Vernon W. Ruttan and Yujiro Hayami*

STRATEGIES FOR AGRICULTURAL DEVELOPMENT†

During the 1960s a new consensus emerged to the effect that agricultural growth is critical (if not a precondition) for industrialization and general economic growth. Nevertheless, the process of agricultural growth itself has remained outside the concern of most development economists. Both technical change and institutional evolution have been treated as exogenous to their systems.

In this paper we review the evolution of thought with respect to the process of agricultural development that is implicit in much of the literature on agricultural and economic development; we elaborate the concept of induced technical and institutional innovation which we have employed in our own research on the agricultural development process; and we discuss the implications of the induced innovation perspective for the design of national and regional strategies for agricultural development.

THEORIES OF AGRICULTURAL DEVELOPMENT

A first step in any attempt to evolve a meaningful perspective on the process of agricultural development is to abandon the view of agriculture in pre-modern or traditional societies as essentially static.[1] Viewed in a historical context, 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 modernizing economy. Similarly, a theory of agricultural de-

* Vernon W. Ruttan is Professor, Department of Agricultural and Applied Economics and Department of Economics, and Director, Economic Development Center, University of Minnesota. Yujiro Hayami is Professor, Department of Economics, Tokyo Metropolitan University.

† Minnesota Agricultural Experiment Station Scientific Journal Paper Series 72-8078. This is a revision of a paper prepared for the Food Research Institute's Conference on Strategies for Agricultural Development in the 1970s. The research on which the paper is based was financed through grants to the University of Minnesota Agricultural Experiment Station and Economic Development Center from the Rockefeller Foundation. The paper represents a revision and extension of material presented in Yujiro Hayami and Vernon W. Ruttan, *Agricultural Development: An International Perspective* (Baltimore, Md., 1971).

[1] Even in pre-modern times, agriculture was characterized by the continuous, though relatively slow, development of agricultural tools, machines, plants, animals, and husbandry practices. The rate of development was influenced by long-run patterns of population growth and price fluctuations. For Western Europe see Slicher van Bath (*70*). Comparable historical detail is not available for Asia. However, the view expressed here is consistent with the material presented by Ishikawa (*32*). See also Boserup (*7*); Geertz (*15*); and Smith (*71*).

velopment should provide insight into the dynamics of agricultural growth—into the changing sources of growth—in economies ranging from those in which output is growing at a rate of 1.0 percent or less to those in which agricultural output is growing at an annual rate of 4.0 percent or more.

It seems possible to characterize the literature on agricultural development into four general approaches: (a) the conservation; (b) the urban industrial impact; (c) the diffusion; and (d) the high payoff input models.[2]

The Conservation Model

The conservation model of agricultural development evolved from the advances in crop and livestock husbandry associated with the English agricultural revolution[3] and the concepts of soil exhaustion suggested by the early German soil scientists.[4] It was reinforced by the concept in the English classical school of economics of diminishing returns to labor and capital applied to land and labor.[5] The conservation model emphasized the evolution of a sequence of increasingly complex land- and labor-intensive cropping systems, the production and use of organic manures, and labor-intensive capital formation in the form of physical facilities to more effectively utilize land and water resources.

The Urban-Industrial Impact Model

The conservation model stands in sharp contrast to models in which geographic differences in the level and rate of economic development are primarily associated with urban-industrial development. Initially, the urban-industrial impact model was formulated (by von Thünen) to explain geographic variations in the intensity of farming systems and in the productivity of labor in an industrializing society.[6] Later it was extended by T. W. Schultz (*64*, pp. 283–320) to explain the more effective performance of the factor and product markets linking the agricultural and nonagricultural sectors in regions characterized by rapid urban-industrial development. The model has been tested extensively in the United States (*17*; *18*; *44*; *56*; *69*; *74*) but has received only limited attention in the less developed world (*45*, pp. 311–78; *63*, pp. 379–85).

The Diffusion Model

The diffusion of better husbandry practices was a major source of productivity growth even in pre-modern societies (*4*; *7*; *60*, pp. 113–34; *78*). The diffusion approach to agricultural development rests on the empirical observation of substantial differences in land and labor productivity among farmers and regions.

[2] These four models are characterized in much greater detail in Hayami and Ruttan (*25*, pp. 26–43).

[3] The "classical" description of the English agricultural revolution is in Lord Ernle (*11*). In recent years agricultural historians have stressed the "evolutionary" in contrast to the "revolutionary" aspects of these changes. See, for example, Habakkuk (*16*); Mingay (*38*); and Timmer (*76*).

[4] See Usher (*78*). Liebig attributed the decline of classical civilization to soil exhaustion. This view of the relationship between soil exhaustion and the decline of civilizaton has remained a persistent threat in the "underworld" of conservation literature. For a discussion of some of the doctrines about soils, see Kellogg (*35*).

[5] For a review see Barnett and Morse (*6*, pp. 101–47).

[6] See Dickinson (*10*) for a discussion of von Thünen economics and Nou (*48*, pp. 184–230) for a history of the impact of von Thünen's work on economic thought.

The route to agricultural development, in this view, is through more effective dissemination of technical knowledge and a narrowing of the dispersion of productivity among farmers and among regions.[7]

The diffusion model of agricultural development has provided the major intellectual foundation for much of the research and extension effort in farm management and production economics since the emergence, in the last half of the nineteenth century, of agricultural economics as a separate subdiscipline linking the agricultural sciences and economics. The developments that led to the establishment of active programs of farm management research and extension occurred at a time when experiment-station research was making only a modest contribution to agricultural productivity growth.[8] 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 emphasizing the relationship between diffusion rates and the personality characteristics and educational accomplishments of farm operators.[9] The insights into the dynamics of the diffusion process, when coupled with the observation of wide agricultural productivity gaps among developed and less developed countries and a presumption of inefficient resource allocation among "irrational tradition-bound" peasants, produced an extension bias in the choice of agricultural development strategy 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 programs, based explicitly or implicitly on the diffusion model, failed to generate either rapid modernization of traditional farms 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 that the key to transforming a traditional agricultural sector into a productive source of economic growth is investment designed (*65*) 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, as identified by Schultz (*65*), can be classified into three categories: (a) the capacity of public and private sector research institutions to produce new technical knowledge; (b) the capacity of the industrial sector to develop, produce, and market new technical inputs; and (c) 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 an economic doctrine has been due in substantial part to the success of efforts to develop new high-productivity grain varieties suitable for the tropics (*8*; *39*; *73*). New high-yielding wheat and corn varieties were de-

[7] See, for example, the review of Bailey (*5*, pp. 130–31) and the specific case of Mosher (*40*).

[8] For a review of these developments in the United States see Taylor and Taylor (*75*, pp. 326–446).

[9] For a review of diffusion research by rural sociologists see Rogers (*53*; *54*, pp. 111–35).

veloped in Mexico, beginning in the 1950s, and new high-yielding rice varieties in the Philippines in the 1960s. These varieties were highly responsive to industrial inputs, such as fertilizer 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. The impact on farm production and income has been sufficiently dramatic to be heralded as a "green revolution." The significance of the high payoff input model is that policies based on the model appear capable of generating a sufficiently high rate of agricultural growth to provide a basis for overall economic development consistent with modern population and income growth requirements.

