lag in shifting from a natural-resource-based to a science-based agriculture. The effects of lags in the application of knowledge are also important sources of regional disequilibria in many countries. In countries such as Mexico and India, differential rates of technical change have been an important source of the widening disparities in the rate of growth of total agricultural outputs, in labour and land productivity, and in income and wage rates among regions.

It seems increasingly clear that elimination of both the international and domestic disequilibria in agricultural productivity will require a continuing reallocation of research resources and of development investment in favour of the agriculture sector and towards rural areas. It was a major step forward when the allocation of research resources

Table 3. Present structure of the international agricultural research network

| Centre  | Location               | Research  | Coverage  | Date of initiation | Budget for 1976 (\$000) |
|---|------------------------|---|---|--------------------|-------------------------|
| IRRI<br>(International Rice Research Institute)                               | Los Banos, Philippines | Rice under irrigation, multiple cropping systems; upland rice   | Worldwide, special emphasis in Asia   | 1959               | 9 588                   |
| CIMMYT<br>(International Centre for the Improvement of Maize and Wheat)       | El Batan, Mexico       | Wheat (also triticale, barley); maize (also high-altitude sorghum)  | Worldwide   | 1964               | 10 506                  |
| IITA<br>(International Institute of Tropical Agriculture)                     | Ibadan, Nigeria        | Farming systems; cereals (rice and maize as regional relay stations for IRRI and CIMMYT); grain legumes (cow-peas, soybeans, lima beans, pigeon peas); root and tuber crops (cassava, sweet potatoes, yams) | Worldwide in lowland tropics, special emphasis in Africa  | 1965               | 10 759                  |
| CIAT<br>(International Centre for Tropical Agriculture)                       | Palmira, Colombia      | Beef; cassava; field beans; swine (minor); maize and rice (regional relay stations to CIMMYT and IRRI)  | Worldwide in lowland tropics, special emphasis in Latin America   | 1968               | 7 916                   |
| WARDA<br>(West African Rice Development Association)                          | Monrovia, Liberia      | Regional cooperative effort in adaptive rice research among 13 nations with IITA and IRRI support   | West Africa   | 1971               | 850                     |
| CIP<br>(International Potato Centre)  | Lima, Peru             | Potatoes (for both tropics and temperate regions)   | Worldwide, including linkages with developed countries  | 1972               | 4 044                   |
| ICRISAT<br>(International Crops Research Institute for the Semi-Arid Tropics) | Hyderabad, India       | Sorghum; pearl millet; pigeon peas; chickpeas; farming systems; groundnuts  | Worldwide, special emphasis on dry semi-arid tropics, non-irrigated farming. Special relay stations in Africa under negotiation | 1972               | 13 800                  |
| IBPGR<br>(International Board for Plant Genetic Resources)                    | FAO, Rome, Italy       | Conservation of plant genetic material with special reference to crops of economic importance   | Worldwide   | 1973               | 939                     |
| ILRAD<br>(International Laboratory for Research on Animal Diseases)           | Nairobi, Kenya         | Trypanosomiasis; theileriosis fever   | Africa, mainly east coast   | 1974               | 4 573                   |
| ILCA<br>(International Livestock for Africa)                                  | Addis Ababa, Ethiopia  | Livestock production system   | Major ecological regions in tropical zones of Africa  | 1974               | 6 400                   |
| ICARDA<br>(International Centre for Agricultural Research in Dry Areas)       | Lebanon, Syria, Iran   | Crop and mixed farming systems research, focussing on sheep, barley, wheat, broad beans, and lentils  | Worldwide, emphasis on the semi-arid winter precipitation zone  | 1976               | 3 300                   |
| <b>Associate Centres</b>  |                        |   |   |                    |                         |
| AVRDC<br>(Asian Vegetable Research and Development Centre)                    | Shanhua, Taiwan        | Vegetable improvement, (Mung beans, soybean, Tomato, sweet potato, Chinese cabbage, white potato); cropping systems   | South, Southeast, and South Asia  | 1971               | 1 954                   |

|  |                          |   |           |      |       |
|--|--------------------------|---|-----------|------|-------|
| IFDC<br>(International<br>Fertiliser<br>Development<br>Centre) | Muscle<br>Shoals,<br>USA | Development of new and<br>improvement of<br>fertiliser materials<br>and processes | Worldwide | 1975 | 2 348 |
| IFPRI<br>(International Food<br>Policy Research<br>Institute)  | Washington,<br>DC, USA   | Food policy   | Worldwide | 1975 | 1 000 |

