The Technological Component of Agricultural Development

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1. Introduction

Although it has long been recognized that inventions and technical improvements in agricultural production have been an important factor in increasing agricultural output, it is only within the last 25 years that serious thought has been given by economists to (a) the implications of technological advance in agriculture on output, prices, farm incomes, factor proportions, and the demand for factors; and (b) how new technologies are generated and adopted and how society benefits from this process.

In the late 1940's and early 1950's several agricultural economists in the United States focused on technological change in agriculture to help explain secular movements in farm prices and incomes. Starting in the mid-1950's there have been a series of inquiries into the nature and benefits of technological

* I am indebted to Vernon W. Ruttan, Yujiro Hayami, Lee R. Martin, Robert Evenson, and Willis Peterson for numerous helpful comments and suggestions.
change in agriculture. A still later stage of research is characterized by inquiries into the economic organization and productivity of research organizations.

The importance of technological change in the development of agriculture in the poor countries has been increasingly recognized. Both Schultz and Jorgenson stress the importance of technological advance in agriculture as a way of breaking out of the traditional farming mold and as an important component of sustained growth in the total economy. Although this view has been held for some time by numerous people working in agriculture it has only recently begun to be embodied in a significant way in the thinking and writing of development economists and planners.

Furthermore, it has also been recognized that agricultural technologies cannot generally be successfully transferred from one country or area of the world to another. The importance of biological, social, and cultural factors in agricultural production compared with industrial production means that agricultural production methods must be adjusted for variations in these factors. Thus, it is now generally recognized that basic scientific knowledge in agriculture can have a high degree of international mobility, but that specific technological developments must fit into the particular environments within a country. Basic scientific knowledge must be adapted to local conditions and this means a geographic dispersion of research and development in agriculture.
Recognizing the importance of technological change in agricultural development is an important step forward. But a great deal remains unknown about the process by which new technology is generated and the implications of any particular technology or set of technologies for the pattern of development. There are many questions about technological change which we cannot now answer satisfactorily. If new technology is important what are the "best" ways to generate and employ it? What will be the effects of alternative patterns of technological advance on levels of outputs, input requirements, and returns to the factors of production or income distribution? How does a new technology in one area induce organizational or technical changes in other areas? In what ways can new technology change the comparative advantages of products among regions within a country and between countries? How does the process of technological advance change the institutional structures within which production takes place? How much technological advance is enough? Appropriate answers to all of these questions are important for attaining a high degree of efficiency in the allocation of resources for (a) achieving more rapid rates of agricultural and economic development, (b) achieving desired (feasible) patterns of income distribution, and (c) maintaining a reasonable degree of consistency in political, social and economic development. All of these considerations are especially important for many of the developing nations where rapid rates of development are desired, but where developmental resources are scarce and many institutions (including the political structure) are lacking or weak. High penalties can result
from inefficient use of these scarce resources, including the generation of an economic development path that is inconsistent with established long-run political and social objectives. The simple "recipe" for agricultural development may be very illusive or even nonexistent.

But how can we learn more about the process of technological advance in developing countries in order to answer some of the questions posed above. The study of technology in agriculture has proved to be difficult in highly developed countries where data are relatively plentiful. One of the main problems is that the vast amount of data on the agricultural production process available in a country like the United States is not well suited for the measurement of the impact of technological advance on the output and structure of agriculture.

This is true not only of the aggregative data, but especially so for data at the firm level.

In this paper I present a suggested approach for studying agricultural technological advance that is feasible, timely, and useful to those concerned with agricultural development (planners, program administrators, research administrators, and researchers). The information that could flow from such an approach would permit one to develop answers to at least some of the tough questions about the alternative rates and patterns of agricultural development that are practicable in different time periods and under different resource situations.
In Section II, I present a conceptual framework for looking at the role of technology in the agricultural development process. This includes both the role of technology in the production process and the generation of technology. Section III deals with the structure of the agricultural research process. In Section IV, I present a suggested approach for studying the processes of technological advance in the agricultures of developing countries. Finally a few concluding remarks are made in Section V.
II. The Conceptual Framework

Let us consider technological advance as the nucleus of economic advance. This may not be bad either from a conceptual or pedagogical point of view, since it is now widely accepted that technological change is one of the most important determinants of economic growth.