As interpreted generally, the model is sufficiently inclusive to embrace the central concepts of the conservation, urban-industrial impact, and diffusion models of agricultural development. The unique implications of the model for agricultural development policy are the emphasis placed on accelerating the process of development and propagation of new inputs or techniques through public investment in scientific research and education.

The high payoff input model, as developed by Schultz (*65*), remains incomplete as a theory of agricultural development, however. 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 is not fully incorporated into the Schultz model.[10] The model does treat investment in research as the source of new high-payoff techniques. 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 factor and product price relationships induce investment in research in a particular direction.

AN INDUCED DEVELOPMENT MODEL

An attempt 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, must start with the recognition that there are multiple paths of technological development.

Alternative Paths of Technological Development

There is clear evidence that technology can be developed to facilitate the substitution of relatively abundant (hence cheap) factors for relatively scarce (hence expensive) factors in the economy. 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 fertilizer for land. The constraints imposed by an inelastic supply of labor, in countries such as the United States, Canada, and Australia, have been offset by technical advances leading to the substitution of

[10] In a more recent paper Schultz stressed the need to direct research toward the analysis of this process (*67*, pp. 90–120).

animal and mechanical power for labor. In both cases the new technology, embodied in new crop varieties, new equipment, or new production practices, may not always be substitutes for land or labor by themselves; rather they may serve as catalysts to facilitate the substitution of the relatively abundant factors (such as fertilizer or mineral fuels) for the relatively scarce factors. It seems reasonable, following Hicks, to call techniques designed to facilitate the substitution of other inputs for labor, "labor-saving," and those designed to facilitate the substitution of other inputs for land, "land-saving." In agriculture, two kinds of technology generally correspond to this taxonomy: mechanical technology to "labor-saving" and biological and chemical technology to "land-saving."[11] The former is designed to facilitate the substitution of power and machinery for labor. Typically this involves the substitution of land for labor, because higher output per worker through mechanization usually requires a larger land area cultivated per worker. The latter, which we will hereafter identify as biological technology, is designed to facilitate the substitution of labor and/or industrial inputs for land. This may occur through increased recycling of soil fertility by more labor-intensive conservation systems; through use of chemical fertilizers; and through husbandry practices, management systems, and inputs (i.e., 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 Charts 1 and 2.[12] The construction of an induced development model involves, in addition to the elements considered in the models discussed earlier in this paper, an explanation of the mechanism by which a society chooses an optimum path of technological change in agriculture.

Induced Innovation in the Private Sector[13]

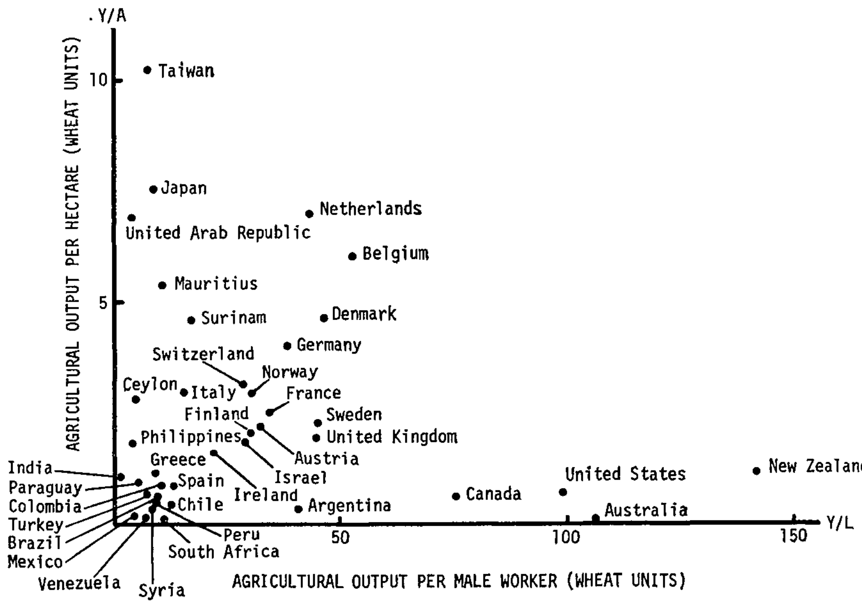
There is a substantial body of literature on the "theory of induced innovation." Much of this literature focuses on the choice of available technology by the individual firm. There is, also, a substantial body of literature on how changes in factor prices over time or differences in factor prices among countries influence the nature of invention. This discussion has been conducted entirely within the

[11] The distinction made here between "mechanical" and "biological" technology has also been employed by Heady (*27*). It is similar to the distinction between "laboresque" and "landesque" capital employed by Sen (*68*). In a more recent article Kaneda employs the terms mechanical-engineering and biological-chemical (*34*).

[12] The productivity and factor use data presented in Charts 1 and 2 have been analyzed in several earlier publications (*19*; *20*; *21*; *24*; *25*).

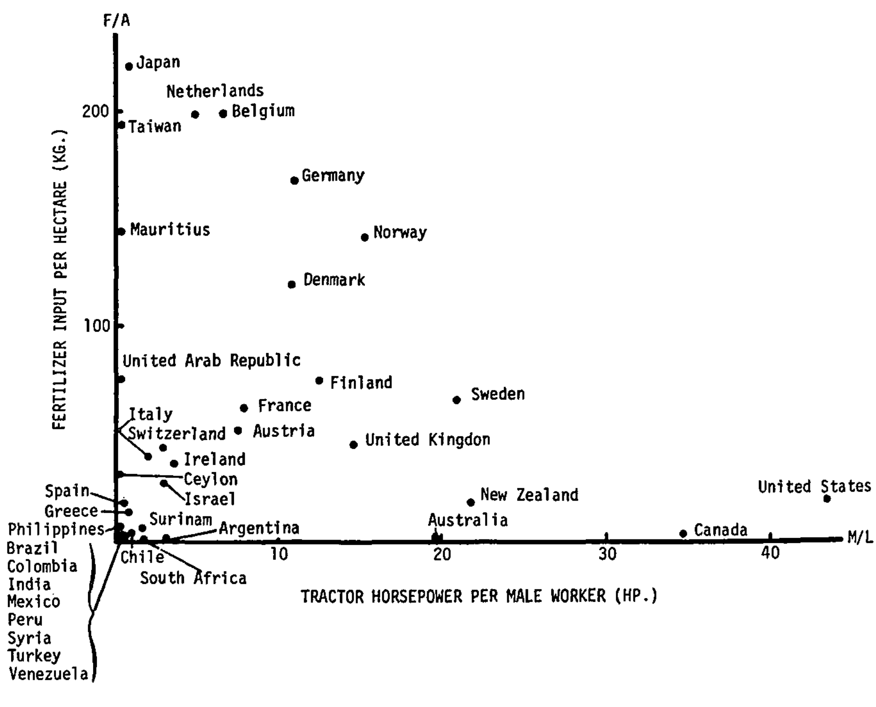
[13] The term "innovation" employed here embraces the entire range of processes resulting in the emergence of novelty in science, technology, industrial management, and economic organization rather than the narrow Schumpeterian definition. Schumpeter insisted that innovation was economically and sociologically distinct from invention and scientific discovery. He rejected the idea that innovation is dependent on invention or advances in science. This distinction has become increasingly artificial. See, for example, Solo (*72*); Ruttan (*57*); and Hohenberg (*31*). Our view is similar to that of Hohenberg. He defines technical effort as the product of purposive resource using activity directed to the production of economically useful knowledge. ". . . technical effort is a necessary part of any firm activity, and is only in part separable from production itself. Traditionally it is part of the entrepreneur's job to provide knowledge to organize the factors of production in an optimum way, to adjust to market changes, and to seek improved methods. Technical effort is thus subsumed under entrepreneurship" (*31*, p. 61).