Source: J.G. Crawford, 'Development of the international agricultural research system' in *Resource Allocation and Productivity in National and International Agricultural Research*, edited by Thomas M. Arndt, Dana G. Dalrymple, and Vernon

W. Ruttan, University of Minnesota, Minneapolis, 1977, pp 282-3. Crawford's basic material was reproduced in Nicholas Wade, 'International agricultural research', *Science* Vol 188, 9 May 1975, p587. Budget data for 1976 were

obtained from the Secretariat of the Consultative Group on International Agricultural Research, World Bank, Washington, DC, USA.

<sup>7</sup>The accounting for inter-country differences in labour productivity utilises coefficients obtained from estimating an inter-country 'meta-production function' of the Cobb-Douglas form. The percentage differences in output per worker can be expressed as the sum of percentage differences in conventional and non-conventional factor inputs per worker, weighted by their respective production elasticities. The coefficients used in the growth accounting were derived from data centred on 1960. Preliminary results obtained by Saburo Tamada from data centred on 1970 are generally consistent with the results presented in Tables 4 and 5. See Saburo Yamada and Vernon W. Ruttan, 'International comparisons of productivity in agriculture', paper presented at National Bureau of Economic Research, Conference on Productivity Measurement, Williamsburg, Virginia, 13-14 October 1976, *continued on p 214*

in developing countries broke away from the mould that had been established in the developed countries and began to emphasise the development of biological technologies designed to raise output per unit of land area in order to release the constraints imposed by an inelastic supply of land. It is now time to begin to make the next step and look directly at the most abundant resource available in most poor countries, people, and the low productivity of human resources in rural areas.

The importance of this refocussing can be illustrated from the data presented in Tables 4 and 5.<sup>7</sup> The sources of labour productivity differences among countries are classified into three broad categories – resource endowments, technical inputs, and human capital. Land and livestock serve as proxy variables for resource endowments; machinery and fertiliser for technical inputs; and general education and technical education in agriculture for human capital.

Land and livestock represents a form of long-term capital formation embodying inputs supplied primarily from within the agricultural sector. In traditional systems of agriculture indigenous,

Table 4. Accounting for inter-country differences in labour productivity

|   | Between 11 developing countries <sup>a</sup><br>and 4 recently developed<br>countries <sup>b</sup> |           | Between 11 developing countries <sup>c</sup><br>and 9 older developed countries <sup>c</sup> |           | Between 9 older developed<br>countries and 4 recently<br>developed countries. |           |
|---|--|-----------|--|-----------|---|-----------|
|   | %  | Index     | %  | Index     | %   | Index     |
| Difference in output per<br>male worker | 93.6   | 100       | 83.5   | 100       | 61.5  | 100       |
| Difference explained:                   |  |           |  |           |   |           |
| <b>Total</b>                            | <b>90.0</b>  | <b>98</b> | <b>71.1</b>  | <b>85</b> | <b>50.5</b>   | <b>82</b> |
| <i>Resource endowments</i>              | <i>32.6</i>  | <i>35</i> | <i>17.5</i>  | <i>21</i> | <i>29.1</i>   | <i>47</i> |
| Land                                    | 9.7  | 10        | 1.8  | 2         | 9.7   | 18        |
| Livestock                               | 22.9   | 25        | 15.7   | 19        | 19.4  | 31        |
| <i>Technical inputs</i>                 | <i>24.5</i>  | <i>26</i> | <i>24.3</i>  | <i>29</i> | <i>10.4</i>   | <i>17</i> |
| Fertiliser                              | 14.6   | 16        | 14.5   | 17        | 3.9   | 6         |
| Machinery                               | 9.9  | 10        | 9.8  | 12        | 6.5   | 11        |
| <i>Human capital</i>                    | <i>32.9</i>  | <i>35</i> | <i>29.4</i>  | <i>35</i> | <i>10.9</i>   | <i>18</i> |
| General education                       | 19.5   | 21        | 17.6   | 21        | 3.3   | 6         |
| Technical education                     | 13.4   | 14        | 11.7   | 14        | 7.6   | 12        |

<sup>a</sup> Brazil, Sri Lanka, Colombia, India, Mexico, Peru, Philippines, Syria, Taiwan, Turkey, United Arab Republic.