In figure 1, let the large circle represent the set of activities involved in agricultural development. This set is defined broadly to include not just farming -- the production of food and fiber -- but also factor markets, product markets, trade in both agricultural products and factors of production used in the agricultural sector and the relevant institutions governing the behavior or performance of these activities. The small circle represents the subset of agricultural development consisting of the generation and application of new technologies. We can refer to this as the technology subsector.

The technology subsector is divided into two parts. One, consisting of the impact of technological change on production, is represented by the generalized production function:

\[ Q = f(X_1, \ldots, X_n | \lambda_1, \ldots, \lambda_n), \]

where \( Q \) is the output of some product or group of products; \( X_i \) is the \( i \)th factor used in the production of \( Q \); and \( \lambda_i \) is the \( i \)th technical coefficient.

Technological change can affect (1) in basically three ways. First, it can alter the \( \lambda_i \)'s on existing factors used in production. This type of change would reflect an improvement in the quality of
Figure 1.

\[ Q = f \left( X_1, \ldots, X_n \bigg| \alpha_1, \ldots, \alpha_n \right) \]

\[ (X_i, \alpha_i) = g \left( R_1, \ldots, R_m \bigg| \beta_1, \ldots, \beta_m \right) \]
existing resources. Second, a new technology could result in the introduction of a new factor into the production process adding a new \( X_i \) and \( \alpha_i \) and also changing the values of some or all of the remaining \( \alpha_i \)'s. Finally, a new technology might be represented by a new input or operate on all the old inputs in such a way as to leave the old \( \alpha_i \)'s unchanged -- all the change in the function is accounted for by the new \( X_i \) and \( \alpha_i \).

The other portion of the technology subsector contains the processes by which new technological change is generated. This will generally be a set of research activities (broadly defined) that deal with (a) improving the quality of resources, (b) developing new factors of production, and (c) the organization of existing resources into new combinations which lead to improvements in productivity. Let their activities be represented by the function

\[
(X_i, \alpha_i) = g \left( R_1, \ldots, R_m \parallel \beta_1, \ldots, \beta_m \right),
\]

where \((X_i, \alpha_i)\) are the products of research resulting in either the production of a new factor of production or the improvement in the quality of an existing factor, the \(R_i\)'s are a set of resources used in the research process, and the \(\beta_i\)'s are the technical coefficients associated with the research resources or factors of production.

We can view \((2)\) as the research production function. It may be more difficult to specify and measure than \((1)\), but nonetheless it is assumed to exist.

One can ask what is the relationship between \((1)\) and \((2)\)? This depends on one's view of how new technologies are generated. If one
assumes that most technological development takes place autonomously, then the relationship between the two functions is weak. It would consist entirely of the processes by which new knowledge is diffused. If, on the other hand, one views technological development as a response to perceived needs and it is, therefore, induced by some set of economic forces, then the linkage between (1) and (2) are much stronger. There is strong evidence to support the view that the bulk of technological advances are induced and there exists a linkage between (1) and (2) involving not only the dissemination of new knowledge, but also a set of economic forces which signals the need for new methods.

\[ \sqrt{33}, 34/ \]

**Farm Level Production Function**

Is knowledge about the way in which alternative technologies affect the farm level production function useful for the process of planning agricultural development? The answer is obviously yes. Let us trace through some of the implications of such knowledge.