CHART 1.—INTERNATIONAL COMPARISON OF AGRICULTURAL OUTPUT PER MALE WORKER AND PER HECTARE OF AGRICULTURAL LAND*



* Output data are 1957–62 averages; and labor and land data are of year closest to 1960.

CHART 2.—INTERNATIONAL COMPARISON OF TRACTOR HORSEPOWER PER MALE WORKER AND OF FERTILIZER INPUT PER HECTARE OF AGRICULTURAL LAND*



* Fertilizer data are 1957–62 averages; and labor, land, and tractor data are of year closest to 1960.

framework of the theory of the firm. A major controversy has centered around the issue of the existence of a mechanism by which changes or differences in factor prices affect the inventive activity or the innovative behavior of firms.

It had generally been accepted, at least since the publication of *The Theory of Wages* by J. R. Hicks (*29*, pp. 124–25) that changes or differences in the relative prices of factors of production could influence the direction of invention or innovation.[14] There have also been arguments raised by W. E. G. Salter (*59*, pp. 43–44) and others (*1*; *13*; *36*; *60*) against Hicks's theory of induced innovation. The arguments run somewhat as follows: Firms are motivated to save total cost for a given output; at competitive equilibrium, each factor is being paid its marginal value product; therefore, all factors are equally expensive to firms; hence, there is no incentive for competitive firms to search for techniques to save a particular factor.

The difference between our perspective and Salter's is partly due to a difference in the definition of the production function. Salter defined the production function to embrace all possible designs conceivable by existing scientific knowledge and called the choice among these designs "factor substitution" instead of "technical change" (*59*, pp. 14–16). Salter admits, however, that "relative factor prices are in the nature of sign posts representing broad influences that determine the way technological knowledge is applied to production" (*59*, p. 16). If we accept Salter's definition, the allocation of resources to the development of high-yielding and fertilizer-responsive rice varieties adaptable to the ecological conditions of South and Southeast Asia, which are comparable to the improved varieties developed earlier in Japan and Taiwan, cannot be considered as a technical change. Rather, it is viewed as an application of existing technological knowledge (breeding techniques, plant-type concepts, etc.) to production.

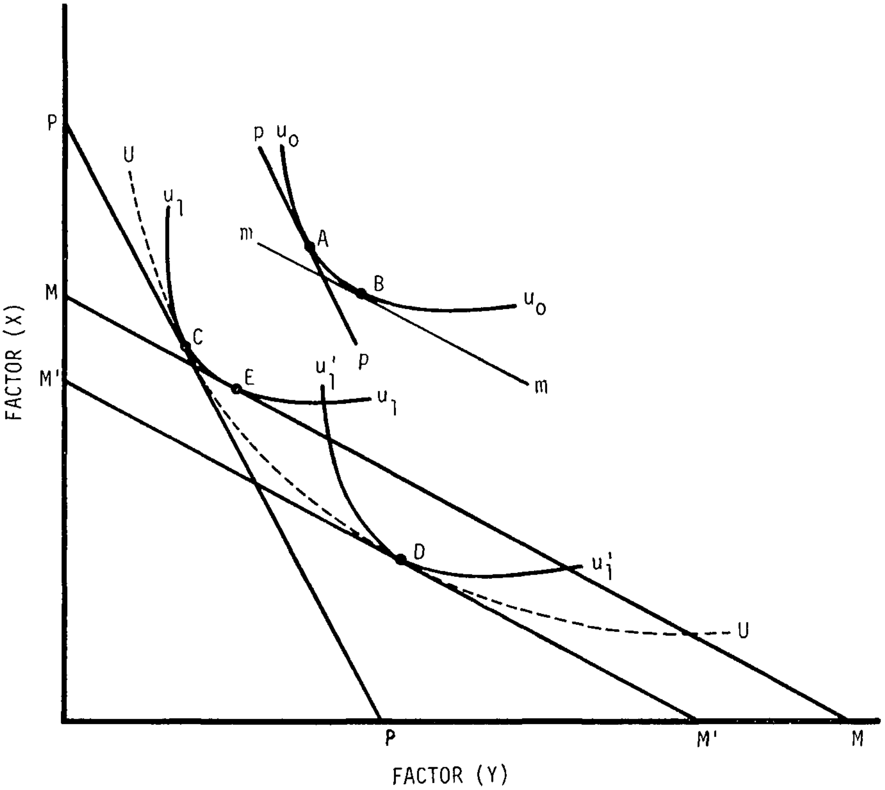
Although we do not deny the case for Salter's definition, it is clearly not very useful in attempting to understand the process by which new technical alternatives become available. We regard technical change as any change in production coefficients resulting from purposeful resource-using activity directed to the development of new knowledge embodied in designs, materials, or organizations. In terms of this definition, it is entirely rational for competitive firms to allocate funds to develop a technology which facilitates the substitution of increasingly less expensive factors for more expensive factors. Using the above definition, Syed Ahmad (*1*) has shown that the Hicksian theory of market induced innovation can be defended with a rather reasonable assumption on the possibility of alternative innovations.[15]

We illustrate the Ahmad argument with the aid of Chart 3. Suppose at a point of time a firm is operating at a competitive equilibrium, A or B, depending on the prevailing factor price ratio, p or m, for an isoquant, u_0, producing a given output; and this firm perceives multiple alternative innovations represented by isoquants, u_1, u_1', . . . , producing the same output in such a way as to be enveloped by U, a concave innovation possibility curve or meta-production function which can be developed by the same amount of research expenditure. In order to minimize total cost for given output and given research expenditure, innovative efforts of this firm will be directed toward developing Y-saving technology (u_1) or X-

[14] See also the review of thought on this issue in Ahmad (*1*).

[15] See also discussions by Fellner and Ahmad (*12*, *2*), and by Kennedy and Ahmad (*37*, *3*).