<sup>b</sup> Australia, Canada, New Zealand, USA.

<sup>c</sup> Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, Switzerland, UK.

Source: Adapted from Yujiro Hayami and

Vernon W. Ruttan, *Agricultural Development: An International Perspective*, The Johns Hopkins University Press, Baltimore, 1971, pp 98-101.

**Table 5. Accounting for inter-country differences in labour productivity between the USA and selected countries.**

|   | India | Japan | UK   | Argentina | Canada |
|---|-------|-------|------|-----------|--------|
| <b>Difference in output per male worker</b> |       |       |      |           |        |
| % Index                                     | 97.8  | 89.2  | 55.8 | 60.0      | 24.0   |
|   | 100   | 100   | 100  | 100       | 100    |
| <b>Difference explained:</b>                |       |       |      |           |        |
| Total index                                 | 104   | 74    | 89   | 76        | 98     |
| Resource endowments index                   | 33    | 33    | 33   | -8        | 20     |
| Technical inputs index                      | 26    | 25    | 24   | 40        | 51     |
| Human capital index                         | 45    | 10    | 33   | 44        | 28     |

See footnote 7.

Source: Adapted from Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective*, The Johns Hopkins University Press, Baltimore, 1971, pp 96-101.

labour-intensive capital formation represents almost the only source of growth in labour productivity. Fertiliser, as measured by nutrient consumption in commercial fertiliser, and machinery as measured by tractor horsepower, are employed as proxies for the whole range of inputs in which modern mechanical and biological technologies are embodied. The proxies for human capital include measures of both the general educational level of the rural population and specialised education in the agricultural sciences and technology. General education is viewed as a measure of the capacity of a population to utilise new technical knowledge. Graduates in the agricultural sciences and technology represent the major source of scientific and technical personnel for agricultural research and extension.

The difference in average agricultural output per worker between the eleven developing and the nine older developed countries was 83.5%. Differences in human capital investment alone account for over one-third of the difference. Differences in land resources per worker account for only 12% of the difference. It seems apparent that in spite of the limitations of land resources in the developing countries they could achieve levels of output per worker comparable to the European levels of the early 1960s through a combination of investment in human capital, investment in experimental stations and industrial capacity to make modern technical inputs available to their farmers, and investment in the labour-intensive capital formation characterised by livestock and perennial crops, and by land and water development.

The difference in average agricultural output per worker between the nine older developed countries and the four recently developed countries was 61.5%. The results are quite different from the comparison between the developing countries and the older developed countries. Technical inputs and human capital account for only slightly more than one-third of the difference. Resource endowments account for close to half. It appears that output per worker in the older developed countries would have great difficulty in approaching the levels of the recently developed countries in the absence of substantial adjustments in labour/resource ratios. However, the older developed countries have clearly failed to take full advantage of the growth opportunities available to them through greater investment in technical manpower and in agricultural science capacity. The individual country comparisons tend to reinforce the inferences based on the group comparisons. Failure to take full advantage of the

continued from p 213  
14 November, 1975 (conference volume in press).

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potential growth from human capital and technical inputs are significantly more important than limitations in resource endowments in accounting for differences in output per worker.

It is clear that a fundamental source of the widening disequilibrium in world agriculture has been the lag in shifting from a natural-resource-based to a science-based agriculture. 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 role of education as a factor affecting the productivity of agricultural labour is particularly important during periods in which a nation's agricultural research system is introducing a continuous stream of new technology into the agricultural system. In an agricultural system characterised by static technology, there are few gains to be realised from education in rural areas. Rural people who have lived for generations with essentially the same resources and the same technology have learned from long experience what their efforts can get out of the resources that are available to them. Children acquire the skills that are worthwhile from their parents. Formal schooling has little economic value in agricultural production.