We can start by assuming there are two alternative technological developments that improve upon (1) in some well defined way. Let these be

(1a) \[ Q' = f' (X_1, \ldots, X_n \mid L_1, \ldots, L_n') \]

(1b) \[ Q'' = f'' (X_1, \ldots, X_n \mid L''_1, \ldots, L_n'') \]

\[ 1/ \] Here I assume that both the private and public sector require planning information.
Product Markets: It is obvious that the price of the output, Q, will be a function of, among other things, the level of output and, therefore, of technology. Thus, we can trace out the impact on $P_Q$ of moving from (1) to (1a) or to (1b). We would have to specify the conditions under which a new equilibrium was established. For example, is it legitimate to assume that $P_Q$ is fixed regardless of the level of output? This would be the case where there was an effective price support program. Or, are we to assume that $P_Q$ varies with Q? We may also have to determine whether or not international trade is part of our market. The change in technology could have significant implications for the competitive position of a country in international trade. This can be of considerable importance if the level and composition of trade is large enough to affect the amount of resources available for development. The fact that technological change can significantly alter the competitive position of countries in trade may seem obvious, but the full significance of it may not be accounted for in the agricultural development planning of less developed countries. The same argument holds for changes in the comparative advantage among regions of a country. We will discuss this later in the paper.

Besides changing the level of output, technology can seriously affect the qualitative characteristics of a product in either a favorable or unfavorable direction. The literature on development and trade is replete with examples of the impact of qualitative changes in products on consumption and trade. For example, qualitative changes in agricultural products may have a different affect on price in the home
market than in the export market thus leading to either an improvement or deterioration in a country's competitive position.

Knowledge about how the level of output is affected by a technological change is valuable for planning necessary changes in the structure of the product market. First, a larger volume of output will require more storage, transportation, and distribution facilities. These may be either of the conventional type, or require some new developments in the marketing system. An example of the latter is the need for rice drying facilities associated with the production of the ADT-27 rice variety in India. The growth cycle of the older varieties corresponds closely with the monsoon season and harvesting takes place after the monsoon rains. Thus, natural drying of rice is adequate. In addition, the native varieties of rice have an inherent period of dormancy and are not subject to sprouting at a relatively high moisture content. The new rice variety, ADT-27, has a much shorter growing season, so that harvesting takes place during the rainy period. Further, ADT-27 sprouts at a moderate or high level of moisture content of the grain. Thus, grain drying facilities are a necessary adjunct to the production of ADT-27 to realize increased profits resulting from higher yields and investments in these facilities must accompany the expanded use of ADT-27.  

2/Vernon W. Ruttan has pointed out that this property of ADT-27 rice is a signal to the plant breeder to breed a dormancy property into the variety.
**Factor Markets:** We are also interested in what a technological change means for the markets for agricultural inputs. Given some knowledge about the behavior of product prices with respect to changes in output levels, we can determine how the demands for factors of production are changed by a given technological advance. This knowledge, together with information about the likely rate of adoption of a new technology and the nature of the supply relations for factors of production would enable us to estimate the impact of technical change on factor prices. In a longer-run sense this information would provide a valuable guide to planning investments that expand the supply of production resources.

We would want to know not only how technological change expands the demand for factor of production, but also how it alters the price elasticity of demand for a particular input. Information on the price elasticity of demand for a given factor of production is important in determining the gains that an economy could achieve from lowering prices of the factor. This, in turn, would signal the need for improved technology in the input supply industry. The expansion of demand for an input as well as its price elasticity of demand is also important for capturing the benefits of economies of scale that might exist in the factor supply industry. Sahota [27] has shown in his study of the fertilizer industry how important lower fertilizer prices stemming from technological advance and exploitation of scale economies in the fertilizer industry have been in sharply increasing fertilizer use, and consequently, farm output in the United States.
An important element in the analysis of the factor markets is the nature of the complementary relationships among factors of production. The existence of complementarities in agricultural production is well recognized. However, their study may involve a great deal more disaggregation of the production function than is usually the case. It may not be sufficient to treat capital as an aggregate variable. Rather, we may very likely want to look at individual components of the total capital input. The bundle of complementary relationships may vary among the production of different commodities, among regions, and among technologies. The different possibilities would have to be sorted out.

Knowledge about the nature of the complementarities among factors of production in agriculture and how these change with technological advance is important in planning a balanced expansion of factor supplies. If, for example, optimum yields from a new seed variety can be achieved only when the new seed is combined with water and fertilizer in fairly fixed proportions (i.e., there is a high degree of complementarity among the three inputs), then a balanced expansion in the availability of fertilizer and irrigation water is called for in order to fully exploit the benefits of the new seed technology.