CHART 3.—FACTOR PRICES AND INDUCED TECHNICAL CHANGE



saving technology (u_1') depending on the prevailing factor price ratio, p (parallel to PP) or m (parallel to MM and MM′). If a firm facing a price ratio, m, developed an X-saving technology (u_1') it can obtain an additional gain represented by the distance between M and M′ compared with the case that developed a Y-saving technology (u_1). In this framework it is clear that, if X becomes more expensive relative to Y over time in any economy the innovative efforts of entrepreneurs will be directed toward developing a more X-saving and Y-using technology compared to the contrary case. Also in a country in which X is more expensive relative to Y than in another country innovative efforts in the country will be more directed toward X-saving and Y-using than in the other country. In this formulation the expectation of relative price change, which is central to William Fellner's theory of induced innovation, is not necessary, although expectations may work as a powerful reinforcing agent in directing technical effort.[16]

The role of changing relative factor prices in inducing a continuous sequence of non-neutral biological and mechanical innovations along the iso-product sur-

[16] The above theory is based on the restrictive assumption that there exists a concave innovation possibility curve (U) which can be perceived by entrepreneurs. This is not as strong a restrictive assumption as it may first appear. The innovation possibility curve need not be of a smooth well-behaved shape as drawn in Chart 3. The whole argument holds equally well for the case of two distinct alternatives. It seems reasonable to hypothesize that entrepreneurs can perceive alternative innovation possibilities for a given research and development expenditure through consultation with staff scientists and engineers or through the suggestions of inventors.

face of a meta-production function is further illustrated in Chart 4. U represents the land-labor isoquant of the meta-production function which is the envelope of less elastic isoquants such as u_0 and u_1 corresponding to different types of machinery or technology. A certain technology represented by u_0 (e.g., reaper) is created when a price ratio, p_0, prevails a certain length of time. When the price ratio changes from p_0 to p_1, another technology represented by u_1 (e.g., combine) is induced in the long-run, which gives the minimum cost of production for p_1.

The new technology represented by u_1, which enables enlargement of the area operated per worker, generally corresponds to higher intensity of power per worker. This implies the complementary relationship between land and power, which may be drawn as a line representing a certain combination of land and power [A, M]. In this simplified presentation, mechanical innovation is conceived as the substitution of a combination of land and power [A, M] for labor (L) in response to a change in wage relative to an index of labor and machinery prices, though, of course, in actual practice land and power are substitutable to some extent.

In the same context, the relation between the fertilizer-land price ratio and biological innovations represented by the development of crop varieties which are more responsive to application of fertilizers is illustrated in Chart 4. V represents the land-fertilizer isoquant of the meta-production function, which is the envelope of less elastic isoquants such as v_0 and v_1 corresponding to varieties of different fertilizer responsiveness. A decline in the price of fertilizer relative to the price of land from r_0 to r_1 creates an incentive for farmers to adopt crop varieties which are described by isoquants to the right of v_0 and for private seed companies and public research institutions to develop and market such new fertilizer responsive varieties.

Induced Innovation in the Public Sector

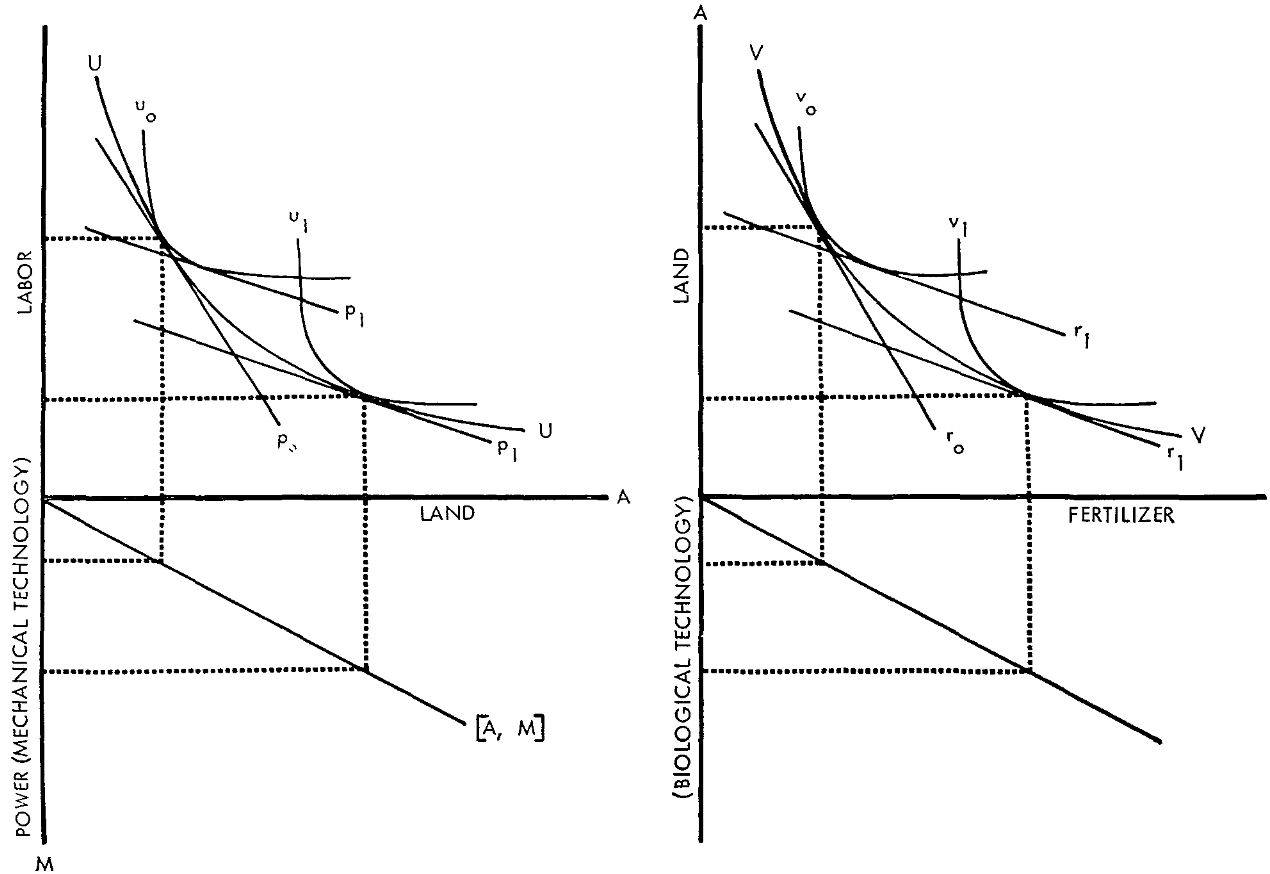
Innovative behavior in the public sector has largely been ignored in the literature on induced innovation. There is no theory of induced innovation in the public sector.[17] This is a particularly critical limitation in attempting to understand the process of scientific and technical innovation in agricultural development. In most countries which have been successful in achieving rapid rates of technical progress in agriculture, "socialization" of agricultural research has been deliberately employed as an instrument of modernization in agriculture.

Our view of the mechanism of "induced innovation" in the public sector agricultural research is similar to the Hicksian theory of induced innovation in the private sector. A major extension of the traditional argument is that we base the innovation inducement mechanism not only on the response to changes in the market prices of profit maximizing firms but also on the response by research scientists and administrators in public institutions to resource endowments and economic change.