As soon as new technical opportunities start becoming available, this situation changes. Technical change requires the acquisition of new husbandry skills; additional resources such as new seeds, new chemicals and new equipment have to be acquired from non-traditional sources. New skills in dealing with both natural resources and with factor and product markets have to be acquired. New and more efficient factor and product market institutions linking agriculture with the non-agricultural sector have to be developed. The economic value of education to farmers and farm workers, and to the larger society, experiences a sharp rise as a result of the disequilibria introduced by new technical opportunities.<sup>8</sup>

The under utilisation of labour resources in rural areas poses a serious challenge both to agricultural scientists and administrators whose training and experience is in the natural sciences and to those whose training and experience is in the social sciences. They must begin to view the existence of poor or under-utilised labour resources as an opportunity for development just as they have in the past viewed poor or under-utilised land and water resources as an opportunity for development. The challenge to make productive use of the under-utilised labour in Brazil's Northeast must be given at least as high a priority as the challenge to make more productive use of the problem soils of the llanos or of the Amazon basin. The new high-payoff agricultural technologies will increasingly be those which have the effect of increasing the demand for under-utilised labour resources that put people to work more days per year and more productively. The high-payoff institutional innovations will be those which enable the people living in rural areas to both upgrade and achieve more effective command over the physical and human resources that are available to them, in order to expand their capacity to respond to the new technical opportunities that are becoming available.

\* There is substantial evidence, over a wide range of developed and developing countries that, under conditions of rapid improvement in agricultural technology, a 1% increase in the level of general education (measured in terms of schooling or literacy ratios) has approximately the same impact on agricultural output as a 1% increase in the agricultural labour force. See, for example, Zvi Griliches, 'Research expenditures, education, and the aggregate agricultural production function', *American Economic Review*, Vol 54, December 1964, pp 961-974; Hayami and Ruttan, *op cit*, Ref 4, pp 90-96; and D.P. Cnauthari, 'Farmers education, agricultural innovations and employment in North India', *International Labour Review*, forthcoming. There is also some empirical evidence that intensive extension activity can serve as a partial substitute for formal education at lower levels of education but that at higher levels of education schooling and extension are complements. See for example Abdul Halim, 'The economic contribution of schooling and extension to rice production in Laguna, Philippines', *Journal of Agricultural Economics and Development*, Vol 7, January 1977, pp 33-46. The return to education is, of course, sensitive to the level of other inputs. Under conditions of static technology it is possible to overinvest in education. See, for example, Arnold C. Harberger, 'Investment in men versus investment in machines: the case of India', *Education and Economic Development*, C. Arnold Anderson and Mary Jean Bowman, eds, Aldine, 1965, Chicago, pp 11-50. For a skeptical perspective on the 'human capital' literature see Mark Blaug, 'Human capital theory: a slightly jaundiced survey', *Journal of Economic Literature*, Vol 14, September 1975, pp 850-855.

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### **A perspective**

The induced technical and institutional innovation perspective does not imply that the progress of agricultural technology can be left to an 'invisible hand' – to the undirected market forces that will direct technology along an 'efficient' pattern determined by 'original' resource endowments or relative factor and product prices. The production of the new knowledge leading to technical change is the result of a process of institutional development. The invention of the public sector agricultural research institute – the socialisation of agricultural research – was one of the great institutional innovations of the 19th century.

Technological change, in turn, represents a powerful source of demand for institutional change. The processes by which new knowledge can be brought to bear to alter the rate and direction of technical change in agriculture is, however, substantially greater than our knowledge of the processes by which resources are brought to bear on the process of institutional innovation and transfer. The developing world is still trying to cope with the debris of non-viable institutional innovations; with extension services with no capacity to extend knowledge or little knowledge to extend; cooperatives that serve to channel resources to village elites; price stabilisation policies that have the effect of amplifying commodity price fluctuations; and rural development programmes that are incapable of expanding the resources available to rural people.

Yet the need for viable institutions capable of supporting more rapid agricultural growth and rural development is even more compelling today than a decade ago. As the technical constraints on growth of agricultural productivity have become less binding there is an increasing need for institutional innovation that will result in a more effective realisation of the new technical potential. The trial and error approaches involved in *ad hoc* production campaigns and rural development programmes have been costly in terms of human resources and have rarely been effective in building rural institutions that have prevailed beyond the enthusiasms of the moment.

One implication of the induced innovation perspective is the growing interdependence between advances in knowledge in the natural and social sciences as they relate to agricultural and rural development. In the absence of new technical opportunities – new sources of disequilibrium in the productivity of physical and human resources – there would be little demand for new knowledge about the institutional dimensions of agricultural and rural development processes. Similarly, unless social science research can generate new knowledge leading to viable institutional innovation and more effective institutional performance, the potential productivity growth made possible by scientific and technical innovation will be under utilised.

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- 73-3 Collier, W. L., Soentoro, G. W., *Recent Changes in Rice Harvesting Methods*.
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