**Factor Proportions**: An important consideration in the study of agricultural technological advance, particularly for developing countries, is how it affects factor proportions in the agricultural sector and in the total economy. We are interested in knowing whether a particular technical change is capital saving (using), labor saving (using) or neutral with respect to the relative use of capital and labor. 15, 21,
This is important from at least two points of view. First, factor proportions determine in large measure the income distribution pattern within a country. A nation may have adopted certain policy objectives with respect to income distribution based on social and political considerations. If the pattern of technological advance results in patterns of income distribution that seriously deviate from the accepted norms, social and political frictions may develop and may become so severe as to impede the rate of economic development.

Second, the typical less developed country is long on unskilled labor and short on capital and skilled labor. Poor nations will try to expand the domestic rate of capital accumulation and expand its supply of skilled labor. But this is generally very difficult for a country to do without any outside assistance. Thus, capital and skills are brought in from abroad. These come as technical assistance and economic aid from foreign countries or international organizations, assistance from foreign private foundations and other private groups, and from foreign private investment. It is important that the technological mix embodied in or implied by the foreign resources used in development be consistent with the composition of resource use desired in the long-run.

In many nations the "ideal" form of technological advance is one that gives rise to a high degree of economic efficiency using labor intensive (capital extensive) production methods. But this may not be the case for all industries. Some industries must be capital intensive to operate effectively and efficiently, or even at all; e.g., the
The basic question which arises in our framework of analysis is how new technologies used in agricultural production affect factor proportions in both agriculture and in the rest of the economy. Both the sectoral and aggregate implications may be very important. Technological changes which may be neutral with respect to factor proportions in agriculture could be either very labor intensive or very capital intensive with respect to the rest of the economy. Since the development of modern agriculture involves the establishment of linkages between the agricultural and other sectors, changes in agriculture can and ideally should have a significant impact on the nonagricultural sectors. We are here adding the technological component to the intersectoral linkages that Hirschman \(16^{16}\) considers so important in the development process.

Let's consider a new set of agricultural technologies consisting of new seed varieties and fertilizer. Assume, for purposes of illustration, that this package of new inputs is neutral with respect to factor proportions in agriculture. However, the new fertilizer industry that is established would likely be very capital intensive while the new seed industry could be quite labor intensive. The net effect for the total economy would depend on the relative importance of the two factors -- fertilizer and new seed -- but it is very likely that the fertilizer input will be the dominant one in value terms.
This means that in planning agricultural development it may not be enough to look just at the affect of new technologies on factor proportions in agriculture. Rather, we should look also at the forward (product market) and backward (factor market) linkages between agriculture and other sectors and take into account the secondary and tertiary effects of a given technological change.

**Geography of Technical Change:** In addition to the changes in the production function and the rate of adoption, the degree to which a given technical change can be generalized geographically determines its aggregate impact on the product and factor markets. Some technological improvements seem to have widespread application. In recent years the new Mexican wheat varieties being used extensively in India, Pakistan, and Turkey would fall in this category. Other technological improvements seem to be more location specific; e.g., the new rice varieties developed at the International Rice Research Institute in the Philippines.

Further, there is some evidence to indicate that as the agricultural technological base grows, the new technologies tend to become increasingly location specific.

In a study of technical change in three commodities -- sugar cane, bananas, and rice -- Evenson, Houck and Ruttan suggest that there are four stages in the technological development processes associated with plant varieties. Stage I is concerned with the selection of natural (wild) varieties; i.e., finding those wild varieties that are the best producers. This stage tends to be very location specific.
Wild varieties have survived through a process of natural selection; they are the varieties proven to be most resistant to local disease conditions. This stage of technical development does not generally lend itself to the geographic transfer of varieties because of different disease, soil, and climatic conditions in other areas. The second stage in the plant development process consists of crossing native varieties from different areas and selecting those new varieties that exhibit the highest degree of adaptability. Stage II constitutes a widening of geographic adaptability. However, Stage II represents a random approach to development of new varieties with disease resistant characteristics. Stage III is characterized by breeding for specific disease resistant characteristics, i.e., a move away from a random to a systematic approach. In this stage, plant varieties become more location specific than in the previous stage. Finally, Stage IV is characterized by plant breeding programs designed to develop plants adapted to specific soil and climatic conditions. This represents a further degree of location specificity over Stage III.