We hypothesize that technical change is guided along an efficient path by

[17] There is a growing literature on public research policy. See Nelson, Peck, and Kalachek (*43*). The authors view public sector research activities as having risen from three considerations: (a) fields where the public interest is believed to transcend private incentives (as in health and aviation); (b) industries where the individual firm is too small to capture benefits from research (agriculture and housing); and (c) broadscale support for basic research and science education (pp. 151–211). For a review of thought with respect to resource allocation in agriculture see Fishel (*14*).

CHART 4.—FACTOR PRICES AND INDUCED MECHANICAL AND BIOLOGICAL INNOVATION



price signals in the market, provided that the prices efficiently reflect changes in the demand and supply of products and factors and that there exists effective interaction among farmers, public research institutions, and private agricultural supply firms. If the demand for agricultural products increases, due to the growth in population and income, prices of the inputs for which the supply is inelastic will be raised relative to the prices of inputs for which the supply is elastic. Likewise, if the supply of particular inputs shifts to the right faster than others, the prices of these inputs will decline relative to the prices of other factors of production.

In consequence, technical innovations that save the factors characterized by an inelastic supply, or by slower shifts in supply, become relatively more profitable for agricultural producers. Farmers are induced, by shifts in relative prices, to search for technical alternatives which save the increasingly scarce factors of production. They press the public research institutions to develop the new technology and demand that agricultural supply firms supply modern technical inputs which substitute for the more scarce factors. Perceptive scientists and science administrators respond by making available new technical possibilities and new inputs that enable farmers to profitably substitute the increasingly abundant factors for increasingly scarce factors, thereby guiding the demand of farmers for unit cost reduction in a socially optimum direction.

The dialectic interaction among farmers and research scientists and administrators is likely to be most effective when farmers are organized into politically effective local and regional farm "bureaus" or farmers' associations. The response of the public sector research and extension programs to farmers' demand is likely to be greatest when the agricultural research system is highly decentralized, as in the United States. In the United States, for example, each of the state agricultural experiment stations has tended to view its function, at least in part, as to maintain the competitive position of agriculture in its state relative to agriculture in other states. Similarly, national policymakers may regard investment in agricultural research as an investment designed to maintain the country's competitive position in world markets or to improve the economic viability of the agricultural sector producing import substitutes. Given effective farmer organizations and a mission- or client-oriented experiment station system, the competitive model of firm behavior, illustrated in Charts 3 and 4, can be usefully extended to explain the response of experiment station administrators and research scientists to economic opportunities.

In this public-sector-induced innovation model, 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 to consciously 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 (*46*). Or they may, in the Rosenberg terminology, view themselves as responding to an "obvious and compelling need" to remove the constraints on growth of production or on factor supplies.[18] It is only

[18] Rosenberg has suggested a theory of induced technical change based on "obvious and compelling need" to overcome the constraints on growth instead of relative factor scarcity and factor

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 significant problems in the society.[19] Under these conditions, it seems reasonable to hypothesize that the scientists and administrators of public sector research programs do respond to the needs of society in an attempt to direct the results of their activity to public purpose. Furthermore, we hypothesize that secular changes in relative factor and product prices convey much of the information regarding the relative priorities which society places on the goals of research.

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 the basic scientists respond to the requests of the applied researchers, they are in effect responding to the needs of society. It is not uncommon that major breakthroughs in basic science are created through the process of solving the problems raised by research workers in the more applied fields.[20] It appears reasonable, therefore, to hypothesize, as a result of the interactions among the basic and applied sciences and the process by which public funds are allocated to research, that basic research tends to be directed also toward easing the limitations on agricultural production imposed by relatively scarce factors.

We do not argue, however, that technical change in agriculture is wholly of an induced character. There is a supply (exogenous) dimension to the process 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 (or scientific innovation) which lowers the "cost" of technical and entrepreneurial innovations may have influences on technical change in agriculture unrelated to changes in factor proportions and product demand (*42*; *62*). Similarly, advances in science and technology in the developed countries, in response to their own resource endowments, may result in a bias in the innovation possibility curves facing the developing countries. Even in these cases, the rate of adoption and the impact on productivity of autonomous or exogenous changes in technology will

---

relative prices (*55*). The Rosenberg model is consistent with the model suggested here, since his "obvious and compelling need" is reflected in the market through relative factor prices. C. Peter Timmer has pointed out that in a linear programming sense the constraints which give rise to the "obvious and compelling need" for technical innovation in the Rosenberg model represent the "dual" of the factor prices used in our model (*77*). For further discussion of the relationships between Rosenberg's approach and that outlined in this section see Hayami and Ruttan (*26*).

[19] The issue of incentive is a major issue in many developing economies. In spite of limited scientific and technical manpower many countries have not succeeded in developing a system of economic and professional rewards that permits them to have access to, or make effective use of, the resources of scientific and technical manpower that are potentially available.

[20] The symbiotic relationship between basic and applied research can be illustrated by the relation between work at the International Rice Research Institute in (a) genetics and plant physiology and (b) plant breeding. The geneticist and the physiologist are involved in research designed to advance understanding of the physiological processes by which plant nutrients are transformed into grain yield and of the genetic mechanisms or processes involved in the transmission from parents to progenies of the physiological characteristics of the rice plant which affect grain yield. The rice breeders utilize this knowledge from genetics and plant physiology in the design of crosses and the selection of plants with the desired growth characteristics, agronomic traits, and nutritional value. The work in plant physiology and genetics is responsive to the need of the plant breeder for advances in knowledge related to the mission of breeding more productive varieties of rice.

be strongly influenced by the conditions of resource supply and product demand, as these forces are reflected through factor and product markets.

Thus, the classical problem of resource allocation, which was rejected as an adequate basis for agricultural productivity and output growth in the high-payoff input model, is, in this context, treated as central to the agricultural development process. Under conditions of static technology, improvements in resource allocation represent a weak source of economic growth. The efficient allocation of resources to open up new sources of growth is, however, essential to the agricultural development process.

Institutional Innovation

Extension of the theory of "induced innovation" to explain the behavior of public research institutions represents an essential link in the construction of a theory of induced development. In the induced development model, advances in mechanical and biological technology respond to changing relative prices of factors, and to changes in the prices of factors relative to products, to ease the constraints on growth imposed by inelastic supplies of land or labor. Neither this process, nor its impact, is confined to the agricultural sector. Changes in relative prices in any sector of the economy act to induce innovative activity, not only by private producers but also by scientists in public institutions, in order to reduce the constraints imposed by those factors of production which are relatively scarce.

We further hypothesize that the institutions that govern the use of technology or the "mode" of production can also be induced to change in order to enable both individuals and society to take fuller advantage of new technical opportunities under favorable market conditions.[21] The Second Enclosure Movement in England represents a classical illustration. The issuance of the Enclosure Bill facilitated the conversion of communal pasture and farmland into single, private farm units, thus encouraging the introduction of an integrated crop-livestock "new husbandry" system. The Enclosure Acts can be viewed as an institutional innovation designed to exploit the new technical opportunities opened up by innovations in crop rotation, utilizing the new fodder crops (turnip and clover), in response to the rising food prices.