The transmission of new technology from one country (or region) to another becomes more difficult as the plant breeding process produces varieties that are increasingly location specific. The highest degree of geographic mobility of new varieties would be under Stage II. Geographic transfers of new technology becomes increasingly difficult in Stages III and IV.

The degree to which new agricultural technologies are widely or narrowly adapted and the geographic pattern of investments in
agricultural development have important implications for the regions within a country that will share in the fruits of development. It is easy for regions of a country to get left behind in the development process. There may be a strong proclivity for research institutions to concentrate on those areas where the short-run pay-off will be the fastest and most dramatic. And, this would make good economic sense, in the short-run at least. But if the high pay-off research is limited to a relatively small geographic area and a small part of the farm or rural population, the results could be socially and politically disastrous in the long-run. Major disparities in the regional distribution of income are not something that development planners should consciously or unconsciously foster if there are alternatives available. And, alternatives can be provided if new technologies are available to most of the farmers and developmental investments are made to expand the area in which existing technologies can be profitably employed.

Hsieh and Ruttan point out that variations in rice yields among the Philippines, Thailand, and Taiwan are explained more by differences in environmental conditions than in differences in technology. They point out that: "... despite the yield potential inherent in the new rice varieties now being introduced there seem clearly to be basic deficiencies in the sequence of development programming which may prevent the Philippines and Thailand from repeating the experience of Taiwan. In Taiwan a major share of the basic investment in irrigation was already completed before the beginning of the biological revolution that led to the yield take-off in the 1920's. Furthermore,
the irrigation development leading to effective water control was a prerequisite to the effective diffusion of the new higher yielding labor-intensive, 'fertilizer consuming' rice varieties. Institutional innovations such as extension work, farmers' associations, irrigation associations, and land reform followed and complemented both the investment in water control and the technological change.

"Neither the Philippines nor Thailand yet place major emphasis on the development of irrigation systems designed to provide a dependable water supply in both wet and dry seasons to a major portion of the area devoted to rice production. It seems apparent that this lag of land and water resource development behind the institutional and technological changes will impose serious limitations on achievement of the output potential associated with the technological advances that are now being realized." \(\text{[17, p. 337]}\) To this we could add that in areas within the Philippines and Thailand where irrigation is adequate, farmers who are growing the new rice varieties are improving their economic position relative to farmers in other areas.

Institutional Change: \(\text{3/}\) It is very unlikely that the process of farm technological change will be neutral with respect to a variety of institutions that are part of or serve the agricultural sector. In a sense, existing institutions reflect, among other things, the existing level of technology and in many developing countries the state of the

\(\text{3/In this section I do not discuss institutional changes directly associated with the production of new technology. These are discussed in the next section.}\)
arts has not changed at all or changed very slowly over a long period of time. A rapid acceleration in the rate of technological advance can make the existing institutions obsolete and create the demand for a whole new set of them. Also, existing institutions can act as barriers to the adoption of new technologies. I will not try to give an exhaustive list of all possible institutional changes. Rather, let's look at two examples.

First, consider the role of land tenure arrangements. They can act as either a deterrent or as a facilitator of technological advance on farms. A landlord-tenant arrangement where the landlord receives a large fixed share of the output but contributes nothing to production other than land is not likely to be one where tenants have a strong incentive to adopt new practices that require substantial expenditures. And certainly the tenant has no incentive whatsoever to make capital investments on the farm, such as a tubewell, that may be an essential element in realizing the full benefit of a new technology. But just as existing tenure arrangements can act as a barrier to the adoption of new techniques, the new techniques can provide the incentives to alter the institutional arrangements.

Second, let us look at credit institutions. As new farm technologies alter the level, composition, and seasonal distribution of farm output; change the level and mix of farm inputs; require new investments and result in a new set of risk and uncertainty the traditional credit institutions will become obsolete. Again, there is a simultaneous set of problems. The lack of an adequate credit structure will
retard the rate of technological progress, yet the high economic returns from new technologies provide a strong incentive to alter the institutional structure.

Knowledge about the nature of technological change can provide a set of signals that indicate the direction and possible magnitude of changes in the institutional structure of agriculture required to realize the full benefits of the new technologies.

Research Production Function

What are the characteristics of the process by which technical changes in agricultural production are generated? In other words, what does the research production function, (2), look like and how is it linked to the agricultural production function, (1)?

Although conceptually a research production function sounds sensible, there is, to my knowledge, no empirical investigations that have actually defined such a function and obtained parameter estimates in any formal sense. But lets assume that empirical research on the research production is possible. Such investigations would define the specific characteristics of the relationship between new technologies and a set of research resources.

There are a number of interesting questions about the nature of the research production function that bear directly on the efficiency with which research resources are used. One is the question of existence of economies of size in research organizations. Evenson indicates that there are economies of size in the agricultural experiment station structure of the United States. But the source of such
economies is far from clear. It is plausible to think in terms of a minimum mass of research resources that is required before any significantly relevant research results are obtained. But such a mass has yet to be defined. Further, large research organizations can benefit from specialization of functions and more fully benefit from complementarities that may exist among disciplines.

Both of these characteristics may make the larger research organization a more attractive place to work and attract more productive research people; i.e., resources employed in larger units may be of a higher "quality" than those in smaller units. This latter point, of course, does not reflect a scale economy.

Another interesting question is the way in which the degree of location specificity of new technologies affects the optimum allocation of research resources. Here we would be concerned with the optimum degree of decentralization of research activities, degree of specialization in technology product, and the optimum degree of coordination among separate research activities.

This is only part of the story, however. Another consideration is the nature of the linkage between (1) and (2).

If the development of new technologies is an autonomous process and, therefore, does not respond directly to the demands for new technology generated in the process of agricultural development, then it would be difficult to think of planning research for and coordinating it with agricultural development plans and programs. We would view new technologies as being generated by a random process.
If, on the other hand, much of the new technologies are induced by specific needs arising in the course of development we have quite a different situation. Schmookler points out that this clearly seems to have been the case in the United States.

Proceeding on the basis that new technologies are induced by development needs, planners could specify the pattern of agricultural development they want and derive from this the type of technological development required. Or, development planners could select, from among a number of alternatives, a particular path of technological development which is most nearly optimum in terms of the desired pattern of economic development.

The agricultural research institutions must be in a position to receive some guidance as to what research products will have the highest developmental pay-off. This guidance can come in a variety of ways. It can come via a set of market forces reflected in the prices of farm products. These prices and the forces behind them, worked through the farm level production function, provide a guide to the relative pay-off from altering the production function in different ways. A set of signals can also come from the nonmarket or public sector in the form of investment decisions that affect the quantity and quality of resources available to the agricultural sector. Clearly

4/Agricultural price policies implemented by the public sector should not be ignored. For example, a low food price policy based on low cost imports in the form of food aid would provide quite a different price signal than a policy of supporting farm prices at a level that provided a clear incentive to farmers to expand output.
a major public investment program to expand the supply of and area covered by irrigation water would be a clear signal to plant breeders to work in the direction of adapting water (and fertilizer) responsive varieties to a wider geographic area.

It is important that information that can be a guide to the allocation of research resources be received by the research institutions. It is equally important that there be a flow of information from the farm level production process back to the research institutions on the performance of new technologies. How else are researchers to know if they are properly interpreting the signals they receive and efficiently allocating scarce research resources.
III. The Agricultural Research Process

Even though there is strong evidence to suggest that the technological changes that have occurred in agriculture have been induced by economic forces, this does not mean that the generation of the new technologies was planned in any formal sense. In the United States, Canada, and Western Europe, for example, there was very little formal and comprehensive planning in the historical development of agriculture.