A major source of institutional change has been an effort by society to internalize the benefits of innovative activity to provide economic incentives for productivity increase. In some cases, institutional innovations have involved the reorganization of property rights, in order to internalize the higher income streams resulting from the innovations. The modernization of land tenure relationships, involving a shift from share tenure to lease tenure and owner-operator systems of cultivation in much of western agriculture, can be explained, in part, as a shift in property rights designed to internalize the gains of entrepreneurial innovation by individual farmers.[22]

[21] At this point we share the Marxian perspective on the relationship between technological change and institutional development, though we do not accept the Marxian perspective regarding the monolithic sequences of evolution based on clear-cut class conflicts. For two recent attempts to develop broad historical generalizations regarding the relation between institutions and economic forces, see Hicks (*30*) and North and Thomas (*47*).

[22] For additional examples see Davis and North (*9*).

Where internalization of the gains of innovative activity are more difficult to achieve, institutional innovations involving public sector activity become essential. The socialization of much of agricultural research, particularly the research leading to advances in biological technology, represents an example of a public sector institutional innovation designed to realize for society the potential gains from advances in agricultural technology. This institutional innovation originated in Germany and was transplanted and applied on a larger scale in the United States and Japan.

Both Schultz (*66*) and Kazushi Ohkawa (*49*) have argued that institutional reform is appropriately viewed as a response to the new opportunities for the productive use of resources opened up by advances in technology.[23] Our view, and the view of Ohkawa and Schultz, reduces to the hypothesis that institutional innovations occur because it appears profitable for individuals or groups in society to undertake the costs. It is unlikely that institutional change will prove viable unless the benefits to society exceed the cost. Changes in market prices and technological opportunities introduce disequilibrium in existing institutional arrangements by creating profitable new opportunities for the institutional innovations.

Profitable opportunities, however, do not necessarily lead to immediate institutional innovations. Usually the gains and losses from technical and institutional change are not distributed neutrally. There are, typically, vested interests which stand to lose and which oppose change. There are limits on the extent to which group behavior can be mobilized to achieve common or group interests (*50*). The process of transforming institutions in response to technical and economic opportunities generally involves time lags, social and political stress, and, in some cases, disruption of social and political order. Economic growth ultimately depends on the flexibility and efficiency of society in transforming itself in response to technical and economic opportunities.

AGRICULTURAL DEVELOPMENT STRATEGY

The induced innovation model outlined above does not possess formal elegance. It is partial, in that it is primarily concerned with production and productivity. Yet it has added significantly to our power to interpret the process of agricultural development.

Research which we have reported elsewhere indicates that the enormous changes in factor proportions which have occurred in the process of agricultural growth in the United States and Japan are explainable very largely in terms of changes in factor price ratios (*23*; *25*). When we relate the results of the statistical analysis to historical knowledge of advances in agricultural technology, we conclude that the observed changes in input mixes have occurred as the result of a process of dynamic factor substitution along a meta-production function, associated with changes in the production surface, induced primarily by changes in relative factor prices. Preliminary results of the analysis of historical patterns of technical change in German agriculture (by Adolph Weber); in Denmark, Great Britain, and France (by William Wade); and in Argentina (by Alain de

[23] Also see North and Thomas (*47*).

Janvry) add additional support to the utility of the induced innovation model in interpreting historical patterns of technological change and agricultural development.

The question remains, however, as to whether the induced development model represents a useful guide to modern agricultural development strategy. In responding to this concern two issues seem particularly relevant.

First, we would like to make it perfectly clear that in our view the induced development model, in which technical and institutional change is treated as endogenous to the development process, does not imply that agricultural development can be left to an "invisible hand" that directs either technology, or the total development process, along an "efficient" path determined by "original" resource endowments.

We do argue that the policies which a country adopts with respect to the allocation of resources to technical and institutional innovation, to the capacity to produce technical inputs for agriculture, to the linkages between the agricultural and industrial sectors in factor and product markets, and to the organization of the crop and livestock production sectors must be consistent with national (or regional) resource endowments if they are to lead to an "efficient" growth path. Conversely, failure to achieve such consistency can sharply increase the real costs, or abort the possibility, of achieving sustained economic growth in the agricultural sector.

If the induced development model is valid—if alternative paths of technical change and productivity growth are available to developing countries—the issue of how to organize and manage the development and allocation of scientific and technical resources becomes the single most critical factor in the agricultural development process. It is not sufficient to simply build new agricultural research stations. In many developing countries existing research facilities are not employed at full capacity because they are staffed with research workers with limited scientific and technical training; because of inadequate financial, logistical, and administrative support; because of isolation from the main currents of scientific and technical innovation; and because of failure to develop a research strategy which relates research activity to the potential economic value of the new knowledge it is designed to generate.

The appropriate allocation of effort between the public and the private sector also becomes of major significance in view of the extension of the induced development model to incorporate innovative activity in the public sector. It is clear that during the early stages of development the socialization of much of biological research in agriculture is essential if the potential gains from biological technology are to be realized. The potential gains from public sector investment in other areas of the institutional infrastructure which are characterized by substantial spillover effects are also large. This includes the modernization of the marketing system through the establishment of the information and communication linkages necessary for the efficient functioning of factor and product markets.[24]

[24] Hayami and Peterson (22) show that the returns to investment in improvements in market information is comparable to the returns that have been estimated for high payoff research areas such as hybrid corn and poultry.

In most developing countries the market systems are relatively underdeveloped, both technically and institutionally. A major challenge facing these countries in their planning is the development of a well-articulated marketing system capable of accurately reflecting the effects of changes in supply, demand, and production relationships. An important element in the development of a more efficient marketing system is the removal of the rigidities and distortions resulting from government policy itself—including the maintenance of overvalued currencies, artificially low rates of interest, and unfavorable factor and product price policies for agriculture (*41*).

The criteria specified above for public sector investment or intervention also implies a continuous re-allocation of functions among public and private sector institutions. As institutions capable of internalizing a large share of the gains of innovative activity are developed, it may become possible to transfer activities, the production of new crop varieties for example, to the private sector and to reallocate public resources to other high payoff areas. Many governments are presently devoting substantial resources to areas of relatively low productivity—in efforts to reform the organization of credit and product markets for example—while failing to invest the resources necessary to produce accurate and timely market information, establish meaningful market grades and standards, and establish the physical infrastructure necessary to induce technical and logistical efficiency in the performance of marketing functions (*58*).