Planning is a much more real and important function in the development of the poorer nations. And, this planning function influences not only the allocation of resources in the public sector, but in the private sector as well. This brings us to a key component of our framework. Historically, the development of technology lagged behind the evolution of a set of key economic forces. In many instances these economic forces had their roots in previous technological constraints. And, they did not always behave in a smooth and predictable way. What I am saying, in effect, is that the induced approach to technical change many times involved economic crises of minor or major proportions. Such a pattern of induced innovation does not necessarily lead to an optimum allocation of resources in the short- or intermediate-run, particularly as allocative efficiency is related in some degree to economic (and political) stability.

But because this is the way things may have been, does it have to be the same in the future? I think not. Certainly research and development in the nonagricultural sectors has moved somewhat away from
the "crisis" induced approached to a more planned induction of technical change. The decision makers and policy planners in much of modern industry and some public sector areas like the space and military programs decide on a particular set of objectives. They then view the adequacy of existing technology for achieving these objectives. If the state of the arts is inadequate, an organized program of research and development is carried out to provide the missing technology.

This type of approach has not been general in agricultural development, although there have been a few steps in this direction. Certainly the research work of the Rockefeller Foundation in Mexico was strongly oriented toward producing a new set of technologies consistent with stated agricultural development objectives. Stakman, Bradfield and Mangelsdorf state that "By 1941 some of the wiser Mexicans realized that a revolution in agriculture was needed to supplement the agrarian revolution if Mexico was to feed her rapidly growing population."

The same orientation is somewhat characteristic of the Rockefeller-Ford Foundations program at the International Rice Research Institute in the Philippines. But research programs such as these are the exception. And it has to be argued that in the main agricultural development planning and planning agricultural research are two separate activities that are only weakly linked.

Agricultural research resources are just as scarce, if not more so, than other developmental resources. Their efficient use is obviously important. How, then, can there be a higher degree of efficiency in agriculture research? One way is to more full integrate the
research process into the development process as already suggested above. Research priorities will flow from the priorities established in development planning with respect to development targets and objectives. This will mean identifying the technological, institutional, and resource constraints that prevent a higher rate of growth; determining needed complementary actions of these three types of constraints; and following through the implications of easing these constraints on the pattern of subsequent development as discussed earlier. Johnson and Tolley [18] have made a start on a conceptual model for establishing research priorities consistent with development objectives. Much more work needs to be done.
IV. A Suggested Approach

It is important to gain as much knowledge as is feasible about the characteristics of new technologies and their implications for the pattern of economic development. I see no reason why additional information cannot be obtained from our existing research programs at very little additional cost. Further, it may be desirable to change existing research programs to provide still more information valuable to development planners.

Let me illustrate how this might work. Take the example of developing a new grain variety. The plant breeders and agronomists are interested in certain characteristics like yield potential, fertilization and water requirements, disease resistance, adaptability to different types of soil and climates, and possibly in certain quality characteristics of the grains. From the information generated by the typical research process one can construct a production function associated with the new technology. But this will be a very constrained production function. The function would be more complete if the new technology was also tested under actual farm conditions where, for example, labor requirements could also be studied. This type of information is often ignored on the typical experiment station. From a sample of farms employing the new techniques a more complete production function of the type suggested in Section II could be estimated. The rate of adoption of the new technology could also be studied in the sample. A study of the farm enterprises through time would allow researchers
and others to assess how the demands for new technology change through time (i.e., as the development process moves through successive stages) and how the research product should be changed in response to these demands.

The sample of farms would not have to be excessively large and the cost of obtaining the desired information could easily be with the resource capacity of a typical developing nation. It would be important to design the sample in such a way as to maintain an adequate sample size (by replacement) through time. The basic data obtained should be analyzed as quickly as possible and the results made available to all interested individuals and institutions. One way to ensure full use of the basic information is to have it in a form that large numbers of analysts within and possibly outside the country can have ready access to the basic data. And, of course, the analysis of the data should become an integral input into the technology generating institutions and organizations.