A second issue is whether, under modern conditions, the forces associated with the international transfer of agricultural technology are so dominant as to vitiate the induced development model as a guide to agricultural development strategy. 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 reference to diffusion of mechanical technology from the developed to the developing countries. It is argued that the pattern of organization of agricultural production adopted by the more developed countries—dominated by large scale mechanized systems of production, in both the socialist and nonsocialist economics—precludes an effective role for an agricultural system based on small scale commercial or semicommercial farm production units (*51*; *52*).[25]

We find this argument unconvincing. Rapid diffusion of imported mechanical technology, in areas characterized by small farms and low wages in agriculture, tends to be induced by inefficient price, exchange rate, and credit policies which substantially distort the relative costs of mechanical power relative to labor and other material inputs. Nural Islam reports, for example, that as a result of such policies the real cost of tractors in West Pakistan was substantially below the

[25] Owen argues that differentiation of a rural commercial sector from the rural subsistence sector is the first step toward development of relevant agricultural development policies. The "optimum sized commercial farms will comprise *the maximum amount of land* that can be farmed at a profit by an appropriate set of labor where the latter uses a relatively advanced level of technology for the particular farming area. . . . the optimum sized subsistence farm plot is one that comprises *the minimum amount of land* that is necessary to assure to the household concerned the minimum acceptable standard of subsistence living . . ." (*51*, p. 107).

cost in the United States (*33*). The preliminary findings of work by John Sanders in Latin America also stresses the role of market distortions in inducing mechanization.

We are also impressed by the history of agricultural mechanization in Japan and more recently in Taiwan. Both countries have been relatively successful in following a strategy of mechanical innovation designed to adapt the size of the tractor and other farm machinery rather than modifying the size of the agricultural production unit to make it compatible with the size of imported machinery.[26]

We do insist that failure to effectively institutionalize public sector agricultural research can result in serious distortion of the pattern of technological change and resource use. The homogeneity of agricultural products and the relatively small size of the farm firm, even in the western and socialist economies of the West, make it difficult for the individual agricultural producer to either bear the research costs or capture a significant share of the gains from scientific or technological innovation. Mechanical technology, however, has been much more responsive than biological technology to the inducement mechanism as it operates in the private sector. In biological technology, typified by the breeding of new plant varieties or the improvement of cultural practices, it is difficult for the innovating firm to capture more than a small share of the increased income stream resulting from the innovation.

Failure to balance the effectiveness of the private sector in responding to inducements for advances in mechanical technology, and in those areas of biological technology in which advances in knowledge can be embodied in proprietary products, with institutional innovation capable of providing an equally effective response to inducements for advances in biological technology, leads to a bias in the productivity growth path that is inconsistent with relative factor endowments. It seems reasonable to hypothesize that failure to invest in public sector experiment stations capacity is one of the factors responsible in some developing countries for the unbalanced adoption of mechanical, relative to biological, technology. Failure to develop adequate public sector research institutions has also been partially responsible, in some countries, for the almost exclusive concentration of research expenditures on the plantation crops and for concentration on the production of certain export crops—such as sugar and bananas—in the plantation sector.

The perspective outlined in this paper can be summarized as follows: an essential condition for success in achieving sustained growth in agricultural productivity is the capacity to generate an ecologically adapted and economically viable agricultural technology in each country or development region. Successful achievement of continued productivity growth over time involves a dynamic process of adjustment to original resource endowments and to resource accumulation during the process of historical development. It also involves an adaptive response on the part of cultural, political, and economic institutions, in order to realize the growth potential opened up by new technical alternatives. The "induced development model" attempts to make more explicit the process by which

[26] This development is reviewed in Hayami and Ruttan (*25*).

technical and institutional changes are induced through the responses of farmers, agribusiness entrepreneurs, scientists, and public administrators to resource endowments and to changes in the supply and demand of factors and products.

CITATIONS

1 Syed Ahmad, "On the Theory of Induced Invention," *Econ. J.*, June 1966.
2 ———, "Reply to Professor Fellner," *ibid.*, Sept. 1967.
3 ———, "A Rejoinder to Professor Kennedy," *ibid.*, Dec. 1967.
4 Edgar Anderson, *Plants, Man and Life* (Berkeley, Calif., 1967).
5 L. H. Bailey, "Extension Work in Horticulture" (Agr. Exp. Sta., Bull. 110, Ithaca, N.Y., 1896).
6 H. J. Barnett, and Chandler Morse, *Scarcity and Growth, the Economics of Natural Resource Availability* (Baltimore, Md., 1963).
7 Ester Boserup, *The Conditions of Agricultural Growth: The Economics of Agrarian Change Under Population Pressure* (Chicago, 1965).
8 L. R. Brown, *Seeds of Change* (New York, 1970).
9 Lance Davis and Douglass North, "Institutional Change and American Economic Growth: A First Step Towards a Theory of Institutional Innovation," *J. Econ. History*, Mar. 1970.
10 H. D. Dickinson, "Von Thünen's Economics," *Econ. J.*, Dec. 1969.
11 Lord Ernle, *English Farming, Past and Present* (6th ed., London, 1961).
12 William Fellner, "Comment on the Induced Bias," *Econ. J.*, Sept. 1967.
13 ———, "Two Propositions in the Theory of Induced Innovations," *ibid.*, June 1961.
14 W. L. Fishel (ed.), *Resource Allocation in Agricultural Development* (Minneapolis, Minn., 1971).
15 Clifford Geertz, *Agricultural Involution: The Process of Ecological Change in Indonesia* (Berkeley, Calif., 1966).
16 H. J. Habakkuk, "Economic Functions of English Landowners in the Seventeenth and Eighteenth Centuries," in *Essays in Agrarian History*, I, ed. by W. E. Minchinton (New York, 1968).
17 D. E. Hathaway, "Urban-Industrial Development and Income Differentials between Occupations," *J. Farm Econ.*, Feb. 1964.
18 D. E. Hathaway, A. J. Beegle, W. K. Bryant, *People of Rural America* (1960 census monograph, Washington, D.C., 1968).
19 Yujiro Hayami, "Industrialization and Agricultural Productivity: An International Comparative Study," *Developing Economies*, Mar. 1969.
20 ———, "Resource Endowments and Technological Change in Agriculture: U.S. and Japanese Experiences in International Perspective," *Amer. J. Agr. Econ.*, Dec. 1969.
21 Yujiro Hayami and Kinuyo Inagi, "An International Comparison of Agricultural Productivities," *Farm Econ.*, XI, 10, 1969.
22 Yujiro Hayami and Willis Peterson, "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities," *Amer. Econ. Rev.*, Mar. 1972.
23 Yujiro Hayami and V. W. Ruttan, "Factor Prices and Technical Change in Agricultural Development: The United States and Japan, 1880–1960," *J. Pol. Econ.*, Sept./Oct. 1970.
24 ———, "Agricultural Productivity Differences Among Countries," *Amer. Econ. Rev.*, Dec. 1970.
25 ———, *Agricultural Development: An International Perspective* (Baltimore, Md., 1971).
26 ———, "Professor Rosenberg and the Direction of Technical Change," *Econ. Dev. and Cult. Change*, forthcoming, 1972.