The information thus generated plus knowledge about adoption rates would be valuable data for the development planner. Some of it would be a signal to the planner that resources and technology that will be required to support the adoption of the new technology do not now exist or exist in insufficient quantities. Thus, new resource allocation decisions will be required to ensure as smooth and possibly as rapid an uptake of the new technology as possible. To the extent that lead-time exists, it will help to avoid abrupt changes in resource allocation in other sectors of the economy and "crises" in the development process.
In addition, the development planner may be able to choose among several alternative technologies; he can select those that come closest to giving the desired pattern of development within the agricultural sector and within the total economy. Development of the agricultural sector is not limited to increasing production per unit of land or labor. It also involves the disposition of the additional product in ways that will be profitable to producers and of economic benefits to the nation, and the creation of the resources required to realize the benefit of the new technology. In other words, agricultural development involves the closer integration of the agricultural sector with the rest of the economy.

The additional information generated by the approach to technological development presented in this paper could permit a smoother development process and most likely a more efficient allocation of resources. It could, for example, result in a sharper focus on the importance of water development to the continued adoption of new rice varieties in Southeast Asia that Hsieh and Ruttan refer to. It could identify short-comings in existing institutional structures such as land tenure patterns, extension services, credit institutions, etc. and possibly suggest directions and magnitudes of required changes. It could suggest changes in the competitive position of countries in international trade that could have an extremely important impact on the future course of development. It could suggest an ordering of research priorities. And, it could suggest a different level and composition of foreign economic assistance.
As the process of technological development eases or eliminates certain constraints, new ones will come into play. The supply of irrigation water may not be a constraint when the supply of new seeds that are fertilizer and water responsive are inadequate. But once supplies of the new seeds and fertilizer become abundant, the supply of irrigation water becomes the factor limiting growth in agricultural output. This may very well be the pattern that develops in India, for example, when the High-Yielding Varieties Program succeeds in a few years to cover the approximately 32.5 million acres of adequately irrigated land, about 10 percent of the cultivated area, with new seed varieties, fertilizer, and pesticides. Beyond then, the future rate of grain production will be heavily influenced by the rate at which irrigated area is expanded. India agricultural planners have not yet given irrigation development anywhere near the priority accorded new seed varieties and fertilizer. Yet, a logical sequence of development efforts is reasonably clear.

Just one final point. The integrated framework for analyzing technological advance presented in this paper would permit a more comprehensive research approach to the subject. Many individuals could be working simultaneously on different aspects of technological advance. But their separate work could or should relate to the same basic set of issues. Thus, their separate research work can be viewed as being additive into a comprehensive whole. The complexity of the subject and the need for timely research results almost certainly requires a "team" approach. The framework presented in this paper would provide one possible basis for organizing a "team" effort.
V. Concluding Remarks

The importance of a rapid rate of agricultural technological advance in achieving more rapid rates of agricultural development is becoming increasingly obvious. Yet we know little about the complicated processes involved in the generation and adoption of new production techniques.

Many developing countries are trying to achieve a rate of progress in agricultural development in a few decades that took centuries to accomplish in the developed countries. This more rapid tempo of development can significantly increase the cost of inefficient allocations of research and developmental resources. Ways should be found to gain greater information about the role of technology in agricultural development as a way to maximize the return from the limited bundle of developmental resources available to the poor countries. The approach suggested in this paper is one possible way to gain much of the needed information on a timely basis and with a practicable amount of resources. A well conceived and sharply focused program of agricultural research need not be large to have a major impact on a country's economic development. [1, p. 84-91] This is particularly true if it is part of a balanced program of agricultural development that involves a logical sequence of investments, institutional developments and research priorities.
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6. Evenson, R. E., J. P. Houck, Jr., and V. W. Ruttan, Technical Change and Agricultural Trade: Three Examples (Sugarcane, Bananas, Rice), Staff Paper P 68-4, Department of Agricultural Economics, University of Minnesota, December 1968.