27 E. O. Heady, "Basic Economic and Welfare Aspects of Farm Technological Advance," *J. Farm Econ.*, May 1949.
28 ———, *Economics of Agricultural Production and Resource Use* (Englewood Cliffs, N.J., 1952).
29 J. R. Hicks, *The Theory of Wages* (London, 1932).
30 ———, *A Theory of Economic History* (London, 1969).
31 P. M. Hohenberg, *Chemicals in Western Europe: 1850–1914* (Chicago, 1967).
32 Shigeru Ishikawa, *Economic Development in Asian Perspective* (Tokyo, 1967).
33 Nural Islam, "Agricultural Growth in Pakistan: Problems and Policies." Paper presented at Conference on Agriculture and Economic Development, The Japan Economic Research Center, Tokyo, Sept. 6–10, 1971.
34 Hiromitsu Kaneda, "Economic Implications of the 'Green Revolution' and the Strategy of Agricultural Development in West Pakistan," *Pakistan Dev. Rev.*, (Karachi), Summer 1969.
35 C. E. Kellogg, "Conflicting Doctrines about Soils," *Sci. Mo.*, June 1948.
36 Charles Kennedy, "Induced Bias in Innovation and the Theory of Distribution," *Econ. J.*, Sept. 1964.
37 ———, "On the Theory of Induced Invention—A Reply," *ibid.*, Dec. 1967.
38 G. E. Mingay, "The Agricultural Revolution in English History: A Reconsideration," in *Essays in Agrarian History*, II, ed. by W. E. Minchinton (New York, 1968).
39 A. H. Moseman, *Building Agricultural Research Systems in the Developing Nations* (New York, 1970).
40 M. L. Mosher, *Early Iowa Corn Yield Tests and Related Later Programs* (Ames, Ia., 1962).
41 Hla Myint, U., "Market Mechanisms and Planning—The Functional Aspect," in *The Structure and Development of Asian Economies* (Tokyo, 1968).
42 R. R. Nelson, "The Economics of Invention: A Survey of the Literature," *J. Bus.*, April 1959.
43 R. R. Nelson, M. J. Peck, and E. D. Kalachek, *Technology, Economic Growth and Public Policy* (Washington, 1967).
44 W. H. Nicholls, "Industrialization, Factor Markets, and Agricultural Development," *J. Pol. Econ.*, Aug. 1961.
45 ———, "The Transformation of Agriculture in a Semi-Industrialized Country: The Case of Brazil," in *The Role of Agriculture in Economic Development*, ed. by Erik Thorbecke (New York, 1969).
46 W. A. Niskanen, "The Peculiar Economics of Bureaucracy," *Amer. Econ. Rev.*, May 1968.
47 D. C. North, and R. P. Thomas, "An Economic Theory of the Growth of the Western World," *Econ. Hist. Rev.*, 23, 1 (second series) 1970.
48 Joosep Nõu, *Studies in the Development of Agricultural Economics in Europe* (Uppsala, Sweden, 1967).
49 Kazushi Ohkawa, "Policy Implications of the Asian Agricultural Survey—Personal Notes," in *Regional Seminar on Agriculture: Paper and Proceedings* (Makati, Philippines, 1969).
50 Mancur Olson, Jr., *The Logic of Collective Action: Public Goods and the Theory of Groups* (New York, 1968).
51 W. F. Owen, "Structural Planning in Densely Populated Countries: An Introduction with Applications to Indonesia," *Malayan Econ. Rev.* (Singapore), Apr. 1969.
52 ———, *Two Rural Sectors: Their Characteristics and Roles in the Development Process* (Indiana Univ. Intl. Dev. Res. Center Occas. Paper 1, Bloomington, Ind., 1971).
53 E. M. Rogers, *Diffusion of Innovations* (New York, 1962).
54 ———, "Motivations, Values, and Attitudes of Subsistence Farmers: Toward a

Subculture of Peasantry," in *Subsistence Agriculture and Economic Development*, ed. by C. R. Wharton, Jr. (Chicago, 1969).

55 Nathan Rosenberg, "The Direction of Technological Change: Inducement Mechanisms and Focusing Devices," *Econ. Dev. and Cult. Change*, Oct. 1969.

56 V. W. Ruttan, "The Impact of Urban-Industrial Development on Agriculture in the Tennessee Valley and the Southeast," *J. Farm Econ.*, Feb. 1955.

57 ———, "Usher and Schumpeter on Invention, Innovation and Technological Change," *Quar. J. Econ.*, Nov. 1959.

58 ———, "Agricultural Product and Factor Markets in Southeast Asia," *Econ. Dev. and Cult. Change*, July 1969.

59 W. E. G. Salter, *Productivity and Technical Change* (Cambridge, Eng., 1960).

60 P. A. Samuelson, "A Theory of Induced Innovation Along Kennedy, Weisacker [Weizsacker] Lines," *Rev. Econ. and Stat.*, Nov. 1965.

61 C. O. Sauer, *Agricultural Origins and Dispersals: The Domestication of Animals and Foodstuffs* (2nd ed., Cambridge, Mass., 1969).

62 Jacob Schmookler, *Invention and Economic Growth* (Cambridge, Mass., 1966).

63 G. E. Schuh, "Comment," in *The Role of Agriculture in Economic Development*, ed. by Erik Thorbecke (New York, 1969).

64 T. W. Schultz, *The Economic Organization of Agriculture* (New York, 1953).

65 ———, *Transforming Traditional Agriculture* (New Haven, Conn., 1964).

66 ———, "Institutions and the Rising Economic Value of Man," *Amer. J. Agr. Econ.*, Dec. 1968.

67 ———, "The Allocation of Resources to Research," in *Resource Allocation in Agricultural Research*, ed. by W. L. Fishel (Minneapolis, Minn., 1971).

68 A. K. Sen, "The Choice of Agricultural Techniques in Underdeveloped Countries," *Econ. Dev. and Cult. Change*, Apr. 1959.

69 D. G. Sisler, "Regional Differences in the Impact of Urban-Industrial Development on Farm and Nonfarm Income," *J. Farm Econ.*, Dec. 1959.

70 S. H. Slicher van Bath, *The Agrarian History of Western Europe, A.D. 500–1850* (London, 1963).

71 T. C. Smith, *The Agrarian Origins of Modern Japan* (Stanford, Calif., 1959).

72 Carolyn Shaw Solo, "Innovation in the Capitalist Process: A Critique of the Schumpeterian Theory," *Quar. J. Econ.*, Aug. 1951.

73 E. C. Stakman, Richard Bradfield, and P. C. Mangelsdorf, *Campaigns Against Hunger* (Cambridge, Mass., 1967).

74 A. M. Tang, *Economic Development in the Southern Piedmont, 1860–1950: Its Impact on Agriculture* (Chapel Hill, N.C., 1958).

75 H. C. Taylor, and Anne Dewees Taylor, *The Story of Agricultural Economics in the United States, 1840–1932* (Ames, Ia., 1952).

76 C. P. Timmer, "The Turnip, the New Husbandry, and the English Agricultural Revolution," *Quar. J. Econ.*, Aug. 1969.

77 ———, personal communication, Oct. 9, 1970.

78 A. P. Usher, "Soil Fertility, Soil Exhaustion, and their Historical Significance," *Quar. J. Econ.*, May 1923.

79 N. I. Vavilov, *The Origin, Variation, Immunity and Breeding of Cultivated Plants*, trans. by K. Starr Chester, XIII, 1–6 of *Chronica Botanica*, 1949–50. (Waltham, Mass., 1951).